# SOLAR ENERGY TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

## 2020 PEER REVIEW REPORT

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# List of Acronyms

| | |
|---|---|
| **BAPVC** | Bay Area Photovoltaic Consortium |
| **c-Si** | crystalline silicon |
| **CdTe** | cadmium telluride |
| **CIGS** | copper indium gallium selenide |
| **CO2** | carbon dioxide |
| **CSP** | concentrating solar-thermal power |
| **DC** | direct current |
| **DER** | distributed energy resource |
| **DG** | distributed generation |
| **DOE** | U.S. Department of Energy |
| **DOT** | U.S. Department of Transportation |
| **DuraMat** | durable module materials |
| **EERE** | Office of Energy Efficiency and Renewable Energy |
| **EV** | electric vehicles |
| **Gas CC** | natural gas combined cycle |
| **Gas CT** | natural gas combustion turbine |
| **GW** | gigawatts |
| **IP** | intellectual property |
| **kW** | kilowatt |
| **kWh** | kilowatt-hour |
| **LCOE** | levelized costof electricity |
| **LMI** | low- and moderateincome |
| **NREL** | National Renewable Energy Laboratory |
| **NSTTF** | National Solar Thermal Test Facility |
| **O&M** | operations and maintenance |
| **PI** | principal investigator |
| **PV** | photovoltaics |
| **R&D** | research and development |
| **sCO2** | supercritical carbon dioxide |
| **SETO** | Solar Energy Technologies Office |
| **Si** | silicon |
| **SNL** | Sandia National Laboratories |
| **T2M** | technology to market |
| **TRL** | technology readiness level |
| **U.S.** | United States |
| **VC** | venture capital |
| **Vdc** | voltage (direct current) |

# Letter From The Director

In 2010, solar was a negligible fraction of U.S. electricity supply, with costs that were four to five times higher than conventional electricity sources. Reducing costs was the primary priority for solar technology research, and the U.S. Department of Energy (DOE) launched the SunShot Initiative in 2011 with an aggressive cost target and a timeframe to unlock solar deployment—$0.06 per kilowatt-hour (kWh)[1] by 2020 for utility-scale photovoltaic (PV) systems.

Over the past decade, we have seen the solar industry successfully reduce costs for utility-scale systems, reaching the SunShot 2020 cost target in 2017 and cutting costs further to $0.045 kWh in 2019. These cost declines have been fueled by global economies of scale, innovation, and increased confidence in the long-term performance of solar technologies. As a result of these cost declines and federal, state and local incentives, solar deployment has increased significantly over the past decade. Solar power now supplies nearly 3 percent of U.S. electricity with 80 gigawatts (GW) of installed capacity in early 2020.[2] Some regions of the country are seeing even higher penetrations, with solar generating more than 10 percent of electricity annually, with moments where solar and wind have generated 70 percent or more of the instantaneous power.  For the past seven years, solar has been one of the top three sources of new electric generating capacity added to the grid.

This rapid increase in deployment brings new challenges and new opportunities for solar energy research, through a focus on how solar energy integrates with other technologies and the grid. Solar power electronics, primarily inverters, need to support the stability of the grid in real-time. The design and operation of the distribution system, which now hosts over 2 million individual PV systems, must adapt to accommodate two-way power flow and remain cyber-secure in areas with high penetrations of PV. And we want to harness opportunities for these distributed energy resources to provid ntial PV systems, like customer acquisition, permitting, interconnection, and installation labor, have decreased much more slowly than hardware costs and require new approaches. For CSP, a lack of scale in deployment and a need for a step change in technology (i.e., Generation 3 CSP) have hindered cost reductions.

At the same time, we continue to place a priority on reducing solar electricity costs, which supports greater energy affordability. We have not yet achieved the cost targets DOE set for commercial and residential PV systems or concentrating solar-thermal power (CSP) systems. While costs have fallen significantly, the soft costs of commercial and residential PV systems, like customer acquisition, permitting, interconnection, and installation labor, have decreased much more slowly than hardware costs and require new approaches. For CSP, a lack of scale in deployment and a need for a step change in technology (i.e., Generation 3 CSP) have hindered cost reductions.

We will also tackle the challenges and opportunities solar faces as a more mature technology. These include enabling all Americans to have access to solar energy, applying solar in new market segments, growing beyond electricity generation—such as desalination, fuel production, and industrial process heat—and dealing with the waste stream produced when solar technologies reach their end of life.

This coming decade will be an incredibly exciting time to be working on the advancement and application of solar energy technologies. While our challenges today are different than those of the prior decade, they are no less significant, and we continue to need your innovative ideas and hard work to realize solar energy's potential as a power source for the country and the world.

Becca Jones-Albertus

**Becca Jones-Albertus, Director**
Solar Energy Technologies Office
U.S. Department of Energy

1 The original SunShot goal was $1 per Watt, but throughout the course of the decade, it became clear that levelized cost of electricity (LCOE) was a better metric than installed cost, as it included important factors like cost of capital, operations and maintenance costs, system degradation rate and lifetime. SETO calculates LCOE without subsidies in an area of average U.S. climate.

2 Wood Mackenzie Power & Renewables/SEIA U.S. Solar Market Insight, *Annual U.S. PV Installed Capacity and Forecasts (MWdc), Cumulative Pre-2010 - 2020YTD*, May 2020. Capacity is in DC. The U.S. Energy Information Administration reports an installed AC capacity of 59 GW at the end of 2019.

3 : U.S. Energy Information Administration, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861.
e.g., CAISO, "2019 Statistics," http://www.caiso.com/Documents/2019Statistics.pdf.

# Executive Summary

SETO held its 2020 peer review April 6-8, 2020 virtually, due to the COVID-19 pandemic. The peer review brought together independent, third-party experts in the solar industry to evaluate SETO-funded solar research and development projects as well as overall progress toward SETO goals. The findings help to inform SETO's work, investments, and strategy.

The plenary session of the peer review was attended by approximately 800 people, including awardees and SETO staff. Assistant Secretary of the Office of Energy Efficiency and Renewable Energy Daniel R. Simmons gave the keynote address, followed by a presentation from SETO Director Dr. Becca Jones-Albertus that highlighted the current state of the solar industry, SETO's history, and SETO's accomplishments and capabilities. The remainder of the peer review was divided into breakout sessions for the different technology tracks, where SETO staff presented on current research and development projects and held discussions with reviewers.

This report summarizes the wide range of feedback from the reviewers, on project and portfolio levels. Overall, reviewers are confident that SETO is developing funding opportunities that are making a positive impact on solar energy, funding for projects is effectively allocated, and the projects are helping to meet the goals of the office. While there are no major gaps in funding or opportunities, there are three recurring themes that appeared across all the tracks.

The first is that SETO should broaden its approach to goal setting and measurement beyond the levelized cost of electricity (LCOE) metric. Reviewers noted that while LCOE is an important metric, especially when studying specific geographic regions, it does not incorporate grid interaction costs, which will become increasingly important. Other potential metrics are energy payback and carbon intensity. Additionally, measurement of progress could be linked to the technology readiness level of the work being funded.

The second theme is the dissemination of research findings and the importance of stakeholder engagement. Reviewers believe that the critical findings of projects do not always reach all of the industry players who could benefit from the information. While many projects incorporate stakeholder engagement tasks, the reviewers said SETO should not solely rely on awardees to communicate that information to the industry and would benefit from developing additional strategies to increase dissemination. Sharing project results more broadly will give SETO's funding greater impact and relevance.

Finally, reviewers believe SETO should place greater emphasis on "solar plus" solutions, which carries implications for all the tracks of the peer review. Storage plays a large part in this, as CSP and battery technology will become increasingly important in improving the dispatchability of solar energy. Additionally, as more people choose to drive electric vehicles, solar energy can play a larger role in powering them. Solar-generated heat can also play a larger role in industrial processes. While solar panels on rooftops are important to advancing the industry, broader applications should be considered.

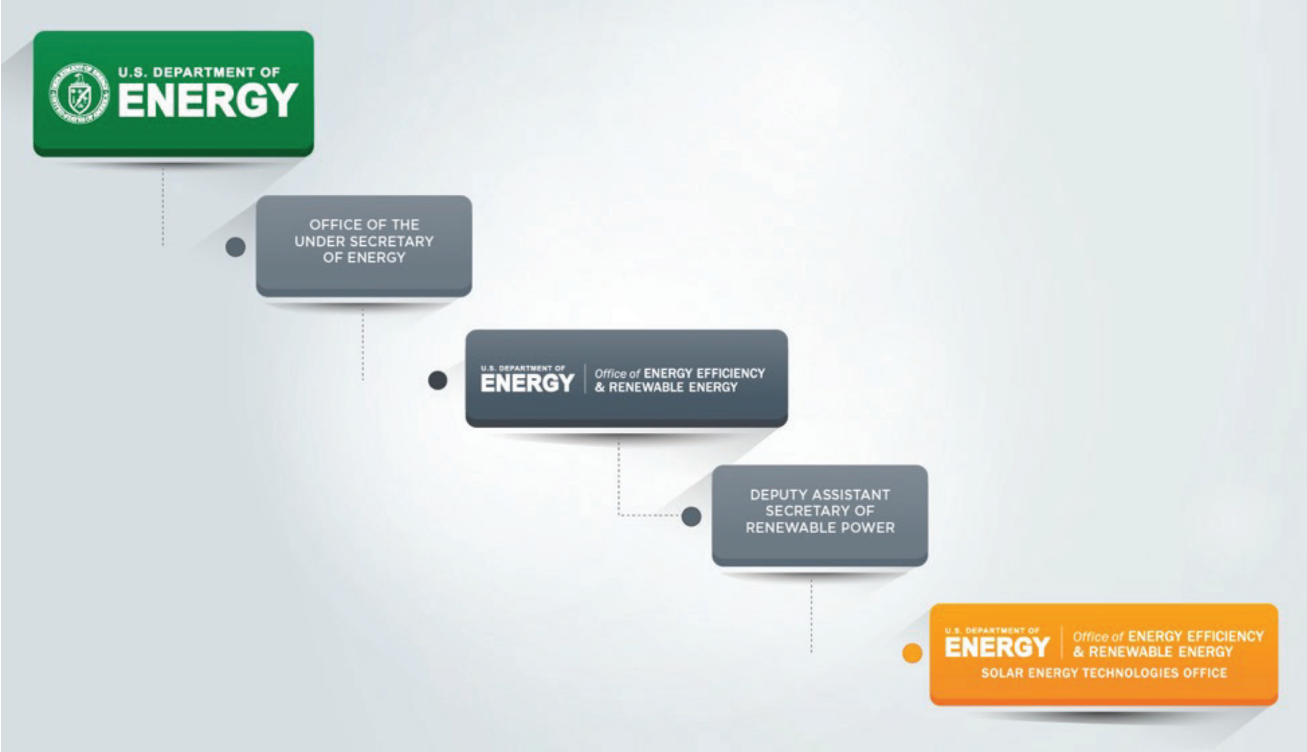
# Introduction

SETO funds early-stage research, development, and demonstration of solar energy technologies with the goal of improving the affordability, performance, and value of solar technologies on the grid. The office works toward these goals in three ways:

- Advancing research, development, and demonstration of PV and CSP technologies to drive U.S leadership in innovation and reductions in solar electricity costs.
- Enabling solar to support grid reliability and pairing it with storage to provide new options for community resilience.
- Providing relevant and objective technical information on solar technologies to stakeholders and decision-makers.

SETO is the primary funder of solar technologies research within the DOE. Within DOE, SETO sits within the Renewable Power pillar of Office of Energy Efficiency and Renewable Energy (EERE). There are nearly 400 active projects in the office's portfolio, currently touching 38 states across the country and the District of Columbia. These projects are led by National Laboratories (currently 40 percent of projects); universities (currently 35 percent of projects); and businesses, nonprofits, and state and local governments (currently 25 percent of projects), with many projects having a diverse set of partners supporting the work.

The federal government has funded solar technologies research since the 1970s, from the very beginnings of the DOE. When establishing the Department, Congress specified that one of its purposes was "to place major emphasis on the development and commercial use of solar…and other technologies utilizing renewable energy resources." The first office to combine separate PV, CSP, and solar buildings (solar hot water) programs was the Office of Solar Energy Technologies, which was created in 2000. The office was formally named the "Solar Energy Technologies Office" in 2012 and from 2011-2017 was also known as the "SunShot Initiative."




*US DOE Organizational Chart*

Because of this long history, DOE's solar office has impacted nearly every part of the industry, driving down the cost of solar technologies, addressing the challenges of adding it to the grid, and easing the process for consumers to go solar. For example, DOE funding has a long history of supporting research and development of cadmium telluride (CdTe) thin-film solar cells, which have been commercialized by First Solar, the largest U.S. manufacturer of photovoltaic modules. The office has also led the world in developing CSP technologies, including funding the first demonstration of molten salt tower technologies. Numerous other companies credit DOE funding to the early development of new solar technologies that later became commercially successful, and SETO awardees have achieved nearly half of all solar cell efficiency world records.[4]

## Office Leadership and Structure

Since November 2019, the office has been led by Dr. Becca Jones-Albertus. Prior to that, she was the deputy director for three years while Dr. Charlie Gay was director. She joined SETO in 2013 as the Photovoltaics program manager. Maria Vargas joined the team as deputy director (on detail) in November 2019 and is also the director of DOE's Better Buildings Initiative. The office is divided into five teams, as described below. Each team manages between 60-150 active projects, develops funding opportunity announcements, and directs ongoing national laboratory research.

**Dr. Becca Jones-Albertus**
*Director*

**Maria Vargas**
*Deputy Director (on Detail)*

**Dr. Elaine Ulrich**
*Senior Advisor*

**Ebony Brooks**
*Operations Advisor*

**Dr. Lenny Tinker**
*Photovoltaics Program Manager*

**Dr. Avi Shultz**
*Concentrating Solar-Thermal Power Program Manager*

**Dr. Guohui Yuan**
*Systems Integration Program Manager*

**Garrett Nilsen**
*Manufacturing and Competitiveness Program Manager*

**Open Position**
*Strategic Analysis and Institutional Support Program Manager*

*SETO Management Team*

**Photovoltaics** – The PV team works to improve efficiency and reliability and lower manufacturing costs of PV panels, with an overall goal of driving down the cost of electricity from solar photovoltaic technologies. The team funds innovative concepts and experimental designs across a range of materials that have the potential to make solar energy among the least expensive forms of electricity.

**Concentrating Solar-Thermal Power** – The CSP team supports the development of novel CSP technologies that help to lower costs, increase efficiency, and provide more reliable performance relative to current CSP technologies. This team supports research and development that advances Generation 3 CSP technologies, which utilize high-temperature components and integrated assembly designs with thermal energy storage that can reach operating temperatures greater than 700 degrees Celsius. The team also works to advance new applications for the technology, from solar desalination to thermal industrial processes.

4 Based on SETO analysis of NREL's efficiency chart.

**Systems Integration** – The Systems Integration team works to enable the safe, reliable, and cost-effective integration of solar energy on the nation's electricity grid, developing solutions that ensure compatibility with existing infrastructure while enabling a smooth transition to a secure and resilient grid of the future. The Systems Integration team collaborates with other DOE offices as part of the DOE's Grid Modernization Initiative.

**Strategic Analysis and Institutional Support** – The Strategic Analysis and Institutional Support team supports the development of analysis, tools, and data resources that reduce the cost of solar technologies alone and on the grid. This includes an emphasis on programs that reduce the soft costs of solar like the costs associated with permitting, siting, interconnecting, or financing a system, which often are the result of information gaps that slow decision-making and increase costs.

**Manufacturing and Competitiveness** – This team—also known as "Technology to Market"—works with private companies to investigate and validate groundbreaking, early-stage solar technology and support a skilled workforce. The goal is to strengthen innovative concepts and move them toward readiness for greater private sector investment and scale-up to commercialization. Manufacturing and Competitiveness, in close collaboration with the office's other teams, also manages several prize programs, which leverage American innovation and competitive spirit to advance new ideas in solar energy.

## Solar Energy Technologies Office Cost Targets

In 2011, the Energy Department launched the SunShot Initiative with its ambitious goal: to drive down the cost of solar electricity to be cost-competitive with traditional energy sources by 2020. The target was a levelized cost of energy of 6 cents per kWh. To accomplish this goal, SETO undertook a broad strategy ranging from research and development of solar generation and integration technologies, to better installation, design, and permitting approaches for solar energy systems.

When DOE established the SunShot goals, solar represented a tiny fraction of the country's electricity supply, with about 2 gigawatts (GW) of solar capacity[5] and a utility-scale LCOE of $0.28 per kWh.[6] After just seven years of remarkable progress, the industry achieved the utility-scale goal of the SunShot Initiative in 2017—three years early.

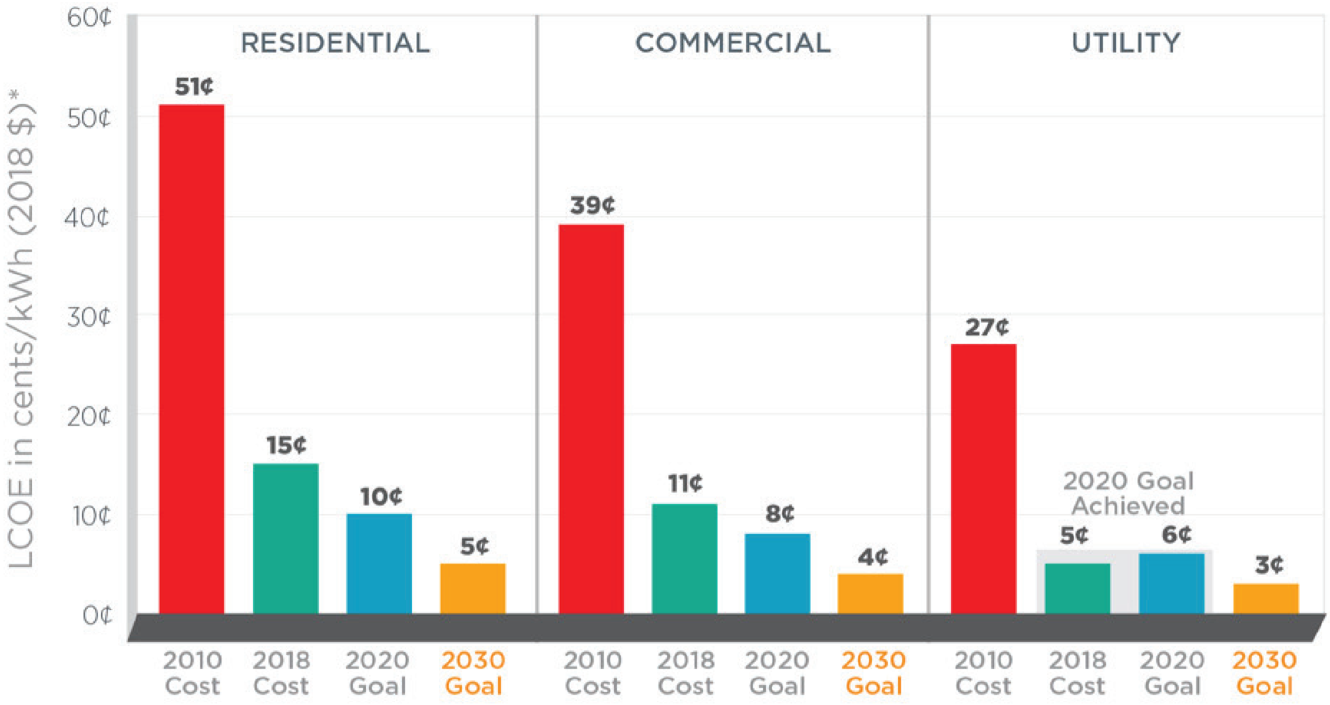
Now, as we start a new decade, solar provides about 3 percent of U.S. electricity,[7] with nearly 80 GW installed and more than 2.4 million solar energy systems.[8] In some states and regions, solar represents over 10 percent of annual electricity generation.[9] Instantaneous solar and wind generation can reach a much higher level, 70 percent or higher in some cases.[10]

Work still remains to hit the 2020 commercial and residential cost targets, for which the soft costs (e.g., customer acquisition, siting, permitting, interconnecting, financing and installing) are roughly two-thirds of total system costs and have been more difficult to reduce than hardware costs. However, these costs have fallen significantly—roughly 70 percent—since 2010.

In 2016, recognizing the importance of continued cost reductions to industry growth and solar's affordability, DOE established cost targets for 2030, which seek to cut the levelized cost of (solar) energy (LCOE) an additional 50 percent, while facilitating grid integration and opening new markets. Achieving these targets would make solar one of the most affordable sources of new electricity generation.[11] The 2030 targets for the unsubsidized LCOE at the point of grid connection[12] are:

- $0.03 per kWh for utility-scale PV
- $0.04 per kWh for commercial rooftop PV
- $0.05 per kWh for residential rooftop PV

5 Wood Mackenzie/SEIA Solar Market Insight Report, May 2020.
6 https://www.energy.gov/eere/solar/sunshot-initiative
7 U.S. Energy Information Administration (EIA).
8 Wood Mackenzie/SEIA Solar Market Insight Report, May 2020.
9 U.S. Energy Information Administration (EIA). In California, solar has reached 19 percent.
10 California reached 70% on May 15, 2019, http://www.caiso.com/Documents/2019Statistics.pdf. Maui peaked at 80% on April 14, 2018, https://www.hawaiianelectric.com/ documents/about_us/company_facts/power_facts.pdf.
11 U.S. Department of Energy. The SunShot Initiative's 2030 Goal: 3¢ per Kilowatt Hour for Solar Electricity. 2016. https://www.energy.gov/sites/prod/files/2016/12/f34/SunShot%202030%20Fact%20Sheet-12_16.pdf
12 U.S. Department of Energy Solar Energy Technologies Office. "Goals of the Solar Energy Technologies Office." https://www.energy.gov/eere/solar/goals-solar-energy-technologies-office

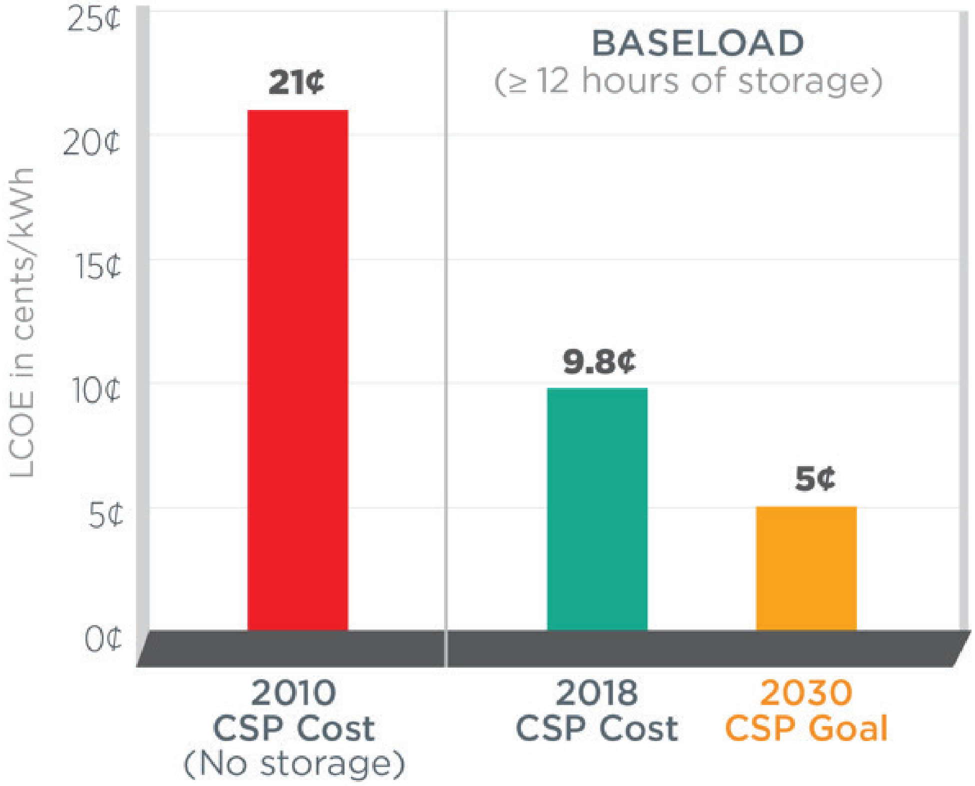



*2010 and 2018 costs, with 2020 and 2030 PV LCOE cost targets across the three solar market segments: residential, commercial, and utility-scale. The PV LCOE numbers are calculated based on average U.S. climate and without the Investment Tax Credit. For example, a $0.03 LCOE for utility-scale would translate to $0.02 to $0.04 LCOE across the continental United States because of differences among locations in the amount of sunlight and in temperature, snow accumulation, and wind speed. The 2020 residential and commercial goals have been adjusted for inflation.*

In addition, the office has set a cost target for next-generation CSP plants, which incorporate thermal energy storage to provide solar energy when the sun is not shining. These next-generation plants raise the temperature of the heat they deliver to the power cycle, thereby increasing the efficiency of the plant. The Generation 3 Concentrating Solar Power Systems (Gen3 CSP) funding program provided $85 million for research to advance high-temperature components and develop integrated assembly designs with thermal energy storage that can reach operating temperatures greater than 700 degrees Celsius (1,290 degrees Fahrenheit). If successful, these projects could enable significantly higher solar-to-electricity conversion efficiencies, particularly in combination with advanced power cycles based on supercritical carbon dioxide. CSP funding is also addressing other system costs, including those of the heliostat field, operations and maintenance, and advanced power cycles.

As a result of the recent progress in cost reduction and the rapid growth in solar deployment, research must address the challenges solar faces as a more mature industry. A modern grid must integrate diverse generation and energy-efficiency resources, including those that are customer-sited and variable, while ensuring reliable power. It must also be dynamic and integrate sensor data to better satisfy customer demand and detect and mitigate disturbances. Strong protection against physical and cyber risks is also imperative. In order to accomplish these tasks, SETO participates in DOE's Grid Modernization Initiative, a crosscutting effort that aligns grid modernization efforts across multiple DOE program offices. As part of the initiative, SETO's systems integration team supports targeted technology R&D that addresses the technical challenges with achieving higher solar penetration, while supporting a safe, reliable, secure, and cost-effective electric power system.

13 U.S. Department of Energy Solar Energy Technologies Office. "Generation 3 Concentrating Solar Power Systems (Gen3 CSP). https://www.energy.gov/eere/solar/ generation-3-concentrating-solar-power-systems-gen3-csp.



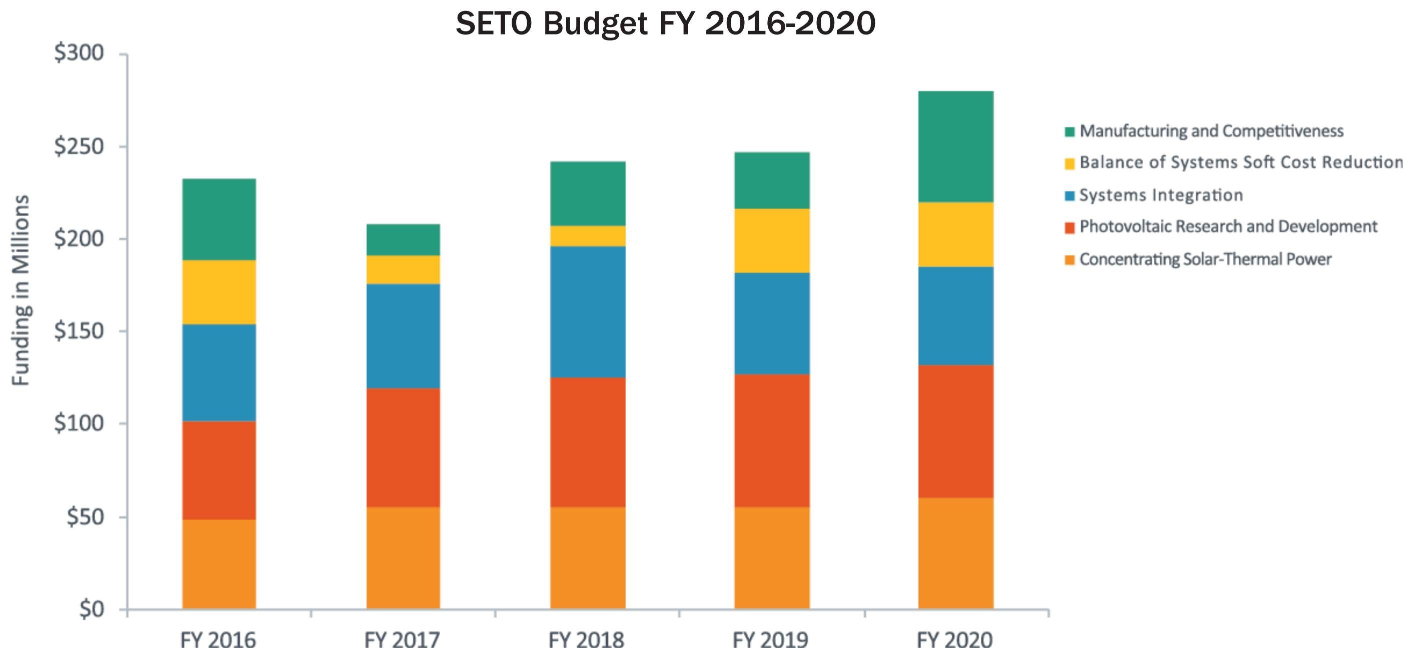

*2030 CSP LCOE cost targets for CSP plants with 12 or more hours of storage.*

It is expected that the 2020s will be a decade of continued solar growth across the U.S. into new markets, like agricultural businesses and multi-family housing. These new areas require additional research to tackle complex challenges, whether related to cost, technology, or other requirements such as permitting. Agricultural solar applications, for example, may need different siting and installation practices than typical utility-scale solar systems. In addition, communities that want to use solar to increase their resilience may need different cost-benefit models than those that want to use solar only for energy production. The office will continue to provide objective information, pilot smart innovation, and develop and disseminate best practices to continue the growth of solar in more diverse and unique applications.

Growing solar manufacturing in the United States is a key priority for DOE. Due to a number of factors including the Section 201 tariffs, the country's PV module capacity more than tripled in 2019, according to a forthcoming report from the National Renewable Energy Laboratory about domestic solar PV manufacturing expansions. While the growth in solar PV module manufacturing is encouraging, SETO is also working to expand the opportunities for manufacturing across the value chain—from PV cells to power electronics, to developing the tools used in operations and maintenance. A strong U.S. solar manufacturing sector and supply chain enable the nation to keep pace with the rising domestic and global demand for solar energy products. As the solar industry enters the next decade, SETO is working to integrate solar into the fabric of the American landscape—to help communities achieve their energy and resiliency goals, explore new applications of solar, drive innovation and entrepreneurship, and lower electricity costs.

## SETO Budget and Funding Overview

SETO is funded through the annual appropriations process in Congress. In the past five years, the solar office budget has increased roughly 20 percent, from $230 million in fiscal year (FY) 2016 to $280 million in FY 2020. Since FY 2017, Congress has specified amounts for specific budget areas that segment SETO's funding. These budget areas do not exactly correspond to SETO's team structure, but determine the amount of funding that we must allocate to specific research areas. The breakdown by budget area over time is shown below.




*SETO's budget areas are determined by Congress through the annual appropriations process.*[12]

Congress also directs some funding to certain technology areas and funding programs such as Solar Ready Vets and the National Community Solar Partnership. From FY 2017 to FY 2020, Congress directed the office to fund solar desalination technologies, resulting in the $21 million Solar Desalination Funding Program and the $10 million American-Made Challenges: Solar Desalination Prize.

SETO's funding supports projects at National Laboratories, universities, businesses (nonprofit and for-profit), and government agencies. Each of these groups has unique capabilities and needs, so specific funding opportunities may target different groups. For example, funding that provides access to unique facilities for testing and measurement or strategic analysis is typically focused at National Laboratories. Funding aimed at developing novel, high-risk technologies is primarily focused at universities. In contrast, funding opportunities advancing emerging solar technologies are typically open to all stakeholder groups and coordinated with a transition to the private sector through project partnerships.

14 The National Renewable Energy Laboratory. Solar Photovoltaic (PV) Manufacturing Expansions in the United States, 2017-2019: Motives, Challenges, Opportunities, and Policy Context.

15 Note: "Balance of Systems Soft Costs Reduction" is primarily managed by SETO's "Strategic Analysis and Institutional Support" team.

The office awards most of its funding through competitive solicitation processes. The primary mechanisms are:

**Funding Opportunity Announcements (FOAs) (typically 55-70 percent of funding):** FOAs solicit projects from across the research, industry, National Laboratories, and stakeholder community to achieve the office's goals. Historically the office ran multiple FOAs each year on different topics, but since 2018, SETO has run one annual umbrella FOA with numerous topics spanning the office's priorities. On average, these projects run from two to five years in length and range from $250,000 to $5 million in size. Projects must meet aggressive milestones to receive funding.

**Prizes and Challenges (typically up to 10 percent of funding):** Prizes and challenges establish goals that teams must achieve and reward the ones that perform the best. Prizes help to spur innovation and competition while encouraging private-sector engagement by lowering the barrier to entry for government funding. SETO has executed several competitions, including the Solar in Your Community Challenge, and helped to launch the American-Made Challenges, an effort that encourages the development of innovations that can be manufactured in the U.S. The office has launched three rounds of the American-Made Solar Prize, as well as the Solar Desalination Prize, as part of this effort.

**Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs (typically 4 percent of funding):** The SBIR/STTR programs are competitive, congressionally mandated funding opportunities that encourage U.S.-based small businesses to engage in high-risk, innovative research and technology development with the potential for future commercialization. The program is managed by DOE's Office of Science and awards projects in technology areas across the entire department. It is part of the larger SBIR program across the federal government, which is administered by the Small Business Administration. SETO funds companies that are working to advance the affordability, reliability, and performance of solar technologies on to the grid. SETO also funds projects at small businesses through its FOA processes.

**National Laboratory Funding:** SETO partners with the National Labs and its researchers to develop innovations that lower the costs of solar energy. Today, 40–50 percent of SETO's funding is awarded to National Labs through multi-year funding programs specially designed for National Labs, FOAs (described above), and collaborative research projects with industry stakeholders and other offices and initiatives in the DOE. Specific funding related to labs (typically 25-35 percent of total SETO funding) includes:

> **Lab Calls:** Every three years, the office issues calls for proposals on particular topics that are only available to National Laboratories. Similar to the FOAs open to the public, National Labs submit proposals that are then evaluated by merit reviewers and DOE technical staff before selections are made.
>
> **Programs and Initiatives:** SETO funds programs, collaborative initiatives, and prize competitions at the National Labs, enabling the labs to bring together diverse partners and connect them with lab and other resources. SETO's funding enables the labs to provide expert information and technical assistance to a broad set of stakeholders.
>
> **Directed Research Projects at the National Laboratories:** SETO also directly initiates research projects at the National Labs on strategic priorities on an ongoing basis. For example, projects conduct informative analysis on solar energy technologies and the solar industry, such as using bottom-up, techno-economic cost modeling.
>
> **The Technology Commercialization Fund (TCF):** TCF is a competitive laboratory funding opportunity designed to help commercialize promising energy technologies developed at National Laboratories. The TCF is administered by the DOE's Office of Technology Transitions and is part of a set of initiatives to foster stronger partnerships among DOE facilities, private companies, and other entities that bring energy technologies to the marketplace. SETO awards funding to projects focused on bringing solar energy technologies from the labs to market.

## Peer Review Overview

The SETO 2020 peer review, held virtually due to the COVID-19 pandemic, engaged leading solar industry experts to review progress across the portfolio. The review covered nearly 400 active projects in the office's portfolio, accounting for nearly $750 million in federal funding. Reviewers evaluated the relevance and impact of each individual project and the portfolio as a whole. Further, reviewers examined how the office aims to meet the industry's future needs, whether it asks the right questions, and how it should adjust to the changing energy landscape. The findings outlined in this report will help identify strategies to shape SETO's work in the future.

### Funding and Research Area Terminology

**Budget Areas**

Congress provides funding to SETO in the following areas:

- **Photovoltaics,**
- **Concentrating Solar-Thermal Power,**
- **Systems Integration,**
- **Innovations in Manufacturing and Competitiveness, and**
- **Balance of Systems Soft Costs Reduction**

**Teams**

The office is structured in the following teams:

- **Photovoltaics,**
- **Concentrating Solar-Thermal Power,**
- **Systems Integration,**
- **Manufacturing and Competitiveness, and**
- **Strategic Analysis and Institutional Support**

**Tracks**

The peer review will evaluate the portfolio in the following tracks:

- **Photovoltaics,**
- **Concentrating Solar-Thermal Power,**
- **Systems Integration,**
- **Soft Costs, and**
- **Planning and Strategy**

These tracks combine projects from different teams

*While there are some consistent terms that are used to divide the office's portfolio into different areas, some areas, like "soft costs," change across the congressionally determined budget areas, the office's team structure, and the peer review tracks.*

Nearly 100 reviewers divided among five tracks: Photovoltaics, Concentrating Solar-Thermal Power, Systems Integration, Soft Costs, and Strategy and Planning. The tracks reviewed all the projects managed by SETO's teams; however, the projects managed by the Manufacturing and Competitiveness team and the Strategic Analysis and Institutional Support team were bucketed into the relevant technology track rather than in a separate track. The Strategy and Planning track, which does not directly map to a specific team, includes strategic analysis projects that investigate the industry as a whole and inform SETO priorities, and examines the entire SETO portfolio from a broader perspective.

**CSP Track**

*Includes projects from...*

**CSP Team**

*Supports early-stage research and development projects in CSP.*

**Manufacturing and Competitiveness Team**

*Moves projects toward readiness for greater private sector investment and scale-up to commercialization.*

**Stategic Analysis and Institutional Support Team**

*Supports the development and dissemination of analysis, tools, and data resources.*

*The CSP peer review track includes projects from the CSP team, the Manufacturing and Competitiveness team, and the Strategic Analysis and Institutional Support team.*

For purposes of the peer review, the five tracks were subdivided into 18 topic areas to facilitate presentation and discussion during breakout sessions. During these breakout sessions, SETO staff provided a broad overview of the office's strategy, funding, and projects in that area and allowed for discussion amongst reviewers. These topics were reviewed based on how the projects within them help to achieve the office's broader goals and where the office could break new ground. Reviewers were also able to discuss critical areas that needed improvement in that topic area, such as stakeholder engagement, technology relevance, or other areas.

## SETO Peer Review Tracks and Topic Areas

### Photovoltaics

- Commercial PV Technologies
- Reliability and Standards Development
- System Design and Energy Yield
- New Cell and Module Structures, Designs, and Processes

### Concentrating Solar-Thermal Power

- CSP Systems
- High Temperature Thermal Systems
- Power Cycles
- Solar Collectors
- Desalination and Other Strategy and Planning Processes

### System Integration

- System Operation Reliability
- Power Electronic Devices and Control
- System Planning Models and Simulations
- PV for Resilient Distribution Systems

### Soft Costs

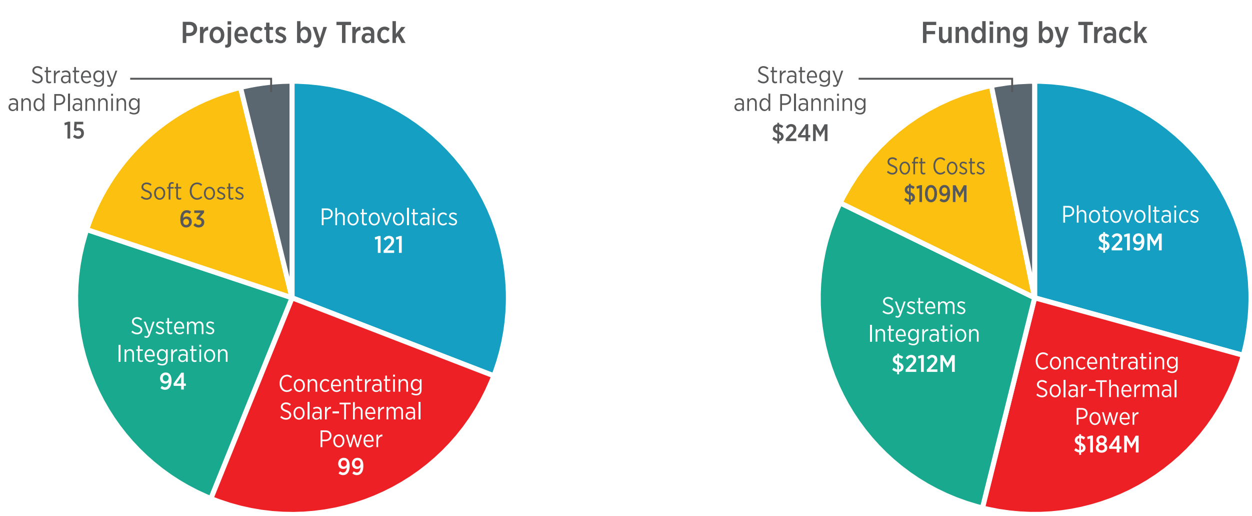
- PV Markets and Regulation
- Solar Energy Access
- Workforce

### Strategy and Planning

- Technology to Market
- Cross-Cutting
- Portfolio Review

*Projects in the SETO peer review are divided among five tracks and 18 topic areas.*

The peer review covered 391 projects at various stages of their project cycles—some had recently been selected and hadn't yet begun work, while others were about to conclude. Projects were not distributed evenly throughout the tracks—roughly 30 percent of the projects and funding were reviewed in the Photovoltaics track, while the Strategy and Planning track reviewed just four percent of projects and three percent of funding. However, the Strategy and Planning track also examined the portfolio as a whole. Insights from each track will inform our overall strategic planning.




*The projects in the peer review are divided by research areas with breakdown by number of projects (left) and funding (right) shown.*

## Final Report Outline

This report details the feedback provided by independent, third-party reviewers regarding SETO's overall goals and strategy and how the portfolios address these goals, the appropriateness of project selection and funding amounts, and the effectiveness of these projects in advancing the solar industry as a whole. SETO assigned each reviewer an average of 15 projects to review. These project-level reviews will inform the review of the topic area, tracks, and portfolio as a whole.

This report is organized by track and topic area, and includes the responses written by chairs and lead reviewers, as informed by the project-level reviews and group discussions held with and without SETO staff during the peer review. The project-level reviews can be found in the appendix of this report.

# Photovoltaics

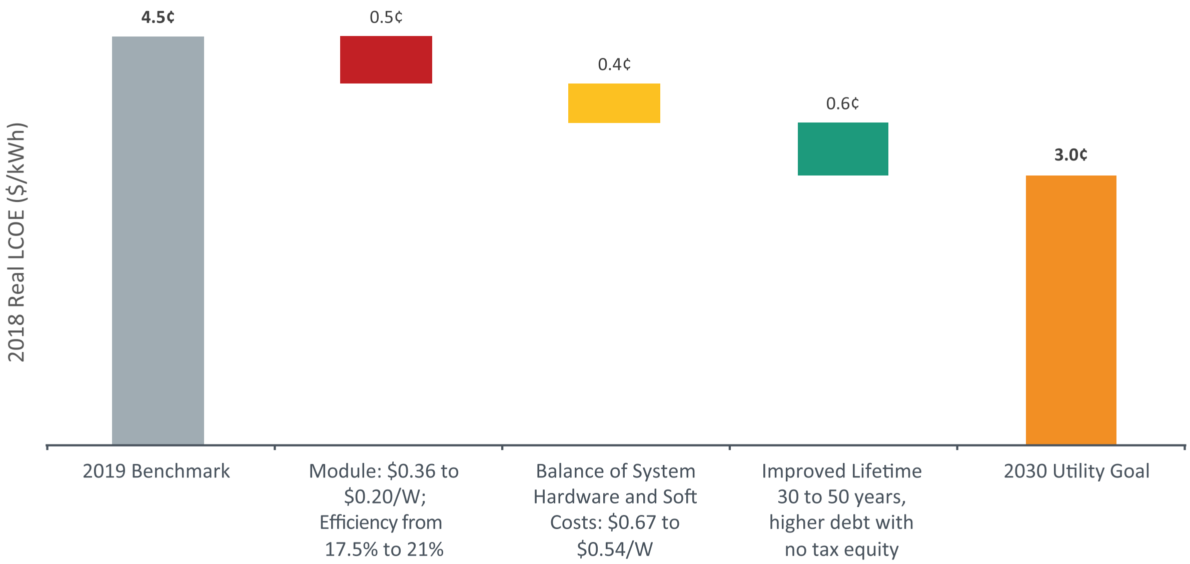
Projects in the Photovoltaics track support research and development of technologies that drive down the costs of solar electricity by improving efficiency and reliability of PV and lowering manufacturing costs. This portfolio of projects spans the Photovoltaics, Manufacturing and Competitiveness, and Strategic Analysis and Institutional Support teams, funding innovative concepts and experimental designs across a range of technology approaches that show promise to achieve significant cost reductions.

There are 121 active projects reviewed as part of the Photovoltaics track, projects that total more than $219 million in federal funding; nearly one in three SETO projects. The projects focus on innovations that have the potential to achieve commercial success in the short term or in 10-20 years. This creates an innovation ecosystem in the United States, supporting the long-term growth of the solar industry.

The projects in the Photovoltaics track work to maintain U.S. leadership in photovoltaic research and development, with a strong record of impact over the past several decades. Approximately half the world's solar cell efficiency records, which are tracked by the National Renewable Energy Laboratory, were supported by the DOE, mostly by the SETO Photovoltaics team and its predecessors.

The Photovoltaics track includes 10 projects from SETO's Manufacturing and Competitiveness team, which investigates and validates groundbreaking, early-stage solar technology to strengthen concepts and move them toward readiness for greater private sector investment and commercialization. These projects help to strengthen the U.S. energy manufacturing sector and supply chain to produce cost-competitive photovoltaic systems. A few projects from the Strategic Analysis and Institutional Support team are also included, which support the development and dissemination of analysis, tools, and data resources related to the cost and value of solar technologies alone and as they integrate with other technologies on the grid.

The PV industry has come a long way in the past decade, with the cost of electricity produced by residential solar installations dropping more than 70 percent and the cost of utility-scale installations dropping more than 80 percent.envisions further cost reductions in the coming decade, which motivates the current research and development projects in the Photovoltaics track.

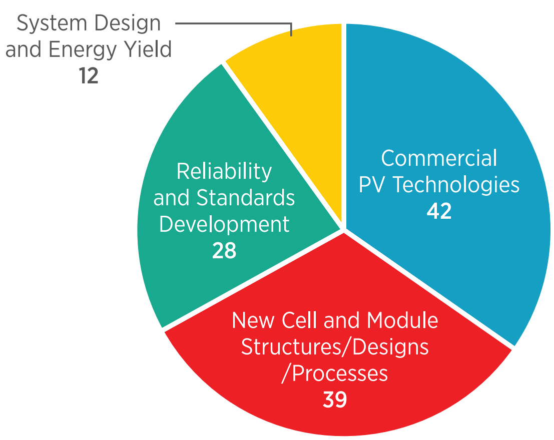



*Sample scenario for reducing costs to $0.03 per kWh for utility-scale systems.*

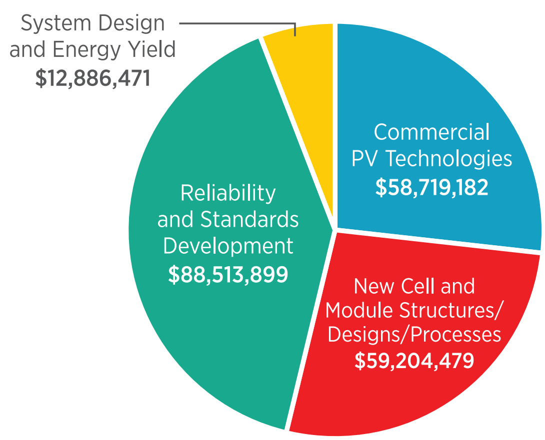
As shown in the figure above, future improvements in the module cost, balance of systems hardware and soft costs (such as installation and permitting), and lifetimes of photovoltaic technologies have the potential to further reduce the cost of solar power and contribute to greater energy affordability. SETO is working toward a levelized cost of $0.03/kWh for utility-scale solar photovoltaics, $0.04/kWh for commercial systems, and $0.05/kWh for residential rooftop systems. SETO set these targets to provide a cost cushion for augmenting technologies that can work in concert with photovoltaics to better support the grid, such as energy storage. Various combinations of improvements to module efficiency, system component price, and system lifetime will help reach the goal, but further advances in reducing project development and construction time and reducing the cost of capital for project financing (covered by work in the Soft Costs track) are also important pieces of the puzzle.

SETO supports photovoltaic module technologies that have the potential to be manufactured domestically or serve as material inputs to global photovoltaics manufacturing while offering a competitive advantage over commercial technologies. These initiatives support both novel devices and novel materials. Novel device research in the portfolio includes advanced versions of silicon, thin-film, and III-V cells, as well as tandem concepts combining two different photovoltaic materials. Novel materials in the current portfolio include advanced module packaging, new photovoltaic absorbers, and innovative methods of making electrical contact in a cell.

**Photovoltaics (PV) Projects by Topic Area**




**Photovoltaics (PV) Funding by Topic Area**



The Photovoltaics track has focused its projects in four major topic areas: Commercial Photovoltaic Technologies, Reliability and Standards Development, System Design and Energy Yield, and New Cell and Module Structures, Designs, and Processes.

Below is a summary of the findings from reviewers in the Photovoltaics track, written by the track chairperson, Dr. Sarah Kurtz, Professor of Engineering at the University of California Merced, based on her observations and the group discussions during the peer review. Following the track summary, the four topics within the Photovoltaics track are highlighted in greater detail, written by lead reviewers:

- Commercial Photovoltaic Technologies (Terry Jester, CEO, SolPad)
- Reliability and Standards Development (Rhonda Bailey, Founder, RB RE Consulting LLC)
- System Design and Energy Yield (Scott Stephens, Director, Clearway Energy Group)
- New Cell and Module Structures, Designs, and Processes (John Benner, Executive Director, Bay Area Photovoltaic Consortium at Stanford University)

Individual project reviews for the Photovoltaics track can be found in the Photovoltaics Appendix.

## Reviewer Feedback: Goals and Strategy

SETO has set a primary goal of $0.03 per kilowatt-hour (kWh) for the levelized cost of energy (LCOE) in Kansas City, MO for utility-scale PV. The goal for commercial PV is $0.04/kWh, and the goal for residential PV is $0.05/kWh. The Photovoltaics track has also identified goals of being able to recover 90 percent of the mass of a PV module for less than $10 cost/module and to make solar accessible for all Americans. More general (non-quantitative) goals include moving toward longer-lifetime modules (maybe 50 years), supporting solar-related jobs, and increasing solar-related manufacturing, including for the supply chain.

The Photovoltaics track follows a strategy of simultaneously increasing efficiency, lowering cost, and improving reliability and durability for modules and other system components as a pathway to lowering the overall cost of solar electricity. This strategy combines system design, yield models, and data validation to guide the efforts toward lower and more reliable LCOE. Low solar LCOE costs, especially combined with low costs of storage, are projected to lead to rapid adoption of solar in the next decades. Although the advancement of solar energy is considered to be SETO's mission, it is not documented as a metric; no target metric has been set, so it is not treated here as a goal.

The Photovoltaics track prioritizes proposals that are most likely to contribute to meeting SETO's goals. This strategy naturally funnels funding toward research directions that show promise, though a portfolio evaluation balances funding across areas of interest. The strategy to support increased U.S. manufacturing appears to focus on development of new technology that could be rapidly scaled in the United States, with a notable emphasis on perovskites. The strategy for strengthening cadmium telluride (CdTe) manufacturing relies on strong involvement by First Solar. The strategies for strengthening manufacturing of silicon and copper indium gallium selenide (CIGS) modules are unclear.

## Reviewer Feedback: Alignment with Goals

Projects have been selected for their ability to improve reliability or efficiency and to reduce cost. In particular, the emphasis on reliability is quite apparent, with about 40 percent of funding in that category. Some of the projects called out as being particularly useful included Photovoltaic Performance Modeling, PV Fleet, and NREL's Core Reliability project.

It is less clear that the projects align well with the goal of increasing U.S. manufacturing, though success with perovskites could position the United States to extend its thin-film manufacturing leadership that First Solar has already established so well.

## Reviewer Feedback: Funding and Resource Allocation

Given the promise of solar energy to play a dominant role in future sustainable-energy systems, the United States would benefit from a larger budget for SETO. Within the Photovoltaics track, the funding balance is appropriate, but reviewers recommend some adjustments within the topic areas:

- Commercial PV Technologies could have greater impact if companies take a more active role in projects and provide a higher level of cost share.
- New Cell and Module Structures, Designs, and Processes funding is currently dominated by perovskite projects, with a small budget for organic PV (OPV). Organic electronics are becoming successful as organic light emitting devices, mostly through Chinese leadership. The very small budget for OPV mostly abdicates any possibility of U.S. leadership, despite the progress that has been made and potential for organic electronics (including OPV) to become a dominant technology. The opportunity for OPV should be considered along with crosscutting and innovative concepts (e.g., that could enable semi-transparent modules for use on greenhouses and other ways to split the solar spectrum between PV and fuels, industrial heat, or other value-added applications). Some reviewers expressed the contrary sentiment that it would be better to keep funding where it is rather than expanding support of OPV or other high-risk approaches.
- Reliability and Standards Development work should place more emphasis on balance of system components, which are widely reported to fail more frequently than modules, with an eye on the goal of making the entire system (including inverters and racking) last or be easily serviced for 50 years. Storage should be included in this broadened scope, with a current acute need to quantify battery degradation as a function of usage patterns.
- Reviewers noted that Systems Design and Energy Yield is currently funded as about 10 percent of the Photovoltaics track funding, which seems like a small amount for such an important topic. Further discussion noted that some of the Reliability and Standards projects address performance of PV systems, suggesting that the funding is larger than 10 percent, and is, therefore, already appropriate. Performance and reliability are closely linked, and these efforts should be managed in such a way as to take advantage of their synergies, regardless of how they are categorized for review purposes.

## Reviewer Feedback: Topic Area Value

All four topics in the Photovoltaics track provide important value. The emphasis within each area could be shifted to increase the total value, as described above. Some reviewers felt that DOE should stop funding areas that are not showing progress; other reviewers resonated with the observation that it is easy to eliminate a program, but very difficult to rebuild that expertise if there is renewed interest in that technology at a later date, suggesting that continuing a small effort—possibly at the National Labs—may be a good strategy.

## Reviewer Feedback: Advancing the Mission

SETO's mission is to advance solar energy. The established goals are necessary but not sufficient to substantively advance that mission. The selected projects are designed to improve PV module reliability and to develop technology that can increase efficiency or reach lower costs, advancing the technology. But to advance the mission as quickly as we would like, it will be necessary to make that solar electricity dispatchable. This is a critical time to answer many questions about PV-plus-storage systems. Enabling PV-plus-storage systems enhances resilience for residential and commercial systems; for utility-scale, it enables utilities to count PV toward their reserve margins, facilitating wide adoption.

Substantively advancing the manufacturing sector of the U.S. solar industry is likely to require a more strategic approach. We encourage SETO to investigate the best strategies, possibly including a post mortem analysis of how the CIGS program could have been more successful in recent years. SETO's strategy for perovskites will require identifying an entry market.

## Reviewer Feedback: Areas of Improvement

SETO's largest blind spot is related to a lack of projects in the Photovoltaics track that study inclusion of storage in PV systems. (Note from SETO staff: Storage is supported by the Systems Integration team and Strategic Analysis and Institutional Support team; this comment and the narrative below are for the PV-grouped projects, not SETO as a whole.) For solar energy to be a primary energy source, it must be made dispatchable. An understanding of how batteries will perform and age in PV systems will be critical as the fraction of PV systems deployed with battery storage increases. While it might seem that the study of batteries is outside SETO's scope, it is critical that it be included in the study of PV systems. Information provided by battery companies today is inadequate for completing PV system-plus-storage designs, and the success of the batteries to provide multiple years of dispatchable solar energy is becoming increasingly critical to the financial success of solar projects as electricity prices decrease in the middle of the day. PV designers and installers now need to learn how to implement batteries into their systems. SETO is well positioned to support research and standards development to enable PV-plus-storage systems to be implemented reliably and at a competitive cost. Battery requirements for PV systems differ from those for mobile applications. There is no other government agency focused on developing the battery or other storage system that will best serve what is likely to turn into a huge market for grid-tied storage. Therefore, SETO should contribute to filling that void. Wherever possible, SETO should partner with agencies like ARPA-E and EERE's Office of Electricity to test emerging battery technologies in grid-integrated systems. A request for information aimed at those active and interested in PV-plus-storage could help to identify the breadth, prioritization, and future needs of the industry.

## Reviewer Feedback: Final Track Feedback

- PV reviewers believe that SETO has assembled a carefully crafted and executed program, but that there is room to further increase impact and relevance through increased communication and engagement with the community. Key opportunities include:

- Increased industry leadership for Commercial PV Technologies projects (not just a letter of support, but guidance, active participation, and commitment). Reviewers expressed multiple ideas of how this might be implemented, including that each project could be required to have a task that describes how the interaction with industry is handled, especially for large projects that are designed to help transform the U.S. solar industry. Some reviewers expressed the sentiment that some of the academic projects are doing fine without direct industry engagement and that developing a useful capability without a commitment from a specific company may make it easier to have a success introduced into multiple companies later.

  - Use of a national team to better coordinate the perovskite efforts to enable experts to focus on their areas of expertise, sharing samples and analysis to make the larger effort more effective. A perovskites national team might include individuals with industry experience so as to not repeat the mistakes of the CIGS industry. Coordination with other government agencies, such as the National Science Foundation, could also be beneficial.

  - Active engagement by SETO to share the results of all efforts, especially those of the Reliability and Standards projects, to encourage newcomers to solar (particularly those doing large procurements of modules) to benefit from SETO's work. DOE has a name that is known to everyone and can be effective at reaching a wider audience, while researchers' stakeholder engagement focuses more on interaction with their industry partners.

  - Expand PV Fleet to include routine analysis of a range of performance loss mechanisms (not just degradation) and share this as aggregated data for the benefit of the community, with the goal of increasing electricity yield from U.S. PV systems.

- Reliability and Standards projects should reallocate efforts to tackle balance of systems reliability. PV systems that can last for 50 years will require not just 50-year modules but also racking that doesn't corrode and inverters that either last or can be serviced easily. Reliability and recyclability should be considered throughout the Commercial PV Technologies and New Cell and Module development work.

- As solar electricity reaches 3 percent of U.S. electricity, SETO should broaden its approach to goal setting. The LCOE metric is still important but will no longer be pivotal in the next decade. High penetration of solar will require dispatchable solar, which is not directly tracked with LCOE. When LCOE is used, it will benefit from being geographically specific in order to inform DOE's strategy for broader deployment. For example, utility-scale systems deployed in sunny regions will generate more electricity than the same systems deployed elsewhere, while New England may find it preferable to deploy PV on buildings. LCOE targets should be identified for the relevant geographical markets, reducing the current confusion that perpetuates an impression of solar still being high cost. Additionally, as the solar industry grows to a role of being able to not just compete but also solve the world's energy problems, SETO should track important metrics like energy payback and carbon intensity.

# Commercial Photovoltaic Technologies

As commercial PV modules become more sophisticated, reliable, and efficient, the research community must be increasingly attentive to the state of the industry's leading edge to ensure cell and module technologies remain relevant. Projects in this topic area focus on more traditional technologies like crystalline silicon, as well as improving other promising technologies like CdTe and CIGS.

More than a third of the projects in the Photovoltaics track focus on commercial PV technologies, totaling nearly $59 million in federal funding. The goal of these projects is to create technologies that have higher efficiencies, lower degradation rates, and lower production costs to reach the goal of $0.03/kWh.

### Reviewer Feedback: Goals and Strategy

SETO's strategy and goals are to advance research and development for PV technologies to improve efficiency and reliability, lower manufacturing costs, and drive down the cost of solar electricity by funding research with a 3- to 15-year horizon, which is beyond industry focus or capabilities.

The reviewers in this track had some trouble seeing a cohesiveness as to how best to accomplish the goals. It was undecided as to whether the Commercial PV Technologies topic should emphasize projects heavily supporting existing manufactured technologies that are mostly manufactured abroad, support emerging technologies for future use in the United States, or support a broad portfolio to catch everything. Reviewers agreed that it is important to continue to fund projects that strengthen the foundation of technologies, characterization, and analysis capabilities to study devices and materials, as well as studies of degradation and reliability as it relates to cell processing and materials.

### Reviewer Feedback: Alignment with Goals

The goals are being adequately addressed within the current project portfolio, but receiving influence from industrial partnership is essential. Each of the projects has potential, though sometimes it is challenging to tell whether a project that has efficiency improvement as its goal will ultimately have the chance to lower LCOE. If an efficiency gain costs too much when compared across the whole value chain (including balance of systems and soft costs), then it will likely never get implemented in commercial companies. This can sometimes be difficult to assess and comes through when evaluating individual projects.

### Reviewer Feedback: Funding and Resource Allocation

The larger projects in this topic have sufficient funding. The smaller projects that received $250,000 in funding appeared to promise a disproportionate number of deliverables for their budget. A larger population of projects could be funded at lower levels. Reviewers realize this is harder to manage, but a two-step approach should be considered where projects first provide proof of basic results, followed by larger implementation of findings with an industrial partner. This is likely specific to projects in the Commercial PV Technologies topic.

### Reviewer Feedback: Project Value

Some projects specifically demonstrate measurable impact on SETO goals, industry, and efficiency of modules, and others meet the milestones but potentially have very little impact on technology readiness. The diversity in projects reviewed were broad in the technology readiness levels and in topics within the PV supply chain. SETO has done a very good job of being agnostic in terms of platform, company, university, or institute; this creates a diverse portfolio, but it is sometimes tough to pick winners. If industry partners aren't part of a project, maybe a project review as a major milestone could include industrial technologists.

### Reviewer Feedback: Advancing the Mission

Some of the projects have impact of varying degrees on SETO goals and the industry; others add to the scientific base. Reviewers agree with the SETO mission advancement, but the connection with the U.S. solar industry is difficult. For projects such as development of new dopants and passivation for CdTe, as well as N-type absorbers for CdTe for longer term, these would contribute to further leadership of U.S. industry and provide an opportunity for U.S. industry to compete against silicon technology, which is mainly manufactured outside the U.S. While it is difficult to pick a technology, each group is trying to push its individual approach/solution, but not working in concert with other awardees. A cluster approach to how projects can complement the industry could solve that problem, specifically for silicon module projects, as there are still silicon module makers in the United States. The cluster approach could also apply to supply-chain projects, specifically trying to promote an area of excellence for the U.S. solar industry to excel, such as CdTe.

### Reviewer Feedback: Areas of Improvement

The portfolio of projects indicates no blind spots. Emphasizing the need for industrial partners as well as including the need to check degradation and reliability for some of the projects would be of particular benefit to the technologists and the technologies. SETO appears to have a hard time stopping the funding on noncompetitive or non-impactful avenues of research.

### Reviewer Feedback: Final Topic Feedback

During the FOA application process, Commercial PV Technologies applicants should demonstrate that they are aware of the status of the industry's current technology, and that their project is relevant to help move the leading edge of the technology (or competing technology) forward from a cost, performance, or reliability metric.

A strategy should be developed to guide the areas within this topic that will be supported by SETO. Perhaps an Industry Advisory Board or working group could provide feedback to projects as they are executed. Reviewers believe in the need to bring some industry growth back to the United States, which could begin with the technology projects being supported and helped by industry experts to persuade the large companies and investment communities to support manufacturing of these products.

Projects devoted to improvement of cells or modules need to incorporate reliability tests. It is essential that the module lifetime not be adversely affected by any change in technique or process and that it be extended to lower LCOE.

# Reliability and Standards Development

As new photovoltaic technologies emerge, it's important that they can reliably produce the amount of power they are rated for and able to stand up to a variety of weather conditions. Projects in this category work to understand what causes degradation of photovoltaic modules and systems, how their reliability and durability can be improved, and help to ensure high-quality products capable of long lifetimes. Additionally, these projects work to create industry-wide standards that warrant consistency across photovoltaic products.

Projects in this category are less than a quarter of the overall Photovoltaics track portfolio, which represents more than $88 million in federal funding. By developing solar products that will last for decades, these projects reduce the cost of PV systems by distributing the initial construction costs over a longer timeframe as well as reducing financing risk by better predicting the evolution of a PV system's output over its lifetime.

### Reviewer Feedback: Goals and Strategy

The primary purpose of funding in the Reliability and Standards topic is to develop understanding of degradation in all types of PV modules and systems, develop standards that allow for consistent evaluation of different technologies, and improve module and system durability and lifetimes. These initiatives support SETO's overall goals by providing significant evidence needed by the industry to extend system useful life assumption up to 50 years. Lower LCOE is also supported by proven reduction in module- and system-level degradation.

SETO goals in project selection include using data from fielded modules to inform and improve on future system performance. Incorporating lessons learned from operating systems into new system deployment can reduce uncertainty. In turn, the expectation is that reduced uncertainty also reduces financing costs. Because this topic seeks to improve both component and system lifetimes, the research tackles problems from small to large scale.

Significant effort is also placed on beginning-of-life testing to be used as a proxy for expected field performance. Progress in this topic would be immensely useful to manufacturers; developers; engineering, procurement, and construction professionals; and financing parties, as much transactional effort is wasted trying to align on lifetime, operations and maintenance costs, and degradation models.

### Reviewer Feedback: Alignment with Goals

This topic funds 28 projects: 12 led by National Labs, 5 led by industry, 10 led by academic institutions, and 1 led by a nonprofit research institute. The reviewers felt that the quality of the work being led at the labs was high and the projects provided high impact/value to the U.S. PV industry. One of the main reasons the research from the labs is held in such high regard is the commitment to engagement from all stakeholders, which improves the quality of the topics and findings. Reviewers also consistently found academic institutions would have benefited from earlier and more industry involvement.

### Reviewer Feedback: Funding and Resource Allocation

The topic consists of $88 million in budget, quoted as being 40 percent of the overall PV budget (for a comparative 23 percent of the total number of projects). Of the $88 million, $72 million is led by National Labs, $5 million is led by industry, $10 million is led by academic institutions, and $1 million is led by a nonprofit research institute. The imbalance in percent of overall funding is primarily due to a few large, high-quality and high-value projects. Because these projects seek to validate product and system durability, meaningful research in this topic is time- and capital-intensive. As mentioned above, projects led by academic institutions could frequently be improved by stronger industry partnering to ensure results are answering the right questions in ways likely to be broadly accepted and adopted. However, while more partnering between academic institutions and private stakeholders is recommended, reviewers were not in favor of diverting more funding to private companies, as ensuring that the learnings are shared and memorialized is considered very important, and there is concern that private institutions will not prioritize dissemination of results.

### Reviewer Feedback: Project Value

The majority of projects were thought to be of high quality and appropriate funding levels. A handful were classified by reviewers as outstanding, and a handful were classified as performing below expectations. Projects thought to be contributing little value were either due to scope that is inappropriate or too narrow, approaches that are "too late," or an apparent lack understanding of prior applicable work.

### Reviewer Feedback: Advancing the Mission

The reviewers agreed that improving fielded system performance, reducing uncertainty, and extending lifetime will help drive the industry to the $0.03/kWh goal. There was also consensus that additional key areas are needed to achieve this, in particular the goal of extending useful life to 50 years.

### Reviewer Feedback: Areas of Improvement

Two reviewers noted that, given the respect garnered by DOE among the stakeholders in the industry, there would be significantly more support for further solar adoption if DOE played a more active role promoting the research that is funded and adoption of PV. In addition, reviewers felt that as extreme weather events become more common due to climate change, research and standards development is needed related to regional challenges, such as module durability in hail beyond the hail test in the current standard, and wind loading and racking design. Furthermore, a significant portion of current and historical research in reliability and standards has focused on modules. One reviewer estimated this at 80 percent of work to date. However, industry discussions regarding extending useful lifetimes are largely focused on balance of system issues (inverter reliability, replacement, and associated costs, and racking/pier corrosion are key topics). DOE should expand reliability funding to components beyond modules. Reviewers also expressed a desire for DOE to consider more focus on end-of-life/circular economy research and how some of the ongoing research and development could inform that area of focus. Finally, an overwhelming message from all PV reviewers was that in order to achieve further PV grid penetration in the next decade, storage will need to be added to most systems. To that end, more DOE funding and ownership around battery energy storage system research is needed. There is a need for standardized data sets from manufacturers, reliability testing, and performance metrics among others. Having the effort led at a DOE/National Lab level is key to getting manufacturers, developers, and financiers on same page—there is more trust in third parties to collect and advise.

### Reviewer Feedback: Final Topic Feedback

More support and higher-quality projects are needed to address balance of system reliability. It is not uncommon for inverters to experience significant downtime or failures within the first five to 10 years of operation. The cost and downtime associated with repowering is significant. Inverter research could either focus on extending useful life or having quickly swappable or serviceable units. Tracker reliability and non-ideality are also key factors in fielded system underperformance. These topics will likely also become more relevant as continued pressure to reduce costs and use fewer materials intersects with extreme weather events. For modules, one reviewer mentioned there is a gap in the current body of work to research degradation mechanisms instead of just failure mechanisms.

Storage, particularly direct current–coupled, will be a key component of future PV installations. Understanding component reliability and interaction with well-understood PV system components is crucial for the U.S. PV industry to stay at the forefront of technology and research. Modeling for value stacking with real-world, sub-hourly system performance is necessary, and tools lack the capabilities needed.

Stakeholder engagement and public dissemination of findings increase the quality and value added by the projects in this topic. Generally, higher-quality projects demonstrated significant collaboration across labs, academic institutions, and industry partners. Research demonstrating a direct line to applicability to fielded systems was rated higher by reviewers. High value is placed on projects whose results are being shared in publicly available dataset repositories and improved software tools in addition to presentations and conferences.

# System Design and Energy Yield

Utility-scale solar installations often include thousands of modules. Projects in this category work to understand how large solar installations can be best configured and monitored to produce the highest amounts of energy. This includes the funding of testing facilities for researchers to examine how technologies perform in real-world scenarios and improve upon their performance.

These projects represent only 10 percent of the overall Photovoltaics track with a total of nearly $13 million in federal funding. As more utilities rely on clean energy to meet customer demands, these projects are critical to helping develop systems that deliver the most solar energy possible, thereby helping to reach the goal of $0.03 per kilowatt-hour.

## Reviewer Feedback: Goals and Strategy

This topic focuses on improving the value of PV systems and ensuring this value is understood by all parties associated with the PV system life cycle. In order to do so, projects in this topic are working to reduce system capital expenditures (CapEx) and operating costs through product and process development, while enhancing the performance, reliability, and lifetime of the system. Empirical analyses and forecasting are conducted to ensure a data-driven approach. This work is focused on ground-mount solar, which is appropriate as these systems are more standardized and employ greater financial leverage.

## Reviewer Feedback: Alignment with Goals

System Design and Energy Yield projects help SETO approach its goals in three ways. The first is through product development, where risk is high because the concept could be flawed or other market solutions could outperform the concept. Further, even if the project is successful, the potential impact is often small because the solution applied to only a small niche of the market. The second way is via data analysis, where risk is generally lower and the impact is much broader. Most of the projects in this area are unique, which holds promise to be disruptive to conventional understanding or practices. The third area is through design and performance optimization, where risk is high at times, but the narrowness and tangibility of the project scopes often increased the likelihood that a success will drive impact.

## Reviewer Feedback: Funding and Resource Allocation

Funding in this topic is low (roughly 10 percent of the Photovoltaics track) relative to the large gap in the industry on agreed-upon tools and performance assumptions. SETO and the National Labs are the undisputed authorities on PV system technologies, so SETO should expand its investments in data analysis and optimization projects. This work is important, as it leverages the continuous improvement of large hardware manufacturers (modules, inverters, and racking) and potentially allows the United States to continue to lead on performance modeling and early adoption of yield enhancement technologies. The United States already leads the world in financing complexity due to the structure of the market, which enables greater tolerance to higher-CapEx technologies but also subjects the projects to greater energy model scrutiny, which will continue with the inclusion of storage. Thus, projects that enable engineering, procurement, and construction officials, developers, and operators to improve system performance, reliability, and lifetime will be very impactful in the United States.

## Reviewer Feedback: Project Value

SETO has done a good job of funding a diversity of projects that comprehensively cover the areas of greatest opportunity within system design. However, projects of high impact could be funded at greater levels, and fewer product development projects could be funded.

## Reviewer Feedback: Advancing the Mission

System Design and Energy Yield funding is critical to the SETO mission and U.S. solar industry. SETO plays an important role in ensuring that optimal designs and data analysis are employed particularly where industry is stuck in a local, not global, optimum. Generally, these issues occur in four areas. The first is in hardware manufacturers' focus on power ratings, which causes them to sacrifice yield (e.g., applying thin anti-reflective coating that is optimized for flash, not 30-year energy). The second is the uncertainty that exists around the full benefit of a technology (e.g., anti-soiling or snow coatings). The third is when a new technology entails significant design complexity to realize the full benefit (e.g., module-level power electronics that promise to not only eliminate power mismatch but also degradation mismatch, backside illumination mismatch, 40+ panel string length, and inverter savings). The fourth is legacy practices that persist despite the availability of new technologies to improve processes (e.g., owner commissioning requirements of voltage curve tracing that could be eliminated with lower-cost aerial inspection). The challenge will be to not only identify and prioritize areas of greatest near-term impact, but also to structure the projects and disseminate the findings in such a way that compels industry to quickly change its designs and behavior.

## Reviewer Feedback: Areas of Improvement

Benchmarking for System Design and Energy Yield projects persistently lags behind commercial performance and costs. In 2025, SETO should assume that bifacial crystalline silicon modules will achieve 22 percent efficiency at a cost of $0.15/W. These values are supported by company road maps, historical progress ratios, and bottom-up supply chain analysis.

SETO may also lack system design and energy modeling workflow knowledge. As an example, there is significant amount of PVSyst (PV system modeling software) post processing. Additionally, there is a lack of quality resource-adjusted performance monitoring. It's important to understand how the workflow of developers and operators may enable SETO and its awardees to ensure that products like the System Advisory Model are more relevant to the solar industry.

Finally, SETO projects are often focused on degradation, which is only one part of the full energy accounting. Performance disaggregation may better enable developers to adopt technologies which increase CapEx but decrease LCOE.

## Reviewer Feedback: Final Topic Feedback

SETO's ability to improve energy yield is significantly higher than the ability to reduce costs (modules and non-module CapEx) or improve component efficiencies. Examples of this include bifacial adoption, snow and soil shedding, energy optimized modules, and anti-soiling. This can create a dilemma for innovators because LCOE reductions require higher CapEx.

Additionally, teams should be more involved in real sites: What are the actual light-induced degradation, soiling losses, snow losses? Investigations of nominally good 10-year-old modules may illuminate degradation modes that persist in today's module designs. Where did all the watts go? National Labs' publications on system performance are gospel to industry.

Finally, it's important for SETO projects to persistently interact with industry practitioners, even if this requires commercial system audits, direct purchase of commercial products, or round-robin characterization of energy modeling tools.

# New Cell and Module Structures, Designs, and Processes

While there are many successful PV technologies on the market today, promising new technologies currently under development have the potential to help reach SETO's cost targets of $0.03/kWh for utility-scale solar energy by 2030 and reach an even lower LCOE in the years to come. Projects in this category focus on improving solar cell architectures for perovskites, organic photovoltaics, and other technologies that are approximately 10-15 years away from entering the marketplace, working to engineer higher performance at a lower cost.

Slightly under a third of the projects in the Photovoltaics track fall under this category, representing nearly $60 million in federal funding. By investigating and refining technologies that are in earlier stages of development, these projects will help SETO achieve its cost targets by opening up the solar market to diversified products.

### Reviewer Feedback: Goals and Strategy

The New Cell and Module Structures, Designs, and Processes topic supports the goal of improving the affordability, performance, and value of solar technologies on the grid. The topic research aims to deliver module technologies that drive down the costs of solar electricity by improving PV efficiency and lowering manufacturing costs while maintaining or increasing module lifetime relative to continuously improving commercial technologies. Within the Photovoltaics track, this topic's research creates innovative PV cell and module technologies that offer a competitive advantage and have the potential to be manufactured domestically or deliver products to the supply chain for global PV manufacturing.

### Reviewer Feedback: Alignment with Goals

The diversity of projects and funding amounts are generally appropriate, and the quality of the scientific work is excellent. National Labs are doing well developing useful resources, delivering high-quality work, disseminating results, and making their resources broadly available through effective collaborations. Execution of some projects has veered into areas of limited utility. Typically, this seems to occur in multi-task projects where balance among tasks has shifted to lower-priority tasks. Reviewers also observed projects in which the initial concept with low-cost potential was lost as solutions adopted to solve immediate research challenges introduced materials or processes likely to be expensive in production. A final example is smaller projects performing detailed characterization or development of new processing techniques on materials or devices far below the state of the art and of declining relevance. Improved collaboration will improve execution by exchanging information, materials, and characterization. This might allow specialists to specialize and not be distracted by tasks outside their expertise. Management needs to better inform investigators of expert resources available within the program. For example, an investigation aimed at exploring a new material should not bog down in process cost analysis when this could be performed more effectively through collaboration. SETO should consider projects with national teams that conduct regular meetings to exchange material and cells, coordinate techno-economic analysis, stimulate creative interactions, and encourage greater diversity of ideas.

### Reviewer Feedback: Funding and Resource Allocation

Funding levels in this topic are well balanced relative to other SETO topics. Funding of areas within this topic raises some concern. Funding organic PV at one-tenth the level of perovskites and one percent of the budget on crosscutting innovative concepts does not reflect the continued advancement in performance of organic photovoltaics and opportunities for continued innovation. Management criteria and strategy for exiting materials and concepts are not transparent. Entering or expanding research in an area is well articulated in FOAs, though there does not seem to be an equivalent process and documentation for reducing emphasis in a technology.

## Reviewer Feedback: Project Value

The majority of the projects are very strong with a few being exceptional and a small number that require immediate management attention. The Hybrid Tandem Photovoltaics project at the National Renewable Energy Laboratory was favored by several reviewers for the delivery of standard nomenclature and testing for three terminal cells applicable to all material systems. The reviewers saw effective collaborator engagement to enable the project to retain focus on the high-value tasks and complete the work within a reasonable budget. National Labs are performing well with work of good quality, good dissemination of results, and excellent collaboration with industry and university investigators. Weak projects were typically universities attempting too broad a scope with little awareness of other resources to assist in their weakest areas.

Reviewer Feedback: Advancing the Mission

The reviewers fully agree that success from these projects will substantively advance the mission of SETO and the U.S. solar industry as a whole. The goals and key milestones in the individual projects are aggressive while still achievable. Successful projects are delivering knowledge and technology that industry can use to drive down the costs of solar electricity by improving efficiency of PV and lowering manufacturing costs.

## Reviewer Feedback: Areas of Improvement

Ongoing improvements in organic PV, such as the recent achievement of 16.88 percent efficiency in single-junction, stable solar cells, should inform future SETO funding opportunities. The balance of funding between perovskite and organic materials does not reflect the relative performance of these two classes of materials. Organic light-emitting devices started at Kodak, moved from the United States to Japan, then South Korea to China. Today, China retains a large program in organic opto-electronics, including PV. Reviewers warn against further shift of support to maintain a balanced portfolio. The funding for innovative research outside of III-Vs and perovskites leaves great risk of being blindsided by the unforeseen. As was highlighted in the opening plenary, 10 years ago we did not expect that silicon could get this cheap. The invention and advancement of perovskite solar cells has also happened within that 10-year frame. SETO must keep the door open wide for continued surprises. SETO should place increased emphasis on design for end-of-life and recycling. SETO could also be blindsided by the impact of a carbon tax. This could dramatically affect the relative strengths of the material system options for PV modules. Similarly, some attributes of module design and characteristics will be reevaluated on the basis of energy storage options.

## Reviewer Feedback: Final Topic Feedback

SETO should enable specialists to specialize and not be distracted by tasks outside their expertise. Project principal investigators should be aware of the factors that will influence the success and adoption of the technologies they are developing, but are not typically the best resource for producing all of the answers. Improved collaboration will improve execution by exchange of information, materials, and characterization. Management should better inform principal investigators of expert resources available within the program. For example, an investigation to explore a new material should not bog down in process cost analysis when this could be performed more effectively through collaboration.

Additionally, SETO should encourage more collaboration among university, National Lab, and industry researchers. In technologies with multiple projects such as perovskites and high-efficiency III-Vs, consider national teams as were formed for thin-film PV some years ago. These teams hold annual or semi-annual meetings to exchange material and cells, coordinate techno-economic analysis, stimulate creative interactions, and encourage greater diversity of ideas.

The balance of funding among topics and within this topic and alignment of the projects with SETO goals are good. It can be improved by opening a wider door for entry of unforeseen innovation.

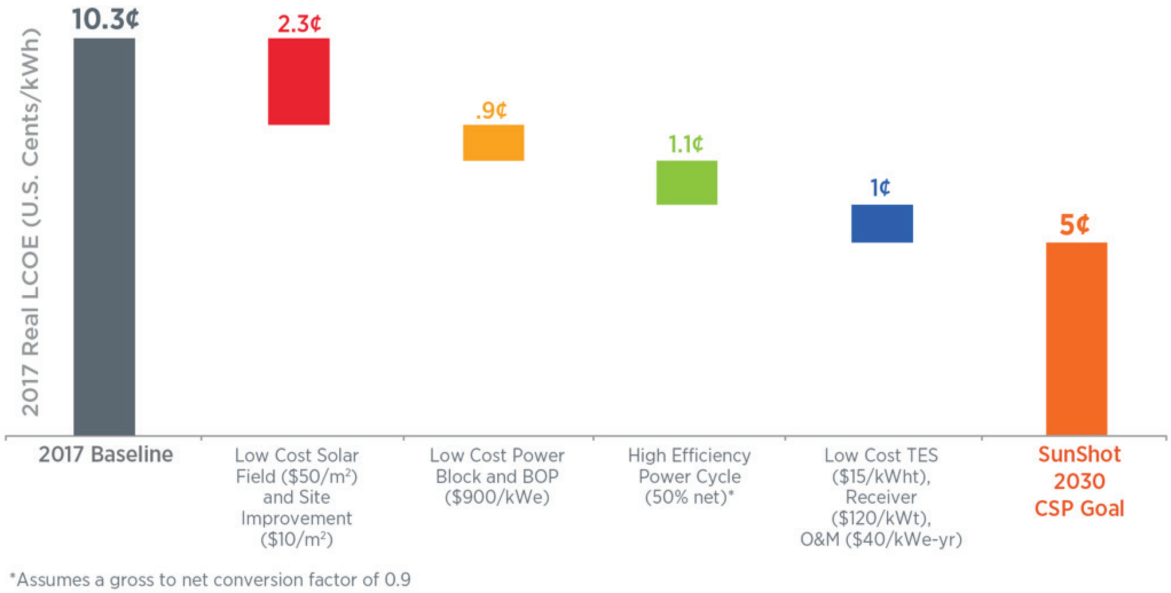
# Concentrating Solar-Thermal Power

Projects in the Concentrating Solar-Thermal Power track support early-stage research to improve the performance, reduce the cost, and improve the lifetime and reliability of materials, components, subsystems, and integrated solutions for concentrating solar-thermal power (CSP) technologies. This portfolio of projects spans our Concentrating Solar-Thermal Power, Manufacturing and Competitiveness, and Strategic Analysis and Institutional Support teams in an effort to make this form of solar energy generation more affordable. There are 99 active projects in the Concentrating Solar-Thermal Power track, receiving more than $180 million in federal funding; approximately one-quarter of SETO projects fall under this category.

CSP technologies can be used to generate electricity by converting energy from sunlight to power a turbine, but it can also be used as heat in a variety of industrial applications, like water desalination, enhanced oil recovery, food processing, chemical production, and mineral processing. Since heat can be easily stored through low-cost integration of thermal energy storage, CSP technologies can supply solar energy on demand, even when the sun isn't shining. Further, CSP systems use traditional turbine-based heat engines, which are used to generate the majority of global electricity. This combination of readily scalable energy storage and proven turbine technology has the ability to provide reliable and flexible renewable electricity production.

In the past decade, the cost of energy produced by CSP technologies has dropped more than 50 percent thanks to more-efficient systems and the wider use of thermal energy storage, which allows solar energy to be dispatchable around the clock and increase the amount of energy a single plant can produce. Projects in this track are working to make CSP even more affordable, with the goal of reaching $0.05 per kilowatt-hour for baseload plants with at least 12 hours of thermal energy storage.

## A Pathway To $0.05 per kWh for Baseload CSP

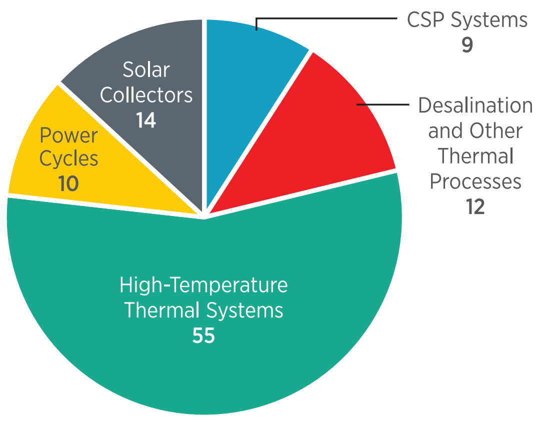



*Sample scenario for reducing costs to $0.05 per kWh for Baseload CSP.*

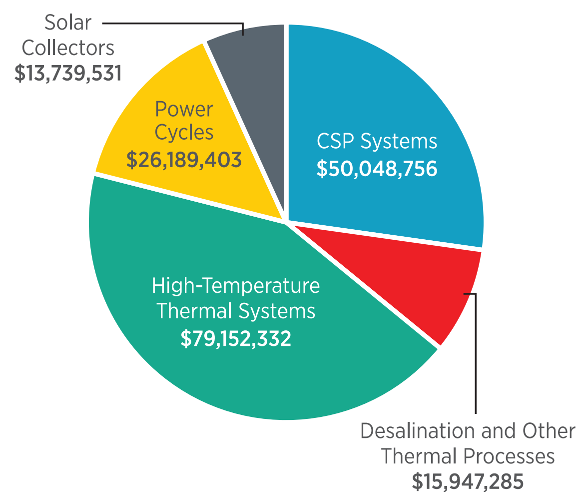
The challenges to achieving these targets require interdisciplinary solutions throughout a variety of fields in science and technology that tackle heat transfer, fluid mechanics, thermodynamics, optical physics, materials science, extreme automation in the solar field, corrosion mitigation, advanced manufacturing, thermo-mechanical engineering design, low-cost sensors and control, and predictive operations and maintenance, among others.

The Concentrating Solar-Thermal Power track also reviewed four projects from SETO's Manufacturing and Competitiveness team, which aims to validate groundbreaking, early-stage solar technology by attracting greater private-sector investment and scaling-up toward commercial readiness. These projects help build a strong clean-energy-manufacturing sector and supply chain that produce cost-competitive solar technologies. This track also includes a few projects from the Strategic Analysis and Institutional Support team, which support the development and dissemination of analysis, tools, and data resources related to the cost and value of solar technologies alone and as they integrate with other technologies on the grid.

### Concentrating Solar-Thermal Power (CSP) Projects by Topic Area




### Concentrating Solar-Thermal Power (CSP) Funding by Topic Area



The Concentrating Solar-Thermal Power track has five major categories: High-Temperature Thermal Systems, Desalination and Other Thermal Processes, CSP Systems, Power Cycles, and Solar Collectors.

Below is a summary of the reviewers' findings in the Concentrating Solar-Thermal Power track, written by track chairperson Frederick Redell, cofounder and managing member of BlüNebü, based on his observations and the group discussions during the peer review. Following the track summary, the five topics within the Concentrating Solar-Thermal Power track are highlighted in greater detail, written by lead reviewers:

- High-Temperature Thermal Systems (Diego Arias, Senior Thermal Engineer, Amazon)
- Desalination and Other Thermal Processes (Holly Churman, Water Business Group Leader, GHD)
- CSP Systems (Frederick Redell, Cofounder and Managing Member, BlüNebü)
- Power Cycles (Milton Venetos, Principal and Founder, Wyatt Enterprises)
- Solar Collectors (Frank Burkholder, Principal Data Scientist, Galvanize Inc.)

Power Cycles (Milton Venetos, Principal and Founder, Wyatt Enterprises)Individual project reviews for the Concentrating Solar-Thermal Power track can be found in the Concentrating Solar-Thermal Power Appendix.

## Reviewer Feedback: Goals and Strategy

SETO is working to advance CSP technology by investing in research and development that leads to achieving targets such as levelized costs of energy, storage, heat, and water, which appear to be a good way to measure the general attractiveness and competitiveness of CSP applications.

The strategy is funding a variety of work that, when combined, pieces together plausible pathways to achieving the targets. The strategy appears to allow industry to innovate and bring forward interesting science that can be funded, provided it has a strong proposal and can be at least tangentially shown to support achieving the targets.

An additional part of the strategy that seems apparent is socializing some of the work in CSP so that an ecosystem can be maintained. This is evident through the best-practices work and some of the open-source work.

## Reviewer Feedback: Alignment with Goals

The portfolio appears to align well with the defined goals. In each area, there appear to be projects that are properly selected to drive progress toward the goals. There seems to be some room for improvement in how to determine if a particular innovation can be traced to realizing the goal. For instance, in the Desalination topic, it appears that using CSP as an energy source rather than other energy sources, as well as the cost difference, leads to a lower levelized cost of water. In the CSP Systems and Collectors topics, which investigate optical systems and how they may be indicating a path to a lower LCOE, it isn't clear that the comparison of how to realize the benefits with the current practice is fully considered. In the Power Cycles topic, additional complexity and the cost of operations and maintenance compared to the innovation isn't clearly presented, which may limit the ability to hit lower LCOE targets. This isn't to say there isn't good science in the portfolio; each project's principal investigator just needs to be pushed to focus on knowing their innovations' advantages and disadvantages.

## Reviewer Feedback: Funding and Resource Allocation

There appears to be some consensus regarding the concern of CSP's applicability in the electricity market. However, there is also some consensus that the CSP program is creating a lot of interesting work. This could be because CSP has a problem of applicability and competitiveness, which means necessity will drive innovation. Given that CSP is struggling in the U.S. electricity market, leveraging the strengths that come out of CSP may yield more benefit.

Considering the electricity market and the share that CSP can address, and then balancing this against process heat and what the thermal storage side of process heat can address, perhaps some shifting of funds into hybrid systems that focus on electrifying heat (either resistive or pumped) and the integration into process heat and storage could open up a bigger part of the market for a portion of the CSP program. Achieving the LCOE goals, though, requires continued focus, and the Gen3 projects require significant funding to continue. It is likely that a lot of the work on these projects will be applicable to other systems, such as pumped thermal energy storage, high-temperature process heat for industrial processes, and other areas in which the United States needs to advance. Reviewers suggest further elaboration on all the offshoot applications and managing the portfolio to balance how much of the market all these innovations can capture, not just focusing on whether it is attached to CSP.

### Reviewer Feedback: Topic Area Value

All the efforts in the CSP portfolio to share CSP innovations and make them widely known and accessible are excellent. This includes the development of best practices and projects focused on open-source applications. But CSP lacks an ecosystem, because in industry, unless a company can see big growth in a field, they don't come to the table. In 2007-2010, many companies wanted to be a part of CSP projects, and they were innovating on their own and developing methods to make projects cheaper, because that was a market they could be a part of. Without this ecosystem, the knowledge base for much of the historical work of what works and what doesn't either disappears or has to be relearned. Also, given that much of the work done to date on thermal energy storage tanks, for instance, is known to only a small group of people and not readily accessible, it is hard for others to enter the market and make it grow.

### Reviewer Feedback: Advancing the Mission

The CSP portfolio can substantially move the U.S. solar industry forward by leveraging thermal energy storage. Success in inexpensive power cycles, both from an operations and maintenance perspective and a CapEx perspective, can drive down the LCOE of CSP. Utilizing a supercritical carbon dioxide cycle could prove successful on the CapEx side, as the equipment should have a higher power density. However, attention is needed to prevent an increase in complexity and reduction in flexibility, as these may increase the operations and maintenance costs and decrease the value of the system if it's less flexible on an evolving grid. Further, the success of CSP projects is very likely to substantially advance the U.S. solar industry through hybrid systems, such as PV and pumped thermal energy storage. This combination has the potential to significantly drive down the cost of long-duration, dispatchable renewable energy, by leveraging the lowest-cost systems in the overall SETO portfolio. The limitation for CSP is its lack of broad applicability due to the high direct normal radiation DNI need, which limits its geographic applicability in the United States. This and the energy cost for PV may severely hamper the deployment of projects that solely focus on CSP in the United States.

### Reviewer Feedback: Areas of Improvement

One blind spot is how some technologies are winning and how the financial structure favors one technology over another. While SETO can't solve this, deepening the understanding may shape SETO's future funding opportunities and how funds are allocated to advance technologies that can either be adopted faster and more broadly or need to make significant advancements to be competitive.

Another blind spot that may exist is the true cost of CSP and the cost that projects have incurred to be successful. While the upfront cost of some CSP projects may have been within a tolerable range, modification and repair costs may be substantial. In addition, operations and maintenance costs may be much higher than predicted for any number of reasons. Some of this will likely be addressed in SETO's best-practices work, which will help minimize this blind spot.

### Reviewer Feedback: Final Track Feedback

SETO should focus a bit more on spreading out the portfolio on the addressable market with some focus on derivative innovations, not just those that have to be attached to CSP. There is a lot of value in thermal energy storage at a wide range of temperatures and durations for process heat. It's also important for SETO to continue work that socializes CSP innovations and makes them more available to be innovated upon.

SETO describes its actions in working toward its goals as "providing relevant and objective technical information on solar technologies to stakeholders and decision-makers." It would be helpful to inform stakeholders and decision-makers on how the range of technologies in SETO's portfolio are deployed, more or less efficiently, in different project structures, which includes the implications of tax policy for more effective decision making.

# Desalination and Other Thermal Processes

To lower the cost of CSP plants, raising the temperature of the heat they deliver to the power cycle has the potential to increase plant efficiency. Plants operating at temperatures greater than approximately 700 degrees Celsius have high potential to unlock these benefits by coupling with advanced high-efficiency power cycles based on supercritical carbon dioxide. Projects in this topic investigate new types of heat-transfer media and thermal transport systems that are capable of reaching higher temperatures, as well as develop the components within those thermal systems. More than half the projects in the Concentrating Solar-Thermal Power track are in this topic, representing just under half of the track's total funding.

### Reviewer Feedback: Goals and Strategy

SETO's goal is to support the development and demonstration of solar energy systems at a commercially relevant scale. These systems will achieve low LCOE by taking advantage of higher thermodynamic efficiencies than those achieved with traditional Rankine cycles by using high-temperature receivers, new power cycles, and energy storage systems.

SETO's strategy is to fund a portfolio of projects that covers fundamental research, early concepts, component development, and megawatt-scale demonstration projects. Different funding mechanisms are also available to support these technologies as they mature from initial concepts to manufacturing.

There are many challenges in this technical topic. For the high-temperature fluids path, challenges include heat-transfer fluids, chemical compatibility of containment materials, reliability of components, manufacturing of heat exchangers, and supercritical carbon dioxide expanders. For the particle-receiver path, challenges include demonstrating the receivers under sun conditions, characterizing thermophysical properties and heat-transfer mechanisms of particles, reliability of containment materials, and heat exchangers.

Due to the uncertainty in the commercial success of CSP systems for electricity generation, SETO understands the importance of extending the applicability of high-temperature systems to other industries and chain values (i.e., ammonia production, renewable fuels). SETO's strategy is to identify industries that have large thermal energy needs and encourage the cross-pollination of applications that could use CSP.

### Reviewer Feedback: Alignment with Goals

The projects in this topic have a mix of early-stage and high technical readiness levels (TRL) that are well aligned with the goals and strategy. The portfolio is well distributed among challenges to develop the technologies. The reviewers recognized the tension between high risk/high reward and low TRL projects versus near-commercial and high TRL demonstration projects, as well as fundamental research projects (chemistry, corrosion, material compatibility) versus demonstration projects.

The reviewers believe SETO should address several areas. Due to the failures seen in molten salt tanks even at low temperatures, SETO should investigate improving materials and designs for molten salt tanks. This will be applicable at high temperatures too. There was one project for ceramic insulation and two other similar projects, but additional research may be needed. Some projects are investigating small-scale corrosion issues; however, these projects will not discover large-scale problems once the salt is flowing at high temperatures. Other demonstration projects that have flowing salt will not benefit from the findings of the small-scale corrosion issues. The projects studying corrosion could scale up to a few hundred kilograms of salt and investigate issues in flowing loops. Concerns involve how these issues will apply to tanks, valves, and components.

The projects investigating fundamental chemistry are time-consuming, and the data will not be readily available by the time demonstration projects begin down-selection. It would be advantageous to develop test standards so individual projects are aware of challenges, lessons learned, and requirements for future scaling up.

There are few projects on manufacturing and scaling up of welding processes for turbomachinery and heat exchangers, but more work may be needed in this area. When the time comes for demonstration projects, few manufacturers will be available with the capability to deliver components for high temperatures, these types of materials, and heat-transfer fluids. The reviewers realized that there is a new funding opportunity that is investigating this problem. Funding mechanisms may be needed to provide some projects with a longer period of performance in order for them to achieve meaningful results. It was not clear from the reviews whether projects are identifying risks and addressing them, or if they have contingency planning if issues appear in projects.

### Reviewer Feedback: Funding and Resource Allocation

Reviewers believe SETO should fund small projects (with high risk and high rewards) but with a short timeline to demonstrate the potential of novel technologies. As new concepts appear to be simple when they are initially proposed, projects need to be able to quickly investigate the overall benefit, find new funding mechanisms for idea maturation, and address challenges that may demonstrate the projects were not a good idea. One concern the reviewers had was the down-selection of projects for megawatt-scale demonstration. Not enough information may be available by the time SETO makes the decision.

### Reviewer Feedback: Project Value

Reviewers believe the projects should be classified in different categories for their evaluation: small projects performing fundamental science into one category, and projects developing components at a larger scale in another category. After this classification, the projects can be evaluated differently. The reviewers indicated the concern with projects doing corrosion studies, as they are fine-tuning salt compositions at a small scale. The results may not be valid at larger scales and with flowing salt.

### Reviewer Feedback: Advancing the Mission

Reviewers believe these projects will advance the U.S. solar industry and SETO's mission. However, reviewers expressed concerns about the future of CSP for electricity generation. To influence further advancement, SETO should further investigate the worldwide CSP industry and support American companies to success in other regions.

### Reviewer Feedback: Areas of Improvement

The reviewers believe investigation of salt chemistry at small quantities needs to be performed at a larger scale (several kilograms) to identify issues that demonstration projects may find. There are no projects on instrumentation (i.e., flow meters, pressure transducers, levels, temperature sensors), which will be needed once commercial demonstration projects take place. A knowledge database is needed to capture previous project information, lessons learned, and areas to investigate in order to avoid repeating mistakes or proposing old ideas. Codes and standards are needed for high-temperature systems, especially for financing and insuring these projects.

Several projects do not have large manufacturers on their team, but they will be needed when multiple components need to be manufactured. Funding opportunities should add questions regarding broader impact, lifecycle, and sustainability; for example, evaluation and consideration of embodied energy and emissions, and evaluation and consideration of product and its operation sustainability (usually quantified by their environmental, economic, and social pillars). Additionally, hybrids with fossil fuels are not being addressed.

### Reviewer Feedback: Final Topic Feedback

The reviewers expressed concern about the commercial viability of CSP for electricity generation. SETO is doing a great job finding other industries that can benefit from high-temperature energy sources. This concern about commercial viability extends to the lack of large equipment manufacturers and commercial developers; when these projects demonstrate technical success, it is not clear how they would become commercial.

The reviewers understand the tension between high risk/high reward and scale-up demonstration projects. The reviewers are concerned with the timeline and scope of projects (fundamental versus application), which will not have enough data by the time of down-selection for large-scale demonstrations.

There needs to be a dedicated effort toward supporting codes and standards, as well as large-scale instrumentation (sensors and controls), which will enable manufacturing and commercial scale developments.

# High-Temperature Thermal Systems

CSP technologies can be used not only to generate electricity, but also to deliver heat to a variety of thermally driven industrial applications. Many of the projects in this topic address solar-thermal desalination, which can treat seawater, brackish water, and contaminated water for use in municipal and industrial water supplies, or serve other reclamation needs. Projects in this topic are improving technologies that use heat to desalinate water or reduce the cost of solar-thermal technologies that can collect, store, and deliver heat to other industrial processes. Projects in this topic represent 12 percent of the track and nearly 9 percent of the track's budget.

### Reviewer Feedback: Goals and Strategy

SETO's goals and strategy for this topic relate to the development and integration of solar-thermal technology with industrial processes and desalination, two families of complex applications that could benefit from the solar energy source. Industrial processes comprise activities such as steam production and wastewater treatment that are critical to efficient production at food and beverage, industrial manufacturing, refining and petrochemical, and other industrial facilities. Thermal desalination is used to reduce dissolved solids concentrations in a diverse set of applications, such as the treatment of seawater to produce potable water for coastal cities, brine management solutions for inland communities seeking to dispose of brackish groundwater treatment waste products, and the treatment of produced water from oil production activities to enable the fluid to be recycled for hydraulic fracturing. This topic area provides an opportunity for solar technology to access markets beyond electricity generation and, in tandem, to address technical and economic challenges that will subsequently enable industrial processes and desalination technologies to reach their full potential.

SETO has established goals to drive the technologies within this topic area, bridging fundamental research and development to full-scale application. For example, SETO has established design criteria for the levelized cost of water (LCOW) for two sets of applications, based on flow rate and total dissolved solids (TDS) content: $0.50 per cubic meter (m3) for large applications comprised of 10,000 m3/day of flow and TDS in excess of 30,000 milligram (mg) per liter (L); and $1.50/m3 for small applications where flow is less than 2,000 m3/day and TDS is greater than 100,000 mg/L. SETO has also established a Solar Desalination Prize Competition, which seeks to connect technology developers with test facilities and potential customers.

Toward this end, SETO's strategy has consisted of identifying, funding, and supporting the development of a suite of research and development projects designed to promote innovations in thermal desalination, low-cost solar-thermal heat, integrated solar desalination systems, and analysis for solar thermal desalination. The current project portfolio includes 12 projects that transect each of these subject matters. Collectively, progress achieved in each project will enable SETO to improve technologies, identify potential markets, and encourage uptake in these markets.

### Reviewer Feedback: Alignment with Goals

The projects selected and managed under this topic area generally align with SETO's defined goals and strategy. Holistically, the suite of projects is likely to drive technological innovation, particularly for integrated solar desalination systems and analysis for solar-thermal desalination. However, the drivers for this progress can potentially be elevated by selecting new key performance indicators to complement LCOW, especially indicators that may be more widely understood compared to this levelized cost metric. For example, establishing the true energy required of an integrated solar-desalination technology and then striving to achieve a defined energy reduction goal that incorporates the use of solar energy, as opposed to other traditional forms, may yield more meaningful improvements than LCOW, which is difficult to quantify, particularly at low TRL. Techno-economic assessments are highly recommended at all stages of technology development to make sure that the "view is worth the climb." However, many of the existing research projects seem to have backed into LCOW, and some of the assumptions, therefore, might not be valid. Thus, it can skew technology progress as it rises through the various TRL.

### Reviewer Feedback: Funding and Resource Allocation

The funding level and number of projects for this topic is appropriate in context with the broader objectives of the CSP portfolio. The Desalination and Other Industrial Processes topic area comprises a relatively small percentage of the overall portfolio. This representation is appropriately balanced with other portfolio priorities, acknowledging the substantial effort and budget required to advance other topic areas within CSP. Importantly, the desalination topic area is powerful in its ability to provide access to a variety of markets, which can provide not only important data to drive research and development but also a venue for full-scale implementation when technologies are sufficiently mature.

### Reviewer Feedback: Project Value

Holistically, the suite of projects in this topic area provides value to SETO's overall objectives by pursuing research and development that are likely to generate useful incremental technological improvements, particularly in the area of solar-driven treatment processes, such as advanced membrane distillation and forward osmosis. Individual projects within this topic area would benefit from identifying and addressing critical issues to achieve continuous improvement; for example, a project spearheaded by the Lawrence Berkeley National Laboratory had identified critical issues related to flux and adjusted its experimental design to address it. Continuous oversight and conversation with principal investigators during subsequent budget periods will enable these projects to stay on track and add value to achieving the strategic goals of this topic and SETO.

## Reviewer Feedback: Advancing the Mission

The success of projects in this topic will advance the mission of SETO and the U.S. solar industry as a whole. Projects that are likely to be particularly impactful in the near-term include data and modeling efforts, such as those led by Columbia University and the National Renewable Energy Laboratory. These projects are designed to aid in market identification and competitive analysis evaluations, which are necessary to identify solar-driven desalination and industrial process opportunities and, subsequently, useful data such as relevant design parameters to inform research and development, engagement with end users to understand market-specific challenges, and, potentially, access to representative water for bench and pilot testing. Reviewers recommend sharing results from projects with water planners and end users at venues such as conferences to obtain market recognition and encourage uptake.

## Reviewer Feedback: Areas of Improvement

There are blind spots across the projects in this portfolio which, if addressed, can enable complex project risks to be mitigated and technical and cost improvements to be made. These blind spots include equipment issues, primarily consisting of the use (or lack thereof) of pretreatment, soft issues such as permitting, and ambiguity related to the applications that the principal investigators are targeting for the use of their technologies. Pretreatment is critical in all desalination applications, particularly where membranes are used. It is important to address assumptions related to the use of this equipment in order to properly characterize total system costs and operating procedures and costs. Issues such as permitting have an effect on realistic timelines for demonstration testing, as well as technology adoption in some applications (for example, some entities within the oil and gas sector call for their own technology readiness evaluations to validate the use of new technologies, depending on the application). Additional specificity in defining the application, such as realistic water quality and quantity requirements, ideally addressed through the acquisition of representative water for testing, can impede the ability for researches to establish appropriate boundary conditions and establish relevance. Addressing these items would help de-risk these projects and enable complex applications to achieve progress. Residual management is another consideration for desalination processes. Many desalination processes leave a residual that is difficult to manage, thus desalination is underutilized in many areas that cannot manage or dispose of this residual or concentrate streams. Solar-thermal desalination can provide significant contribution to treatment or handling of these residual or concentrate streams, as current technologies can be limited by their high energy usage (cost).

## Reviewer Feedback: Final Topic Feedback

Reviewers recommend that SETO focus on three key items:

- Connection with end users early in the research and development process, to establish appropriate boundary conditions and relevance.
- Prioritization of promising markets (such as industrial manufacturing, or concentrate management in inland geographies) to identify relevant design data and promote access to relevant water samples for testing.
- Consideration of additional key performance indicators, such as energy quantification and associated reduction goals, to drive progress.

Because this portfolio contains a variety of projects across a range of TRL, these efforts would enable researchers to understand and respond to relevant goals and data that will drive useful technological improvements.

# CSP Systems

CSP plants use mirrors to reflect and concentrate sunlight onto a focused point where it is collected and converted into heat. This thermal energy can be stored and used to produce electricity whenever it is needed. Projects in this topic area focus on designing, optimizing, and analyzing entire concentrating solar-thermal power systems as a whole in order to reduce the cost of electricity generated by these plants. This topic includes the Gen3 CSP projects, which seek to design a fully integrated high-temperature thermal transport system for next-generation plant designs. Projects in this topic represent just nine percent of the overall track but more than a quarter of the track's budget.

### Reviewer Feedback: Goals and Strategy

SETO's goals and strategy are to advance CSP technologies by investing in research and development that will lead to a competitive LCOE of delivered electricity, which this topic aims to accomplish primarily through the Gen3 CSP systems and competing CSP-plus-storage concepts that have a plausible pathway to achieving the goal. The strategy specifically includes funding pathways that lead to higher-temperature thermal cycles that increase the power cycle efficiency. This involves funding research and demonstrations that advance heat transfer and storage media, heat exchangers, and receivers, among others.

In addition to high temperature, the strategy includes advancing supercritical carbon dioxide (sCO2) cycles to achieve two benefits: a cycle that is expected to have a dramatically smaller equipment requirement due to the sCO2 working fluid, and reduction of CSP operations and maintenance by utilizing a cycle potentially simpler than a Rankine cycle.

The combination of these and other improvements in CSP are the basis for being able to set aggressive goals and for the strategy for identifying projects that can be funded. Another strategy includes developing and disseminating best practices and creating publicly available tools, such as wind modeling, to support the knowledge base for industry newcomers.

### Reviewer Feedback: Alignment with Goals

The Gen3 projects clearly align with the goals and strategy of SETO. The best-practices work appears to be well aligned with what the CSP industry needs. With little market traction at the moment, though, much of the industry's knowledge is at risk of evaporating. The work on integrating pumped thermal energy storage with CSP appears to be a little out of place but doesn't necessarily deviate from the strategy. It appears more like an opportunity to consider other cycles and to leverage technology developed through CSP while potentially making CSP or thermal energy storage broadly applicable without geographic restriction. One area that does appear to have benefit but isn't necessarily aligned with the strategy is the work on hydrogen mitigation. This work is valuable but for lower-temperature trough systems and could add value even if trough systems can be hybridized. However, without it being on the high-temperature path, it doesn't appear perfectly aligned.

### Reviewer Feedback: Funding and Resource Allocation

Reviewers see value in the many derivative technologies that are resulting from this CSP systems work, such as heat exchangers, which are broadly applicable. Reviewers worried that while Gen3 projects could result in value, that it could be discarded without follow-on funding for the most valuable pieces of work. Additional work on best practices is needed and should be focused on areas that have been largely considered simple but carry the risk of rendering the overall technology un-financeable. This mostly includes work needed to understand thermal energy storage tanks. Overall, the number of projects appears manageable and represents an informed approach on what might work instead of broad and indiscriminate funding.

### Reviewer Feedback: Project Value

The Gen3 projects clearly represent superior value. The work on best practices adds unique value and is and can be leveraged by all CSP projects. The real-time optimization work is also unique and adds to the puzzle, but is, in a way, less valuable since it may only marginally move the needle. Where work like this can be open-source, it can help the industry as a whole. The hydrogen work has less value to the overall program but does have value to the operating trough projects.

### Reviewer Feedback: Advancing the Mission

The challenge for this work substantially advancing the U.S. solar industry lies in the difficulty of getting traction and a resurgence in CSP in the United States. Reviewers agree that if CSP were cost-competitive with other renewable energy sources, it may be picked up by utilities, but the unique value CSP brings is not valued by utilities at the current grid mix. Reviewers also felt that CSP is disadvantaged from a tax policy perspective. Without tax policies that don't incentivize a silicon supply, which then favor non-U.S. supply, it is hard to see the projects advancing the U.S. solar industry as a whole.

### Reviewer Feedback: Areas of Improvement

Regarding technology, SETO does not have significant blind spots. From an overall strategy perspective, as already noted, tax policy and financing structures need to be considered when deciding which technologies to invest in. Much like a business, one would invest in things that have an impact on the goal. Additionally, the operations and maintenance costs of CSP may need deeper study. Competing technologies can take advantage of investment tax credits to essentially pay for operations and maintenance, which results in an advantage CSP can't access. In general, CSP needs to be more costly to reduce operations and maintenance, or have more operations and maintenance costs to reduce CapEx.

### Reviewer Feedback: Final Topic Feedback

Full life-cycle employment on technology adoption will be an important area for SETO to illuminate. This may include the need for transition-based economic modeling. Additionally, there is value in creating an open knowledge base to enable continuity of an innovative ecosystem given the current lack of market traction, which is vitally important to realizing the goals of the program.

# Power Cycles

In CSP plants, heat-transfer media can transport and store thermal energy produced by the sun so it can be delivered, at any time of day, to heat engines that generate electricity. This topic focuses on advanced, high-efficiency power cycles that use sCO2 as the working fluid, which have the potential to convert high-temperature solar heat into electricity far more efficiently than conventional power cycles. This topic focuses on advanced, high-efficiency power cycles that explore components of sCO2 turbomachinery, thermal energy storage and sCO2 interactions, and primary heat exchanger designs. Projects in this topic represent 10 percent of the overall track and 14 percent of the track's budget.

### Reviewer Feedback: Goals and Strategy

The SETO goal for the power cycles topic area is to achieve a 50 percent net efficient, 715 degree Celsius, $900 per kilowatt, air-cooled power conversion cycle for use with the Gen3 CSP system. A power conversion cycle that hits these targets will help meet SETO's LCOE target of $0.05/kWh for baseload CSP plants with more than 12 hours of storage and $0.10/kWh for peaker CSP plants with less than six hours of storage.

The strategy to attain these goals is to fund projects to conduct research and development, design, and demonstrate key power cycle subcomponents like turbomachinery, heat exchangers, and seals using suitable high-temperature materials that are compatible with Gen3 CSP candidate working fluids. The goal is also to fund research in cost-effective manufacturing methods for the components to achieve SETO's cost goals.

### Reviewer Feedback: Alignment with Goals

The projects touch all critical components (turbomachinery, heat exchangers, high-temperature materials, seals, and manufacturing methods) needed to reach the goals. The teams have developed good collaborations with appropriate expertise and experienced principal investigators. However, there could be more opportunities to strengthen project teams by including additional National Lab or industry partners.

### Reviewer Feedback: Funding and Resource Allocation

Reviewers believe the diversity of projects and general funding levels seem good and that allocated funding supports experienced principal investigators. However, they did agree there is some redundancy in projects, especially with the 500 degree Celsius heat exchangers and seals. Additionally, some projects have been ongoing for a long time and it is not clear whether tangible progress towards SETO's goals are being achieved.

### Reviewer Feedback: Project Value

No project is clearly superior or inferior to the others, and all are supporting SETO's goals; however, some projects appear to be more impactful than others. For example, heat exchangers are key to sCO2 cycle performance, while better seals have a much more modest impact on performance. Additionally, projects are all at different TRL and are applying different techniques and materials, which complicates direct comparison of the projects.

### Reviewer Feedback: Advancing the Mission

If the projects in this topic are successful, the resulting improvements in high-temperature materials, heat exchangers, and manufacturing methods—along with increased knowledge about material compatibility and corrosion rates, capital costs, and performance of cycle subcomponents—will substantively advance the mission of SETO and the U.S. solar industry as a whole by bringing sCO2 power cycle equipment closer to realization.

### Reviewer Feedback: Areas of Improvement

In general, the projects do not adequately consider operations and maintenance concerns or life-cycle and lifetime concerns. Reviewers also found incomplete techno-economic analysis on many projects and suggest completing some of that analysis up front before projects begin. Additionally, there were transient analysis concerns, as most projects appear to be investigating at steady-state only.

### Reviewer Feedback: Final Topic Feedback

Reviewers believe SETO is funding a good mix of relevant projects but echoed concerns regarding areas of improvement, particularly with transient analysis and interface, with most projects looking at steady-state only. Several projects may need to add tasks to investigate the interfaces between the component the project seeks to demonstrate and other parts of the power cycle; for example, piping connections to a silicon carbide (ceramic matrix) heat exchanger or the application of a carbon nanotube seal to a real seal substrate instead of just a coupon. Anything that adds to the cycle's complexity should be carefully considered to ensure the extra complexity creates added value. More complicated cycles, while often thermodynamically elegant and tempting, necessitate more components that bring the potential for higher capital and operating expense, as well as reduced reliability.

# Solar Collectors

Collectors reflect and concentrate sunlight and redirect it to a receiver where it is converted to heat and then used to generate electricity in concentrating solar-thermal power plants. Collectors can comprise 25 percent or more of the total system capital costs for CSP technologies. This major component must efficiently concentrate light while minimizing fabrication, installation, and operating costs. Collectors that are able to cost-effectively achieve high concentration ratios can directly improve the efficiency of the receiver. Projects in this topic area work to improve the performance and lower the cost of solar collectors and produce prototypes that demonstrate the viability of the technology for future integration into CSP plants. Projects in this topic represent 14 percent of the overall track and 7 percent of the track's budget.

### Reviewer Feedback: Goals and Strategy

The Solar Collector topic has a diverse set of projects that are successfully documenting present and past performance of solar reflector components in the field, as well as developing new optical characterization tools and automated construction methods. Additionally, projects are developing new CSP collectors to support CSP cost and performance goals, as well as for applications in CSP that have been somewhat neglected in the recent past, such as industrial process heat, distillation, and desalination. The projects are also disseminating information about performance of plants and best practices associated with their construction and operation.

Based on these projects, it seems SETO's goals are to document existing CSP power plant and component performance, develop new collectors and collector components in line with SETO goals, and diversify interest into collectors for other CSP applications. As far as strategy, SETO supports the best applications received for funding opportunities and an open-mindedness associated with revisiting applications that have been neglected in recent history.

### Reviewer Feedback: Alignment with Goals

Reviewers believe SETO appears to solicit applications for projects within specific interest areas (for solar collectors). Then if a proposal is interesting, demonstrates a scientific approach, and is relevant to CSP, it receives funding. However, when it comes to the collector topic's alignment with SETO goals, there are practical considerations, such as abrasion and weathering, which will limit their application in industry.

### Reviewer Feedback: Funding and Resource Allocation

While understanding the overall optical performance of the plants seems fundamental to the viability of the technology, operating plants don't seem to prioritize obtaining this information after the plant is built. As stated by some of my colleagues who work in the industry, once the plant is built, the goal is to make it work as well as possible on a budget. Large-scale operations and maintenance tasks associated with changes to improve optical performance (such as re-canting mirrors) are generally regarded as infeasible. If there is no staff to effect change, there is no point in getting the information in the first place. That said, while it's important to gain an understanding of plant optical performance, the amount being spent on optical tools by the National Labs is very large, even where it seems that there is little buy-in from industry as to what tools would actually be useful to them in an operating plant.

### Reviewer Feedback: Project Value

There are several projects in this topic tasked with making a better reflector, though it's quite challenging to beat the performance, longevity, and cost of glass mirrors. Reviewers believe funding should focus on glass mirrors.

## Reviewer Feedback: Advancing the Mission

While projects focused on glass mirror technology will likely be successful, those that don't are not likely to advance SETO's mission. Even if they succeed, they will not provide substantial performance or cost improvements on existing glass mirrors. Existing heliostats are fairly high-performing and cost-effective, considering their strict requirements. SETO has correctly identified the power cycle, the heat-transfer medium, and thermal storage as places to focus research efforts.

## Reviewer Feedback: Areas of Improvement

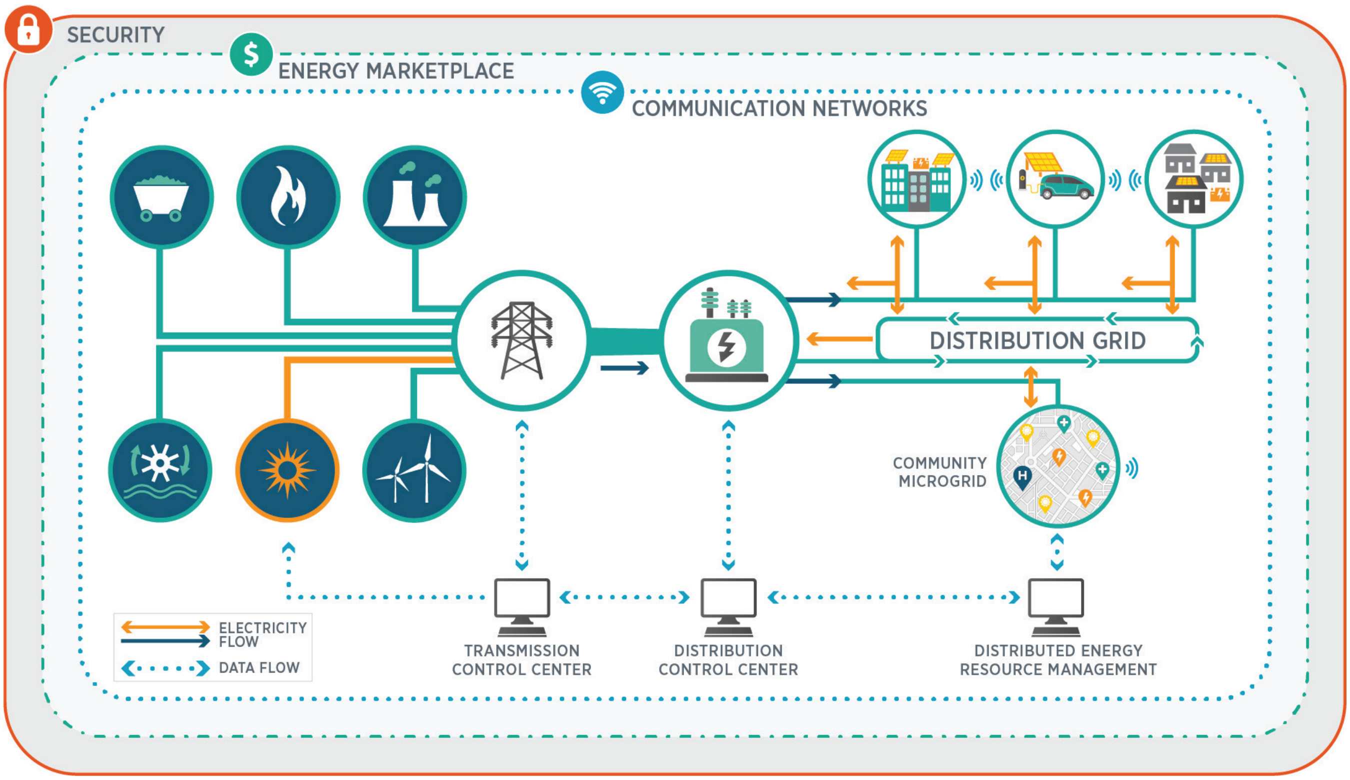
DOE has a long history of funding optical coating research and generating coupon-size optical proofs of concept, but even if those technologies work, they still compete against cheap, durable, highly reflective back-surface mirrors that are widely available. While reviewers understand that SETO wants to fund optical research, the blind spot is that these innovations don't tend to go anywhere for large-scale CSP.

## Reviewer Feedback: Final Topic Feedback

Reviewers agree that SETO should curtail research into coating-based preliminary stage optical material research unless the research expressly addresses weathering durability right away. If solar collector research is to be continued, it should focus on an integrated solar collector (a heliostat) instead of just the optical component.

# Systems Integration

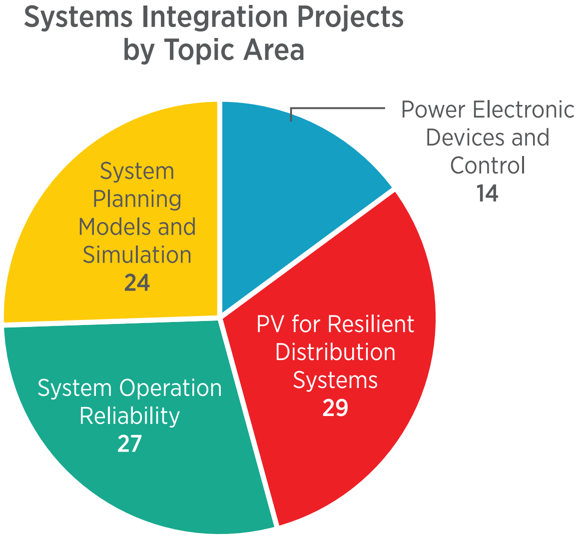
Projects in the Systems Integration track support the advancement of reliable, resilient, secure, and affordable integration of solar energy onto the U.S. electric grid. This portfolio includes all projects from the Systems Integration team and a subset of projects under the Manufacturing and Competitiveness and Strategic Analysis and Institutional Support teams. These research, development, demonstration, and analysis activities support innovations that advance a modernized grid—one that integrates diverse generation and energy-efficiency resources like solar while ensuring reliable power, that utilizes cutting-edge digital technologies to detect and mitigate disturbances, that is economic and scalable, and that provides strong protection against physical and cyber risks. There are 94 active projects in the Systems Integration track, receiving nearly $212 million in federal funding; approximately one-quarter of SETO projects fall under this category.

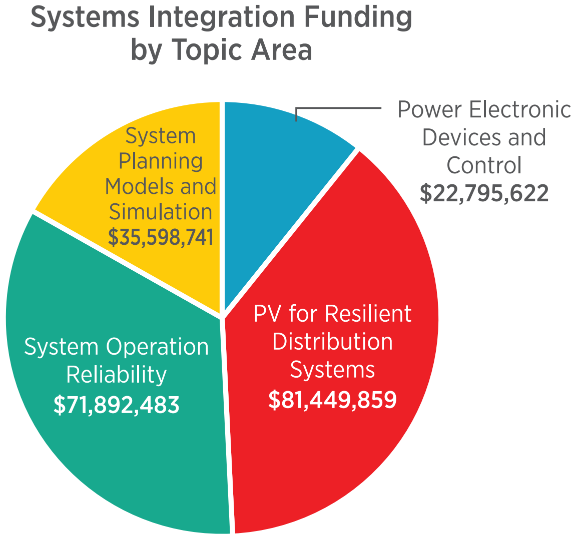



In recent years, solar generation has grown from less than 0.1 percent of the U.S. electricity supply to 2.7 percent per year, according to DOE's Energy Information Administration. In five states, solar electricity represents more than 10 percent of total generation. This rapid solar expansion is occurring on an electric grid that, while having evolved over the past 100 years, still relies upon large, centralized power plants, long-distance transmission lines, and typically one-way distribution power flows. Recent technology advances present new opportunities for solar to not only supply electricity generation but also provide grid services, such as frequency and voltage regulation, as well as real-time control responses that are essential for safe and reliable grid operations. New power electronics capabilities, such as grid-forming and black start, have the potential to restart segments of the distribution system if the grid goes down. Hybrid plants that incorporate energy storage or other renewable technologies could also help to optimally manage variable generation resources.

The Systems Integration track incorporates projects that are part of DOE's Grid Modernization Initiative, which is a cross-cutting effort that aligns grid modernization efforts across multiple DOE program offices. A number of these projects are funded under the Grid Modernization Laboratory Consortium (GMLC) program. They support research activities including grid resilience, energy storage, sensors and measurements, and cybersecurity, where solar energy plays an important role in advancing each of these technology areas, enhancing grid modernization in the process.

The Systems Integration track includes nine projects from SETO's Manufacturing and Competitiveness track, which investigates and validates groundbreaking early-stage solar technology to strengthen and move the concepts toward readiness for greater private-sector investment and commercialization. These projects help build a strong clean-energy-manufacturing sector and supply chain that produce cost-competitive PV technologies, including those that will enable easier integration of solar energy onto the grid. One project from the Strategic Analysis and Institutional Support team supports the development and dissemination of analysis, tools, and data resources related to the cost and value of solar technologies alone and as they integrate with other technologies on the grid.




The Systems Integration track has focused its projects in four major topic areas: Photovoltaics for Resilient Distribution Systems, System Operation Reliability, System Planning Models and Simulation, and Power Electronic Devices and Control.

Below is a summary of the reviewers' findings in the Systems Integration track written by the track chairpersons, Mahesh Morjaria, CEO of REPlantSolutions, LLC, and Dan Woodfin, senior director of System Operations at the Electric Reliability Council of Texas, based on their observations and the group discussions during the peer review. Following the track summary, the four topics within the Systems Integration track are highlighted in greater detail, written by lead reviewers:

- Photovoltaics for Resilient Distribution Systems (Bruce Tshuchida, Principal, The Brattle Group)
- System Operation Reliability (Sebastian Achilles, Managing Director of Power Systems Operation and Planning, GE Power)
- System Planning Models and Simulation (Will Hobbs, Principal Research Engineer, Southern Company)
- Power Electronic Devices and Control (Ananda Hartzell, VP Technology, North America, Fimer Spa)

Individual project reviews for the Systems Integration track can be found in the Systems Integration Appendix.

## Reviewer Feedback: Goals and Strategy

The overall goal of the Systems Integration track is to support early-stage technology and solution development that advances the reliable, resilient, secure, and affordable integration of high levels of solar energy onto the U.S. electric grid. This can be a challenge given solar energy's variable nature.

The Systems Integration goals are divided into four broad topic areas:

- System operation with a focus on real-time situational awareness, forecasting, communications, control, and protection that ensure system reliability with high penetrations of solar.
- System planning with a focus on modeling methodologies and software tools for planning scenarios including PV generation variability, system flexibility, grid stability, and interconnection requirements.
- Power electronics that serve as the critical link between solar PV and the electric grid with a focus on advanced grid capability (e.g., grid forming), reliability improvement, and cost reduction.
- Advancing system resiliency under cyber and physical hazards through distributed solar PV and distributed energy resources (DER), black start capabilities, microgrids, energy storage integration.

Advancements in any of these areas that can be brought to market in the future are key to SETO's mission. There is specific value to the mission in coordination with other DOE programs and objectives. Engagement of industry, regulatory, utility, system operators, as well as research and development stakeholders is fundamental to achieving SETO's mission.

## Reviewer Feedback: Alignment with Goals

Most projects were well aligned with the Systems Integration track's mission, goals, and strategy. However, some projects lacked the explicit linkage from the planned activity to their support of the mission.

Projects across several topics face protective relaying challenges associated with high penetration of PV, which is a concrete issue that needs to be resolved. In the PV for Resilient Distribution Systems topic, cybersecurity and grid resiliency projects lacked cost/benefit analysis. Only a few projects discussed potential risks and remedies around such risks, and several projects were academic in nature and had no commercialization, deployment, or field implementation plans. In the System Operation Reliability topic, projects should increase their attention on aspects related to modeling and representation of PV in bulk power systems under future higher-penetration scenarios and potentially reduce the focus on DER operation optimization. In the System Planning and Models and Simulation topic, projects associated with DER aggregation, control, and coordination seem to be overrepresented. Multi-megawatt-size systems are likely to play a larger role in the future grid, and the unique role of aggregated demand management to increase system flexibility should be emphasized. In the Power Electronic Devices and Control topic, the target inverter costs are not in line with market trends and need to be assessed based on overall plant life-cycle cost reductions. The path to commercialization appeared to be a gap. Novel technical solutions must be capable of significantly outperforming the present state of the art to be successful.

## Reviewer Feedback: Funding and Resource Allocation

Reviewers recommend increasing funding for certain areas of research, such as projects that aim to tackle protective relaying challenges associated with high-penetration PV. Projects that focus on modeling and representation of PV in the bulk power system under future higher-penetration scenarios should have higher funding levels, but these projects should reduce their focus on DER operation optimization. Reviewers also recommend additional funding for "public interest" aspects related to power electronics, such as grid-forming and other grid-stabilizing technology, advancement and standardization in device- and grid-interconnection modeling, and regulatory and rule-making support. Reviewers recommended decreased funding for projects that focus on DER aggregation, control, and coordination.

## Reviewer Feedback: Topic Value

All topics provide value to the greater goals of the Systems Integration track. However, some projects in the Systems Planning Models and Simulation topic are too broad and lack a clear focus. For example, the probabilistic forecasting projects are very similar to one another and have many areas of overlap. To increase value, these projects should better coordinate or eliminate the redundant efforts. In the Photovoltaics for Resilient Distribution Systems topic, a third of the projects had a superior sense of the track goals and excelled at implementation of their plans, while the other two-thirds focused on resiliency and cybersecurity without quantifying the project outcomes and lacked plans for implementation and/or validation. Some of the projects in the Power Electronic Devices and Control topic seemed to focus more on productizing their own device rather than advancing the industry.

## Reviewer Feedback: Advancing the Mission

Projects are generally aligned with SETO goals. Many are likely to have high impact, and their success will contribute to advances of the industry related to those goals. While some of these projects may not lower solar costs in the short run, the topics are necessary research areas that will enhance the role of solar in the future. Focus on more than just direct cost reduction is encouraged to demonstrate the overall market impact. The application of solar as an energy source is likely to result in an increase in installation and maintenance jobs in the United States, though it is not clear if will increase high-end U.S. manufacturing in solar applications. SETO should provide some clarity in defining outcomes, demonstrable performance metrics, and prioritization of technologies that are needed in the short term versus the long term; reviewers generally believe that some of the projects do have potential. Care should be taken when funding projects with questionable commercial application to the detriment of research into solutions for known issues that will impede solar development. The topics lend themselves to advancing the industry, but as noted previously, timelines relative to cost expectations, cost targets, and regulatory compliance would help in this review. Where this is not possible due to the scope, a path to industry advancement and next-step challenges would also help inform the value in this type of review.

## Reviewer Feedback: Areas of Improvement

There were no significant blind spots in the Systems Integration track, but there are several areas for potential improvement:

- Availability of modeling and representation of PV (and other inverter-based resources) in bulk power system studies for technical feasibility assessment of high-penetration scenarios
- Inadequate participation by the utilities/commercial experts that, if remedied, could lead to the effectiveness, practicality, and benefit/added complexity balance of the proposed innovation
- Research completed in isolation (e.g., not collaborating with other concurrent and similar projects, not building on previous DOE-funded work, unawareness of existing commercial capabilities in area of study, or focus on the distribution system without considering bulk system impacts/conflicts)
- More work to support transmission, distribution, and generation planning studies for PV and PV-plus-energy storage hybrids (including storage dispatch)
- Clear justification for microgrid and peer-to-peer transactive energy projects seem to be lacking. There is some level of skepticism of market viability of peer-to-peer models. Additional work needs to be done to justify research in this area.
- The techno-economic potential for widespread microgrids seems low, and higher-level feasibility analysis needs to be done before funding detailed technical work.
- Power electronics failures and sensitivities in the industry continue to place a lack of confidence in these PV technologies and needs to be improved.

### Reviewer Feedback: Final Track Feedback

Reviewers believe more work needs to be done to support transmission, distribution, and generation planning studies for PV and PV-plus¬-energy storage hybrids (including storage dispatch) with emphasis on future infrastructure, markets, controllable loads, and DER integration and coordination. There should be continued emphasis on management of uncertainty, grid integration, and improved resiliency. Projects should focus on feasibility of operation over optimization of operation to support upcoming challenges due to high levels of PV penetration in U.S. grids.

Projects should continue to increase focus on the factors that drive and inform power electronics development in coordination with emerging regulations, program guidelines/requirements, and contextualized cost targets and milestones. SETO should focus on funding projects that define functional requirements for power electronic devices in the grid (near-term and in the future). Examples of this include grid-forming versus grid-following capability and the required low-voltage ride-through boundaries.

Projects should continue to focus on cybersecurity and resiliency, but with a hierarchical architecture and definition on criticality. For example, it's important to know which assets at what voltage level on the transmission or distribution network need to be robust and available, or how the benefit/cost analysis should be performed.

# Photovoltaics for Resilient Distribution Systems

The rapidly increasing amount of distributed solar PV and other DER onto our electric grid can provide greater resilience to critical infrastructure and critical loads by integrating them into emergency response and recovery procedures. Projects in this topic area are developing new tools to manage situational awareness and controls to help the grid withstand disruption while continually providing electricity to customers. All projects in this topic consider various cyber and physical hazards to ensure the continuity of electric power service and/or faster service recovery. Projects in this topic represent approximately one-third of the Systems Integration track and nearly 40 percent of the track's budget.

### Reviewer Feedback: Goals and Strategy

The PV for Resilient Distribution topic was more of a "catch-all" bucket under the name of system resiliency and includes everything from cybersecurity, communications and situational awareness, advanced inverters, microgrids, and emergency operations to transmission and distribution modeling. Project types varied from setting standards developing software, improving operations, to developing hardware. While there are some instances in which projects may actually increase costs, all projects share the goal of expanding the role of solar resources and advancing the reliability, resiliency, and security of interconnected solar resources.

Strategies to achieve the goals include development of tools for system control and situational awareness, application of new technologies for system resiliency, improving cybersecurity, and improving methods to provide support for businesses working with solar energy. The wide range and variation of the projects and their scales makes the review process challenging, as no common scale can be applied. Furthermore, the maturity of the projects (i.e., how likely they would be deployed or commercially available within the next few years, or whether they are more academic in nature) varied quite significantly.

### Reviewer Feedback: Alignment with Goals

While some projects are well aligned with the SETO goals, many projects did not provide enough information on budget, timeline, and tasks. Furthermore, many projects focused on cybersecurity or grid resiliency, which made it challenging to quantify the benefits. In general, most projects lacked cost/benefit analysis, and only a few projects discussed potential risks and remedies around such risks. There were several projects that had no commercialization or deployment plans, and in the worst case there weren't even field implementation plans, leading the reviewers to believe such projects could end up being a purely academic study that may barely contribute to SETO's overall goals.

### Reviewer Feedback: Funding and Resource Allocation

In general, the number of projects in this topic seems appropriate. Many projects appeared relevant, but many, particularly those addressing cybersecurity or grid resiliency, seemed to overlap each other. A few projects commanded a large budget (in excess of $4 million from SETO) without a concrete description of the final product. And some projects did not have a fully developed budget or showed inconsistency in the budget (for example, inconsistent funding distribution between personnel, contractual, equipment/tools, and other charges), leaving the reviewers to question the validity of federal funding. In general, the projects would benefit from having more focused goals and outcomes that can be field-demonstrable. Going forward, SETO should help the project teams by setting standards, defining requirements on key technologies, and asking for quantifiable outcomes. This will also help screen out projects with overlapping scopes.

### Reviewer Feedback: Project Value

Several projects are obviously superior in the sense of goals, implementation, and how they were thought through. However, a majority (about two-thirds) of the projects were less impressive—many of them focused on resiliency and cybersecurity without quantifying the project outcomes. These projects will likely add value, but the overlap dilutes the per project value. Several projects lacked plans for implementation and/or validation (for example, there were projects with individual developers or integrators, making it hard for system integration justification and missing stakeholders for realization), leaving the reviewers to think they may end up being an academic exercise and not too valuable in real-life conditions.

### Reviewer Feedback: Advancing the Mission

A large number of projects focused on rather peripheral topics, such as grid resiliency and cybersecurity, for which benefits are hard to quantify. These projects will not necessarily lower solar costs in the short run; in fact, they may slightly increase them. However, these topics are necessary research areas that could enhance the role of solar in the future. Therefore, SETO should provide some clarity in defining outcomes, demonstrable performance metrics, and prioritization of technologies that are needed in the short term versus long term, because the reviewers generally believe that some of the projects do have true potential.

### Reviewer Feedback: Areas of Improvement

The projects generally appear to be well developed and on the right track. A number of projects lacked key stakeholders, such as utilities to help with field testing, or commercialization experts to carry the product developed through the project to the next step. SETO may want to emphasize such needs for the longer-term success of the projects (i.e., beyond the DOE funding period). Alternatively, SETO could suggest prioritization to achieve demonstrable outcomes. This does not mean that long-term technologies cannot be funded—they can perhaps be pursued through a separate track. Finally, some projects were in the early stages with limited information available to justify goals and challenges, making it hard for the reviewers to assess the likelihood of their success.

### Reviewer Feedback: Final Topic Feedback

SETO may need to engage more key stakeholders such as electric utilities and National Laboratories where the projects may be tested and validated. Additionally, there should be separate tracks based on the topic. Such tracks may be:

- Energy storage and hybrid projects, including microgrids
- Power electronics with distinction between active grid-forming inverters and other passive inverters, with a focus on advanced technology that can potentially enhance the role of solar, rather than those with limited contributions to SETO goals
- Cybersecurity and resiliency, but with a hierarchical architecture and definition on criticality (for example, what assets at what voltage level on the transmission or distribution network need to be robust and available, or how the benefit/cost analysis should be performed)

SETO may benefit from more attention to the project cost, stage of development, and what share is requested from DOE.

# System Operation Reliability

With increasing amounts of solar energy connected to the grid, it's important for utilities and bulk power system operators to have real-time information about and control capabilities for the amount of generation that's occurring at any given moment, in order to reliably operate during normal and abnormal conditions. Projects in this topic area deal with control and coordination of solar generation at both bulk power and distribution levels, in accordance with the desired state of grid operation. Projects are focused on sensing and communication, system protection and fault recovery, dynamic power flow control, and data analytics and decision algorithms. Projects in this topic represent more than a quarter of the Systems Integration track portfolio and a third of the track's budget.

### Reviewer Feedback: Goals and Strategy

The goals of this topic include enabling connection of PV without significant increase in grid hardware infrastructure, as well as adding visibility to utilities and system operators of real-time information of distributed resources and enabling control of such resources. This includes control, coordination, and aggregation of distributed resources (with focus on PV). The dependable and secure detection and isolation of faulty equipment in a grid with high PV penetration (low and different short circuit contributions) is also part of the goals.

### Reviewer Feedback: Alignment with Goals

Most projects reviewed are in the areas of DER visibility, coordination and aggregation, and protective relaying approaches for high-penetration PV systems. Projects are investigating the lower-voltage distribution aggregation and visibility, and few projects more are focused in the distribution/transmission level operation with DER.

### Reviewer Feedback: Funding and Resource Allocation

Reviewers found it challenging to evaluate the funding levels but thought that the number of projects in the topic is good and may generate meaningful contributions associated with the goals. The protective relaying challenges associated with high-penetration PV is a fairly concrete issue that needs to be resolved, potentially not requiring significant technology development. There is, however, a clear need in the industry to assess and incrementally modify existing fault detection (and other) technology for this technical issue. Not resolving this issue could negatively affect the SETO objectives of higher PV deployments.

SETO's role can be significant and reasonable to the size of the problem. There seems to be a reasonable amount of projects in this topic area with the appropriate amount of funding to advance the industry. A seemingly higher number of projects are associated with DER aggregation, control, and coordination, which are aligned with the objectives of the track and topic area. These projects attempt to advance operational aspects high DER operation with a clear focus on real time. A smaller number of projects address modeling aspects in HOMER and dynamic/EMT tools related to PV system or PV inverter control representations. Some of the protective relaying projects include important tasks related to this.

A subject affecting the goals of the track and the topic that reviewers felt is potentially underrepresented is PV modeling aspects for tools that enable assessment of technical feasibility. That is, modeling that enables the understanding of the stability/reliability of a grid with high penetration of renewables, as opposed to models that enable the optimization of a system that operates stably. Many reviewers believe potential blind spots of these projects are the availability of good representation of PV inverters to assess the effectiveness of the technology proposed in the project, or the sensitivity to the variations in PV inverter behavior in the assessment of performance of the proposed technology innovations.

Additionally, reviewers feel that aspects related to modeling and representation of PV in bulk power system studies are similarly affecting technical feasibility assessment of future scenarios in the industry overall (by transmission companies, operators, developers, etc.). The outcomes of those assessments have an important impact on the SETO goals of increasing PV penetration to extremely high levels. SETO may want to consider increasing the attention to this subject and reducing the focus on operation optimization.

### Reviewer Feedback: Project Value

Reviewers generally saw few projects that were better formulated and with more concrete contributions than others, which is reflected in the project reviews.

### Reviewer Feedback: Advancing the Mission

Projects are generally aligned with SETO goals. Success of these projects contributes to advances of the industry related to those goals. There may be goals that have a different urgency than others within the track and topic. The related comments from reviewers are along the lines of prioritizing goals related to reliability over operation optimization. This prioritization is not related to importance of the goals but more to the urgency of reliability concerns of systems with high PV penetration.

### Reviewer Feedback: Areas of Improvement

Reviewers found two potential blind spots in this topic. The first is the lack of good representation of PV inverters that assess the effectiveness of the technology proposed in the project; the second is the sensitivity to the variations in PV inverter behavior in the assessment of performance of the proposed technology innovations. Additionally, the reviewers felt that aspects related to modeling and representation of PV in bulk power system studies similarly affects the technical feasibility assessment of future scenarios in the industry (by transmission companies, operators, or developers). The outcomes of those assessments have an important impact on the goal of increasing PV penetration to extremely high levels. SETO may want to consider increasing the attention on this subject and reducing the focus on operation optimization. Other general feedback relates to the participation of industry. There is a perception among reviewers that in several projects, utility participation may be mostly related to providing data for verification of a concept. It would be very beneficial to SETO's goals if utility participation is also part of the later stages of the projects associated to the effectiveness, practicality, and benefit/added complexity balance of the proposed innovation.

### Reviewer Feedback: Final Topic Feedback

While projects are aligned with SETO's goals, reviewers recommend giving future consideration to further increasing the focus of feasibility of operation over optimization of operation, which will best support upcoming challenges due to PV penetration in U.S. grids.

# System Planning Models and Simulation

As more solar energy is added onto the electric grid every day, it's important for utilities and bulk power system operators to plan for a variety of scenarios in order to balance electricity generation from solar and other sources with customer demand. Projects in this topic area are investigating the optimal placement of system components such as solar photovoltaics and energy storage, developing modeling and simulation methodologies for short-term and long-term system planning under various constraints, as well as developing software tools. Specifically, projects are focused on generation variability caused by higher amounts of solar energy on the grid, addressing voltage and frequency stability, improving system flexibility, and developing new interconnection standards. Projects in this topic represent a quarter of the Systems Integration track portfolio and 17 percent of the track's budget.

### Reviewer Feedback: Goals and Strategy

SETO's goals in this area are to select and fund projects that advance the state of the art around solar in: forecasting; use of forecasts in utility/independent system operator operations; communication and control for PV and other DER to support grid and customer needs; and models and tools to aide in generation, distribution, and transmission planning.

Reviewer Feedback: Alignment with Goals

Most projects were well aligned with SETO's goals and strategy for this topic area, though a few projects did not seem well aligned. Reviewers believe that some areas of this topic were not well represented, but that may be due to the way reviewers were assigned to review projects (i.e., each reviewer did not see all projects in the topic, just the ones to which they were assigned).

### Reviewer Feedback: Funding and Resource Allocation

Reviewers generally agree with how funding is distributed in this topic. They did note, though, that some projects seem to be a continuation from previous works. When that was the case, their project cost and new work was not always clearly reported to show differentiation from the previous work.

### Reviewer Feedback: Project Value

While reviewers believed all projects brought value in supporting SETO's goals, some projects were too broad and lacked a clear focus; others seemed unorganized and behind schedule. There was also concern regarding the probabilistic forecasting projects due to similarity and potential overlap. Reviewers suggest a clearer plan for the projects to coordinate or to otherwise make use of redundant efforts would be useful.

### Reviewer Feedback: Advancing the Mission

Examples of high impact projects in the system integration area include the Solar Radiation Research Laboratory, the National Solar Radiation Database, and ongoing development and support of SAM and PVWatts. These support the full range of understanding PV system performance: obtaining high quality solar resource measurements, providing modeled solar resource data for almost every location in the country, and then providing user-friendly tools to model the design, energy output, and financial considerations of PV and other renewable energy systems. These tools are widely used by project developers, research organizations, and policy makers, and their continued support and improvement is very beneficial to the industry.

Beyond solar resource and system performance work, continued emphasis on modeling, controls, and hardware for grid operation uncertainty reduction, grid integration of PV, and improved resiliency is valuable for grid operators, customers, and the solar industry.

### Reviewer Feedback: Areas of Improvement

One potential blind spot identified by reviewers is that some projects appear to be happening in isolation (e.g., not collaborating with other concurrent and similar projects, or not building on previous DOE-funded work). Additionally, more work needs to be done to support transmission, distribution, and generation planning studies for PV and PV-plus-energy storage hybrids, including storage dispatch. Clear justification for microgrid and peer-to-peer transactive energy projects seem to be lacking. The reviewers agreed that techno-economic potential for widespread microgrids seems low, and higher-level feasibility analysis needs to be done before funding detailed technical work. Similarly, the reviewers were skeptical that peer-to-peer models will be viable and adopted by markets/customers. Additional work needs to be done to justify research in this area.

### Reviewer Feedback: Final Topic Feedback

More work needs to be done to support transmission, distribution, and generation planning studies for PV and PV-plus-energy storage hybrids, including storage dispatch. Additionally, more emphasis should be placed on understanding potential future infrastructure and markets, such as networked microgrids and competitive distribution markets, as well as controllable loads and other DER integration and coordination with storage. Finally, there should be continued emphasis on uncertainty reduction, grid integration, and improved resiliency.

# Power Electronic Devices and Control

Projects in this topic area help the solar industry develop new technologies to improve the hardware devices that serve as the critical link between solar photovoltaic arrays and the electric grid. Given that all photovoltaic-generated electricity must flow through a power electronics device, these projects aim to innovate and discover new hardware solutions to improve equipment efficiency and reliability, reduce photovoltaic plant lifetime costs, enhance capabilities for advanced power flow control, and enable increased amounts of solar energy on the nation's electric grid. Projects in this topic represent nearly 15 percent of the Systems Integration track portfolio and 11 percent of the track's budget

### Reviewer Feedback: Goals and Strategy

The goal for this topic is cost reduction (first cost and LCOE) to make solar energy affordable and accessible for all Americans, both in terms of self-generation and grid-wide cost based on LCOE per kilowatt-hours. This, combined with providing grid support in a reliable, resilient, and secure manner, will continue the growth of this industry and economy in the United States. With respect to power electronics, the multi-pronged approach addresses this through exploring new semiconductor materials, inverter topologies, control strategies, integration of separate functions into single devices, and/or systems to reduce balance of system equipment and redundancy.

Additional focus on the related supply chain (upstream and downstream), device and controls modeling, as well as standardization of communication protocols and regulatory standards, brings added value to power electronics and devices in this application. This is particularly important in driving the mission of commercializing the outcomes of respective projects, evaluating their ongoing viability in the market, and achieving SETO goals.

Identification of advancements in any of these areas that are not or likely won't be market driven, and can be brought to market in the future, is key to SETO's mission. There is specific value to the mission in this capacity for advancements in grid stability, grid interconnection modeling, and overall future grid advancements in coordination with other DOE programs and objectives. Engagement of industry, regulatory, utility, system operators, as well as research and development stakeholders is fundamental to achieving SETO's mission.

## Reviewer Feedback: Alignment with Goals

The selected projects within the topic are in line with the mission, but with the information provided, it is sometimes challenging to see the direct path from the activity underway to how it specifically supports the mission in the project reports. While one of the primary missions of SETO is cost reduction, it seems that the target inverter costs are not in line with market trends and need to be assessed based on overall plant cost reductions—not just inverter cost reduction (because that alone does not support the mission). It may be that a more expensive inverter technology can be disproportionately offset by associated cost reductions or reliability savings elsewhere. In many cases, the application or potential in the emerging regulatory environment would be very helpful to understand. In addition, the path to commercialization, in most cases, appeared to be a gap, not a well-defined path or end goal. An additional point to consider is that, given the steady decrease in cost and increase in efficiency of existing solutions, cost reduction or technical benefits of a novel technical solution must be significantly above the present state of the art before such a technical solution is accepted in the market, as everyone expects there to be new product introduction problems for all new solutions.

## Reviewer Feedback: Funding and Resource Allocation

It seems that additional projects and funding for power electronics and devices could be applied to “public interest” aspects that are not, or cannot, be driven by the market (innovation in the market can be constrained by price erosion). Many of these aspects are already covered, but additional funding is suggested for grid-forming inverters and other grid-stabilizing technology, advancement and standardization in device and grid interconnection modeling, regulatory support and engagement, and other aspects that inform and drive the development of power electronics and devices. More direct collaboration and interaction with rule-making committees could be beneficial.

## Reviewer Feedback: Project Value

Some projects in the power electronics topic appear to be more beneficial and targeted toward the SETO mission than others, but this may be a factor of the content presented rather than actual project content. In addition, it seems that some projects are focused more on productizing their own device rather than advancing the industry, while others clearly included stakeholders to help support the holistic mission of SETO.

## Reviewer Feedback: Advancing the Mission

The projects in this topic lend themselves to advancing the industry, but as noted previously, timelines relative to cost expectations, cost targets, and regulatory compliance would help in this review. Where this is not possible due to the scope, a path to industry advancement and next step challenges would also help inform the value in this type of review. Focus on more than just direct cost reduction is encouraged to demonstrate the impact on the market that these projects can have. If to “advance the U.S. solar industry as whole” means the application of solar as an energy source and the consequent increase in installation and maintenance jobs in the United States, then the answer is yes. If it means increasing high-end U.S. manufacturing in solar applications, the answer is not clear, as the results of the research funded by SETO will generally be available globally, except for those projects targeting help to a particular private producer.

## Reviewer Feedback: Areas of Improvement

Significant blind spots are not noted, other than those previously mentioned. The specific impact of each project on reliability and robustness is not well addressed. Power electronics failures and sensitivities in the industry continue to place a lack of confidence in these PV technologies and need to be improved. With ongoing price pressure and erosion, the market will need support in this capacity with each technology innovation. It is also unclear how these projects will help advance the residential and commercial sector, as opposed to utility-scale distribution and transmission.

### Reviewer Feedback: Final Topic Feedback

SETO should continue to increase focus on the factors that drive and inform power electronics development in coordination with emerging regulations, program guidelines/requirements, and contextualized cost targets and milestones. SETO may want to consider funding projects that define functional requirements for power electronics devices in the grid (near-term and in the future). An example of such a project is a data-driven study determining the required low-voltage ride-through boundaries and performance with a view to eventual incorporation into the IEEE 1547 and P2800 and other industry standards.

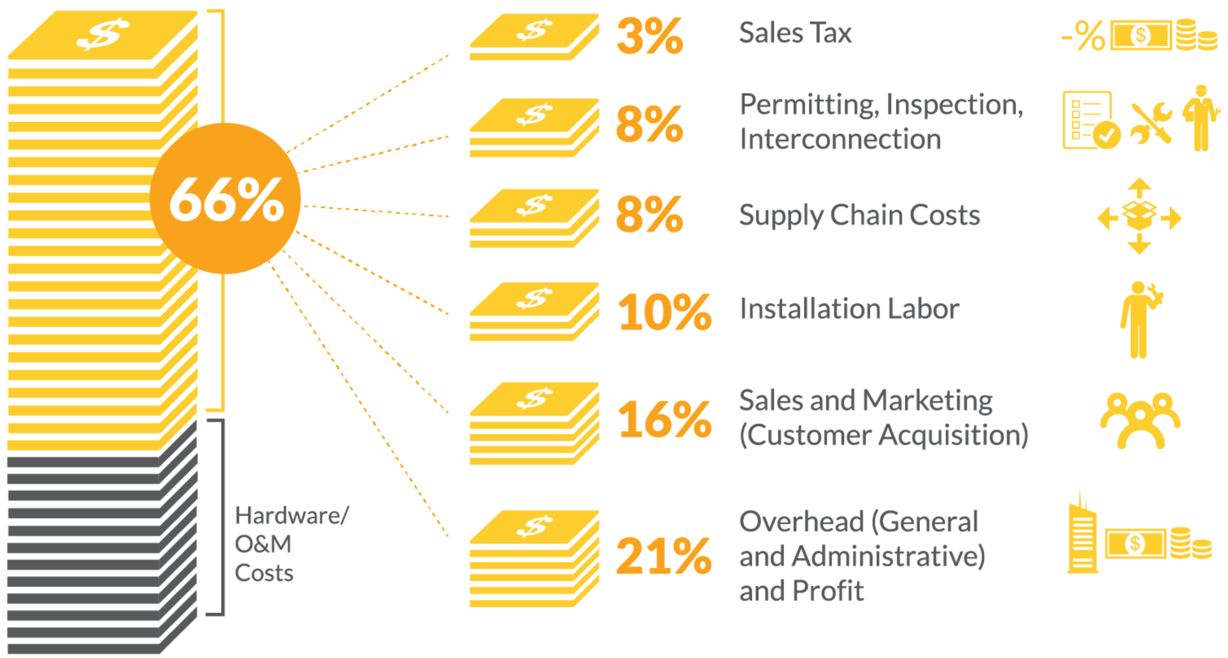
Additionally, upstream supply chain and downstream commercialization are critical factors, and reviewers encourage more focus on how each project fits into a timeline to market (even very-early-stage projects). This was not especially well developed in the presented information.

Finally, quantifying the strengths and weaknesses with respect to reliability and resiliency in overall value to both the market and public interest may help inform project direction and focus on those already in progress. Reducing the cost of energy associated with inverter technology would benefit from a strong emphasis on impact beyond material cost, integrating functions, and eliminating or combining balance of system equipment.

# Soft Costs

Projects in the Soft Costs track address challenges associated with non-hardware cost components of a solar energy system. These include the time and money associated with the design, siting, permitting, installing, interconnecting, and financing of a solar energy system. They also include the sales, general and administrative expenses solar companies incur for customer acquisition, training and certification, supply chain and inventory control, and operating overhead. There are 62 active projects in the Soft Costs track, which is approximately 15 percent of the overall SETO portfolio; Soft Costs projects receive nearly $108 million in federal funding.

The soft costs for residential solar energy systems have declined by approximately 50 percent since 2010 due to improvements in permitting, inspection, installation, and interconnection processes, as well as reductions in financing costs. However, these costs need to fall an additional 60-70 percent to achieve SETO's 2030 cost target and to make unsubsidized residential solar a more affordable electricity option across the country.




*Source: D. Feldman, NREL*

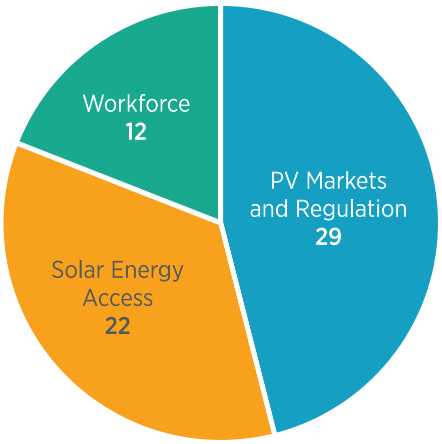
Projects within the soft costs portfolio seek to reduce the "red tape" associated with installing solar energy systems, as regulatory and financing burdens lead to higher costs for both developers and consumers. Across the country, there are more than 18,000 unique Authorities Having Jurisdiction that oversee the approval process for rooftop solar and over 3,000 utilities with specific interconnection standards. As hardware costs continue to decline, these regulatory and financing soft costs comprise of an increasing part of the total cost of a solar energy system.

The solar industry is one of the fastest growing industries in the United States. Ensuring that a diverse, qualified workforce can meet the needs of the solar industry helps to lower costs associated with labor and training. In addition, many jobs are impacted by the growth of solar, including grid operators, first responders, building officials, and financial professionals. SETO develops training materials and programs to help supply a skilled workforce to meet the industry's growing human resource needs, prepare those in the utility industry to manage a modern grid, and help relevant professions keep up with these rapidly emerging and advancing technologies.

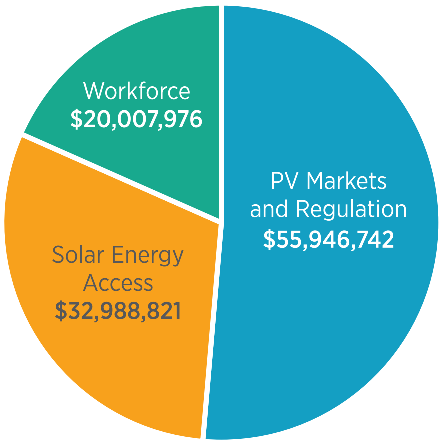
SETO-funded soft costs projects also work to increase solar affordability and expand the market through finance and business model innovations. Several factors limit certain customers from adopting solar, including the high cost and up-front expense of PV systems, a lack of suitable rooftops, a lack of access to low interest rates, low credit scores and/or income below traditionally acceptable underwriting criteria, and an inability of tax-exempt businesses and certain low- and moderate-income populations to use the Investment Tax Credit. SETO is actively developing and piloting new models to deploy inclusive solar projects, with participation from nonprofits and low- to moderate-income (LMI) customers, within their communities.

Projects in the Soft Costs track conduct fundamental research and analysis, identify opportunities for standardization, and seed innovative multi-stakeholder collaborations while disseminating critical research to the solar industry. Additionally, projects assist industry efforts to streamline and standardize permitting, inspection, and interconnection.

Soft Costs Projects by Topic Area




Soft Costs Funding by Topic Area




Projects in the Soft Costs track fall into three major categories: Solar Energy Access, Photovoltaic Markets and Regulation, and Solar Workforce.

Below is a summary of the findings from reviewers in the Soft Costs track, written by the track chairperson, Dr. Karen Wayland, CEO of kW Energy Strategies, based on her observations and the group discussions during the peer review. Following the track summary, the three topics within the Soft Costs track are highlighted in greater detail, written by lead reviewers:

- Solar Energy Access (Karen Wayland, CEO, kW Energy Strategies)
- Photovoltaic Markets and Regulation (Mary Ann Ralls, Director of Regulatory Council, National Rural Electric Cooperative Association)
- Solar Workforce (Gilbert Campbell, Principal and Cofounder, Volt Energy)

Individual project reviews for the Soft Costs track can be found in the Soft Costs Appendix.

## Reviewer Feedback: Goals and Strategy

The Soft Costs track focuses on reducing non-hardware costs of solar installations, with projects in this track encompassing a wide breadth of subject areas, from financing to environmental impacts to data analytics and training.

The long-term goal of the track is to reduce soft costs by 60 to 70 percent to meet SETO's aggressive cost target of $0.10/kWh for residential PV systems. Other goals include increasing access to solar for those who cannot own or rent PV systems, reducing the permitting and interconnection processes, and increasing the number and diversity of trained solar industry workers.

More than half the Soft Costs budget is allocated to the PV Markets and Regulation topic (almost $56 million), followed by Solar Energy Access (almost $33 million), and Workforce ($20 million). Funding has been awarded to a diverse set of entities, including for-profits, nonprofits, academic institutions, state and local governments, and the National Labs.

## Reviewer Feedback: Alignment with Goals

Given that hardware costs are falling significantly faster than soft costs, the work to create certainty in permitting, customer acquisition, interconnections, and regulatory processes, as well as de-risking the financing of systems will contribute to this track's goal. The PV Markets and Regulation topic in particular has a good balance of discrete projects tailored to specific segments, such as supporting agricultural solar development, and projects with broader applicability, such as developing strategies to combine solar and demand-side management to support resiliency and overcome grid integration challenges. Reviewers appreciated that projects focused on diverse market segments, such as rural communities. In the Workforce topic, individual projects do a reasonably good job aligning with the goals and strategy, though the overall portfolio is heavily tilted to one aspect of solar jobs (solar installation). There is an inherent tension, however, between reducing soft costs and increasing access and building a well-trained workforce. Reviewers noted that the latter two are important societal goals that may lead to higher soft costs, at least in the short term.

## Reviewer Feedback: Funding and Resource Allocation

Reviewers felt funding levels were appropriate for the situation in which the decisions were made (pre-pandemic). Projects with broader applicability and impacts, either to stakeholders, regions, or customer classes, received the most funding because they had the most intricate or comprehensive goals. However, the review team recommends SETO evaluate the potential slowdown of solar projects that stem from COVID-19 and how funding strategies may need to be adjusted to address those impacts. Reviewers recommended that training programs be more expansive to include training in longer-term career pathways in clean energy jobs and careers beyond solar installation. The Soft Costs track should develop a longer-term strategy to determine funding needs for these extended career pathways.

## Reviewer Feedback: Topic Value

Reviewers did not identify any of the topics as clearly superior or inferior and felt that the majority of the projects in each topic were well designed and would contribute to advancing the solar industry. However, some projects shared several common concerns that might dilute their value. Reviewers were unclear whether the projects are actually capable of moving the needle on identifiable soft costs, and in ways that can be quantified. They also weren't sure if the value of one project could be replicated or somehow demonstrated in other states, stakeholder groups, or sectors of the industry. Reviewers also believe projects should ensure all relevant stakeholders are included in the project to achieve and demonstrate the objectives and goals. As previously noted, some of the projects may not contribute to the goal of reducing the cost of solar projects as measured by $/kWh. Reviewers recommend developing metrics beyond the $/kWh for quantifying the benefits of the Soft Costs portfolio.

### Reviewer Feedback: Advancing the Mission

Reviewers believe that the majority of the projects in the Soft Costs portfolio are consistent with SETO's goals and will contribute to a robust solar industry. The value propositions of projects differ in magnitude, but that is a strength of the SETO mission—to support diverse efforts to grow the solar industry. With respect to the Solar Workforce topic, reviewers feel SETO should focus on projects that invest in emerging skill development and careers and not only legacy careers like solar installation. SETO should share insights from the higher skill training grants with entry-level projects to encourage career ladder development and provide aspirational goals for entry-level trainees. Diversity and inclusion should also be a major emphasis in all of the projects. SETO should promote diversity at all skill levels, not just entry-level installer positions. One overarching recommendation is that SETO should develop a program communications strategy for disseminating the results of its awards, rather than relying on grantees to share lessons learned.

### Reviewer Feedback: Areas of Improvement

SETO needs to signal—in the questions asked during the application process—that diversity and equity are high priorities and need rigorous tracking and analysis. This should include ensuring that awardees are supporting under-resourced groups' participation effectively as they bring them into processes to tap their wisdom, and including equity and diversity metrics when awardees report on successes and meeting, trainings, and other activities. SETO should consider including application questions to ensure that quantitative modeling, tracking, and reporting investigate differential impacts within LMI communities, not just net impacts. This will help ensure replicability and maximize full potential and scale, and can be an early warning system for flawed or inequitable approaches. SETO could host a forum for awardees and others on best practices for rigorous equity analytics and stakeholder engagement. To ensure equity issues are not overlooked in the financing realm, SETO should ensure applicants are including environmental justice and economic inclusion experts. SETO could also include diversity among project leadership/partners in reporting requirements.

### Reviewer Feedback: Final Track Feedback

Overall, the SETO Soft Costs program is an impressive collection of projects that will support a robust solar future. However, SETO must reevaluate its goals and strategies in light of COVID-19, as the impacts of the pandemic and economic downturn on the solar industry become clearer. To scale the successes of individual projects, SETO should develop a communications strategy to disseminate the results of individual projects and lessons learned across the portfolio, rather than relying on awardees to communicate to their own stakeholders. While each project lasts two to three years, the impacts of a project may only just emerge at the end of the funding period. While awardees submit a final report with metrics for success, SETO will only truly know if a project has enduring impact if it develops a process for measuring metrics beyond the life of a project. Similarly, SETO should quantify the impact of its soft costs portfolio beyond reductions is $/kWh.

# Solar Energy Access

Projects in this topic are working to expand access to solar energy by integrating science, business, and market strategies to develop solar finance and business model innovations that improve access to capital and accelerate market growth. This includes community solar models, where multiple participants subscribe to a single solar energy system, represent one of those innovations. High financing costs make solar unaffordable for some consumers and limit the solar market's ability to expand its customer base. These projects enable local financial institutions, such as community banks, credit unions, and community development financial institutions, to fund solar projects in their local communities, enabling increased access to affordable solar energy for businesses and individuals in LMI communities. Projects in this topic represent more than a third of the Soft Costs track and 31 percent of the track's budget.

## Reviewer Feedback: Goals and Strategy

To make solar energy more affordable, new finance mechanisms must be developed so everyone can have access to solar power. Projects in the Solar Energy Access topic are working toward SETO's goals by thinking outside the box and funding projects with unique approaches to accessibility, which, if replicable, will allow expansion of solar across the country.

## Reviewer Feedback: Alignment with Goals

The projects in the Solar Energy Access topic align well with SETO's defined goals and strategy. All seem to be similar in what they're trying to accomplish: increasing access to solar energy and working to make the market more robust for LMI customers. Some of the projects have a more tangible approach, while others take a broader, investigative approach, working with community solar developers to create blueprints and best practices contracts.

## Reviewer Feedback: Funding and Resource Allocation

Reviewers are split when it comes to the number of Solar Energy Access projects and amount of funding. Some found that solar energy access is a very important part of lowering soft costs and believe there should be more projects in this arena to enable that. Others found overlap among several of the projects in how they are trying to achieve an increase in community solar; they believe it is a relatively small sub-segment of broad-scale solar adoption and would have less of an impact on lowering soft costs.

## Reviewer Feedback: Project Value

Overall, each project is playing an important role in achieving the goals of increased solar energy access, though some projects take more innovative approaches than others. For example, the projects from the Clean Energy States Alliance are doing an excellent job of engaging stakeholders and will result in lessons learned that can benefit others across the country, especially pertaining to the establishment of relationships between philanthropic organizations and the banking community. Reviewers had a more favorable outlook for projects that had very defined foci and tangible results, like the Solstice Initiative projects and the EnergyScore project. However, reviewers also felt that a market sizing exercise was absent from many projects and that they should be designed with the goal of catalyzing action, as opposed to studying approaches.

## Reviewer Feedback: Advancing the Mission

These projects are advancing SETO's mission and the solar industry as a whole. Reviewers did, however, notice that while several projects are developing models that will be successful in their respective regulatory markets, the success of the projects is fully dependent on specific policy contexts. This limits the scaling of projects on a national level, especially for projects dealing with community solar. It's important to look at the issue from both lenses, though: We must find solutions that will work in multiple policy contexts while simultaneously providing recommendations for states. Reviewers expressed the challenges faced by SETO, understanding that its role is for research and development and cannot cross into policy advocacy.

## Reviewer Feedback: Areas of Improvement

Reviewers agreed that the most significant blind spot associated with the Solar Energy Access topic pertains to getting the message into the market. While it's important to develop best practices that can be used by communities across the country, the information serves no one if it sits on a shelf. Reviewers suggested creating a requirement for projects that includes a handoff of information to industry partners who will be able to implement change.

In addition to the dissemination of information, reviewers had thoughts on approaches to reaching LMI solar customers. They agreed that a ground-up approach where people are being signed up to participate in community solar one by one is time-consuming and expensive. They suggest funding projects that work with housing authorities to bring community solar to hundreds of consumers at a time. They did recognize, however, that the LMI market segment has various sub-segments that can make this more challenging, like age, race, or population density. The more data these projects can collect, the larger an impact the projects will have.

### Reviewer Feedback: Final Topic Feedback

Information dissemination should be a key part of each project. It's important that the results are shared with multiple stakeholders in the solar industry to effect change and ensure that successes can be implemented by others. Additionally, because the policy climate is different depending on which part of the country you're in, applicants should be required to demonstrate a broad value chain to other regions or industry sectors. Finally, the more data a project can collect, the better. Some data may apply to one segment of the market, and other data may not. Community solar and LMI solar markets can drastically vary, and having large amounts of data will ensure project insights are more broadly applicable.

# Photovoltaic Markets and Regulation

To meet SETO's goals, the solar industry must innovate and automate processes that make it easier for consumers, businesses, utilities, solar companies, and others to adopt solar power. Recognizing that the perceived risk of investing in a solar energy project can be much greater than the actual risk, projects in this topic support market players who are working to develop data-driven resources and improve access to capital. Additionally, some of the projects in this topic provide state and local decision-makers with timely and actionable resources, peer networks, and technical assistance to lower local market barriers and establish best practices in order to expand solar power access throughout American communities. Other projects in this topic also work to reduce the costs of siting utility-scale solar power plants that are associated with environmental permitting, compliance monitoring, and impact mitigation. Projects in this topic represent nearly half of the Soft Costs track and slightly over half of the track's budget.

### Reviewer Feedback: Goals and Strategy

Projects in this topic are working to limit the barriers that people and organizations face when attempting to use solar energy. Solar isn't just on residential rooftops; it affects many different industries. Projects in this topic will help lower the costs associated with solar by better integrating them into industry-specific processes and streamlining the process of going solar for all consumers.

### Reviewer Feedback: Alignment with Goals

Overall, the projects in this topic align well with defined goals and strategy. Reviewers believe there is a good balance of discrete projects tailored to specific segments, such as supporting agricultural solar development, and projects with broader applicability, such as developing strategies to combine solar and demand-side management to support resiliency and overcome grid integration challenges. Reviewers appreciated that several projects focused on diverse market segments such as rural communities.

### Reviewer Feedback: Funding and Resource Allocation

Reviewers observed that projects with broader applicability and impacts, either to stakeholders, regions, or specific customer classes, received the most funding because they had the most intricate or comprehensive goals.

### Reviewer Feedback: Project Value

Overall, projects are on the same playing field. Reviewers generally thought highly of the projects that focused on environmental concerns and real estate. However, some projects shared a few common concerns that might dilute their value. There are several projects for which reviewers questioned their capability in terms of moving the needle on identifiable soft costs in ways that can be quantified. There was also concern regarding whether the value of the project could be replicated or somehow demonstrated in other geographic areas, among different stakeholder groups, or in other sectors of the industry. Additionally, reviewers felt some projects needed to include more stakeholders to best achieve their objectives and goals.

### Reviewer Feedback: Advancing the Mission

Generally speaking, the projects in this topic are working to advance SETO's mission. Value propositions differ in magnitude, but that is a strength of the SETO mission: to support diverse efforts to grow the solar industry.

### Reviewer Feedback: Areas of Improvement

Reviewers agree there are no significant blind spots across the projects in this topic. But it is important to note that in some cases, it appears there are certain segments within this topic for which SETO is looking to fund innovative projects. Strategic outreach plans for the FOAs that are targeted to specific groups could result in higher-quality applications that have broader impacts on soft costs.

### Reviewer Feedback: Final Topic Feedback

When selecting projects that deal with PV markets and regulation, SETO should consider their long-term impact on soft costs and if the strategy proposed will actually help make solar energy more affordable. Additionally, SETO should consider whether projects' anticipated results can be replicated elsewhere or to other segments of the solar industry, including consumers, and other regions of the country. Finally, it's important that the principal investigators of each project are urged to include multiple stakeholders across the industry in the work, to best support and reach the project's goals and objectives.

# Solar Workforce

Solar jobs have risen rapidly in the past decade. Training a prepared and skilled workforce that enables the solar industry to meet growing deployment demands is a high priority. Projects in this topic address the critical need for high-quality, local, accessible training in solar energy system design, installation, sales, and inspection, as well as power systems engineering and related professions like building safety officials and first responders through a variety of training programs. Additionally, these projects help to develop a pipeline of knowledgeable and educated solar energy professionals through collegiate competitions, fellowships, and other research opportunities. Projects in this track represent nearly 20 percent of the Soft Costs track and nearly 20 percent of its budget.

### Reviewer Feedback: Goals and Strategy

One of the ways to lower solar costs is by ensuring there is a well-trained workforce to keep up with the growing demand for solar energy. If there are fewer workers, prices will rise to keep up with demand. Projects in the workforce topic support SETO's goals by lowering solar energy costs through training programs designed to perpetuate an educated workforce.

### Reviewer Feedback: Alignment with Goals

The individual projects do a reasonably good job aligning with SETO's goals and strategy. There are projects underway that work to lower overall soft costs by creating more jobs within the industry that would make it easier for hiring companies to find the talent needed to fill gaps. The overall portfolio, though, is heavily tilted toward solar installation jobs, which is just one aspect of the industry.

### Reviewer Feedback: Funding and Resource Allocation

While the funding for workforce projects is appropriate under normal circumstances, a reevaluation is recommended in light of the COVID-19 pandemic, which could lead to a slowdown of solar projects. It's currently unclear how the pandemic is going to reshape the industry, but these factors should be taken into consideration when forming the next FOA that pertains to the solar workforce. Additionally, there should be more projects that focus on longer-term careers in the solar industry. The portfolio has plenty of projects that focus on installation jobs, but this is just one small facet of the industry.

### Reviewer Feedback: Project Value

All projects in the Solar Workforce topic create value for the solar industry and in reducing soft costs, though reviewers noted several exceptional projects. The Grid-Ready Energy Analytics Training with Data project takes a broad yet targeted approach to training utility professionals so they are able to handle larger amounts of solar energy on the grid. The Cyberguardians and STEM Warriors project works with veterans in need of employment who have specialized skills in the information technology arena and helps translate them into expertise that applies to the solar industry. The Expanding the Solar Workforce Through the Illinois Community College System project connects education and training providers, job seekers, industry, and local communities; this type of interconnected system with several industry partners is critical for job placement and curriculum development. These projects are doing outstanding work, and there should be more like them in the workforce portfolio that provide opportunities aside from installation jobs. For example, a project that teaches high school students how to become installers upon graduation should also prepare them for other similar vocational careers that lead to career growth; it should educate them on the solar industry as a whole and the many career options within it. A robust menu of options based on student interests, desires, and capabilities is not reflected in most of the projects reviewed, especially projects focused on special populations, such as those involved in the justice system, people of color, and, in some cases, veterans.

### Reviewer Feedback: Advancing the Mission

While the success of the workforce projects will advance SETO's mission and the U.S. solar industry as a whole, there should be substantial thought into a broader long-term strategy. Reviewers believe SETO should adopt a forward-looking orientation, focusing on projects that invest in emerging skill development and careers, not only legacy careers like installation. Reviewers also encourage SETO to share insights from the higher-skill training projects with entry-level projects to encourage career ladder development and provide aspirational goals for entry-level trainees.

Diversity and inclusion should also be a major emphasis on all of the projects. SETO should promote diversity at all skill levels, not just entry-level installer positions. Diversity should be viewed as an opportunity to get hidden or undervalued talent "on the field" and provide the innovative and intellectual fuel for moving the industry forward.

### Reviewer Feedback: Areas of Improvement

Solar companies are facing significant revenue and job losses due to the COVID-19 pandemic, according to emerging reports from the Solar Energy Industries Association. Residential projects and solar installation jobs are particularly vulnerable, as people are less likely to allow strangers into their homes to complete installations. This underscores the problem of training workers for installation jobs with no access to careers in emerging sectors of the industry. SETO should consider this as part of its strategy moving forward.

Additionally, it is recommended that SETO require workforce applicants to have committed employer relationships in place, with memorandums of understanding, as a condition for receiving funding. Those employer commitments should include "bridges" from training to employment, such as internships and apprenticeships.

Finally, workforce projects should include more cost sharing. By training people to work in the solar industry, college programs and private industry receive a direct benefit—colleges receive funding to complete the trainings, and private industry has access to a skilled pool of applicants they don't have to vet. These parties should be sharing some of the funding responsibilities.

### Reviewer Feedback: Final Topic Feedback

Training programs should be more expansive to include training in longer-term career pathways in clean energy jobs beyond solar installation. A longer-term strategy should be put in place that will determine funding needs for the future workforce.

SETO should first study examples of other industries that have developed successful diversity initiatives with career ladders, then develop projects that engage electric utility, water and waste water, and oil and gas companies. These companies have robust training programs, long-term jobs, existing diversity and inclusion programs, and are starting to hiring people with criminal backgrounds. It is our belief that they can add great value in helping to train and employ our clean energy workforce to meet industry needs.

SETO should put more emphasis on diversity and inclusion. In the questions asked during the application process, it is imperative that diversity and equity are a high priority, and need rigorous tracking and analysis as well.

# Strategy And Planning

The Strategy and Planning track reviewed individual projects selected for their potential to support SETO's strategic direction, while also taking a broader look at the full SETO project portfolio. The 15 projects reviewed in this track include those that conduct high-level analyses of solar technologies, including technoeconomic and market analyses, as well as projects piloting collaborations with other offices within the Department of Energy on data and analysis that spans multiple technologies and may be critical to solar energy's growth in the energy sector. These projects total approximately $24 million in federal funding and 3 percent of the overall portfolio.

Strategy and Planning Projects by Topic Area


Strategy and Planning Funding by Topic Area


The main focus of this track for the peer review, though, was a broader portfolio-level review that considers the office's near- and long-term strategies, technology targets, and organizational effectiveness. Reviewers attended breakout sessions from all SETO tracks, sampling the office's portfolio of nearly 400 projects to gain a greater understanding of the overall strategy. This includes a selection of Manufacturing and Competitiveness projects to evaluate the programming, project management, and strategies used by SETO to support U.S. businesses in solar.

Below is a summary of the findings from reviewers in the Strategy and Planning track, written by the track chairperson, Danny Kennedy, CEO of New Energy Nexus, based on his observations and the group discussions during the peer review. He was assisted in writing this summary by lead reviewers:

- Sharon Allen, Chief Innovation Officer, Smart Electric Power Alliance
- Sander Cohan, Director of Innovation, Enel Green Power North America
- Kathleen Hogan, former Deputy Assistant Secretary for Energy Efficiency, EERE, DOE
- Joe Stekli, technology scout, Electric Power Research Institute

Individual project reviews for the Strategy and Planning track can be found in the Strategy and Planning Appendix.

## Reviewer Feedback: Goals and Strategy: Near Future

SETO's high-order goals are clean and articulate: Improving the affordability, performance, and value of solar technologies on the grid. Indeed, SETO has made substantial progress to date in meeting these aggressive goals. It also appears that the congressional budget aligns with the DOE and SETO teams' structure, and this structure supports critical technical areas where progress is necessary to meet the program goals. When it comes to defining the topics in the peer review tracks, the systematic process of how ideation of key gaps, problems, or issues get prioritized and turned into a topic area should be better documented to make clear how that portion of the process works. Further, the breadth and depth of the stakeholder engagement efforts in the processes could be clearer, given the importance of this feedback as part of establishing priorities.

In addition to meeting technical goals, SETO demonstrated that it evaluates other important considerations when building its portfolio. These issues include items such as the role of the government, gaps in research and development funding for specific technologies and topics, and the signal that U.S. government funding can provide to the broad research community. After selecting funding opportunity topics or specific projects, SETO can justify its choices clearly based on the technical goals above and these additional factors. However, there is a "missing middle" in the selection process that is certainly performed by the office but lacks a formal process.

Specifically, this "missing middle" is the lack of a clearly articulated process around the consideration of opportunity cost for taking on one activity that meets all of SETO's criteria as opposed to another. In the course of discussions with the SETO staff, it is clear there is a weight given to the technical targets and these broader portfolio considerations. But this process is not formalized, meaning there is difficulty in communicating the justification for selecting one appropriate topic over another after the fact. It also does not allow SETO to evaluate its full selection process to look for faults or find improvements in the methodology employed.

SETO has a number of funding mechanisms to use in meeting its goals that allow it to partner and/or work with different stakeholders in different ways (e.g., directly with the National Labs, supporting National Labs partnering with private and nonprofit entities, soliciting research proposals broadly, new collaborative approaches). These have each contributed to substantial progress and provide effective means of meeting program goals. The question is one of knowing which mechanism(s) to use for which efforts and how to structure each as effectively as possible. There is substantial learning underway as to how to effectively use the prize mechanism, as an example, to address different types of problems. As this learning increases, this mechanism could see greater use.

SETO views itself enhancing the innovation ecosystem on both the supply and demand side for solar. Reviewers agree and believe it is the best approach for the journey between specific project deliverables and delivering on those high-order, decadal goals. But ecosystem design and construction are notoriously tricky, and it may benefit SETO to be more explicit about how this work is accomplished. There are at least four inputs that SETO impacts in these ecosystems: people, information, sales, and money.

These things move both the supply and demand side of the solar market. There seemed to be awareness of these levers mostly on the supply side in how SETO identifies emerging solutions (new ideas); driving new intersections and connections across fields (synergies lead to new ideas/more value and therefore sales); widening the funnel of solutions being tested (more new ideas); testing, validation, and data sharing to de-risk (attracting money); increasing the diversity of participants (more people, more ideas); providing opportunities for showcases and recognition (pre-sales); and supporting new partnerships (sales and money). Getting more explicit about this and setting quarterly and annual markers, like objectives and key results or similar measures, may be useful in SETO's journey from beginning to the end state or goal.

These markers support team members' ability to ensure delivery of the mission and larger goals of SETO. They allow SETO to adjust course during the work, perhaps using even/over filters or another planning tool. For example, in 2023 when SETO appears to see good progress in utility-scale cost reduction due to balance of system improvements, operations and maintenance applications, and new financing on a 50-year lifetime, SETO may direct the track leads to support projects and programs for the next couple of years that increase inputs of people, ideas/information, sales, and money into reducing the costs of commercial and residential roof installations, even over progressing cost-down in utility scale. The point here is that it's important to make the decision filter in the middle as explicit as possible.

Another high-level insight reviewers learned in the review process is the value of heuristics (mental shortcuts that allow people to solve problems and make judgments quickly and efficiently) to SETO's planning and strategy work on a daily basis. It was universally agreed that the SunShot goals set under Secretary Steven Chu galvanized the organization. While SETO has clearly articulated high-order goals, there is no catchy vision to encapsulate them and move the team and the community around SETO forward. Having achieved its Moonshot, what is the next mission for SETO? Leadership needs to find something that will inspire and move efforts past the SunShot goals through the 2020s to 2050 and more. On a daily basis, the team chooses between what it could or should support with hundreds of millions of dollars; the lens by which it chooses needs to be second nature to be effective.

While it is not for reviewers to say what this would be, they strongly recommend SETO finds such a calling. And this may be where the current situation with COVID-19 comes most clearly into play. For starters, reviewers encourage a more expansive goal than just cost-reduction measures—it may not motivate in the same way as before to shave a penny off the cost of solar when millions of Americans are without work. Perhaps in the post¬–COVID-19 period there is a focus on work and jobs for one million people as the U.S. supports industry and builds resilient supply chains as part of the more general macroeconomic learnings from the pandemic. Or perhaps there is something about moving us all toward the accessibility of solar for everyone. This is up to SETO, but now is the time to show leadership and seize the moment.

A final high-level thought is that as a material portion of funding is provided through SETO's FOA process, the solicitation of stakeholder input becomes foundational to ensure robustness. One tactic to reach key constituents across a diverse perspective would be to co-locate DOE brainstorming sessions alongside a major industry event, making it easy for stakeholders already attending to show up a day early or stay a day later to participate. Cross-fertilization helps ensure ecosystems evolve over time. Another idea to ensure wider stakeholder engagement is to require FOA applicants to list the key stakeholders who would benefit from the project (not generically like utilities, but rather senior distribution planners, as an example) such that a composition of the advisory board represents those who potentially benefit. This could augment FOA processes SETO already executes.

### Reviewer Feedback: Balanced Portfolio

Reviewers feel the portfolio is balanced. It was easier to see the benefit of the FOA process than all the benefits of the direct work with labs, and the prize programs are probably too young to reveal whether they generate long-term systemic benefits. If there is any shift, it may be to emphasize systems integration and soft costs over the hardware sectors. Meeting the right players to continue to advance the mission is constant work, and as discussed with senior leadership, SETO needs to own the outreach and storytelling to constantly reach this generation and future generations of solar energy leaders. Reviewers believe there should be greater reliance on DOE for this work, but perhaps third parties could be of assistance.

Based on the strengths and weaknesses of the projects in this track and the overview of other tracks attained in their breakout sessions, reviewers believe the production of redundant data sets and information in partnership with some of the National Labs is an area where possible savings or reduction of funding could occur. However, it was challenging for reviewers to tell if and why some of those efforts are maintained. For example, it was unclear if there is a strategy of building redundant knowledge in order to keep private-sector players honest in the same business.

Intentionality is a key component to understanding whether a program effectively uses funds. If attention is paid to understanding the research program's intended target and its expected impact on this target, and a strategy to disseminate results to the greater public, then it should become clear whether the funds allocated are effective.

It is apparent from the project review that the projects are a mix of different focuses and different technology phases. Some projects, notably the ones that are working to build out databases and understanding of markets, fall firmly within a scope that plays toward the strength of a federal agency. These projects address new markets or fundamental research that a private industry developer or entity would not have the wherewithal or credibility to study. Nevertheless, the research undertaken is essential for industry actors like developers to invest capital in full-scale deployment. This is a case where relatively small amounts of funding can have substantial impact on the marketplace by highlighting and identifying a market opportunity that would otherwise not be apparent. But for each program that embodies this characteristic, there are several that are too concrete in nature, focused on immediate market opportunities that are already well understood by the marketplace. These often-replicated actions are already underway by private-sector companies or resulted in projects that benefited a narrow group of (or even singular) stakeholders. While SETO has an opportunity to add value in this case, there is the potential for a worst-case outcome where money is spent to create a product that is inferior to a similar product created from a competing private-sector effort.

In addition to avoiding outcomes with narrow or sub-optimal outcomes, having an effective view of target stakeholders and communication mechanisms can also serve SETO by providing an avenue to sideline projects that don't have immediate value in the current marketplace but could have value in the future. By ensuring that project outcomes do not get lost or are not obfuscated from their potential audience, delayed research can remain available to a future audience, if and when the research becomes relevant again.

### Reviewer Feedback: Measuring Impact

Measuring the impact of multifaceted programs, portfolios, and projects is complex. In SETO's case, there are multiyear planning goals to guide progress and provide a high-level framework for the desired impact for the vast majority of annual program funding. At the same time, meaningful progress is made in smaller steps, in different segments of the technology development and delivery chain, with potential to improve the uptake of solar energy in many different and significant market applications (applications that are increasingly ones of integrating solar with other technologies to meet society's needs) in many different geographies, climates, and energy markets.

SETO could benefit from developing or implementing a more consistent approach to measuring impact linked to the technology readiness level (TRL) of the work being funded, meaning that it is clear that different types of measures make sense for different types of projects. Fundamentally, measuring impact is about moving the needle in some way toward critical goals, while writing papers, presenting at conferences, and seeding new companies are important but not necessarily the core desired impact. For some of the later TRL and technical assistance work, SETO could consider more upfront characterization of the necessary cost and performance characteristics for solar to compete in key market segments, climates, and geographic settings, particularly when employed as an element in the larger energy system. A fuller framework could assist in the setting of priorities and clearer impact goals at a portfolio or project level. Essentially, SETO would be fleshing out the representative aspect of the work. A number of projects seem to do this, starting with fleshing out important use cases, but more of this approach is likely useful. This would complement both the articulation of the strategy and the storytelling of accomplishments.

When it comes to measuring impact for a given project, reviewers acknowledge that this has many nuances. For projects that fund work at TRL 7 and above, one consideration is to have a follow-on phase that would motivate the teams to take the learnings from the project and secure two to three more companies to imbed the tools, models, software, or new hardware. While writing papers at the end of the project and speaking at a conferences is important, successful projects have impact by expanding and benefiting beyond the one company where the project was completed.

On the question of measuring the benefit of knowledge and technology developed with SETO support for the global scientific community versus U.S. economic advantage, reviewers believe it is a false choice. There have been obvious network effects at play in the solar research and development community, and the greater the number of nodes of excellence that push the boundaries of understanding, the more rapidly the value created has grown. Consumers, employees of solar across the value chain, and the grid itself benefit from the spread of low-cost solar. Growing the pie is the best strategy for research and development, as opposed to trying to protect your little slice.

### Reviewer Feedback: Technology and Program Strategy

SETO's breadth across the five teams provides great coverage. To reach the stated goals, it is important to not lose sight of solar as a component of the larger grid system. SETO might consider expanding its thinking around "solar plus." For example, forecasting is an important element in hosting capacity, yet it isn't just about forecasting solar energy. Utilities need to understand the propensity of adoption of electric vehicles, storage, and demand response in conjunction with solar to solve the grid's pain points. The modeling of solar with these other elements is a key area in need of innovation.

As a result, it may be that slightly more emphasis is needed on the Systems Integration portfolio and Soft Costs, which is often a catchall for creating the conditions for successful integration of solar into existing systems. As for PV, it seems the current thinking and work around perovskites is timely, although it is unclear whether SETO's contribution can be impactful compared to other progress across the world on this subset of the technology. As for CSP, the interest in industrial heat processes seems to be the right focus at this time in the development of the industry and should be held for the decade.

As far as missing areas of research in the portfolio, reviewers recommend that building-integrated PV projects focused on the cladding of the built environment become an important area of research this decade. Additionally, reviewers are pleased to see the fledgling work on agricultural solar specializations. Jobs in the solar industry and solar finance may be larger targets for funding in the future. Jobs will be greatest in the distributed settings for solar and are the premium value sought by government policy. Additionally, finance for assets that are small and modular and perform double duty will flow more easily.

### Reviewer Feedback: Solar in the Future Energy System

Per the above, greater focus on systems integration and reducing soft costs of combining solar plus other legacy elements of our energy system may behoove SETO in the 2020s. Aside from the speculative market in building integrated photovoltaics for all surfaces of the built environment (maybe even path and road surfaces, which DOE has historically dabbled in but not sustained investment to our knowledge), reviewers believe there is probably a need to develop a better understanding of solar-plus-hydrogen scenarios. The additive chemicals and industrial processes beyond hydrogen seem more speculative but probably worthy of some early-stage investment at this time. Desalination seems like an area where there is already intellectual traction to build upon.

The overarching scenario to work with when developing future strategies is complete electrification using renewables, meaning the vehicle fleets of America go electric. This is not just the privately owned vehicle but also the buses, delivery vans, trucks, boats, and airplanes, which will necessitate new ways to plug into the sun. Plugging all these assets into the grid is increasingly seen as an advantage by grid planners like the California Independent System Operator (CAISO), which will deal with this scenario becoming reality sooner than most, and should be the a priori assumption of SETO planning and technology research and development. In other words, no part of SETO's research agenda should be devoid of this emerging reality.

## Reviewer Feedback: Technology to Market and U.S. Manufacturing

SETO's technology-to-market portfolio seems impressive—150 companies received just over $250 million, multiplying that 25 times over to create $6 billion in value. The architecture of the program, from the Innovative Pathways funding program to the prizes and competitions to the small-business and incubator model, are well conceived. For this mix of approaches to work, though, they must be maintained for the long haul. Lots of small bets will not result in lots of successful companies quickly. To take a lesson from the Israeli innovation ecosystem that took a refugee state at the end of the 20th century to the second spot on the Nasdaq, the principles of success in such endeavors need to be competent, entrepreneurial leadership; patience for results, impatience for action; and, to remake the point, a bias to action.

Reviewers noted a disconnect between the early-stage work (pre-TRL 4) in which SETO has invested and the early-stage ideas SETO helps take to market, which should be further investigated. If SETO is doing early-stage work that cannot be de-risked sufficiently for the venture community to be an off-taker, it does not mean it is not worthy; venture capital is only a tiny fraction of how business is capitalized in America and will become increasingly irrelevant in the post¬–COVID-19 era. If this is the case, there needs to be a focus on other means to scale and commercialize technology, starting with the Small Business Innovation Research program but including corporate and strategic introductions. This could include public-sector players ranging from the Department of Defense to the agencies that will be charged with implementing private-public programs that create jobs post–COVID-19.

The value SETO generates from U.S.-funded research is historic work and should be manifested in a mission that uplifts all Americans and benefits the worldwide community. Mission-oriented innovation programs—as written about by Mariana Mazzucato—are more about market-making and shaping than market-fixing. It is not SETO's job to simply shave a penny off the price of a wafer but, more importantly, to work out the integration and benefit such low-cost solar can bring to the grid. The ability to invest in power electronics and tools and policies that will make that integration, and its related soft costs, lessen is clear. Thus, the percentage of budgets spent in the Systems Integration and Soft Costs tracks versus Photovoltaics and Concentrating Solar-Thermal Power tracks may need to be rebalanced.

The kinds of technology that may become the mainstay of this mission could include power electronics and ways to manage the interconnection of lots of solar to the grid. The United States is a great testing ground for this hardware, with one of the oldest, most diverse, and largest grids in the world. As mentioned above, if jobs become the metric by which government agencies and programs become measured over the coming decade to recover from COVID-19, then the hardening and smartening of the grid to integrate the solar assets we have spent the past 50 years finessing may be a great area of strength for SETO. The same could be said for the non-hardware technologies, financial products, insurance engineering, and permitting and impact assessment tools required for this process of mass integration of geographically and physically diverse assets into the grid. Some experimental areas, like solar integration with electric vehicle charging infrastructure, may be a great place to expend effort given the likely backing of this by states, utilities, and localities for years to come. Leaning into the solar-mobility segment is exactly the sort of work a mission-oriented innovation program could do, and it is full of high-road jobs that are much needed.

## Reviewer Feedback: Organization Effectiveness and Stakeholder Engagement

Reviewers believe SETO needs to improve the dissemination and communication of its work. Dissemination is essential for uptake, which along with research findings is crucial for impact in the industry. It is quite difficult to find information on the outcomes of SETO projects, which can deter impact and can also reduce efficiencies up front when companies apply to FOAs and challenges without full awareness of the existing body of research.

Better understanding key stakeholders of the research is essential for communications. With the growth of digital tools, stakeholders of research have volumes of data flowing at them; how they differentiate and find value from SETO's work becomes important in creating a dissemination plan. SETO should consider requiring a dissemination plan for each project and should be an active participant in that creation. Understanding the key stakeholders of research is necessary to craft a plan that meets their information needs, their preferences for how they receive information, and their motivations. The dissemination plan should address the why (purpose of research), what (key findings of the outcomes), who (the very specific audiences who would have interest), and how (the channels needed to reach stakeholders).

Communications seems to be a key area of development for SETO leadership to invest in coming years. This helps with sticking to plans and honing strategies. It will also attract great talent. Good communications create outsized impact, not just in the internal communication of project management but also in broadcasting and narrowcasting the results and impacts of the programs for consumption by local and global audiences. SETO has gone from being a giant in the scene with a massive budget when the solar market was small, relative to almost all players, to being a relative minnow in a much larger market with a budget similar to some of the corporations in the space. One way a quarter of a billion dollars can shift a market that's three-quarters of a trillion dollars is by being vocal and using DOE's platform to shape the direction of research and development efforts elsewhere, and promulgating the data and insights that are valuable everywhere.

Outreach is also something SETO should own and do in-house, since it has a long-standing reputation in the solar space. There is no innovation ecosystem organization as well-funded, staffed, and storied as SETO. While it is not the role of government to advocate, it is the job to tell the stories of success of government-funded research. Lean in and use it to garner the involvement SETO needs. Collaborate with partners from Powerhouse to Greentown Labs and the Department of Defense to the United Nations' International Renewable Energy Agency, but also keep a strong sense of SETO's role in the mission and who is needed on the journey.

This is not necessarily a "general public" effort, but rather a segmented audience effort to address the right eyes and ears at the right time with outreach and solicitations, as well as awareness and education, to achieve the best results and highest impact. This is professional work best done by organizers and communications experts overseen by the scientists and entrepreneurs, who make up your population. An example is the work SETO does with returning veterans, which seems a nonnegotiable mandate from Congress that has been well pursued with partners but could be expanded with new gusto during the job creation push that will likely come post–COVID-19 for cities, counties, and states.

This is not the domain of broad-brush websites but rather specific tool kits and a purpose-written curriculum. Workshops, meetings, articles, and papers summarizing the same may need to be supplanted with bespoke learning journeys (possibly crafted in virtual reality for future periods of pandemic-driven lockdowns) and searchable databases that deliver the right answers for the right audience at the right time. A knowledge-management process and strategy to match the mighty mission and voluminous work of SETO is well worth the investment. It would be best paired with the strategic communications capacity that makes outreach and stakeholder engagement continuously improve. In that way, SETO can use strategy and planning to increase the affordability and accessibility of solar and create value and jobs in the community.

# Photovoltaics

# List of Reviewers

**Rhonda Bailey**, RB RE Consulting

**Atiye Bayman**, MiaSole

**John Benner**, Stanford University

**Jason Bobruk**, SolarEdge

**Howard Branz**, Branz Technology Partners

**Evelyn Butler**, Solar Energy Industries Association

**Danny Cunningham**, ARPA-E

**Denis De Ceuster**, DDC Solar

**Jianming Fu**, Kansas State University

**Katharina Gerber**, California Energy Commission

**Markus Gloeckler**, First Solar

**Ethan Good**, SunEdison

**Steve Hogan**, Hogan Renewables Technology

**Terry Jester**, SolPad

**Zakya Kafafi**, Lehigh University

**Greg Kimball**, SunPower

**Sarah Kurtz**, University of California Merced

**Alex Mayer**, Michigan Technological University

**Rommel Noufi**, Consultant

**Robert Opila**, National Science Foundation

**Jon Previtali**, Wells Fargo

**Paul Sharps**, Sandia National Laboratories

**Bruce Sohn**, MEGE Associates

**Joe Song**, Sol Systems

**Scott Stephens**, NRG Renew

**John Wohlgemuth**, PowerMark Corporation

# Analysis Methodology

Reviewers had evaluation criteria for each project and scored them on a 1–6 scale:

**1** – Strongly Disagree

**2** – Disagree

**3** – Slightly Disagree

**4** – Slightly Agree

**5** – Agree

**6** – Strongly Agree

In addition to numeric scores, reviewers were asked to provide qualitative comments and feedback to justify the scores awarded to projects. Other criteria only required qualitative feedback.

# Project Evaluation Form

1. **The project's goals, approach, and expected impact:**
   a. Align well with this topic's goals and support SETO's mission (1-6)
   b. Set critical challenges to overcome (1-6)
   c. Implement a high-risk, high-impact approach (1-6)
   d. Match well with the level of DOE funding and planned project duration (1-6)
   e. Add significant value to existing research outside DOE-funded efforts (1-6)
   f. Advance the US solar industry substantially (1-6)

*Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.*

2. **Based on performance to date, the project team:**
   a. Meets important milestones within reasonable timeframes and budgets (1-6)
   b. Measures impact appropriately (e.g. quantitative) (1-6)
   c. Disseminates results frequently and actively engages partners (1-6)
   d. Collaborates with sufficient stakeholders (1-6)

*Using the above criteria, please summarize the performance of this project in 100-200 words.*

3. **Each task in this project adds unique and important value to achieving the overall goals of the project.**

*Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.*

4. **What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

5. **What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

6. **What are the three most important pieces of feedback for this project you would like SETO to consider?**

# Project Reviews

Independent review is an important part of SETO's overall portfolio management process, as it provides alternative viewpoints from leaders in industry and academia on current project activities and strategies. Reviewers who participated in the virtual peer review evaluated projects by assessing project reports and posters written by each project's principal investigator. Any questions about the project were addressed via email exchange between the principal investigator and the reviewer. Each project was assigned two or three reviewers.

Below, you will find a list of the projects reviewed organized by track and topic. Projects are alphabetized by the awardee name and represented in the following format:

**Project Title – Funding Program, Amount Awarded**

*Awardee Name | Awardee Location | Principal Investigator*

Project Description

Project evaluations completed by reviewers are found after the descriptions.

# Commercial Photovoltaic Technologies

### Field-Effect Passivation by Desired Charge Injection into Silicon Nitride Passivation in Crystalline- Silicon Solar Cells – $1,118,958

*Amtech Systems | Tempe, AZ | Principal Investigator: Jeong-Mo Hwang*

This team is developing a low-cost plasma-charging technology that can be used for field-effect passivation in crystalline silicon solar cells and to increase efficiency. The technology uses an inexpensive inert gas plasma that does not cause film deposition or corrosion inside the chamber during charging and does not require regular cleaning of the chamber. To enable the commercial use of this tool, the team is working to mitigate the loss of injected charges during the high-temperature metal-firing process and increase the stability of injected charges by mitigating optical and electronic degradation pathways. These efforts have the potential to enable contact deposition that matches the high performance of aluminum oxide while maintaining the low production costs of conventional passivation materials.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 3 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 2 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 6 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Reliability and stability of proposed passivation schemes need more precise set of metrics than will be studied in this effort

**Reviewer 2:** This project aligns well with SETO mission of promoting fundamental science in PV and impacting the US PV industry. The project description highlighted the challenges the team needs to overcome in particular for mono-facial cells and charge loss on contact firing >700C. The PI is performing the work in test CVD equipment that if successful could translated to industrial scale equipment, hence this would have a high impact. It is high risk insofar as maintaining the negative charge with the SiNx has been shown to be a challenge during contact firing for mono-facial cells. There is a good fit between the funding and the 3 year duration (assuming the accounting error is corrected). This work will be of value to efforts outside SETO who are looking for effective charged field effect passivation layers alternatives to ALD MxOy films. As the PI works for a U.S. based equipment company that is exiting the PV business, there would only be impact on the U.S. PV industry if they could successfully licence the technology.

**Reviewer 3:** No comment.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 2 | 4 | 4 |
| Collaborates with sufficient stakeholders | 3 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Coordination of responsibilities and delegation of sample preparation appear to be undecided or unspecified at this time. Ensuring this is understood upon the project's initialization is critical to maintaining the aggressive work plan.

**Reviewer 2:** I did not seen any reason while the milestones would not be met with the extended end of BP due to the delay. The PI described many quantitative metrics that will be used to determine the efficacy of the technology from fundamental charge density measurements in the modified SiN films to cell efficiency and mini-module performance which included PID and LeTID. They have also focused on mono and bi-facial cells. It's not clear how they intend to disseminate the results. As the focus has moved from incorporating the findings into their own PV equipment to a licensing value proposition, there was no description of how their stakeholder engagement will change to maximize impact.

**Reviewer 3:** No comment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Adoption pathways of this technology are not identified, and no manufacturing partner is part of the project team.

**Reviewer 2:** Score: 5. Comments: Each of the tasks adds important value to validate the final end goal of an encapsulated cell in a mini-module that has improved PID and LeTID which will be key to illustrate the value to potential Licensees. There is significant synergy between from quantifying the electrical properties of the SiN film to the process optimization design of experiment to the final cell performance.

**Reviewer 3:** Score: 4. No comment.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Not many devices built/shown, need more characterization data and loss analysis of proposed remedies

**Reviewer 2:** The change of business model from incorporating the process into their own equipment to a license model will need a different approach to maximize impact from any positive accomplishments. They will need to build a strong IP portfolio from the project in order to make the technology compelling for customers to license.

**Reviewer 3:** Industry partnership would be helpful.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** A third-party validation laboratory should be used to verify effect, strength, and merit of approach and material set.

**Reviewer 2:** They will need to collaborate with a cell/module manufacturer to fabricate full size cells/module utilizing the optimized process so that it can be IEC 61215 certified plus prove it can withstand enhanced accelerated testing (TUV will help with the latter). A developer: Deployment of some kWs of new product will give early validate of the process too once certified. They need to build a strong case for licensing.

**Reviewer 3:** No comment.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Cost projections for the application of this technology appear to use non-standard quantification methods and/or calculators relative to industry standard.

**Reviewer 2:** Revisit the IP strategy in light of moving to licensing business model. Qualify to IEC 6125 and advanced stress testing at full size cell and module to obtain data to help a compelling licencing case. If possible deploy some kWs of full size product in field for early performance/stability validation.

**Reviewer 3:** No comment.

## Bringing High-Efficiency Silicon Solar Cells with Heterojunction Contacts to Market with a New, Versatile Deposition Technique – $1,000,000

*Arizona State University | Tempe, AZ | Principal Investigator: Zachary Holman*

This project aims to enable manufacturable, high-performance silicon solar cells through an innovative deposition technique that will improve cell efficiency and reduce equipment and material costs. In order to arrive at the ideal contact stack that is transparent and can easily be made with inexpensive tools and precursors, the silicon community has been experimenting with stacking new materials within solar cells. The team is developing and using a gas-flow sputter source that is coupled with an aerosol-driven assembly tool. The team aims to use the tool to deposit any type of metal oxide carrier-selective layer or transparent conductive oxide layer with full control of the material composition, without damaging the underlying layers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 4 | 4 | 6 |
| Implement a high-risk, high-impact approach | 3 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 5 |
| Advance the U.S. solar industry substantially | 3 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Highly relevant project to push the HJT performance with iterative improvements to existing processes and toolsets

**Reviewer 2:** The projects goals to develop a low capex process to deposit TCO and pasivation layers from PV cells which will meet or exceed current incumbent processes meets SETO mission for PV cost reduction and ultimately LCOE. The development of a new deposition technology that cannot be simply implemented in existing equipment but requires new tool-set design, build and proof is high risk. If proven (technically and economically) the impact could impact not just high efficiency silicon cells but potentially emerging technologies such as perovskite. The goals and planned outcomes appear to fit well with the level of funding and 3 year duration. Research into new methods of deposition for layers used in PV cell production will be of interest/value to groups outside of DoE funded efforts. If successful this could advance US PV industry. The US based partner, start up Swift Solar, will be responsible for hardware design and process transfer for the full-size deposition tool. There could be a downstream impact in increased availability of high efficiency modules for deployment in PV systems in the US too. The PI did describe the challenges in BP1 with the need to reduce the cluster size and slow the deposition rate to produce thin films as one of the challenges. Other challenges included were descriptions of BP1 goals and did not adequately describe risk mitigation approaches that would be engaged.

**Reviewer 3:** This project addresses the high capex of SHJ cell lines, which is the most important barrier to their commercialization. The technology is unique and new, making it high risk. The potential reduction of capex is impressive if the stated goal of 60% is met. The milestone of demonstrating film performance at least as good as the existing state-of-the-art technologies is challenging, as the existing tools and processes have been developed and tuned for more than 20 years. SHJ is a popular topic of research because of the high efficiencies of SHJ devices, and this project has the potential to be helpful to other R&D efforts in this topic. This project will advance the US solar industry if it leads to successful commercialization by Swift Cot, a US-based company. It also has the potential to provide cheaper high efficiency modules for the US market.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 4 | 4 |
| Collaborates with sufficient stakeholders | 2 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Coordination of responsibilities and delegation of sample preparation appear to be undecided or unspecified at this time between University and company. Ensuring this is understood upon the project's initialization is critical to maintaining the aggressive work plan.

**Reviewer 2:** The PI described milestones well that were underway and completed during the first 12 month period. The description of remaining milestones including 6" cell fabrication and subsequent reliability testing was not adequately described. The tasks described in the first 12 months of the project showed quantitative metrics for film properties and figure of merit improvements from their TEA work on expected Capex and COGS. The PI described the partners responsibilities in the project but not adequately describe the frequency of engagement and framework. Collaboration with start up Swift Solar was described but there was inadequate discuss on additional stakeholder discovery activities for alternative route to commercialize the technology. Also, there was inadequate discussion on engagement with tool-set manufacturers which will be a critical path for industry adoption. This will be important for to identify best design for manufacture and value engineering approaches for the new equipment build.

**Reviewer 3:** Meeting the milestones suffered from the late delivery of critical hardware, which has affected the project. But the team continued to make progress in other areas, which partially offsets the negative impact of missing the associated milestones. The clear and concise table showing milestone progress is very much appreciated. The fact that the cost milestones are quantified is also appreciated, since it is critical to evaluate the potential impact of this project. The project report summary doesn't mention any dissemination of results in published paper in conference, or patent applications.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Unclear on commercialization pathway given the university laboratory environment for test sample preparation and the industrial partner for tool development - who will build production?

**Reviewer 2:** Score: 4. Comments: I would agree with this for the first 12 months of the project although detailed tasks for the remaining time (24 months) were not adequately described.

**Reviewer 3:** Score: 5. Comments: The tasks are straightforward and directly adds up to meeting the overall goal, though the cost milestone (30% capex reduction) is significantly lower than the capex reduction of 60% mentioned in the project overview. The reliability task is critical in order to prove the viability of the technology.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Concept appears to be a proprietary design unique to PI's personal company and therefore non-transferable or changing the industry as a whole. Such is the case that private funding sources should support this endeavor.

**Reviewer 2:** Equipment design for high volume throughput that fits in existing lines takt time is key to making it a compelling technology. This includes all aspects of the offer including MTBF for parts, the quantity of bespoke (one off/unique parts just for the tool-sets) vs off the shelf, maintenance schedules, downtime for maintenance, etc. All these aspects need to be addressed for commercialization.

**Reliability:** The PI mentioned IEC 61215 for reliability validation. He should also consider validating the film robustness with specific tests that go above and beyond standard test and stress these types of films e.g. PID and LeTID tests. Build a strong IP portfolio to protect the process and equipment at this early stage.

Reviewer 3: Even after a large capex reduction, SHJ technology might still remain a niche market. It would be valuable to investigate applications than can be used for mainstream technologies like PERC.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Facilities, staff, and students at ASU capable of completing the prototype devices and samples.

**Reviewer 2:** Equipment manufacturers (see above for rationale). Other SHJ cell manufacturers input

PV groups reliability groups to design technology specific stress tests for encapsulated and un-encapsulated cells.

**Reviewer 3:** This project involves only a few partners, but no others are really needed at this stage, since ASU already produces state-of-the-art SHJ devices.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Proprietary limitations from tool vendors exposing true cost of ownership data, obtaining process recipe details from manufactures and the myriad of combination and variants will likely obfuscate any detailed analysis the team wishes to perform within this project.

**Reviewer 2:** 1) Perform a detailed design failure modes and effects analysis for the AIDA equipment to ensure high reliability and low total cost of ownership for adopters of the technology. Build the findings in their techno-economic analysis. 2) Consider accelerated stress tests for the cells beyond IEC61215 and identify tests are designed specifically for these ultra thin contact and pasivating films. 3) Refine the business plan for commercialization to include additional stakeholders/adopters for the technology. This may increase the probability of success and increase the likelihood of impact.

**Reviewer 3:** 1) High risk and high impact. Developing new tools is very challenging. 2) SHJ and TCO passivation layers are notoriously difficult to optimize. It is very helpful that this technology is developed at ASU, which has state-of-the-art SHJ prototyping facilities. Without those facilities, it would nearly impossible to develop this tool. 3) The technology is unique and innovative, giving it good chance for a US-based company to commercialize it successfully.

## Diagnosing and Overcoming Recombination and Resistive Losses in Non-Silicon Solar Cells Using a Silicon-Inspired Characterization Platform – $1,500,000

*Arizona State University | Tempe, AZ | Principal Investigator: Zachary Holman*

The goal of this project is to develop a characterization platform for non-silicon-based devices in order to gather a precise accounting of power losses that limit device performance. While tools and techniques for silicon-based devices are available, there aren't comparable tools for non-silicon devices. Novel amorphous silicon contacts applied to cadmium telluride absorbers are being characterized using multiple bulk and interface loss-analysis methods. Using this methodology, the team is examining a wider range of absorber materials and creating a platform that enables users to rapidly and accurately assess the quality of a wide range of bulk materials and surface passivation layers, including contact selectivity and contact resistivity.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 3 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1**: This project tackles a limitation in identifying the fundamental causes of performance gaps in thin film solar cells. It is an important area where progress needs to be made to improve performance which directly impacts cost goals. This is not a high risk research, it is systematic learning that needs to be done.

**Reviewer 2:** The project bifurcates on two aspects of addressing voltage shortfall. The metrology section is a adopting established methods to thin-films. The material/device development attempts to demonstrated superior performance with a carrier selective PERC-like contact. Strengths: 1. Solid definition and adaption of new metrics decoupling bulk from interface challenges may help steer future developments 2. Al2O3 has shown indications to be a very interesting passivation material for CdTe Weaknesses: 1. No models have been performed or design contemplation regards what PERC on poly needs to look like 2. Interpretation of these new metrics should be stressed with thin-film device simulations.

**Reviewer 3:** The project objectives of developing a characterization platform capable of of quantitatively identify recombination and resistive losses in thin film devices. This platform is a take off from similar successful platform for the Si technology. The objectives are significant and impactive in the CdTe technology since the nature of major limitations in the performance (especially voltage) are still unsolved, and definite solutions are lacking. This project is capable to specifically identify the location of the losses in the device and implement mitigating solutions. From the onset the PI has pointed with some certainty that the losses are mostly from the contacts, mainly the back contacts, and not as much the absorber.This explains perhaps why the major efforts to increase Voc and efficiency by improving on the carrier concentration and minority lifetime, have only demonstrated meager progress toward the expected/implied higher parameters for the CdTe device. The results from the first year effort have compared different contacts for which will show the highest iVoc (implied/ expected Voc). The PI has shown a good progress toward the target of iVoc of 1 Volt by demonstrating 0.98 volts which shy of only 20 mv. In brief this project has the potential in the 3 year term to demonstrate convincingly where the limitations/losses are coming from, so that researchers can focus on addressing the materials and their properties that impact the calculated iVoc. No weakness per say, however, I recommend that the PI collaborate with a partner who has experience in contacting single crystal CdTe devices used in medical and military imaging. The thrust there is that the contact has to be simple and stable.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has missed a milestone with iVoc but has shown significant progress towards the milestone. It would be expected that they will bridge the gap in the next phase. It would be desirable to see solar cell conversion efficiency measurements as a final verification of success of the project.

**Reviewer 2:** Some good initial progress on the characterization front. Encouraging to see absolute EQE reported and interpreted.

**Reviewer 3:** The 3-year project is just passed its first year. In the first year of the project, the PI has so far demonstrated the capabilities and limitation of the tool on the Si device. He also demonstrated significant progress on CdTe devices from CSU who has modified and engineered new contacts. This collaboration demonstrate efficient collaboration as evident from the results comparing the calculated iVoc of different contacts. This is a good progress for period 1. The Pi is focused on the next criteria for hole selective potential contacts based on knowledge gained to date.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Defined tasks are well aligned with the goals of the project and successful completion would expand evaluation methods available for future work.

**Reviewer 2:** Score: 4. Comments: The tasks on the metrology side of the projects are relatively weak and the tasks defined on the device development very challenging. Would be of interest to develop more thoughtful derisking of the various elements necessary to make the proposed solution work.

**Reviewer 3:** Score: 6. Comments: This project is somewhat unique in the sense that it is the only project with the defined quantitative objective directed at solving issues related to the fundamental properties of the back contact in CdTe devices. The project is valuable to the DOE program and its objectives. The value is derived from its focus on developing the capabilities of identifying specific location of losses and potential solution to the problem. The platform can be made available to other researchers who fabricate devices and have needs for quick feedback. It is designed to address the losses quantitively.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I have not identified a blind spot or major shortcoming. It would be desirable to have conversion efficiency measurements as a final verification of performance improvement.

**Reviewer 2:** Not clear from documents provided that the project has derisked at the “process component” step, what it will take to succeed. Example, how good of an ohmic contact must aSi:H form to make efficient point contacts? Not clear whether the project team has considered differences poly <> sx Si in the development of metrics.

**Reviewer 3:** The fact that thin film devices are based on polycrystalline materials with varying stoichiometry, and non equilibrium junctions, makes it difficult to compare apples to apples. Hence, the PI is cautioned about generalizations of results and adopt one solution for all, or one roadmap for all.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None identified.

**Reviewer 2:** Team probably could use some guidance from simulation/modeling to support the metrology as well as the device development.

**Reviewer 3:** As I recommended above, the PI is encouraged to reach out to researchers in the field of imaging technology based on CdTe.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** It would be desirable to have conversion efficiency measurements as a final verification of performance improvement.

**Reviewer 2:** Project is focused on two key issues for cdte: lack of good metrics and lack of passivating carrier selective contacts. Both aspects are high value activities. The solution development on the material side requires a lot of effort, it is much easier to break things than to find an improved solution. This could be addressed by additional collaboration and/or thoughtful de-risking

**Reviewer 3:** 1. Encourage the PI to reach out to other groups to investigate their devices in order to build a data base that points to trends. 2. Considering that plans usually do not go as anticipated, the project should focus on one technology at a time with thorough experiments and a definite conclusion even if milestones prove to be elusive.In other words answer thoroughly all the questions that arise during the investigation. The nature of this project necessitates it. 3. The platform capabilities to quantify the implied (entitled) device parameters (specially iVoc) is made more valuable if it is used to look at a First Solar device for validation.

## Impact of Undoped Substrates on High Performance Silicon Solar Cells – $200,000

*Arizona State University | Tempe, AZ | Principal Investigator: Andre Augusto*

This project investigates the potential advantages of using undoped silicon wafers to make high-performance solar cells. The team is examining silicon heterojunction cell characteristics built using wafers with a range of low n- and p-type dopant concentrations, and is closely observing the transition from low-level to high-level injection in order to better understand the device physics of these cells. These studies could impact the manufacturing yield of Czochralski-grown wafers for which dopant concentration varies along the length of the ingot, and will help to better understand the effects of doping levels on light and polarization-induced degradation mechanisms. This research aims to lower the levelized cost of energy by improving photovoltaic cell and ingot manufacturing yield, silicon cell power output, and module reliability.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 4 |
| Set critical challenges to overcome | 4 | 5 | 3 |
| Implement a high-risk, high-impact approach | 3 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 4 |
| Advance the U.S. solar industry substantially | 3 | 4 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project benefits from a wealth of expertise that exists within the same academic institution/department - it is probably limited from that bias as well.

**Reviewer 2:** No comment.

**Reviewer 3:** The expected positive outcome is not quantified in terms of expected increased performance or lower costs, and results so far do not indicate that the outcome of this project will have a direct impact on the solar industry. However, the results improve the knowledge base of silicon defects and their impact on lifetime. The fact that the code used within this project will be freely available increases the impact on the research community. The project is not particularly a high-risk project, since it is mainly centered on simulations and characterization.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 5 |
| Collaborates with sufficient stakeholders | 1 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Coordination of the various contributors will be key to maintaining the project's timeline. Many steps require physical sample transfers and experiments can take long periods of time to complete as a result.

**Reviewer 2:** Reviewed efficiency potential vs lifetime and bulk resistivity, while it doesn't look like a good tradeoff, it is good concise work.

**Reviewer 3:** The milestones have all been met, and the temporary setback (availability of sputter system for 2 months) was successfully overcome. The results have been widely distributed nationally and internationally (including an invited talk at a US-based PV company). Making the lifetime calculator in the pveducation website will increase the dissemination of this work.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: Likely methods utilized in the creation of laboratory samples will differ greatly from those envisioned for high-volume manufacturing. Yield, cost, and opportunity assessment requires a partner with capital equipment expertise, notably absent from the project team

**Reviewer 2:** Score: 4. Comments: No comment.

**Reviewer 3:** Score: 6. Comments: The tasks are well aligned with the project goal. They go through the logical succession of simulations, device fabrication and characterization, and together, will deliver a credible and validated model of the physics underlying the interaction between lifetime, device performance and substrate doping.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The approach of "going for FZ-Si to see what ideal looks like" is often times a distraction of researchers looking to gain commercial integration. Undoped substrates have been studied heavily in the semiconductor space and it might be helpful for this group to see those fundamental material probes first before repeating history.

**Reviewer 2:** None noted.

**Reviewer 3:** Since, as indicated in this report, high-resistivity substrates are made using the FZ growing method and are much more expensive than the standard CZ, there are no clear paths for using high-resistivity substrates in high volume production.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This group would benefit from working with NREL.

**Reviewer 2:** None noted.

**Reviewer 3:** None. ASU has all the skills, expertise and equipment required for the successful completion of this project. Collaborating with a silicon wafer manufacturer could be useful if, at a certain stage, it appears that using higher resistivity substrates brings significant performance or cost advantages.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Coordination of the various contributors will be key to maintaining the project's timeline. Many steps require physical sample transfers and experiments can take long periods of time to complete as a result.

**Reviewer 2:** Working outside of the normal industry regimes. While it didn't work well, it confirms where the industry works is okay. Great team.

**Reviewer 3:** 1) Project is well structured, well managed and organized. 2) Results are sensible and well aligned with the project goal. 3) Impact might not be directly substantial to the PV industry, but thanks to the effort to widely disseminate the results, might be useful to the PV research community.

## Operando X-ray Nanocharacterization of Polycrystalline Thin Film Modules – $1,600,000

*Arizona State University | Tempe, AZ | Principal Investigator: Mariana Bertoni*

This project is developing an X-ray based characterization framework that enables module evaluation of cadmium telluride and copper indium gallium selenide cells under a variety of operating conditions with nanoscale resolution. Researchers are using several lab-based mapping and synchrotron-based techniques (fluorescence, diffraction, and spectroscopy) coupled with the collection of IV curves in custom-designed stages capable of handling different temperatures, atmospheres, and illumination conditions to enable higher module efficiencies, longer warranties, and lower degradation rates.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 2 | 5 |
| Set critical challenges to overcome | 5 | 3 | 5 |
| Implement a high-risk, high-impact approach | 3 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 4 |
| Advance the U.S. solar industry substantially | 5 | 3 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Understanding degradation mechanisms and reducing degradation is an important contributor to cost reduction. This aligns with SETO goals. Methodologies that are developed to measure these mechanisms build an important foundation for all thin film technologies. This is not a high risk project.

**Reviewer 2:** The project leverages on several buzz words “in operando” and “machine learning”. Very complex and expensive x-ray based measurements are applied to study uniformities under stress condition. Strengths: 1. Additional material insights could be enabling 2. Advanced x-ray technique may provide unique access to information Weaknesses: 1. Unclear which specific mechanisms that is relevant for commercial PV applications is being studied 2. High risk of results turning into qualitative observation.

**Reviewer 3:** The project strategy and approach addresses a very important problem regarding variation/degradation of device/module performance under stresses. The goal to observe at the nanoscale level changes in structure and composition in-situ under stresses, and determine if the change is irreversible or metastable. The team has developed successfully the tools and sample preparation to carry out the investigations under different conditions relevant to the physical observation of the changes in performance. The latter effort by itself is commendable achievement of meeting the challenges of building the hardware and protocol of sample preparation. Accordingly, the team has shown progress since the start of the project addressing variation and degradation observation in both CdTe and CIGS cells and modules. The results are published in several publication and conferences. I can say that the results and interpretations are consistent with experts previous views of what might be taking place, and also revealing new discoveries such as the creation and annihilation of defects in CIGS, and effect of copper diffusion in current collection in CdTe devices. The project also shows synopsis of results by the team which culminated in meeting the targeted goals. The data produced from the project are beginning to form the basis of library of defects behaviors under different stresses, which in the future will support a modeling tool to predict performance in the future. No weaknesses at this time in the project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 2 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** With MiaSole out of the project, this project will need to find another CIGS partner or focus on CdTe.

**Reviewer 2:** The project succeeded in creating compositional and other x-ray based images of devices. Samples were created, at least one industry interaction on CIGS materials, tooling was facilitated to enable testing. Good progress against the formulated plan.

**Reviewer 3:** The performance from this project seems to be what you expect from a state of the art capabilities and team synergy with skills and experience in the subject matter. The team has met all milestones, numerous publication describing new discoveries, updating tools capabilities, strong interaction among team members, good cyclic investigation culminating in productive feedback to sample owners and industry, as well as guidance for remedies to the degradation problem. The latter is a work in progress.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks are defined and are aligned with objectives.

**Reviewer 2:** Score: 2. Comments: Project has not sufficiently consider upfront what is being to be characterized, why, and how will qualitative data be turned quantitative and actionable. What is the macroscopic behavior seen in devices (modules) and what are plausible hypothesis to confirm? How does a targeted approach prove the hypothesis right or wrong?

**Reviewer 3:** Score: 5. Comments: As mentioned above, the outcomes are new discoveries and are important to adding value to the addressing and finding solutions to the degradation in performance of modules. This project uniqueness is derived from the tools to carry out the investigation in situ under similar conditions to the field operation.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Project may not be able to continue with CIGS work if new partner is not identified

**Reviewer 2:** Definition of what is a industry (technology) relevant sample and problem to study, i.e., a sample under study should be on parity to the commercial or semi-commercial device. Many effects in thin-film can be created by non-optimal processing conditions, how can the team separate from measuring anomalies vs. intrinsic behaviors?

**Reviewer 3:** Cation should be taken not to generalize mechanisms behind degradations/variations before insuring that the specimens examined are representative of the technology. This is because junction and interfaces including grain boundaries in polycrystalline materials/devices are non equilibrium interfaces and stresses can shift equilibrium one way or another depending on the preparation conditions.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** New CIGS partner needs to be identified or the project needs to be focused solely on CdTe.

**Reviewer 2:** Experts with relevant experience in reliability study of thin-films, preferably industrially relevant.

**Reviewer 3:** I think the team is synergetic in capabilities, skills, experience and is composed of universities, national labs and importantly industry.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** I see very few submissions (may be more in the reliability section) investigating degradation and reliability studies. For commercial success and for SETO goals this area is very important and relevant to all thin film. Developing methodologies and analysis capability to study degradation is critical.

**Reviewer 2:** Very difficult techniques that may create opportunity to learn something novel about a very complex material system. Unfortunately, chance for such studies to provide deep insights is low due to the complexity involved. This is an empirical hunt.

**Reviewer 3:** 1) I recommend that the PI initiate a side project of organizing/consolidating data collected in this project as start of a library that will power the engine a predictive model for performance and degradations diagnostics. 2) The team should validate the claims and numbers in section 13 to make sure that the basis does not have assumption that can be too optimistic. Maybe they need to be independently challenged.

## Photovoltaic Foundry: Increasing Manufacturing Capabilities in the US by Developing Passivated Contact Photovoltaic Technology – $1,750,000

*Arizona State University | Tempe, AZ | Principal Investigator: Stanislau Herasimenka*

This project leverages the advanced cell and module prototyping facilities at Arizona State University to support U.S. companies that want to prove the viability of new photovoltaic technologies but don't have equipment that can fabricate them. The foundry focuses on post–passivated emitter rear contact silicon solar cell and module technologies, which are built to capture more light on the back surface of the cell and are expected to grow to dominate the manufacturing landscape. It will allow users to improve process steps and designs and work to reduce production costs.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 6 | 5 |
| Set critical challenges to overcome | 4 | 2 | 5 | 3 |
| Implement a high-risk, high-impact approach | 3 | 3 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 4 | 3 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Processing capability is a requirement to perform meaningful research. The project proposes to establish a foundry to support current and next node technology for Si PV. The stated emphasis is PERC, SHJ, and TopCon with an extension toward tandem application. There is inherent value to have a high quality non-commercial or shareable baseline toolset available for experimentation. Strengths: 1. Processing capability would be enabling to many 3rd party users 2. Good alignment with existing/past efforts and leveraging of talent on the team 3. Open approach proposed to solicit community input to identify needs Weaknesses: 1. It will be very difficult to sustain a high quality process in low volume operation 2. Unlikely that incremental innovation on the basis of Si PV could be sufficiently disruptive to enable in itself US manufacturing.

**Reviewer 2:** Strong technology team, access to a wide array of tools and resources to deliver on this project.

**Reviewer 3:** This project starts on 4/1/2020. The report was written before the start date. Therefore, the scores are just place holders that reflect on the project as proposed work. The comments reflect on the worthiness of the proposed plans/objectives and potential impact as written. The stated objectives and goals of the project are much aligned with the DOE mission. The PV Foundry allows for Si industry access to R&D pilot line and characterization facilities to develop and validate "new cell designs, processes and materials, guided by metrics set by the stakeholders (along with the foundry staff) via joint R&D projects". This goal supports US Silicon research activities to facilitate industry transition to full manufacturing. The project if successful will have significant value to the stakeholders across researchers from universities, and industrial stakeholders to drive their technologies forward past state of the art. The most impact by the foundry operation on lowering cost is derived from showing reliability and manufacturability of the processes pursued by the stakeholders (along with cell efficiencies that are close to state of the art). Demonstrating the latter will impact research and development efforts outside the DOE programs as well as inside. The concept of of establishing a foundry for PV development as described in this project has been undertaken before in Silicon Valley, but for unknown reasons to me, it stopped operation after a short period. Has the PI looked into previous similar undertaking?

**Reviewer 4:** Developing a center that will enable research teams in the US to prove out their technologies at on full size wafers or cells will be valuable for US research teams to be competitive with overseas groups. Therefore, this will support progressing PV innovation in the US. While the project has not started yet, an activity of this nature will be resource intensive (materials, labor, equipment, etc), therefore the DoE funding appears to fit the project duration. The work from the group will no doubt have interest to other groups outside DoE funded efforts. In addition, there will be interest if the ASU/GT team are able to develop the collaboration model to the extent they have some demonstrable examples of technologies that were successfully adopted by new US PV manufacturing start ups. This project has the potential to advance/re-initiate the US PV industry if it attains its goals by the end of the project. The critical challenges associated with how the center will promote the adoption of their partner's technologies was not adequately described i.e. "spark the rebirth of the rebirth of the US PV manufacturing industry" without a well-defined downstream adoption plan. This could be a high impact project if it does translate PV technologies into new US manufacturing line but the document does not adequately describe how the model high risk without a pathway to a supply chain in the US.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 2 | 5 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 1 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 4 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project has not started and cannot be evaluated for current performance.

**Reviewer 2:** Project not started.

**Reviewer 3:** This project just started. No results to assess. However, The stated milestones/targets in the project are reasonable metrics to gauge the progress the individual projects owned by the stakeholders. Also, the baseline is reasonable as long as it represents statistically reasonable number of metrics, and mid-term performance assessed with GO-NOGO decision point by the stakeholder and the Foundry.

**Reviewer 4:** The project has not started yet and there was inadequate detail to assess any milestones related to a timeline and the budget. Most of the description of the measures of impact were qualitative in nature so it was difficult to assess that the impact from the project would be easily measured. How the results will be disseminated to the stakeholders or a model that will be followed for communication purposes for the existing collaborative projects was not described adequately. The PV foundry already has 28 new collaborative projects before the start of the project. It is not clear what their target intends to be for the center to be sustainable.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Tasks are not clearly defined at the moment. The overall approach appears sound.

**Reviewer 2:** Score: 3. Comments: A platform to serve as a user facility has been repeatedly proposed, funded, and attempted by more than (5) organizations by my count (including ASU for years). But the number of innovations that stem from these type of centers are limited when compared with the amount expended. Yes, there are a number of non-quantifiable benefits to this type of facility, chief among them is teaching; however, it is cumbersome to function as a facility for external users due to the high degree of overhead and paperwork required by university administration.

**Reviewer 3:** Score: 5. Comments: This project is expected to have an impact on the Si technology. Its value is clearly stated in the proposed approach. The risk of such a project (Foundry approach to validate and advance stakeholders technologies) lies with demonstrating the ability to perform useful/top quality R&D, similar to universities and national labs, and others.

**Reviewer 4:** Score: 3. Comments: The tasks were described at a high level as objectives, so it was difficult to assess how unique and the value they have at achieving the overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** PIs may underestimate the challenges to operate a high fidelity process at low volume.

**Reviewer 2:** Needs a clearer go-to-market plan than what is offered to fully evaluate potential issues/pitfalls.

**Reviewer 3:** Question not applicable at this time in the life of the project.

**Reviewer 4:** The leadership team for the foundry need to be outward facing with respect developing downstream recipients for the technologies that come through the foundry. Otherwise, the technologies may become stranded albeit at a the next level of development. This is not a simple task but needs to attempted and will involve discussion with SETO and industry stakeholders.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It would be helpful to have a team member that actually operates a baseline process at high quality and at least modest volume. This would enhance the ability to sustain the process.

**Reviewer 2:** This group would benefit from larger, more mature substrate, cell, module manufacturers as partners

**Reviewer 3:** The project intends to involve many stakeholders: many industrial partners from the Si community, graduate students/universities, and national labs.

**Reviewer 4:** Cell manufacturers and module manufacturers to canvass that the work the PV foundry is do continues to be ahead of competitors technology development road maps and to ensure they have competitive resources (skills, tool sets, technology road maps for tandem cell designs, etc).

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Recommend to scrutinize the project regards the track record of operating process lines at high fidelity. What is the operating plan to sustain a quality process and should Go/No-Go milestones be tied to first demonstrating the most simplest process with high fidelity before building additional capability? Justified long-term support for such infrastructure project should be tied to traceable influx of projects and project dollars.

**Reviewer 2:** Needed resource, but need more clarity may not be enough money if going to be impactful

**Reviewer 3:** Since the project practically has not commenced yet, there is no feedback to speak of. However, the nature of the project as a facilitator/validator of technology in development, SETO may want to support the project to fruition.

**Reviewer 4:** 1) Ensure that the foundry offers services that keep up with/are ahead of the advanced processing needs of US research groups to maximize their customer base. 2) Continue to review their business and operating model to ensure that they are fulfilling their objective to transfer novel PV technologies to a production environment. 3) Quantify their milestones as much as possible to be able to measure success and promote their center.

## Understanding Defect Activation and Kinetics in Next Generation Cadmium Telluride Absorbers – $510,750

*Arizona State University | Tempe, AZ | Principal Investigator: Mariana Bertoni*

This project aims to improve the understanding of defects in cadmium telluride photovoltaic solar cells by revealing new information about the way defects form when the semiconductor is treated with chlorine or doped as part of the fabrication process. Doping and chlorine treatment in cadmium telluride solar cell fabrication are both critical processes, but advances to these processes often cancel each other out, which results in the open circuit voltage of the solar cell remaining stagnant. The team is focusing on using nanoscale X-ray imaging techniques and novel spectroscopic approaches to visualize the formation of defects during chlorine treatment under various conditions. The team will use this information to optimize the process to make these cells, improving open circuit voltage and helping to drive down costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 5 | 4 | 6 |
| Implement a high-risk, high-impact approach | 3 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Project objectives are aligned with SETO goals since understanding defect activation and effects of composition on defects may result in performance improvement and hence cost reduction. This is not a high risk project, developing characterization methodologies is part of foundation building. Progress has been shown toward the objectives.

**Reviewer 2:** The team developed a complete set of material characterization methods to gain insight on dopant activation, defect migration and other material/device structural studies. It will provide guidance for industries and academic partners for further improvement of device performance. The risk is relatively low since the project is mainly applying existing methods on the new subjects. But the impact could significant for the development in this type of devices.

**Reviewer 3:** This is a well thought out project, planned to understand how defects are activated and how they are passivated, and hopefully how these defects react under external stresses as a means to understand degradation mechanisms. These objectives are essential for industry to keep making progress. The participation of FS as a partner to validate the approach and value of the outcome is strength to the project. The DOE program supports a group of experts to develop novel techniques at the nanoscale to examine the absorber doping process in situ, and all interfaces development as it is developed and eventually passivated.Data analysis through is accomplished through computer vision, fitting protocols and machine learning frameworks to streamline the studies. The goal is to enable breakthroughs on lifetime/doping level of CdTe modules which will enable higher Voc. This is a major strength of the project. The team is encouraged to pursue the understanding of the mechanisms behind the correlation in order to be able to propose the appropriate remedy to the possible deficiency like structure, composition, or the conditions related to the deposition process. This will be a measurable impact.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 6 |
| Collaborates with sufficient stakeholders | 4 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a relatively small project with small budget and participants.

**Reviewer 2:** The project is relatively young. The team overcame some initial challenges in sample preparation. The new method was validated by their industry partner.

**Reviewer 3:** The team, has performed as expected in setting up the tools to implement the experimental plans; has overcome at least one operational challenge, produced and summarized several results with copious amount of images and data; took the initiative toward automated data analytics and atomistic modeling. The outcome to date involved: completing/and making progress on doped films and devices for first solar, and other As-doped samples for the purpose of imaging As in the CdTe matrix, and the chemical structure and composition of Cu in CdTe. I believe this is a significant progress's/productivity in a short time, while also demonstrating interaction with the team members, especially FS. The initial/first step results produced in the last two quarters are very encouraging. The correlation at nano-scale of the composition and structure of the Cu and its chemical environment in CdTe is strong step in establishing a framework to understand and manipulate processes to enhance performance, for example. First solar evaluated the CdCl2 treatment in that configuration and corroborated that our measurements were representative of their industrial process. The milestones for the first period were completed, The in-situ activation of a sample with CdCl2 presented an operational challenge that was remedied in a timely manner and was verified by the industrial partner to the validity of the experiment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Don't see specific list of tasks for the project.

**Reviewer 2:** Score: 5. Comments: The project correlates structure, composition and process conditions. The acquisition of defects and composition distribution would provide the feedback for the effects of processes such as annealing with chlorine-containing chemicals. The main objectives were improvement for activation of dopants such Cu and As.

**Reviewer 3:** Score: 6. Comments: The first task to establish the state of the art tools enables the project to examine the creation and of certain species/defect, phases, and the potential modification/annihilation of those species. All that is in situ. This is a unique capability. The remaining tasks add value to the project goals through the understanding how defects are activated and how they are passivated. The end results are guidance to how increase Voc and hence efficiency, and hopefully how these defects react under external stresses as a means to understand degradation mechanisms.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Have not identified a blind spot

**Reviewer 2:** The project plan covers all important parts of research.

**Reviewer 3:** I cannot point to any, since the PI is guided by well represented collaborators who can critique the plans and goals.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Have not identified a gap here.

**Reviewer 2:** The team worked sufficiently with collaborators.

**Reviewer 3:** This team formally and informally includes several partners and collaborators.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is one of the projects that adds to the analytical foundation. I believe to strengthen the US solar presence several areas need attention, building characterization and analytical techniques suitable for thin film is one of them.

**Reviewer 2:** Set more measurable milestones. Further extend the study to use the techniques to see dopant activation or other changes in properties through reliability tests such as LID or thermal cycling.

**Reviewer 3:** Expand the level of effort to include other thin film technologies that can benefit from the same capabilities and the same approach and insights, such as CIGS and Perovskites.

## Direct Metallization with Reactive Inks: Assessment of Reliability and Process Sensitivities - $1,400,000

*Colorado School of Mines | Golden, CO | Principal Investigator: Owen Hildreth*

This project is investigating the material and growth properties of reactive metal inks in order to explore their potential use in the metallization of silicon solar cell. The research team seeks to radically change the cost structure of the cell by dramatically reducing silver consumption. This technique is of particular importance to temperature-sensitive devices, such as heterojunction architectures, where the low processing temperatures of reactive inks offer a significant advantage and alternative metallization methods are currently expensive.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 3 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 5 |
| Advance the U.S. solar industry substantially | 6 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The cost of metal inks in PV is relatively large, so advances made here are important. The problem with this proposal, is that "reactive inks" are never described, even broadly. Hence, it is never clear what exactly is being funded here.

**Reviewer 2:** Appropriate topical area for PERC cell lines around the world. All of whom are seeking improved rear contacting schemes that both passivate and are solderable. Well positioned to deliver immediate stimulus to target audience

**Reviewer 3:** Strengths: There is a good alignment of the CSM team's goals to develop the low cost silver metallization and the SETO goals to reduce LCOE. Critical challenges of associated with developing a next Ag ink process including material and electrical characterization were described adequately in the supporting documents. As screen printing has been the industry norm for many decades, developing a new disruptive technology is high risk but the potential cost reduction that would be possible is high reward. The budget appears to be adequate for the work. Weaknesses: It is not clear what impact the long novation will have on the continuity/validity of the work in a rapidly changing PV industry and within the project itself with respect to support resources and equipment availability. There was no discussion of including US Ag ink/paste manufacturers in the conversation to communicate the value proposition and learnings of the project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 2 | 4 |
| Disseminates results frequently and actively engages partners | 3 | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Only one paper has been published, and almost one year of work is missing of the move of the PI. Nevertheless, there are quantitative results for the hero pastes.

**Reviewer 2:** Combinatorial research work encompassing ink properties and printing parameters sorely needed for advancing metallization concepts to the next stage of device evolution.

**Reviewer 3:** Up to the point of the project novation, the team were achieving the important project milestone. The key electrical parameters for measuring the resultant silver contacts were described. Process parameters essential to control the Ag delivery were not described. Reliability of contacts to soldering and accelerated lifetime testing of a tabbed cell was not addressed in the supporting documents. It was not clear form the supporting documents whether the team was frequently disseminating information to their partner (which presumably is ASU). It was not clear what the strategy is to find and then collaborate with stakeholders. This will be key for process validation included techno-economic analysis. The team did start a company and attend NSF iCorp which is good preparation for such outreach and commercial activities.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Each task is important and well described.

**Reviewer 2:** Score: 3. Comments: Access to materials and tool modifications rely on several external project partners, formalized coordination and collaboration agreements will be required for project to be completed in a timely manner.

**Reviewer 3:** Score: 5. Comments: The tasks in the project do add value to the development of a new printing method. Each one addresses a specific aspect for the development and characterization of the silver contact. One area that could be strengthened is reliability of a tabbed, encapsulated cell to understand any potential future issues in the manufacturing supply chain.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** I have real issues with not knowing, even broadly, what are "reactive inks." I realize that there are issues of IP.

**Reviewer 2:** There is a lot of prior art available on printing inks, dispense mediums, and characterization techniques to test reliability - this group would be wise to beef up there approach with more background study.

**Reviewer 3:** Blind spots might include: 1) Additional downstream (i.e. module) reliability testing including adhesion data (pre and post tabbing). 2) Supply chain evaluation; cost and manufacture of the silver precursor materials, operation and maintenance considerations for the equipment. Total cost of ownership of the new process versus the incumbent printing technologies. 3)Appetite for risk of adopters for the new technologies with respect to new contacts.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Might be nice to see contact with PV fabricator.

**Reviewer 2:** Notably absent from the project team are system owners/integrators that benefit from the additional energy harvest of these technology insertions. Module manufacturers like United Solar are producers, but user input will intensify the technology adoption and shorten the feedback loop of observed performance enhancements.

**Reviewer 3:** Reliability groups for best accelerated aging tests for a contact materials. Standard groups for testing requirements. Current paste manufacturers with respect to formulation requirements at large volume. Cell manufacturers with respect to adoption needs and value proposition validation Module manufacturers with respect to stringing equipment and process compatibility.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Decreasing costs of metallization in photovoltaics is very important. 2) What are "reactive inks?" 3) It would be nice to see more publications from this program.

**Reviewer 2:** Reliability and stability of proposed interconnection scheme needs more precise set of metrics that will be studied in this effort.

**Reviewer 3:** 1) This is an innovative Ag contact project which could reduce cost at the cell level. 2) In order to get eventual buy in from the industry, evaluation and reliability testing should include tabbed cells and encapsulated cells. 3) A full total cost of ownership analysis should be performed to identify the key benefits and risk for future adoption.

## New Approaches to Low-Cost Scalable Doping for Interdigitated Back Contact Crystalline Silicon Solar Cells – $615,000

*Colorado School of Mines | Golden, CO | Principal Investigator: Sumit Agarwal*

This project lowers the cost and reduces the complexity of manufacturing interdigitated back contact mono-crystalline silicon solar cells, which provide a promising pathway to achieving a levelized cost of energy of $0.02 to 0.03 per kilowatt-hour by 2030. Currently, these types of cells require patterned doping of the back contacts, which adds several additional steps compared to the more traditional front-grid architecture. The research team is working to develop a photo-assisted, area-selective patterning method that produces high-quality devices and is highly scalable for large-area manufacturing at reduced cost.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 | 4 |
| Set critical challenges to overcome | 3 | 4 | 4 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 3 | 5 |
| Advance the U.S. solar industry substantially | 3 | 1 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Patterning of rear IBC-HJ cells via laser and masking process being proposed the next evolutionary step to achieving cell efficiencies greater than 25%. Many other research groups working in this space and the methods described herein compliment those activities.

**Reviewer 2:** The stated efficiency goal, at 21% efficiency, could have been relevant when this project was conceived in 2016, but are not relevant anymore since mainstream PERC technology (with front and rear contacts) achieve more than 22% today in high volume manufacturing with very low production costs. It is also doubtful that this technique can be extended to front PERC patterning and be more competitive than the current laser-doped selective emitter technology. The target of 1mm patterning pitch is also unlikely to be aggressive enough to reach very high efficiencies.

**Reviewer 3:** No comment.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Cell performance still very low to even identify major hurdles to implementation - the dominating regimes of recombination cannot be tested as fabrication issues still limit a true benchmark.

**Reviewer 2:** The milestones have been met so far, though the change of direction (from UV assisted growth to masked CVD) made this project less attractive, by bringing up other limitations (for instance, cross-doping during deposition). The mitigation strategies (additional plasma etching step) adds an additional processing step. The experimentally achieved efficiency of 15.15% is too low to be relevant as a proof of concept.

**Reviewer 3:** No comment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Adding more process steps and less stable semiconductor layers/coatings to the device is working against the trend of cost and complexity reduction. This team will be challenged by those detractors stating that incremental benefit is at too high a price. Cost of ownership calculations will be a key deliverable for technology advancement.

**Reviewer 2:** Score: 3. Comments: Since high efficiency IBC devices can be already made today (with 27% efficiency as outlined in the project overview), the challenge is to make those devices at low cost. The report doesn't include any cost considerations, targets or milestones related to costs. The path from 15% to 21% efficiency is not sufficiently detailed.

**Reviewer 3:** Score: 4. Comments: No comment.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Work to date does not appear overly extensive or aggressive. A fair amount of modeling and material property inspections, but little in the way of device results or device characterizations.

**Reviewer 2:** The device efficiency might be limited by the high recombination in the depletion zones at the P+/i-polySi and N+/i-polySi interfaces.

**Reviewer 3:** Industrial production of solar cells requires extreme reproducibility that ceramic molding and milling cannot provide. The alignment technique of inserting ceramic pins into holes in the mask and substrate for plasma CVD is likely not transferrable to an industrial scale. Also, the understanding of gap contamination mechanisms and the mitigation strategies we have developed will help other groups to avoid such problems in their study of IBC cells with similar structures and fabrication processes.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Device fabrication and characterization delegated to SubPIs can be problematic, if prioritization at national lab is not given to this effort. The material and deposition can be a success, but heavily gated by turn times at partners.

**Reviewer 2:** As this is a proof-of-concept project, I don't see the need to include anymore stakeholders.

**Reviewer 3:** There should be an industry collaborator because it could have high impact.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Adding more process steps and less stable semiconductor layers/coatings to the device is working against the trend of cost and complexity reduction. This team will be challenged by those detractors stating that incremental benefit is at too high a price. Cost of ownership calculations will be a key deliverable for technology advancement.

**Reviewer 2:** 1) Improvements in PERC made this project obsolete. 2) Even if goals are met, it is unclear that this technology can be cost-effective (no cost goals or projected costs are included in the report). 3) Not much time is left to overcome the significant technical challenges that remain.

**Reviewer 3:** There should not be any follow on work.

## Post-Growth Recrystallization by Halides for High Throughput Copper Indium Gallium Selenide Photovoltaics – $900,000

*Colorado School of Mines | Golden, CO | Principal Investigator: Angus Rockett*

This project uses a combination of a highly adaptable multi-source deposition system and a wide range of post-deposition treatments in an effort to identify successful routes of improving the structural and electronic properties of copper indium gallium selenide films that are compatible with high-throughput manufacturing. If successful, new treatments that use alkali metals, halides, and other extrinsic dopants may be identified that could either improve the performance of copper indium gallium selenide produced using two step production methods and/or reduce the manufacturing costs of copper indium gallium selenide production using single step production methods.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 4 |
| Set critical challenges to overcome | 6 | 5 | 4 |
| Implement a high-risk, high-impact approach | 6 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 3 |
| Advance the U.S. solar industry substantially | 5 | 5 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Identifying cheaper approaches to the manufacturing of CIGS solar cells through reduction of capital cost and the feasibility of cheaper and lower temperature processes. Strengths: 1. This reviewer agrees this is a key challenge to CIGS adoption 2. Team structure and responsibilities well defined Weaknesses: 1. Not enough emphasis on evaluating the alternative proposed methods to be readily scalable.

**Reviewer 2:** Strength: the project explores a new way to make the manufacturing process of CIGS more competitive by increasing throughput and lowering the capital cost. The project plan was reasonably laid out for material and process selection. The objectives were challenging but reachable with systematic studies. Weakness: Integration of anneal process with the deposition process, especially if the best processes include annealing between the deposition. To have an in-situ process, due to the chemical (halides used with anneal), multiple isolation chambers have to be used. The cost of multiple isolation chambers and anneal chambers, as well as the exhaust treatment for the chamber, would add cost to the processes.

**Reviewer 3:** The concept of this project to explore alternative deposition processes, i.e. using fluxes to enhance grain growth and speed up the processing time at lower temperatures, is aligned with the scope of the DOE program to increase performance and lower cost. The work performed to date screens different approaches to film growth at speed and lower temperature budget. The results eliminates certain recipes, but discovers few that have potential. This brings value to the technology in the sense that it builds knowledge for others to build and possibly exclude due to potential negative outcome. The project has met some of the minor milestones, and the the two GO-NOGO milestones. Weaknesses: The approach taken by the team to address the concept behind the objectives is too convoluted and very empirical. This is reflected through the challenges and problems faced in the first period as stated by the PI in the report. Several speculations about what needs to be done next to improve on the processes to yield high materials quality and device efficiencies. The addition of processing steps compared to state of the art adds to the complexity and controls of the process manufacturing stream. Claims by the PI that the processes described are scalable and easily replicated is speculative, because even though the materials can be evaporated, it is not guaranteed that it will scale under good control in terms of uniformity of composition and temperature. The interpretation that the best process to date is the one that uses AgBr as annealing flux after the second stage is also speculative without clearly showing that the CuxSe present at the end of the second stage is not the responsible component. The AgBr of course could add to the material quality, but this has to delineated. The 3-stage process also produces high quality materials and very high efficiency, even at 420 C as shown in the literature. Also, NICE 3 stage process to produce the CIGS absorber on their pilot line is a 10 minutes process. NREL has demonstrated and published, 12 years ago, a 12 minutes process that yielded 17% device. The use of CuL and InCl3 fluxes has been tried before and did not show any advantages.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The technical progress appears adequate. It would be desirable to see more effort put into the project regards what processes and chemistries could eventually be scalable into manufacturing.

**Reviewer 2:** The team laid out a reasonable plan to search for an alternative ways to increase productivity and reduce cost for CIGS PV. First they would screen materials and processes, then focus on the promising ones for optimization. They have appropriate equipment and collaboration resource to execute the project. The ODU team was focusing on devices, while the CSM team was working more on material development and characterization. The team conducted projects on schedule and achieved multiple milestones.

**Reviewer 3:** The progress in this project has been slow, and faced several challenges due to its complexity and "trial and error" implementation. The processing experiments are carried out at two labs, which can present challenges and delays. The milestones to date have been met, however, the achievements are minor and mostly procedural. The 15.7% milestone is noteworthy showing the use of a new fluxing material. To date, the outcomes do not reflect new knowledge that can be adopted by the CIGS community. It is difficult at this juncture to assess what modifications can be pursued in the overall approach to add value to project. The latter, requires reassessment of the path forward.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Tasks and goals are well laid out. Step 3, the evaluation of fitness of the novel approach to manufacturing deserves particular attention and definition.

**Reviewer 2:** Score: 5. Comments: The tasks planned in the project help achieve the final objectives of the project. Building equipment, down select materials, device modeling and characterization all add their values to the project.

**Reviewer 3**: Score: . Comments: The experimental approach toward meeting the objectives are not unique. It is a straight forward approach based on empirical plan. I do not see where the outcomes as expected to be produced by the project may be adopted by the current industry, since it is a significant departure from their roadmaps and the investment they have in capital and years of effort. It is, however, probable that certain specific discoveries/knowledge can be adopted if it has practical value at the time.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Scalability of lab process to high volume manufacturing, cost and safety challenges of handling the proposed chemistries in high volume, requirements of process to achieve repeatability, uniformity and yield. Experience of team members in high volume manufacturing.

**Reviewer 2:** The cost to build multiple vacuum chamber for production tool and its operation.

**Reviewer 3:** A competing process in the deposition of CIGS, is a process that is simple (like a single stage) targeting a slightly Cu poor composition, followed with short anneal with KF. In manufacturing of large modules of CIGS, the issue is non-uniformity across the module in composition and temperature. Hence, yield is not optimum. The formation of high quality 1.5 microns Cu-poor CIGS can be achieved in about 8 to 10 minutes.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Someone with an eye to scalability regards process and tool requirements. A chemist that could enhance the search through careful selection of choices, possibly some DSC studies.

**Reviewer 2:** Industrial partner, which the team was working on to build a advisory board.

**Reviewer 3:** The project needs an industrial partner who will critique periodically the approach to solve a given problem, the novelty of the concept, and the worthiness of the project to the industry. The PI indicated that he attempted to partner with an industry but has not succeeded yet.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** CIGS as a technology has failed over the years to materialize into the market place. This project aims to address one of the key issues, high capital cost required for the formation of the absorber. The approach is interesting and worth developing.

**Reviewer 2:** More detailed cost estimation and reduction for anneal equipment and operation. If it is too costly, the feasibility is questionable. This should be arranged as one of GNG gates.

**Reviewer 3:** The enhancement of the team number of partners to compliment the two partners existing now. Reassessment of the approach the PI has taken to achieve the goals of high rate low temperature processing to achieve high efficiency and low cost. Better alignment of the project with industry so that the outcomes maybe adopted by industry with little disruption to their existing infra-structure and business momentum. The alternative is for a new start-up to adopt the current concept, which is highly unlikely today.

## Advanced Module Architecture for Reduced Costs, High Durability, and Significantly Improved Manufacturability – $1,015,000

*Colorado State University | Fort Collins, CO | Principal Investigator: Kurt Barth*

This project is investigating a new module architecture for thin film photovoltaic modules to reduce manufacturing costs, cap-ex costs, and degradation rates associated with moisture ingress. The proposed method provides an improved process cycle time compared to standard lamination procedures. Key areas of investigation include obtaining a complete understanding of layer formation during the encapsulation process as well as the evolution of material properties, interfaces, and module performance over time during accelerated testing.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 |
| Set critical challenges to overcome | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 |
| Advance the U.S. solar industry substantially | 0 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** While the project calls itself advanced module architecture, the differences between it and some earlier designs are not great. The basic concept of using PIB for edge seals has been around for 20 years and is how most CdTe product is made. The new concept is really only for thin film substrate designs and for these the edge seals are standard construction. So the innovation is in replacing EVA or polyolefin with either a gas or a very low cost polymer since it does not have to transmit light.

**Reviewer 2:** The major strength of this project starts with the recognition for the need significant change to the module architecture in terms of the lamination steps in order to speed the through put and cost of materials. This project is well structured around a focused approach to reduce the speed of module lamination and cost of processing significantly. Its scope is well defined and straight forward which increases the probability of success by minimizing operational challenges. A major strong feature of the project is the elimination of vacuum for lamination, which speeds the process and cut cost. The team has the skills and experience needed: initiating manufacturing processes and testing for reliability.

The project tasks are well defined, straight forward, with efficient milestones schedule. This is reflected through carrying out activities in parallel where needed. No apparent weaknesses, however, the teams not indicated intention of identifying a potential manufacturing partner of the hardware at scale, once the outcomes are ready to be scaled up.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engages partners | 3 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project plan looks well thought out. The early milestones have been met but the program is now planned to run for an extra 6 months – it is begin schedule.

**Reviewer 2:** The performance by the team on the stated tasks is as expected, meeting the promised milestones and in some cases exceeding the goals. The project experienced some mechanical problems which were overcome in a time manner, reflecting on the skills of the team. The PI states that the cost numbers were validated by a third party, a reputed manufacturing entity. The total speed of the lamination process was 194 seconds (Takt 30 sec) compared to current baseline of 12.5 minutes, and cap ex at <50 % of current baseline. I believe that if the reliability testing undergoing now is expected t o yield the desired lifetime, this achievement would be significant in contributing to the DOE program goals.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Eliminating lamination is likely the major improvement that could come out of this project. That would certainly reduce capital equipment costs but probably not enough for a module manufacturer that already has the laminators to switch. So this new technology would likely only be interesting to someone new getting into the PV business with a superstrate thin film product. This is a limited market and would have limited impact on the PV industry.

**Reviewer 2:** Score: 5. Comments: The project is straight forward. The plan was to take a risk at lamination without vacuum, which has been the standard for a long time, and it seems the results indicate a good pay off. As mentioned above, the two major outcomes of achieving much higher speed and appreciable cost reduction add significant value to the PV technology and the DOE goals.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Focusing on packaging for a limited technology is not the best way to have impact.

**Reviewer 2:** I cannot see any blind spot in this straight forward effort.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** For this project to have commercial success, it needs to find a company trying to break into thin film manufacturing with a new technology. While not impossible the track record for new thin film PV module manufacturers is not very good.

**Reviewer 2:** A potential entity to validate scalability of the hardware consistent with the results from the project.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** While new packaging methods can be of value in reducing cost it is critical to evaluate it based on its potential use– what technologies they can be used for. In this case it looks rather limited. Development of a lower cost and maybe even better back encapsulant that doesn't have to transmit much light is probably the best part of this project. This may have more utility than the other features of the new design. Since thin film is still a small part of PV and is dominated by 1 or 2 companies, projects addressing thin film packaging should probably be teamed up with one of those companies.

**Reviewer 2:** See response to previous question.

## Back-Contact Interface Engineering for Higher Efficiency Cadmium Telluride Photovoltaics – $3,500,000

*Colorado State University | Fort Collins, CO | Principal Investigator: James Sites*

The rear contact is one of the performance-limiting components of cadmium telluride solar cells, and it will likely need to be dramatically improved for cadmium telluride to reach monocrystalline silicon cell efficiencies. This project team is working to identify the best materials to use to make high-quality passivated rear contacts for thin-film cadmium telluride solar cells, and possibly bifacial modules, pushing cadmium telluride technology closer to 25 percent efficiency while preventing power loss.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** High risk project investigating a new approach. May have a significant impact on performance improvement.

**Reviewer 2:** The team is experienced in research of this CdTe solar cells. They planned extensive collaboration with the team internally, and outside university and industry teams. They have clear understanding of industry needs and strong awareness of cost-effective manufacturing.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project has not started yet.

**Reviewer 2:** The project just started and hard to measure the performance yet. The report clearly showed the plan for collaboration with several teams, their roles and results expected.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Overall approach is described that align with the objectives

**Reviewer 2:** Score: 5. Comments: The contact resistance to p-type semiconductor and recommendation at the interface are common problems for photo-voltaic devices, including silicon solar cells. The plan proposed multiple approaches to address the issues and each of them has their merit. The plan also included method used in silicon solar cells such as tunneling point contacts to minimize the contact resistance and recombination at the back interface.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None identified.

**Reviewer 2:** More reliability tests would be an important parameter to consider for feasibility of each approach.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Large collaboration, sufficient.

**Reviewer 2:** An institution with experience fabricating tunneling point contact would be helpful to shorten the learning cycle.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Evaluation form contains questions not applicable to projects that have not been started. I provided scores to get the submission to 100%. This project has a strong team with good track record.

**Reviewer 2:** Add reliability tests to screen the approaches. Other back contact such as a thin copper layer suffers instability issues caused by copper diffusion.

## Device Architecture for Next-Generation Cadmium Telluride Photovoltaics – $899,922

*Colorado State University | Fort Collins, CO | Principal Investigator: James Sites*

This project is developing a novel solar cell architecture that will increase the voltage and energy output of cadmium telluride solar cells and address the short lifetimes of photo-excited electrons in the cells. This new architecture should give the cadmium telluride manufacturing community a novel, but highly realistic, approach for solving the voltage limitations of the technology. The resulting product will be compatible with solar panel manufacturing at or below current cost structures.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 5 | 4 | 4 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project outlines the purposeful optimization of the CdTe device structure, in all its component (absorber, contacts, etc). The emphasize here is on material development and device fabrication, supported by in-depth characterization. The PI and Co-PI have a long history within CdTe technology community. Strengths: 1. Solid and structured approach to address all elements of the device 2. Good mix of process, characterization and modeling Weaknesses: 1. Lack of innovation toward new materials.

**Reviewer 2:** Strength: the project addresses the key issues associated with CdTe thin film photovoltaic devices: the front interface, the back interface, and the absorbers. The team collaborated and applied multiple characterization methods to gain improvement and understanding of the issues. They have sufficient resources and access to them to achieve the milestones. Weakness: Characterization of device stability with Cu and Te back interface layers were not sufficiently presented.

**Reviewer 3:** The project objectives aligns well with the requirements to advance the performance of the CdTe technology as described in the DOE FOA. The project has demonstrated progress on the tasks, and showed understanding of the physics necessary for charge transport in the bulk and interfaces, and engineering of device structure. The team is well published in the refereed literature. During the project, the team has demonstrated using the best optimal combination of all the elements of the cells developed under this project, devices with >16% efficiency, Voc about 0.84 V, FF about 0.75. This performance is significantly lower than the state of the art (20 to 22%), especially performance by the largest manufacturer of CdTe, FS. The issue to be addressed then is where in the device are all the deficiencies are taking place and why, considering that the objectives of modifying/engineering new layers and interfaces are supposed to remedy the deficiencies. The device structure contains many layers/interfaces, and incorporations of additives (Te/Se), Cu, and thermochemical activation treatment. At first impression this seems as a complicated structure which brings with it many variables capable of introducing deficiencies, and potential for adding cost. This makes it imperative for the PI to collaborate with FS to truly validate the practicality of the approach. I believe that milestones related to performance in terms of efficiency, Voc, reliability, have to be practically measured in relation to state of the art. Of course, exceptions are fundamental studies related to the understanding of material and device physics.

## 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project team has been able to investigate the proposed modifications through experimentation. Some of targeted improvements have led to improvements in the device, e.g., Te back contact and others have to led to increased understanding (e.g. exploration of Mg for back contact).

**Reviewer 2:** The team has met most of milestones. They have collaborated with multiple teams in the field. They also get feedback and suggestions from First Solar. Some of the milestones were quantitative for their efficiency gains by the improvement of device structure and processes.

**Reviewer 3:** The project has demonstrated good physics understanding of new specific interfaces introduced in a modified device structure. The team has disseminated the knowledge in many publications. However, the meager results in terms of demonstrated high impact, especially as it relates to impact on current industry, points to the need for a change in strategy of approach for the remainder of the project, and in future efforts. (see also comments under Q 1. I believe based on the last two years efforts in the CdTe research, the strategy should be emphasizing simplification of the components of the device, whether it is CdTe or CdTeSe.

## 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, all the avenue outlined in the proposal are fundamentally interesting and worth pursuing.

**Reviewer 2:** Score: 5. Comments: The project tasks including exploration of device structures such as front and back interface materials, absorber thickness and composition variation for bandgap tuning, modeling to gain understanding of the experimental results.

**Reviewer 3:** Score: 4. Comments: The project has explored well the possibilities of new structure with new interfaces. The results are useful and point to new strategies and approaches. As such, the project has contributed to the base knowledge.

## 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** There is risk that improvements demonstrated are not repeatable or transferable to other process methods. It is unclear that any progress to ultimate enhanced eff capability for CdTe was achieved in this project until said improvement can be incorporated into a very high performing and high stability device.

**Reviewer 2:** Device reliability tests for new device structures.

**Reviewer 3:** I believe the strategy and approach to keep adding layers and other additives and post thermochemical activations to remedy the observed deficiencies in material properties and device performance, has run its course and the benefits to efforts expended are not justified. I believe that a simple approach should focus on basic device physics of a pin structure with the best dopant demonstrated to date by the community research, without all the added "aid" measures can be achieved by a synergetic team guided by a industrial partner.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Team is connected to many cross-functional activities and activities.

**Reviewer 2:** Reliability test facility and personnel.

**Reviewer 3:** I believe an industrial partner committed to timely participation to validate approaches and results, is essential at this time in the technology roadmap. The approach developed at Washington state university in developing the optimum doped bulk CdTe as a sublimation source to produce the film will be a good partner.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Project indirectly supports good capability/infrastructure that has active users (other projects). Project has gone a little "stale" with a shift toward Group V absorber. While this project helps to maintain/improve a baseline process at CSU, it is not sufficiently addressing the need to innovated "new ideas and approaches" to overcome the performance limiting aspects.

**Reviewer 2:** The project covers needed areas for improvement in CdTe type of photovoltaic devices. Hope the team would set higher goals for improvement and also consider more reliability tests to make the improvement more comprehensive and robust.

**Reviewer 3:** Redirecting the strategy/approach for achieving the main objectives: higher efficiency targets competitive with state of the art, prospect of reliability, simpler device structure that convincingly is on a roadmap to low cost of manufacturing of the cell components, and a partner that serves to validate progress/results in a manufacturing scenario.

## Doping Cadmium Telluride and Cadmium Selenium Telluride for Higher Efficiency – $750,000

*Colorado State University | Fort Collins, CO | Principal Investigator: Walajabad Sampath*

This project is working to significantly enhance the voltage and efficiency of cadmium telluride and cadmium selenium telluride solar cells through p-type doping with group-V atoms. Colorado State University, with help from multiple partners including the National Renewable Energy Laboratory and First Solar, is using arsenic to increase the density of holes in the absorber by two orders of magnitude. The team seeks to increase the cell voltage by 100 millivolts and improve cell efficiency by up to 20 percent. The key to success will be the activation of a major portion of the dopant atoms so that they each contribute a hole to the absorber while minimizing the recombination that commonly results from non-activated dopant atoms. The team will ensure that its cell-fabrication steps are compatible with low-cost, large-scale manufacturing.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a high risk and high reward project and the goals align with SETO goals. Successful outcome of the project may strengthen US solar industry, seems mostly through First Solar's implementation potential. It appears that this project is aligned with others that are part of the review. I consider this a positive aspect.

**Reviewer 2:** The project focused on a critical issue for further improvement of CdTe/CdSeTe solar cells. The team worked closely with other fellow researchers in this field. The project objectives were quantitative and provided clear targets to focus and achieve. Weakness: No reliability tests were included as part project plan. Light induced degradation or other degradation mechanism were detrimental to solar devices.

**Reviewer 3:** Goal is to implement Group V doping for CdTe into a poly device fabrication process. CSU has a long history of succcessfully operating a poly process. Deliverables are structured clearly around device and material metrics. Strengths: 1. Device leverages prior public investments in infrastructure 2. Project team has deep engagement with cdte community and industry 3. Project scope widely supported by prior years work in sx CdTe Weaknesses: Lack of clarity of separating funded tasks between funding sources.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Good progress has been made towards the objectives. The project appears to have communication with other groups and collaboration.

**Reviewer 2:** The team has achieved milestones on time or ahead of schedule. The milestones were quantitative and measurable. They have engaged with many other research teams. However, more direct collaboration with industrial partners could help make the project results more applicable to industry, in addition to current interaction through workshops or other meetings.

**Reviewer 3:** Project team claims to have hit a great number of milestones early in the project. Integration of said milestones into working devices appears yet to be fundamentally challenged. While high lifetimes and high doping is reported, Voc of Gr V doped device is very low. Also, the 20% deliverable of efficiency was achieved without Gr V doping. Would recommend to clarity the deliverable structure and the intent.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks are well aligned with achieving goals. It would be good to add degradation and reliability testing since composition changes can impact degradation.

**Reviewer 2:** Score: 5. Comments: The experiments of doping incorporation and post treatment are essential for the projects. Measurements of dopant incorporation, carrier density for dopant activation, as well as minority carrier lifetime provided feedback to the experiments. Additional reliability tests would add value to the projects.

**Reviewer 3:** Score: 4. Comments: Tasks are not clearly defined in documentation, it only explains the overall objectives.

### 4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Commercial success requires no changes to degradation and reliability with the new composition. This needs to be tested before the project is completed.

**Reviewer 2:** Reliability tests.

**Reviewer 3:** Transferability of the developed process may be limited. NREL has recently developed a VTD system, it would be good if CSU could collaborate with them to generalize learning and be less platform dependent.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** No issue found here.

**Reviewer 2:** More direct collaboration with industrial partners.

**Reviewer 3:** Effort is well integrated into the CdTe communities effort to transition to Group V doping. Collaboration through this and other project exists.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** Commercial success requires no changes to degradation and reliability with the new composition. This needs to be tested before the project is completed. I see that this is missing in many of the project tasks. Even if there is no collaborator that can test this, it needs to be mentioned as a risk factor.

**Reviewer 2:** Reliability tests to screen any big issues before investing too heavily into a new technology

**Reviewer 3:** CSU process capability is an infrastructure and it seems logical for SETO to continue its support. Clarity on project deliverables by funding source is low, but possibly not critical. Project has still much to accomplish given the best communicated Voc is below 700mV for a Group V doped device.

## Technology Development for 22.5 Percent Efficient P-Type Passivated Emitter and Rear Contact Solar Cells – $700,000

*Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Ajeet Rohatgi*

This project is developing key technologies to achieve commercial-size passivated emitter and rear contact cells with a 23 percent efficiency up from a current efficiency of about 22 percent. The team will integrate multiple technologies to create the solar cell, including spatially controlled doping profiles, passivated rear contacts, advanced annealing treatments, and high-resolution screen printing. Together, these technologies will reduce carrier recombination rates in the junction region, at the back surface field, and at the interfaces within each contact while also minimizing front shading and rear light absorption. To improve solar cell performance, the team is using the same process on n-type silicon to produce rear junction n-type cells with spatially controlled front surface fields.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 4 | 6 | 4 |
| Implement a high-risk, high-impact approach | 3 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Most modeling has shown this architecture to be a candidate for quickly increasing the performance of a typical Si solar cell; however, most groups are far from obtaining the modeling results - this project will hopefully shed light on that reason.

**Reviewer 2:** No comment.

**Reviewer 3:** The project goals are well aligned with the direction of the PV industry (poly passivation to increase efficiency, possibility of upgrading existing PERC lines to this technology, which raises its potential impact. Other technologies based on poly passivation often uses N-type substrate. This project focuses on P-type, which is currently cheaper and more available than N-type, but makes meeting higher efficiencies more challenging. If successful, this project will produce cell efficiencies (22.5%) that are marginally above (or at) mainstream PERC efficiencies (22.2%), and below best-of-class N-TOPCon in production (23% production average at Trina in 2019). The impact on the US PV industry is indirect, since they are no domestic Si PV cell high volume manufacturing; but the technology developed within this project has the potential to make more efficiency PV panels available for the US market. This is mostly an integration effort, putting different existing technologies together to produce a higher efficiency device.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** No comment.

**Reviewer 3:** Cost considerations are often raised in the project summary, but without quantifiable targets or milestones. Four milestones have been met so far, though it is unclear from the project summary if all the milestones so far have been met according to the schedule. Two presentations have been submitted for the IEEE conference, which is respectable considering that the project started a little more than one year ago.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Very high quality results, publications and technologies developed within this project.

**Reviewer 2:** Score: 4. Comments: No comment.

**Reviewer 3:** Score: 4. Comments: The 3 main tasks (rear p-TOPCon, P-type lifetime and front emitter with improved metallization) are necessary (and should be sufficient) to get the efficiency goal. They are few details, however, regarding the challenge of keeping a low metallized rear J0e with a thinner rear poly layer (100nm target instead of the achieved low J0e with 250nm). Note that this project is similar, but complementary, to another project by the same PI (DE-EE0007554) which is ending in a few months.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Impact of a successful project deliverable set will be highly sought after by commercialization partners, given apparent integration simplicity -this needs to be identified earlier in the project.

**Reviewer 2:** Eventually an industrial partner will need to be involved, but with Dr. Rohatgi's knowledge of industrial processes, this should not be hard.

**Reviewer 3:** Advanced hydrogenation processes, as those developed by UNSW, have shown good results in increasing lifetime in P-type silicon (especially in conjunction with tabula rasa and phosphorous gettering). Those hydrogenation processes would help this project to reach the bulk lifetime and efficiency goals.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Could partner with NREL to produce and characterize devices as well as test reliability and durability

**Reviewer 2:** Eventually an industrial partner will need to be involved, but with Dr. Rohatgi's knowledge of industrial processes, this should not be hard.

**Reviewer 3:** A large number of research and academic institutions work on similar passivation and devices, and it might have been a good idea to leverage their expertise by adding some of them as partners to this project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** PIs have a demonstrated track record of being able to deliver projects like this

**Reviewer 2:** Good work headed by knowledgeable folks. Promising for US manufacturing.

**Reviewer 3:** This project is not particularly innovative, but combines known technologies and techniques into an integrated device that is closer to the existing PERC technology. This makes it more evolutionary than revolutionary, but (if successful), ready to be used in high volume production. Most research related to poly passivation rely on using N-type substrates, which have naturally better lifetime, but are more expensive (~10%) than P-type. This project focuses on P-type, probably because of its lower cost. But it remains to be seen if high lifetime P-type will be cheaper than high lifetime N-type in the near future. The development of metallization pastes is critical in order to reach the passivation and efficiency milestones. A close collaboration with Heraeus is beneficial to the success of this project.

## Pushing the Efficiency Limit of Low-Cost, Industrially-Relevant Silicon Solar Cells by Advancing Cell Structures and Technology Innovations – $1,425,000

*Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Ajeet Rohatgi*

This project aims to advance manufacturable silicon cell technologies to above 22 percent efficiency through the use of passivated selective emitter and selective back surface field contact geometries. The improved contact and metallization methods investigated during the course of the project will reduce recombination and improve cell performance by up to two percent absolute efficiency. Multiple fabrication methodologies will be investigated to determine the most cost-effective method for producing the laterally patterned doping profiles needed to realize this high-performance cell technology.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Baseline cell concept builds upon at acceptable and relevant levels for modification and customization.

**Reviewer 2:** This project directly addresses the SETO goals by developing high efficiency solar cell structures while keeping the costs lower than competitive high efficiency cells (IBC or SHJ). The project is well aligned with the mainstream PV industry direction (higher efficiency, compatible with existing supply chain and PERC cell lines). The efficiency goals were certainly aggressive when this project was started in 2016 (>22.5%), but not aggressive enough compared to today's PERC best-in-class. However, the best experimental efficiency from this project to date is at a very respectable 22.6%, and the team intends to reach 23% before the end of this project. Note that PV cell manufacturers such as Trina are already producing similar structures in high volume manufacturing at more than 23% average efficiency, and 24% champion cells. The impact on the US industry will be indirect, since there are currently no domestic manufacturers ready to produce those cells in high volume, but it will make higher efficiency modules available for the US market. And very importantly, the dissemination of the learning will be very valuable to the PV community. The report doesn't mention any reliability characterization or results, though reliability is critical if the goal is to see this technology scale to high volume manufacturing. The team intends to reach higher efficiencies using multi-busbar technology, which hasn't gained much traction in the market, despite being available for a few years now.

**Reviewer 3:** The project goals are well aligned with DOE overall goals in support of the mission. It demonstrated the successful development of passivated contacts at the front and back of the cell for n-type class of Si cells. It set challenging targets and approach to improve the properties of both contacts and reduced the J0e values appreciably. The methodology helped overcome the challenges which culminated in the integration of the optimum results into taking the project cell efficiency from the 21% level to exceed 22.6%. The advances exceed the current HIT and IBC cells efficiency of 22%. The PI argues that the impact of the advancements will impact the manufacturing industry by showing that the new development can be adapted to current manufacturing line at lower LCOE cost. In the remainder of the project term the team will emphasize the further improvement in the B diffused contact (FRONT), which will enhance the efficiency further to 23%.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 3 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Work proposed within the scope of the general industry technology roadmap.

**Reviewer 2:** The vast majority of the milestones have been met, though the overall project is 1 year late. 4 papers have been published or submitted. The institutions included as project partners are two of the best organizations involved with TOPCon research and development, but unfortunately, no PV cell manufacturers seem to be involved with this project.

**Reviewer 3:** The project met 29 of the 30 milestones by overcoming several challenges methodically, and the 3 GO-NOGO decision targets. The team has also published numerous papers describing the advances. This is a productive project justifying the federal funding, especially that it demonstrated the highest efficiency best in class for a commercial ready Si solar cell.

It is very likely that in the remaining period the project will attain the 23% milestone, and a step toward the 2030 DOE goal. This also will strengthen the argument to look into the benefit to risk ratio of adapting the advances to existing manufacturing hardware.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Scope of project and comprehensive partner list will be difficult to coordinate, and a risk in meeting stated objectives

**Reviewer 2:** Score: 4. Comments: The project plan is well structured. Each metric has direct relevance to the overall goal. But even if projected costs in high volume manufacturing are critically important, no quantified costs or cost projections are included in the report.

**Reviewer 3:** Score: 5. Comments: The project achievements represent a valuable opportunity to rapidly integrate the outcomes of the project, capabilities, and technologies of the team and the industrial collaborators to produce highest efficiency best in class commercial ready cells.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI in this effort is a very well known, respected leader in conventional cell design and fabrication - that can sometimes lead to a fixed way of thinking and an immediate dismissal of alternatives that could prove valuable in the long-term. This group needs to constantly be sampling other group's approaches and comparing against their own and concurrently propose new methods in areas that have not been updated in some time.

**Reviewer 2:** The results for the metallized J0e of the homogeneous Boron emitter is very good at 21fA and better than the result of the selective emitter (metallized J0e of 28fA). Those results conflict with the fact that the team plans to integrate the selective emitter in their device (instead of the homogeneous emitter) to increase the efficiency above 22.6%. The bulk lifetime at 1ms is mediocre for N-type silicon and is likely a factor limiting efficiency. What is it so low, and how does the team plan to increase it to 3ms? Using SiO2 as the top ARC layer increases the cell current and efficiency when tested in air, but has no effect after encapsulation, hence no effect on module power and no real life value.

**Reviewer 3:** Judging from the the goals of this project and the successful achievements/advances, I do not identify a gap in the approach and results to identify a blind spot.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This group would benefit from larger, more mature substrate, cell, module manufacturers as partners.

**Reviewer 2:** It would be useful to include a PV cell manufacturers, and/or equipment or material suppliers (for example silicon suppliers, metal paste suppliers).

**Reviewer 3:** The team consists of three high standing institutions in the US and Europe. integration formally with one or more industrial partners will add more value to the future of the project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Laboratory setting will be pressed to provide more than rough prototypes, but high-volume manufacturing data can be captured in a follow-on work.

**Reviewer 2:** Even if some large PV companies with large R&D resources have published superior results with similar structures in high volume production, this doesn't lessen the impressive results of this project. This project is very well aligned to existing research and development by most research institutions and manufacturing companies. The impact will be substantial as long as results, methods and knowledge are well disseminated, so it can accelerate the industry transition to the next technology. What is the exit strategy off this project? What does the PI plan to do with the results?

**Reviewer 3:** Integration of industrial partners with the team for rapid translation of the results into a commercial ready Si cell and demonstrate the claim of lowering the cost.

## Brittle Fracture Wafering of Silicon Ingots for Low-Cost, High-Efficiency Crystalline Silicon Solar Cells – $1,073,288

*Halo Industries | San Mateo, CA | Principal Investigator: Andrei Iancu*

This project is developing and prototyping new solar wafer manufacturing technologies with the goal of significantly reducing the materials cost of all existing crystalline silicon solar cell architectures. The objective is to streamline the solar wafer fabrication process through more efficient and automated production line tools that eliminate silicon waste while reducing both process and operational complexity. Using a proprietary technology, this will reduce silicon solar cell material costs by at least 40 percent as well as drastically improve operational efficiencies for the majority of solar wafer fabrication steps through process simplification and automation.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 5 |
| Set critical challenges to overcome | 2 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 2 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 4 | 3 |
| Advance the U.S. solar industry substantially | 2 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Market for this approach is small, cost reduction efforts, while significantly reduced in this project are still rather gating for widespread adoption.

**Reviewer 2:** No comment.

**Reviewer 3:** It is a high risk project, competing with existing wire sawing technology that have made drastic improvements these past 5-10 years, and continues to improve. The expected impact can be reasonably substantial (the order of 1 to 2 cents per Watt, if successful). The impact on the US industry can be substantial if the tool under development can be designed and manufactured domestically.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 3 | 4 | 2 |
| Collaborates with sufficient stakeholders | 3 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project not started.

**Reviewer 2:** No comment.

**Reviewer 3:** The team hasn't been able to procure the necessary laser to build their prototype tool, which affects second milestone. It is unclear how the first milestone (development and testing of a pilot tool) could have been accomplished without having a laser with the necessary specifications.

There is only 10 months left in the project for the most important and challenging milestones (demonstrating samples meeting specification and tool throughput) The team has decided not to share or disseminate their results in order to protect their IP, which is understandable.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Using the planned output from this project, new technology entrants into the value chain can be put in context with their respective valuation to incumbent and alternative approaches.

**Reviewer 2:** Score: 4. Comments: No comment.

**Reviewer 3:** Score: 5. Comments: The milestones included in the project are necessary to prove the viability of the technology (building pilot tool, develop process to meet desired wafer specs and tool throughput, cost modeling and customer validation). The customer evaluation is critical in order to validate the technology. No details are included in the report summary, but I doubt that 300 samples will be sufficient for a proper validation. Also, the throughput milestone of less than 5 minutes per wafer is too low to prove that this technology can be cost-effective. The goal of 10 seconds per wafer (as stated in the poster) is more appropriate, but much more aggressive than the milestone.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** While the kerf loss, bow and TTV targets are very good for this project, it is clear that the team has underestimated or purposefully understated the capabilities of conventional wiresawing. This need to be rectified. Also, the tact-time metric per wafer is crazy high at 20/wafer!

**Reviewer 2:** No industrial collaborators.

**Reviewer 3:** In order to compare the cost of this technology to traditional wiresawing, the authors assume that the silicon loss during sawing is at nearly 50%, which is outdated. State-of-the art technology is at 25%.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Likely methods utilized in the creation of laboratory samples will differ greatly from those envisioned for high-volume manufacturing. Yield, cost, and opportunity assessment requires a partner with capital equipment expertise, notably absent from the project team

**Reviewer 2:** Finish funding. Have PI establish an industrial collaborator.

**Reviewer 3:** The team could have chosen to collaborate with the few US-based institutions that have the capabilities to process solar cells (such as ASU or NREL). This would be helpful to get early validation and open feedback, and can be done without having to reveal Halo's IP or trade secrets.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The containment of this project's scope will likely be exceeded by both the complexity of the task and the ongoing technology development and process migration, making the timely delivery of the conclusions questionable.

**Reviewer 2:** Finish funding. Have PI establish an industrial collaborator

**Reviewer 3:** The team was successful at fabricating prototypes with impressive results (TTV, wafer thickness) on relatively large silicon samples, but at a very low throughput. The key for future success will be to increase this throughput by 2 orders of magnitude, which is far from being proven. The throughput milestone at 5 minutes per wafer is still too low to demonstrate commercial viability. In order to justify the cost reductions, the PI compares the Halo technology to outdated wire saw technology; and wire saw technology will continue to improve in the near future, reducing the potential impact of this technology.

## Development of a Low-Cost Single Crystal Silicon Substrate Process for Solar Cells with Efficiencies Higher than 23 Percent – $2,500,000

*Leading Edge Crystal Technologies | Gloucester, MA | Principal Investigator: Alison Greenlee*

This project will improve Leading Edge's floating-silicon method for producing high-quality single crystalline wafers, as opposed to the conventional process of using wire saws to slice the wafers off a block of silicon called an ingot. Sawing creates silicon shavings that waste material, whereas this technology produces continuous thin silicon ribbons. The goal of this work is to remove any contaminating oxygen impurities in the silicon while it changes from liquid to solid, through increased understanding and better-engineered floating silicon furnaces.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 3 | 6 |
| Set critical challenges to overcome | 5 | 5 | 3 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 3 | 5 |
| Advance the U.S. solar industry substantially | 6 | 4 | 2 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project has the potential to concurrently improve cost and performance of Si-based PV cells and modules. The product being developed can be directly used by the most widespread PV technology (PERC) as well by up and coming new technologies (TopCon and HJT). If successful, it will have a large direct impact on the worldwide PV cell manufacturing industry, will have an indirect impact on the US PV industry by reducing the cost and improving the performance of PV modules, and potentially have a direct impact on the US PV industry if this product ends up being manufactured in the US.

**Reviewer 2:** Strengths: The project would help quantify and validate advantageous electronic attributes of the Floating Silicon Method (FSM) wafers over current state of the art CZ grown wafers with respect to low [O] at the FSM wafer surfaces. The characterization technique SIMS noted in the project description should be able to provide a [O] profile map for the wafers and compare with CZ and Multi wafers. This should help identify the optimal process conditions to produce the denuded layer. Weaknesses: Funding for this project appears large. In the project scope I do not see any discussion or objectives to determine the FSM cell suitability with downstream users (cell and module manufacturers). This could be manufacturing process validation of the low [O] surface for wafer handling (mech yield/brittleness), Ag contact screen printing and firing robustness for initial yield and long term reliability), actual cell IV performance versus equivalent CZ cell, module assembly and energy yield to name a few. In summary, what is the total value proposition for this technology in the PV supply chain to make it compelling for adoption and not be a stranded technology at the end of the project.

**Reviewer 3:** The project aims to decrease the overall costs of Si-PV through substantial decrease of oxygen concentration in Silicon wafers. And while I agree that higher cell efficiency plays a role in cost-competitiveness of PV technologies, I think that this approach may at the same time lead to the overall increasing manufacturing costs. Here are my thoughts on this: Major drawback of floating silicon method is the low speed of ribbon manufacturing, which depends on the pulling rate and correlates to the heat required for the process. A reasonable throughput of manufacturing will likely result in high energy costs, which may be ok for countries with low energy prices and low efficiency standards, yet I see this as a major obstacle for this technology entering the US market. Also, some companies tried to commercialize this technology in the past (i.e. Evergreen Solar) and went bankrupt. It bids the question, why would it be different at this time? Also, lower oxygen concentration is undoubtedly a positive result, yet, it is not clear how it will affect other critical single crystal silicon characteristics, such as density of crystal defects?

**Reviewer 4:** Pulled single crystal ribbons can provide a much needed disruption to present wafer production methods. Kerf waste, damage removal and sawing expenses can be eliminated. The ability to make low dislocation density single crystals is an important improvement, but the technology will still present many challenges including avoidance of metal contamination during a longer oxygen out-diffusion period. This is a large and ambitious project. If successful, this company has the potential to bring a substantial fraction of wafer production back to the US, which is very exciting.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 3 | 5 |
| Collaborates with sufficient stakeholders | 3 | 2 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project just started in February 2020, so it is not possible to assess those questions, so I entered average scores. Regarding the quantitative impact, additional milestones (such as lifetime and cell efficiency) are directly related to the potential impact of the project and are missing.

**Reviewer 2:** While the SOPO has not been supplied/completed yet, the objectives described should be able to be completed in the time (3 BPs). The [O] profile in the wafer and LID will be characterized as described supporting documentation. There is no discussion on characterizing the wafers with industry standard cell and module process and comparing with CZ PERC devices. I could not assess whether the data would be disseminated frequently and what level of engagement would occur with the partner. No discussion of the approach to was presented relating to stakeholder identification and engagement. The project appears to focus on FSM equipment and process definition for [O] denuded layer and LID. Efficiency goal is defined in the title of the project but is not discussed quantitatively anywhere else in the document. There is no discussion of objectives to validate the suitability of the FSM wafer for adoption in state of art manufacturing lines and any risk mitigation approaches to ensure any early issues that may be identified for mechanical and electrical aspects of a low [O] denuded layer. There was not objectives to perform a TEA, reach out to manufacturers, performance outdoor energy generations (to substantiate superior energy gen claim), or status and plan post SETO funding.

**Reviewer 3:** Project has started in February 2020, it is difficult to evaluate this section because of the project's newness.

**Reviewer 4:** This project has just begun work and cannot be judged on performance of their SOW. However, previous results are impressive. Hopefully, this large SETO grant will help them attract private capital and accelerate their work.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: No tasks have been defined yet since this project isn't started yet. But the objectives are relevant to the project goal.

**Reviewer 2:** Score: 4. Comments: Needs more definition on FSM wafer suitability for cell and module to achieve the over all goal of >23% cell.

**Reviewer 3:** Score: 4. Comments: The provided overview doesn't list tasks, so, it is not possible to provide a good estimate.

**Reviewer 4:** Score: 5. Comments: It's good they are doing SIMS, but will need to measure O-B pair degradation measurements to prove the point by projects' end.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** An important aspect of this project relates to reducing the impact LID by reducing the concentration of oxygen in the bulk silicon. But recent advances in hydrogenation processes (such as those developed by UNSW) are already mitigating this effect.

**Reviewer 2:** Validation regarding fitting the FSM wafer into the whole PV supply chain though and stakeholder out-reach in the industry.

**Reviewer 3:** The PI should take a closer look at the economics of the proposed technology and evaluate the actual costs of improvement. I cannot see what tasks will be completed, but a techno-economic analysis should be one of them.

**Reviewer 4:** The single focus on reducing oxygen content by diffusion it out after pulling may be ill advised. The team needs to continue to track impurity content, dislocation, defect densities and lifetime as they change processing conditions. Discussions suggest that they know that is important, but do they have the equipment and/or collaborators? Is it possible to apply this technique to pull high quality n-type wafers instead of p-type? Has the company considered finessing the B-O defect issue that way? Of course, eliminating the O-B metastability will permit manufacturers to use their present p-wafer processing techniques and facilitate large market penetrations. But there is a trend toward high efficiency cells on n-wafer that must be tracked.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** When this project is at the stage of being able to produce enough substrates, it would be useful to include cell and module manufacturers, and start reliability characterization (especially of course LID and LeTID)

**Reviewer 2:** Cell manufacturers (beyond GiT cell lab), module manufacturers, accelerated reliability testing to determine the robustness of the contacts made on the low [O] denuded surface, collaborations with groups such as NREL's outdoor test facility to validate the claim that the low [O] device may have better energy yield when deployed. Lastly, equipment manufacturer to cost the FSM equipment.

**Reviewer 3:** I don't know what stakeholders and organizations are involved with the project. Hopefully it includes people from academy as well as potential technology users.

**Reviewer 4:** The collaboration with GaTech is important, so they can define any process changes needed to use the wafers. After that, there will need to be joint experimentation with large cell makers to see if their wafers actually deliver on their promise in modified versions of todays production lines.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Validation should be made through fabrication of high efficiency cells; Characterize LID and LeTID as soon as possible. 2) Include lifetime and cell efficiency in the milestones. 3) Include cost analysis (extra cost per watt in future high volume manufacturing) of proposed furnace modification.

**Reviewer 2:** 1) This project needs elements associated with industry adoption. There needs to be a clear description of positioning for follow on funding and key actions post SETO so the technology is not stranded. 2) Need for a section in the SOPO for a TEA to validate the commercial competitiveness of the technology. 3) A clear stakeholder engagement plan to regularly test the value proposition of the technology is still attractive as the market needs change during the project. This would include a competitive technology analysis relating to CZ incremental improves and cell manufacturer development.

**Reviewer 3:** Cell efficiency is just one of many factor that enable a new technology to enter the market. SETO team needs to consider the energy input into new process and what it would mean for a large-scale implementation. Also the scalability of the process - can it be applied on a large scale? How complex is the implementation of this technology into real-life applications?

**Reviewer 4:** 1) Pay attention to other defects, metal impurities and cell quality to ensure wafer quality remains high as the O is removed. 2) Ensure that new wafer-to-cell processes are developed to take best advantages of the wafers developed.

## Refinement of the Floating Silicon Method: A Low-Cost Monocrystalline Silicon Wafer Manufacturing Process – $1,500,000

*Leading Edge Crystal Technologies | Gloucester, MA | Principal Investigator: Peter Kellerman*

This project is developing the first kerfless manufacturing process that continuously produces single-crystal silicon wafers. This process leverages breakthrough developments in heat transfer and crystal growth to yield high quality wafers at unprecedented production rates, underpinning a potential 60 percent cost reduction over existing single-crystal wafer production. As a drop-in substitute in the existing solar supply chain, these wafers have the potential to reduce the all-in solar module manufacturing cost by 25 percent. This project will support the production of sample wafers from an experimental production machine that will be used to both refine the process and demonstrate wafer performance to the industry. These wafers and corresponding cells will generate the market traction needed to initiate further commercialization of the technology.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 6 | 4 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** The project goals supports SETO's mission to reduce cost due to higher silicon utilization and reduced waste. The supporting document did not fully explain how it would increase cell efficiency beyond segregated [O] near the surface and lower precipitation in the bulk as no cell results were provided. The project does set critical the critical challenges for the equipment to produce wafer that will meet industry standard wafer specifications by the end of BP2. The only thing missing is an actual cell measurement as an indication of compatibility with all cell processes. The project illustrated high risk in the form of a innovative and unique method for single crystal Si growth with all the adoption challenges that will come with it. High impact too, as the silicon utilization (W/g) will be much higher than existing technologies if efficiencies can be matched. DoE funding matches the planned duration with the team finding significant cost share too. This project be of significant interest and value to research outside of DoE funded effort due to its unique and compelling approach. If the capital cost and O&M costs including low labor costs, consumables and throughput are all competitive with CZ methods this potentially be located in the US.

**Reviewer 3:** This project is very ambitious, since the competitive technology (CZ pulling and wafering) has made very substantial continuous progress and has reached a high level of maturity. This project combines challenges from a physics and equipment perspective. The team seems to have credibly identified the issues that reduce lifetime, and has already fixed most off them. There seem to be an appropriate attention on costs with the development of a cost model and getting feedback about cost drivers from companies in the PV industry. If successful, this project has the potential to have a significant direct impact on the US industry since it could lead to domestic manufacturing, and/or to the availability of cheaper PV modules for the US market.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** The milestones were well defined in the document and matched the timeline. The document described measurable metrics at each stage of the work with a industry standard thickness and TTV as a target by the end of BP2. The team appears to be actively collaborating with their partner Georgia Tech UCEP. The team have reached out to three companies from the silicon photovoltaics industry have been engaged to discuss the cost drivers for the industry and how it relates to FSM technology.

**Reviewer 3:** Milestones have been mostly met but further work is needed to integrate all metrics (dimensional, resistivity, lifetime and lifetime distribution) on the same samples. No papers have been published (not surprisingly assuming that the company needs to keep some level of confidentiality to protect their technology), but seems to have reached multiple PV industry partners and PV specialists for feedback.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: This is an extremely challenging project with a lot of things that can go wrong. The PI has identified a lot of sources of contamination that are the kinds of findings necessary to develop an industrial process. Facility requirements are sometimes not considered in creating a new process to be implemented.

**Reviewer 2:** Score: 5. Comments: The equipment based and material based tasks are complementary to meet the meet the overall goals of the project. Simulating the high temperature history that their FSM wafer will experience in order to predict final lifetime helped validate equipment design improvements as well as determine if that the silicon product was competitive.

**Reviewer 3:** Score: 5. Comments: The team is focusing on the right metrics: lifetime after processing, thickness, TTV, resistivity integrated in the same substrate, and pull speed as it relates to costs. The samples seem to be characterized properly and the metrics are relevant to the overall goal. If all the milestones are met, the technology will be closer to a potential commercialization.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** Cell performance at this early stage is an important factor to establish a baseline for even if it is some off of final efficiency expectations. As cell techniques continue to evolve (e.g. surface passivations, carrier specific contacts, bi-facial cells, etc.) for SHJ and PERC processes the team should understand all challenges for industry adoption and have a plan to address them Also, wafer dimension trends, the industry moving to beyond 156mm (e.g. 157mm or wider). What constraints does FSM have here.

**Reviewer 3:** The surface of the ribbons are likely to be very different from standard wafers and texturing the surface might be challenging and should be investigated, if it hasn't been already done. Same for mechanical properties of the substrates as it relates to propensity to break during processing or moduling.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No comment.

**Reviewer 2:** Cell and module manufacturers to discuss full product integration and what is required beyond wafer production.

**Reviewer 3:** When closer to the proof of concept, it should be valuable to engage with an equipment supplier, unless the company intends to manufacture the tool themselves.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is the kind of project that can change manufacturing in the US. This quality of work is the kind of industrial "bridge" needed for commercialization. Keep funding it.

**Reviewer 2:** 1) Define a total cost of ownership model for potential investors or customers of the technology to communicate the compelling nature of the growth method. 2) Include real cell efficiency targets in any future (or current if possible) to establish a baseline to build on, identifying any potential future cell process road blocks for adoption. 3) Engage with cell and module manufacturers to identify full product integration (wafer => cell => module) needs.

**Reviewer 3:** 1) Very challenging project, both technically, and to make this technology cost competitive with existing technology. 2) Potentially high impact for the US PV industry. 3) Good results and successful trouble shooting add lots of credibility to the team.

## Exploiting Fixed Charge at Selective Contacts for Silicon Photovoltaics – $200,000

*Lehigh University | Bethlehem, PA | Principal Investigator: Nicholas Strandwitz*

In a silicon solar cell, thin metal lines are applied to the silicon absorber that serve as electrical contacts in the solar cell. These electrical contacts must efficiently conduct current out of the absorber layer to boost solar cell performance. However, sometimes there are undesirable barriers that form between the two layers that hinder the efficient conduction of current. This team is investigating the use of alumina oxide as a fixed charge layer in the solar cell. They will deposit it between the absorber layer and the front contact of the solar cell to mitigate the effect of these barriers. This project uses atomic layer deposition to grow alumina and the contact layers in the lab and will use a variety of techniques to reveal the structural, chemical, and interfacial electronic properties of the material in order to determine the suitability of this strategy for commercial photovoltaic applications.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 3 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 3 |
| Advance the U.S. solar industry substantially | 3 | 3 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Straightforward integration simulation, fabrication, and characterization effort, well designed in terms of proof-of-concept through demonstration.

**Reviewer 2:** This project focuses on fundamental understanding of fixed charge collective contacts for emerging cell design technologies. The project document does describe the key metrics to be tracked and associated critical challenges to be overcome in order to meet the project goals. If this project is successful it will have a high impact assuming it can be translated to commercial processes and lines. The project objectives, sizeof funding and the project time length (assuming 2 year, typo in report) match with the SETO funding level. Weakness: It is not clear how this this project will advance the US PV industry and which US stakeholder would take up the technology if successful nor is there a clear pathway for the PI to transfer this type of innovation on his own.

**Reviewer 3:** The project summary explains the significance well.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 3 |
| Collaborates with sufficient stakeholders | 2 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Simulations and rapid prototyping appear to be a core competence of the project team and will quickly illustrate the opportunities in this project.

**Reviewer 2:** A detailed timeline of milestones was not shown in the report so it is difficult to determine if the time frame is reasonable. The measures of impact are described in electronic properties including fixed charge density, Schottky barrier height (only quantifiable properties shown) and "figure of merit" terms. No cell performance (I V and efficiency measurements) are discussed. As a result, it is difficult to determine if the PI is measuring impact appropriately. The team do not appear to have a partner although they have been active disseminating their results in the form of publications in peer a reviewed journal. The PI ad team do not appear to be collaborating with potential stakeholders in the PV industry. They could potentially put more effort into this to gain direction for what cell manufacturers need and to make sure Lehigh's work fits well with the PV industry's road map on contacting technologies.

**Reviewer 3:** The summary of the project explains well what it has accomplished.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Sample preparation is conducted using all the facilities within the partner network and will increase the flexibility in the processing options.

**Reviewer 2:** Score: 4. Comments: I would agree that the four main objects as defined in the project description do add value to meeting the overall objectives of the project. This could have been strengthened if there was PV cell performance and compatibility studies to complement the electrical measurements.

**Reviewer 3:** Score 4. Comments: No comment.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Unclear on commercialization pathway given the university laboratory environment.

**Reviewer 2:** Compatibility with existing cell line process including tool set availability for volume manufacturing. Communication even at an early level with potential manufacturers to determine their need and fit. An early TEA would be useful to understand any cost blind spots. Similar work being performed in other laboratories and that his work is differentiated enough.

**Reviewer 3:** I think it will need some collaboration or partnership with industry at some point before it ends.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Impact of a successful project deliverable set will be highly sought after by commercialization partners, given apparent integration simplicity.

**Reviewer 2:** Other labs working in the area. This may be obtained by attending technical conferences to some extent but direct communication would be more effective. Cell manufacturer discussions for their potential road map development to ensure there would be a fit for his technology eventually Equipment companies. ALD equipment availability, throughput and cost (Capex $k/W) expectations to introduce the technology as a specific process step.

**Reviewer 3:** There are no collaborators or stakeholders mentioned.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Universal approach to p-Type and n-Type architectural platforms provides direct comparison avenues for consideration in high volume manufacturing lines.

**Reviewer 2:** 1) This is an early stage technology and, as a result, is a good fit for DoE funds. 2) There needs to be an element of the project that assesses the probability that it will fit in a future cell line at a quantified cost for a quantified benefit. 3) There needs to be an emphasis on cell performance (maybe by collaborating with a US group who can incorporate their metal oxide films into their process) to make the value proposition of the technology more compelling to a future stakeholder.

**Reviewer 3:** The potential to increase efficiency of the current cell production methods.

## Hydroscanner - Water Ingress Evaluation Tool – $250,000

*Lawrence Livermore National Laboratory | Livermore, CA | Principal Investigator: Mihail Bora*

Water reduces the lifespan of solar panels and accelerates the degradation rate for the module's power efficiency. This project is developing an imaging system to measure how much water gets into photovoltaic modules and related packaging materials, including encapsulants, moisture barriers, and edge seals.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 3 | 6 | 4 |
| Implement a high-risk, high-impact approach | 3 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 5 |
| Advance the U.S. solar industry substantially | 3 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Development of a piece of hardware that can determine where a PV module has delaminated is useful but not game changing. This can probably be most useful as a research tool since it is not a particularly portable unit. Hard to imagine using something like this to inspect large fields of modules although it may be very useful in the laboratory to evaluate field returns or the results of accelerated stress tests. Ultimately I think you will find that delamination is not a major cause of module failures today.

**Reviewer 2:** Project intends to prove the viability of a tool to directly measure moisture ingress in glass-glass modules. Strengths: 1. Novel approach to a common problem. 2. Very clearly defined objective Weaknesses: 1. Tool can detect gross issues, not so clear that low level of diffuse moisture is detectable.

**Reviewer 3:** This imaging technology could (if proven) be applied to in house manufacturing quality validation and potential predict layer delamination in field deployed modules, As a result it fits SETO's goals for system cost reduction including module lifetime extension beyond 25 years. The PI described the critical challenges as matching the optical output images from their IR camera to the on-set of real, in-field degradation modes (i.e. backsheet and encapsulation delamination) and the resultant high ground to string leakage current which is a very difficult relationship to prove. It is high risk as the relationship between determine moisture content in a module and accurately predicting what the performance prognosis of the module will be after for X years in the field is very difficult due to the variability over time/weather conditions. The impact could be high if successful as it could help rapidly validate new encapsulants and back sheets. There is a lot of interest for new non destructive testing techniques and protocols for predicting module lifetime outside of SETO. This could have a significant impact on the downstream US PV industry in terms of PV system performance assurance. This is a one year project and the objectives do seem optimistic considering effort needed to design samples and perform lengthy stress testing (i.e. extended damp heat stress tests with multiple sample types).

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 0 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 0 | 4 | 4 |
| Collaborates with sufficient stakeholders | 0 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project has not started yet so I have not graded this section.

**Reviewer 2:** Project not yet started. For a technique that has potentially broader and more diverse applications, it seems strange how narrow the scope is defined.

**Reviewer 3:** Project not started, no project timeline or milestones given. The document did not describe the approach the team will take to relate camera images to quantifiable mechanisms for delamination and the structure the team will take to build a compelling to validate and cross-validate their findings. The PI did not describe how the results would be disseminated and the involvement of the other team members adequately to assess. The PI did not adequately describe how they team will reach out to stakeholders to get their feedback on new technique.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Interesting concept to try to develop a commercially available instrument. Should provide some interesting results from the laboratory but this is probably not something that can be used for inspecting large numbers of modules in an array. Business model seems to be based on their cost share partner doing the work for a fee rather than to sell equipment. This service work model is probably a good fit but not a big business.

**Reviewer 2:** Score: 4. Comments: Yes, outline is clearly spelled out and each step makes sense.

**Reviewer 3:** Score: 4. Comments: The project has not yet started and only high level goals and objects were given.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Once again a very specialized project to develop a tool that will have a limited use in PV.

**Reviewer 2:** Absolute water levels in materials in field conditions are very low, measurement sensitivity may not be sufficient.

**Reviewer 3:** Industry acceptance will be a big barrier for this new technique. The team will need to identify and prove clear relationships to the qualitative images from the IR camera and real field failures. A comparison can be made to the gradual acceptance of NIR camera use for cell crack imaging and the relationship to true power degradation. There will need to be a high level of quantification of measurements and high certainty/correlation of predicted outcome in module performance.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Once the instrument is operational, the partner will have to determine how much interest there is in this new service. That will depend a lot on how sensitive the equipment is, how fast it can make measurements and whether it is portable enough to use in the field. The team would have been stronger if a module manufacturer had been added as a team member.

**Reviewer 2:** NREL has done extensive work on optimizing adhesion reliability and testing, they could probably help in this project.

**Reviewer 3:** Certified testing Labs; Duramat engagement; Relevant PVQAT groups for guidance; IEC committee early stage guidance; Established testing subject matter expert groups e.g. ASU group, etc.; Module manufacturers.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Development of such equipment is very specialized and may only be of interest to a few. 2) Having a national lab develop something like this may not be particularly useful if there is no built in need for the instrument. Is delamination a major failure mode being seen in the field for today's modules? 3) Will this project have much of an impact on the PV industry? Only if the right customer(s) can use it as a tool to improve their products.

**Reviewer 2:** Unclear what is the probability of success, however, if successful a technique like this could be very useful. It should be relatively straightforward to validate data around sensitivity and, hence, applicability.

**Reviewer 3:** 1) Quantify the images features from module samples and cross correlate them with other techniques (beyond Karl Fischer titration). Analogy is the actions taken to validate EL imaging for cells. 2) Test the need of the various customers that would eventually use this technique in the different parts of the value chain; R&D engineers and module manufacturers for QA to PV field maintenance companies. 3) Engage with established testing subject matter expert groups in the US e.g. ASU group, PVQAT, Duramat, etc. for guidance in quantifying the new technique for industry acceptance.

## Advanced Thin Film Core Technology: Cadmium Telluride – $8,850,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigators: Wyatt Metzger*

This project addresses core photovoltaic cell research to maximize the performance of photovoltaics using advanced thin-film CdTe technologies. Solar cells just several microns thick—one-tenth the diameter of a human hair—can be made on inexpensive and abundant glass, plastic, or metal foil very quickly with materials such as cadmium telluride and copper indium gallium selenide. This has reduced market costs for solar energy and cleared paths for novel, flexible, lightweight applications, including integrating solar energy into buildings, aircraft, and military applications. This project will advance the fundamental materials science, physics, and chemistry of thin-film technologies and seeks to improve solar cell efficiency while further reducing costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** I consider this a high risk high reward project as it requires significant investment and investigates a new approach. It can provide sustained benefits to research as well as the industry though collaborations. One drawback is the benefit is only for CdTe, but considering that that is the strongest thin film presence in the US, it is warranted.

**Reviewer 2:** The project aimed solving a fundamental issue with CdTe solar cells: alternative dopant to Cu with stable performance. The project also upgraded equipment at NREL for its core capability in CdTe solar cell research. The team has strong knowledge of corresponding manufacturing process and worked closely with industry partner First Solar on the adoption of results gained from the project in manufacturing.

**Reviewer 3:** The project goals align very well with the DOE goals. The approach of this project and intended impact centers around updating tools for the project and bringing to today state of the art. This is a must for the group at NREL, since the previous equipment was plagued with interruption and breakage. The other two tasks focus on two important areas within the CdTe device to understand the bulk properties effect on limiting the device voltage, and the chemical and physical properties of the front and back interfaces in the device. This is a well rounded project with collaborators, including FS, and use of optimized CdTe bulk charges developed in another project under the same program. This maximizes the potential for the project to impact the technology. The project scope is addresses several problem that is very relevant to industry such as FS. The thrust to use GrV dopant in situ increases the degree of dopant activation. The latter optimizes the carrier concentration and carrier lifetime which in turn increases the probability of voltage enhancement. Another thrust is understanding further properties of interface at contacts, known problem for lower FF. The team has in the past spent significant effort on using single crystal studies as a model for increasing lifetime and concentration to apply to thin film. However, even though they succeeded demonstrating a1 V for voltage, the translation to thin film did not succeed. The question is, what is the strategy now/ what to do different to achieve the goal of higher voltage.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 6 |
| Collaborates with sufficient stakeholders | 4 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Based on the report the project results have been published extensively.

**Reviewer 2:** The team has achieved the planned milestones on time and on schedule to achieve the remaining milestones. They have completed the equipment upgrades without losing the baseline of the processes. They have done the interface and doping studies to achieve their respective milestones. The results were shared with industry partners and the collaboration led to >20% efficiency with solar cells using group-V doping.

Reviewer 3: The team has shown good performance as demonstrated by numerous publications, meeting all milestones, engaging the partners especially FS ( the PI also collaborates with FS through a more directed project toward GrV doping) and other partners like Washington state Univ. The team leverages the capabilities at NREL to also collaborate outside the DOE program to increase the impact of its findings and the use of the unique capabilities.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks to date have resulted in progress towards the goals.

**Reviewer 2:** Score: 5. Comments: The change of p-type dopants for CdTe devices are a work requiring systematic change for the entire devices. Therefore the interface research and improvement is a critical part in addition to the dopant activation and defect study of thin film itself. Equipment upgrades greatly improved the quality of work and operation efficiency.

**Reviewer 3:** Score: 5. Comments: The task of developing and updating new tools within the team is centered around versatility in the available techniques to co-deposit the layers using different conditions for comparison. This should increase the optimization of better interfaces, junctions, and increase the field of collaborations on larger number of problems. This also add value to engage in more depth regarding the activation of dopants and engineering of alternative interfaces.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** This project is a big undertaking. Upgrading equipment and bringing up a baseline can be a time-consuming task and can have setbacks. The timeline for the project may not be sufficient if the equipment has not been ordered yet.

**Reviewer 2:** The report mentioned that the As doping is extremely stable. It would still be interesting and critical to see the stability of entire device especially interfaces through reliability tests.

**Reviewer 3:** I cannot point to an area that is obvious. I believe this is because of the broad aspect of collaboration.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** There could be additional organizations that could be brought into this project as collaborators for certain tasks as is evident from some of the other projects reviewed.

**Reviewer 2:** No critical collaborator is missing.

**Reviewer 3:** The team has a broad circle of collaborators and stakeholders engaged. however, I encourage the PI to engage with M. Bertoni at ASU to leverage the nanoscale capabilities for the two tasks of doping activation and interface chemistry.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** It is not clear to me if an overall strategy has been discussed and guidelines have been provided for funding opportunities to strengthen US solar industry. I believe that there is opportunity for a strong US solar industry both in Si as well as thin film. Here I will provide my thoughts on thinfilm. First, in the perovskite arena the opportunity should not be missed (CIGS was missed) and funding of the projects should cover all challenges such as methodologies for characterization, analytics; film deposition for all films involved in the stack, composition studies for performance as well as reliability, integration and film interactions. This can be done with having a core laboratory at a place like NREL with other institutions being partners in various projects, industrial partners could be signed up as well. Second, in CdTe, with a strong industry the projects should be funded for modeling, methods development, characterization and analytics, performance enhancement, and degradation and reliability studies. I also believe the case for CIGS may not be lost yet despite the current situation. Foundational work should continue as it also has impact on other thin film performance.

**Reviewer 2:** Screening tests for reliability of the devices to see if there is any significant issues through thermal cycling or LID.

**Reviewer 3:** There is two different views on what is the primary limiting barrier regarding the entitlement for a much larger Voc. One is the combination of minority carrier concentration and carrier lifetime; the other is that the front and back contacts are limiting the potential barrier height and are the cause of resistive losses driven by the passivation layers added and the doping of the GrV like As. The first is the view of several researchers (probably not independent views), the second is at the heart of the work by Z. Holman at ASU under this DOE program. This is a ripe opportunity for the community to debate this problem collectively, possibly in a focused workshop ("what is the problem with the CdTe voltage") organized by the NREL team/SETO.

## Advanced Thin Film Core Technology: Copper Indium Gallium Selenide – $2,991,432

*National Renewable Energy Laboratory | Golden, CO | Principal Investigators: Lorelle Mansfield*

This project addresses core photovoltaic cell research to maximize the performance of photovoltaics using advanced thin-film CIGS technologies. Solar cells just several microns thick—one-tenth the diameter of a human hair—can be made on inexpensive and abundant glass, plastic, or metal foil very quickly with materials such as cadmium telluride and copper indium gallium selenide. This has reduced market costs for solar energy and cleared paths for novel, flexible, lightweight applications, including integrating solar energy into buildings, aircraft, and military applications. This project will advance the fundamental materials science, physics, and chemistry of thin-film technologies and seeks to improve solar cell efficiency while further reducing costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 2 |
| Implement a high-risk, high-impact approach | 5 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 3 |
| Advance the U.S. solar industry substantially | 2 | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Project is pursuing multiple challenging topics: PDT, metastability, and PID effects. NREL has a long history in performing CIGS research and a large capability set at its disposal. Strengths: 1. Ppre-existing process capability at NREL 2. Pre-existing know-how at NREL Weaknesses: 1. Questionable relevance to industrial research and lack of clarity of industrial collaboration 2. Reliability objectives have unclear objectives.

**Reviewer 2:** Strength: The team has comprehensive capability from material/device fabrication to characterization. The project objectives were clearly defined, matching with available resources, and benefiting collaborating industry partners. The report also showed good understanding the needs on how the process would be transitioned to production by exploring the co-evaporation method in addition to PDA. Weakness: With industry collaborators in US failing in business, the benefit of this study to US industry is decreasing.

**Reviewer 3:** The concept of investigating the reliability and metastability in CIGS at the device level to uncover physics based mechanisms is a valuable undertaking. The emphasis is on "physics based". However: The project plans/approach as described do not address critical challenges past/beyond state of the art. Judging from the project description and what is described in the results to date, it cannot be concluded that the project is pursuing creative risky approach that will have impact on the technology. It does not convey a leadership positioning. The report contains scarce information in sections 10 through 14. The information is superficial and in some places ambiguous. The slides show summary of results on alkali treatment on base samples and industry samples, but does not much new information/discoveries. The approach is mostly a repeat of what has been done by others, especially in Europe. One of the objectives stated is to carry out the alkali treatment for the purpose of understanding the fundamentals of the treatment, and specifically what the treatment is doing to the surface of the CIGS film. This has not been shown in the report except for changes in the device parameters.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 3 |
| Measures impact appropriately (e.g. quantitative) | 2 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project team reproduced the positive effect of KF. Data presented regards the effectiveness of KF during growth appears too sparse to be conclusive. Overall, lacking indication that understanding is improved, data provided only provides evidence of process exploration.

**Reviewer 2:** Although the team suffered some setback due to breakdown of key equipment, they have achieved important results. For example, they have identified an effective process for KF co-evaporation to achieve equivalent or better results to KF PDT. This would lower cost and the process is compatible to existing production technology, more transferable to mass production.

**Reviewer 3:** Based on the report and the summary slides, this project is under-performing when viewed against the objectives and goals. The milestones are not defined in the report, and therefore it is difficult to judge whether some of the results are the milestones? The alkali treatment results describe only that in some cases the improvement is observed and in other it is not. The extent of the results are limited to device performance parameters, but not the understanding of the fundamentals and mechanisms of the treatment. The report does indicate expected publications. The PI does not explain why only 20 mv is the expected increase due to alkali treatment? A 20 mv enhancement translate to increase of 0.5% in efficiency if the other parameters stay the same. This is modest improvement as a goal for this project. The tasks on degradation and metastability studies also, describe limited results without any indication of milestones and goals to be reached. The project is non-cohesive in its overall direction; lacks new ideas and novel approaches to improve on state of the art. Hence it is difficult to assess it for impact.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The study of PDT effect seems to be well developed. There is pre-existing knowledge in the CIGS community and this makes the study very targeted on the surface/interface effect of the PDT. The approach seems reasonable and may provide new insights. The metastability and PID intentions are much less clear.

**Reviewer 2:** Score: 5. Comments: The PDT study on both the devices made in house and industry partners established baseline for effectiveness of the method. The co-evaporation of KF provided a new method for mass production. The studies of degradation further built a device against potential issues in field application.

**Reviewer 3:** Score: 2. Comments: The project objectives and goals as described in the report are not unique among the technology R&D being carried out worldwide. The approach is empirical with some sense of "trial and error" implementation. The execution and results are significantly behind state of the art with little to add to the existing knowledge in the CIGS technology/community. As such it will add little value to the significance of the goals.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Processes in thin-films are often closely coupled, performing processes in unique ways may help to perform good experiments, but not lead to the same and, hence, meaningful end result. Example, avoidance of surface oxidation, is necessary to study the interface, but does it affect performance? Reliability such as metastability is typically something related to point defects and/or electronic transition as evidence by very short time constants. Fabricating devices is not the challenge, performing high quality measurements and appropriate models are

**Reviewer 2:** The team covered all the important aspects of the project.

Reviewer 3: The major barrier for the CIGS technology manufacturing is manufacturing at scale that compete with an ever changing/advances made in Si and CdTe technologies. Every year the bar is raised for performance and dropping cost. Hence, the CIGS pressing problem is not efficiency. It is related to throughput and yield emanating from non-uniformity in composition and temperature. The latter is derived from the nature of the process that needs very high temperature sources with reliability of operation. The team needs to focus on whether it can contribute in this area. Otherwise, physics based reliability studies (degradation) is valuable area to contribute.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** An industrial advisor/representative that could ensure that the work results are applicable and transferable to devices in general.

**Reviewer 2:** True industry partners with potential of mass production.

**Reviewer 3:** A team member from industry who can dedicate time to constant collaboration guided by the industry. A team member who is expert on the defect chemistry in CIGS and who can focus on understanding the creation of defects and passivation/annihilation in the CIGS material.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Mechanisms of the PDT is a good scope for academic or National Labs to explore. It provides ample of opportunity for work, including the impact of PDT (different alkali etc.) on stability, metastability, moisture sensitivity. It seems unnecessary, for this project to do anything beyond this and i would recommend to solely focus on this topic.

**Reviewer 2:** Shift the main focus onto co-evaporation instead of PDT. Extend the studies to eliminate degradation.

**Reviewer 3:** 1) Redirecting the team to focus on "physics based " studies of the degradation and meta-stability in CIGS. A goo base of knowledge exist in this regard in the literature and PV community at large. The key words here, physics based study" and not measurement and observation. 2) The project needs to be assessed in regard to the hardware capabilities status and the mix of skills with the consideration that it is a National Lab.

## Application and Development of Advanced Electro-Optical Characterization for Highly Efficient and Reliable Thin-Film Solar Cells – $1,800,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Darius Kuciauskas*

To determine the sources of power and performance losses in thin-film solar cells, this project works to develop new electro-optical photovoltaic characterization techniques to look at the interfaces between different layers inside thin-film devices. The team will integrate new capabilities with state-of-the-art thin-film characterization at the National Renewable Energy Laboratory in collaboration with national lab, industry, and university researchers. This collaborative research enables the development of more efficient and reliable solar cells, with particular emphasis on cadmium telluride.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: The project is exploring a new method to characterize thin film solar cells, to use modeling interpret the data and to build physical model for further understanding. The new method of electro-optical with one-photon and two-photon excitation time-resolved photoluminescence microscope, 1PE/2PE TRPL microscope is quite unique and provided other researchers a new angle to gain insight of device characteristics. The team work extensively with teams in industry, universities and research institutions, which would help provide more opportunities for validation and application of the methods. Weakness: the milestones were not measurable. The experimental results were not sufficiently supporting the attribution of carrier depletion at GB to the variation in carrier density due to the difficulty of manipulating passivation at the GB's in CdTe.

**Reviewer 2:** Expanding the analytical capability to measure performance gap for solar cells is important to improving performance of solar cells and hence reduction of cost. This aligns with the SETO goals. This type of work is not high risk work, it is systematic and foundational work. For the US thin film solar industry to advance foundational work needs to be done. Unfortunately this project has a single industrial partner.

**Reviewer 3:** This is an exemplary project with exemplary productivity by a team effort with the necessary state of the art tools and manpower skills. Makes very timely research impact with the use of state of art capabilities and effective collaboration with industry other projects within this program, and within NREL. It is focused on studying the fundamental causes of performance losses with emphasis on interfaces at the front and back of the absorber. This is important because these interfaces are how the absorber communicate with the external of the device, and hence there is strong coupling between the contacts and the absorber. This done through experimental newly developed characterization tools, modeling, and theory supported by high power computation. It has the making of a strong project. The collaboration with a mix of organizations who are doing complimentary research under this program and industry, FS, add value to accomplish the goals, not only for this project but also the collaborators projects. No weaknesses to point out at this time in the project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 6 |
| Collaborates with sufficient stakeholders | 6 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The team has met the milestones planned so far. They set the goals to develop a comprehensive set of computational, modeling, and experimental methods for thin film PV device interface analysis. Significant progress has been made in establishing new electro-optical capabilities and new data modeling capabilities. They also established extensive collaborations with many research teams in both academic and industrial institutions. The new capabilities are applied to state-of-the-art CdTe solar cells and used to expand research collaborations with NREL, industry, and university partners working on all thin film PV technologies. The work covers many other material systems which could help further in validation and application of the methods. It would make the research plan stronger if the milestones can be measured more quantitatively.

**Reviewer 2:** Good progress is shown toward the objectives. May be too early in the project to show measurement of impact. Would be desirable to have more industrial partners.

**Reviewer 3:** The team has met all the milestones for the period of performance to date, and has collectively published several papers with the collaborators showing very important results, and the power of the newly developed characterization tools (experimental, and computational). The outcomes/results reveal new discoveries that challenges some of the views being held to date, such as: 1. heterogeneity in efficient devices is caused by doping non-uniformity and less from lifetimes; this is similar to the losses seen in CIGS in the past caused by heterogeneity in point defects (compositionally caused); 2. crystal structure prediction showing energetically favorable interface chemical structure ( also similar to CIGS with favorable interface between two phases with similar crystal structure). This information to date is very valuable foundation and needs to be implemented for validation soon. I believe this project is productive and will stand to make search and practical impact because the mix of stakeholders and strong collaboration with timely feedback.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project consist of three portions: experiments with TRPL to study interfaces of solar cells, data modeling, and first principle physical model simulation. The latter two would help interpret the experimental data and establish the physical models for experimental results. Together they provide a method to gain insight of solar cell development. The new electro-optical capabilities (one-photon and two-photon excitation time-resolved photoluminescence microscope, 1PE/2PE TRPL microscope) provided a new method for other researchers to study device characteristics and process performance. The team applied the techniques for interface studies of CdSeTe/CdTe solar cells which is useful to understand this state-of-art device system.

**Reviewer 2:** Score: 4. Comments: Going forward with the project, the list of tasks would be helpful. The high level description of the tasks align with matching the goal of the project.

**Reviewer 3:** Score: 6. Comments: This project is unique due to its versatile approach to address the issues/problems described in the goals and the justifications for the emphasis and priority of the objectives. Also, this uniqueness is amplified by the synergy and timely collaboration efforts. The latter and other comments made above amplify the value of the data generated and its significance to the goals of the project.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** It would be more convincing if the variation in experiments for sample preparation can be correlated to the measurement response in TRPL. Had discussion with PI regarding to whether they can further enforce their attribution of the variation measured results to variation in carrier density at grain boundaries of CdTe. PI noted that it is rather difficult to passivate the grain boundaries in CdTe to manipulate the depletion nearby. Thus it is difficult to use this method to vary the level of depletion and to see the response of measurement. However, PI suggested the CdSeTe has weaker space charge region which alternatively provided an evidence for attribution. This is very helpful. It would be stronger case for validation if further work along this direction can be conducted.

**Reviewer 2:** I don't see blind spot for the project.

**Reviewer 3:** I cannot point to one.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** At this point, the team has included a good set of partners in both research institute/universities and industry.

**Reviewer 2:** Would like to see more industrial partners.

**Reviewer 3:** The team is composed of national lab scientists with diverse skills a capabilities, industry (FS), and informal relationship with couple of universities performing research under this program. The relationship with Z. Holman at ASU is very valuable.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) More measurable milestones. 2) Further experiments to provide stronger correlation between measurement and change in material structure.

**Reviewer 2:** It is important to build foundational analytical capabilities for the advancement of thin film solar.

**Reviewer 3:** 1) I urge the support of the PI request for the additional requirement of high power computing. 2) This project focus on understanding and thorough/novel examination of the contribution of the front and back interfaces to the loss in performance in CdTe is complimentary to the project with Z, Holman at ASU, supported under this program. It would be valuable if the two projects formalize and coordinate their collaboration.

## Interdigitated Back Contact Polycrystalline Device – $240,105

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: David Albin*

The basic structure of polycrystalline thin-film devices like cadmium telluride and copper indium gallium selenide have not changed significantly over the past 20 years and consist of at least two discrete active layers to transmit, absorb, and separate photo-generated carriers. Though efforts to optimize layers in these structures have resulted in remarkable improvements, there are new efforts to develop a simpler structure that results in a cheaper and more reliable device. This project is investigating the creation of a device structure that consists of an interdigitated back contact solar cell—a solar cell with two metals—to establish the field necessary to separate electron-hole pairs absorbed by a single, cadmium telluride or selenide absorber that has a long lifetime and doesn't have window or buffer layers.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a high risk project with potential for success. Challenges of working on a superstrate structure should be listed. Impact on the success of US solar industry will depend on the barrier to entry assessment for this new approach and new investment.

**Reviewer 2:** The project is narrow in scope and focused on demonstrating the potential for an IBC CdTe device passivated with Al2O3 and uses no buffer layer, no transparent conducting layer (TCO), or additional layers. The absorber is CdTeSe doped and activated with CdCl2 treatment. This simplified design reduces the number of fabrication steps and minimizes potential for degradation (i.e. better reliability). This approach, if high efficiency is achieved, has the potential for reducing cost appreciably. It is also a high risk high pay-off approach, suitable for a national lab undertaking under the DOE program. The PI strategy matches the statement above by breaking down the problem into manageable parts that when combined produced results quickly, and identified barriers to progress in a timely manner. This contributed to the team recovering and get back on schedule. The team has met and surpassed part of the milestones, and have identified those where they fell short. In reaction to the unmet targets the team has identified the barriers, identified an alternative pathway, and showed that the causes for not meeting the milestones are not fundamental and mostly mechanical in nature. Assessing the results to date uncovers several small scale discoveries related to the specific approach, and useful to the technology as a whole: such as lifetimes in the mice seconds, long diffusion lengths, and enhanced grain growth. These results are significant considering that the intended device structure is simple and scalable. The PI is encouraged to reach out to FS and validate the concept practicality in terms of scaled processing and potential cost.

2.Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project has missed a milestone due to impact of CdCl2 anneal on metal contacts. This could have been anticipated.

**Reviewer 2:** The team has shown good progress in demonstrating the overall concept by demonstrating successful outcomes on subcomponents of the intended device structure and needed properties. Two patent applications have resulted. The team have discovered certain properties of the CdTe material that was not known to date. (see comments under Q1). Based on the results to date, they have used the data to model performance parameters related to the operation of the simplified device structure, and indicate efficiencies >20 % potential. The performance to date also indicates that this project is on a trajectory to add value to the DOE program for the future.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks that are outlined are aligned with the objectives of the project.

**Reviewer 2:** Score: 5. Comments: The project is unique because of its simplified device structure. It has the potential for significant cost reduction by eliminating several fabrication steps and the associated materials. The budget of the project is relatively low compared to others in the DOE program. The performance to date indicates that this project is on a trajectory to add value to the DOE program for the future.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** There may be significant challenges in converting to a superstrate structure. These should be listed. Degradation and reliability should be studied since this is critical for commercial implementation.

**Reviewer 2:** The PI is encouraged to seek and alternative to the CdCl2 treatment, and pursue the fundamental understanding of why the Se anneal? maybe responsible for the large grain growth, and what are the grain boundaries properties of those grain compared to ones using CdCl2. It seems both are fluxing the matrix, but the grain boundaries could be different.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

Reviewer 1: Existing collaborators appear to be sufficient.

Reviewer 2: At this time in the R&D of advancing the CdTe technology performance and reliability, validation of the approach and manufacturability needs to be validated by industry.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project and couple others that are investigating application of learning from Is based solar to thin film is high risk but important. For high risk projects it may be important to have more than one funded to spread the risk.

**Reviewer 2:** 1) The project should consult with FS for validation of the potential scalability of the processing steps. 2) Continue the support of the explorations of this project to reach a point where results clearly indicate that progress have stalled.

## Silicon Photovoltaics Core Capability – $10,500,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Paul Stradins*

This project is conducting silicon-based photovoltaic cell research and process engineering. The team is working to define, approach, and invent next-generation silicon photovoltaic materials and device concepts, as well as identify and overcome limitations in efficiency and large-scale production. This work will maintain national laboratory core capabilities and expertise in silicon photovoltaics and support workforce training efforts that develop highly qualified research professionals. This project also supports research efforts with academia and industry that advances the knowledge base of fundamental materials science, physics, and chemistry of silicon-based photovoltaic technologies.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 4 | 3 | 4 |
| Implement a high-risk, high-impact approach | 4 | 3 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project focus fits the SETO mission by developing a new PV cell technology (passivated contacts with polysilicon films) that can be cheaper than the other available high-efficiency technologies (IBC or SHJ). The technology being studied and developed within this project is well aligned with the direction of the PV industry, which will enhance the project impact. In particular, the project includes developing a screen-printed metallization over polysilicon film, which is an important challenge for the successful scaling of the TOPCon technology. The core capabilities developed with this project (prototyping of advanced high-efficiency devices) has the potential to leverage and support research efforts by other US-based academic institutions and PV industries. The goal of 21% efficiency on a full size device in FY21 is not aggressive enough, since mainstream PERC technologies already reaches more than 22.5% at a very low cost, and TOPCon structures are already in production with average efficiencies of 23% (for example Trina, 2019).

**Reviewer 2:** Users/customers/information recipients not identified for any output resulting from this work. Their guidance and/or endorsement noticeably absent from project team.

**Reviewer 3:** No comment.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 2 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 4 | 6 |
| Collaborates with sufficient stakeholders | 6 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Very impressive dissemination of the results with high number of publications and a few patent applications. The team obviously put lots of effort into disseminating their results. The project also includes an impressive range of partners, both with academic institutions, US and foreign companies. The facility issues are unfortunate. The team found acceptable workarounds (processing samples at the Tempress facility and re-aligning the focus of some of their research), but those issues are impacting the project and should be fixed. There is an obvious emphasis on developing technologies that are cost effective (including a techno-economic publication in the FY21 milestones), but no quantifiable cost targets.

**Reviewer 2:** The Tabula Rasa treatments are well known to most in the industry, but have been abandoned for cost reasons, Ga passivated contacts seem like an overkill, but the screen printed passivated contacts could really be implemented, if progress continues.

**Reviewer 3:** No comment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks and milestones are well aligned with the overall goal; they progress naturally from proof-of-concept at the level of individual parameters measured on test structures (J0e of contacts, bulk lifetime, etc.) to full cells that integrate the learning from previous milestones, to mini-modules with reliability characterization and a final techno-economical analysis.

**Reviewer 2:** Score: 4. Comments: This is a critical function that should be an ongoing funding item and platform at NREL - Over the years it has struggled to find focus and lab leadership have hindered team and PI. This project requires increased funding, but also programmatic adjustment. It is clear from the project summary that pieces of research are cutting edge, while other pieces lag dramatically behind industry. Please inject change here.

**Reviewer 3:** Score: 5. Comments: No comment.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Building up and maintaining a PV line will always include facility challenges, such as those that the team ran into (non-functional AWN and the delay encountered while installing the LPCVD tube). Those issues are affecting the outcome of this project and reduce its potential impact. More challenges of the same kind will probably happen again, and the team must find a way (and the support) to fix those issues rapidly when they arise.

**Reviewer 2:** Largest blind spot this group suffers from is an integrated approach to technology integration. The efforts described within are all relatively good stand-alone efforts, but stitched together the cost structure would never work in industry. The sum of the parts, just aren't equally a whole!

**Reviewer 3:** Reliability is mentioned, but should be a top priority.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project already has a wide range of partners, and include an impressive number of US based companies. No additional partners are needed.

**Reviewer 2:** This group would benefit from larger, more mature substrate, cell, module manufacturers as partners.

**Reviewer 3:** None are missing, great team of collaborators.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Building and maintaining a prototyping line is a difficult and expensive task, but necessary for the successful development of new technologies. The research topics are well aligned with the direction of the silicon PV industry (emphasis on passivated contacts, and their metallization). The efficiency goal of 21% is not aggressive enough.

**Reviewer 2:** Users/customers/information recipients not identified for any output resulting from this work. Their guidance and/or endorsement noticeably absent from project team.

**Reviewer 3:** Could be the kind of process that could come back to US Manufacturing. Good team.

## Improved Solar Cell Performance and Reliability through Advanced Defect Characterization and Growth Studies - $1,500,000

*Ohio State University | Columbus, OH | Principal Investigator: Aaron Arehart*

Copper indium gallium selenide photovoltaic solar cells experience defects that reduce efficiency and researchers have been unable to eliminate these defects. If resolved, efficiency could improve from approximately 19 percent to approximately 23 percent. This team is connecting the measured defects to their physical sources using chemical and nano-structural techniques and other photoluminescence-based techniques. Using advanced, physics-based modeling, the team will identify and test copper indium gallium selenide growth conditions of the absorber layer in order to improve cell performance, lower device instabilities, and lower degradation rates, all of which could improve reliability and lower the levelized cost of energy.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 4 |
| Implement a high-risk, high-impact approach | 2 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 4 |
| Advance the U.S. solar industry substantially | 3 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Project proposed to apply advanced characterization to enable optimized growth and, hence, performance of CIGS solar cells. Strengths: 1. Significant numbers of contributors to provide samples/metrology 2. Approach is reasonably well laid out Weaknesses: 1. Correlations between defects and performance are likely, very unclear whether it can provide a new path to solution 2. Baseline process should be close to world class or commercially on parity

**Reviewer 2:** Understanding of the defects that limit performance is critical to improving conversion efficiency and reliability. Both have a significant impact on cost that is the main goal for SETO. Project has shown good progress toward milestones. The team has complementary strengths that serves the project well. The changes in the partners will have an impact on the projects progress since new baseline needs to be established. The reliability studies have not been included. This is not a high risk project.

**Reviewer 3:** Strength: The project is to develop a correlation between physical characteristics (concentration distribution, defect distribution) and electrical/device characteristics (DLTS/DLOS, PL...) for CIGS solar cell. It was found that K incorporation to manipulate the defects to allow significant contrast in various characterization. The method developed here could be useful for other devices such as perovskites. Weakness: the team relied on collaborators to provide samples for their characterization. With the closure of a couple of collaborators, it would make the success of the project a challenge, even though the team mitigated this by engaging with other partners. Its impact to US solar industry is also reduced due to the degrading condition in the industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project just started, not many results to report. One area of concern is the reference performance and is the device that is characterized commercially relevant in performance.

**Reviewer 2:** Project has been shown effective in its impact with the MiaSole results. Dissemination through publications is satisfactory.

**Reviewer 3:** The team characterized key mid-bandgap defects, their variation vs passivation conditions. The also observed improvement in device performance. They have taken samples from industry partners and also collaborated with other groups for characterization to gain full understanding of the mechanism.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Approach and intent is laid out. Gaps in specifying how results could be generalized to be useful at commercially relevant levels.

**Reviewer 2:** Score: 4. Comments: Don't see a list of the tasks going forward. General description is aligned with the project goals. Tasks regarding reliability is not mentioned.

**Reviewer 3:** Score: 4. Comments: Yes. The identification of various traps, the reduction of trap densities by varying Cu, alkali, and Se concentration profiles, their characterization for the responses, and ultimate device performance of the devices are all important parts for the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Definition of representative material quality and device performance, i.e., how to qualify that meaningful devices are tested.

**Reviewer 2:** The project may be limited to academic and research lab partners with no direct industrial beneficiary.

**Reviewer 3:** Redirect the project to other devices instead of struggling looking for collaborating industry partners.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Project has seemingly a long list of partners and direct/indirect contributors. One challenge is that it is not clear whether any of them is able to provide commercially relevant materials.

**Reviewer 2:** Industrial partners are missing, no fault of the research team.

**Reviewer 3:** Organization producing other type of devices.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Good combination of growth, characterization and modeling within the project. A serious attempt in defect spectroscopy. Nanoscopic techniques are very difficult to quantify and perform without introducing artifacts from surfaces. Decent chance that models will be developed from this work, I do not consider it very likely that the work will advance relevant efficiencies.

**Reviewer 2:** The project is focused on CIGS thin film, this is the case for couple other projects in the review. These projects need to be reviewed for broader impact for all thin film applications. CIGS presence in the US has further deteriorated, though a recovery may be possible in the long run, current situation will impact the projects in progress for lack of industrial partners. I still recommend the projects that are ongoing that have shown good progress to be supported.

**Reviewer 3:** Apply the techniques and the project effort to other devices.

## Toward Commercialization of Low-Cost, Crack-Tolerant, Screen-Printable Metallization by Full-Size Module Testing and Field Characterization – $1,000,000

*Osazda Energy | Albuquerque, NM | Principal Investigator: Sang Han*

This project is developing a cost-effective metal paste that strengthens the metal connections in solar cells, improving their resistance to fracture, and minimizes cracks that result from degradation and handling. This will increase the long-term durability of the cells. The team will measure and compare crack tolerance with this paste compared with conventional metallization paste, and work with several partners, including a group at Sandia National Laboratories, to test the modules in the field.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 6 | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 4 |
| Advance the U.S. solar industry substantially | 5 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: The project goal of improving module reliability through increasing cell metallization resilience to cracks should improve the overall energy generation from modules and potentially increase module lifetime. The PI adequately described the critical challenge to incorporate the CNTs in a silver contact paste that could overcome the issues they have identified including CNT fracture and agglomeration. This definition of a process to address these problems will be key for industry adoption. This is high risk project as silver paste composition, homogeneity and rheology are fundamental properties in this high-volume process. It could have a high impact if the team can quantify the energy and longevity improvements in module performance they describe in the impact section. There will be significant interest for other teams working outside the DOE funded efforts as crack resilience propagation and the impact on energy yield. If the paste can be made in the US and ultimately be deployed in module is US based PV systems, it will have a positive impact on the US PV industry. Weaknesses: This is an 18-month project and material and accelerated test intensive. $1.2M may be low for the level of performance validation the team is looking to achieve.

**Reviewer 2:** The team is developing a new silver metal contact paste that contains carbon nanotubes for the industry-dominant passivated emitter and PERC cells. The project is just starting but preliminary results suggest great promise. Greater than 20% efficient PERC cells were made with their paste. And they have very dramatic results on their poster showing that cracks leadings to gaps in the silicon up to about 70 microns wide are electrically bridged by the nanotubes and/or metal that somehow follows the nanotubes across the gap. The team works with D2 Solar which should be able to fabricate full modules for various forms of destructive test. The team will work with Sandia to develop imaging of the modules, presumably for comparison with standard-paste modules that are also destructively tested. Solder and cell cracks has been a major source of silicon solar module power reduction, so such a product should be well-received if it doesn't require much change in the metallization processes and conditions from the standard pastes.

**Reviewer 3:** The project seeks to prove a novel carbon nanotube-silver paste that can decrease degradation and increase lifetime by repairing microcracks. The concept is interesting and has value. A full cost-benefit analysis has not been performed yet, so it is unclear whether the proposed material is less, similar or higher cost than current pastes. If higher cost, there will be more pressure to prove the effectiveness and durability to support adoption.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The PI highlighted the proposed work plan adequately describing the timeline and deliverables thoroughly in the document and poster. The PI described the approach and what will be measured to validate full size 60 cell module performance. The quantifiable metrics that will be used to generate a compelling value proposition were not adequately described, e.g. x% less inactive cell fingers, y% less loss after X hundred dynamic loading cycles etc. The PI described the level of collaboration and partner engagement adequately. The project has not stated yet but the PI described the intention to reach out and engage with strategic partners, downstream customers (i.e., module manufacturers), and investors.

**Reviewer 2:** The project was scheduled to start April 1 and will likely only get started post-COVID. In addition to the entities mention in the writeup, the team should be reaching out to engineering firms like Black and Veatch that guarantee bankability of PV modules and systems; it is always best to engage them early since you'll need their support. The milestones include beyond-standard testing and that's important. The marketing effort will need to have clear, quantitative results as are shown on the poster - but with more reproducibility measures.

**Reviewer 3:** The project engages with national labs. Engaging with independent engineers and manufacturers now to ensure the experiment is designed using appropriate testing they require for acceptance of the claims could be useful.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks described do tackle a unique problem set which is required for the metal matrix composite (MMC) silver paste including paste composition, cell fabrication, process development, mini module and full size module build, performance and reliability testing. There is also emphasis on cost modeling.

**Reviewer 2:** Score: 6. Comments: The task plan is good.

**Reviewer 3:** Score: 5. Comments: More detail around the quantitative testing in BP2 would be useful, but the outlined process is generally reasonable.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Experimentally quantifying the value of the technology and translating that to an impact (reduction) in LCOE is one potential blind spot. I did not see this described in the project Accelerated testing. Choosing an accelerated test protocol that is specifically intended to assess cell defects such as cell cracks, contact continuity and associated failure modes, hot spots, loss of power could be of more value than just the standard suite of accelerated tests, e.g. dynamic loading followed by thermal cycling maybe of more value than UV or damp heat tests.

**Reviewer 2:** Accelerated aging test that crack the cells after long heat and humidity cycling will be valuable.

Reviewer 3: The PI should consider that much of the US market is using more robust products, such as 72-cell and half cut cell products. Many of these innovations were adopted with the intent of addressing the issue of microcracks, increasing lifetime and decrease degradation. These innovations reduce the potential beneficial impact of this product for those modules.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The PI adequately described the stakeholder that will be engaged with. Engagement with teams that are very knowledgeable in and are developing failure mode specific acceleration tests. PVQAT, ASU group, etc. would be valuable at assessing potential failure mechanisms for cell contacts and suggesting specific suites of accelerated tests to qualify the MMC technology to.

**Reviewer 2:** The Engineering firms that validate bankability for banks and insurers (like B&V) should be engaged as early as possible.

**Reviewer 3:** As mentioned above, engaging with IEs and manufacturers now to ensure the appropriate testing is examined to support their acceptance of the claims could be useful.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Determine where in the PV supply chain Osazda Energy would like to operate, is this a licencing opportunity, do they want to become a major ink manufacturer, how will manufacturing be performed on-shore in the US? 2) Quantify performance benefits and model associated improved revenue to communicate with stakeholders. 3) Emphasis on accelerated testing designed for cell contact stressing over standard full suite of accelerated tests. This will produce a data set that is the most relevant for their technology.

**Reviewer 2:** 1) The Si cell manufacturers are risk averse. So you will need joint development agreements and many many joint experiments to get your product into their factories. 2) The business model must be carefully considered. Is selling paste the only source of revenue? 3) As they seem to know, the ability to image and market their advantages at full module scale will be important for making the sale.

**Reviewer 3:** The amount of benefit expected from this project is not clearly established. Supporting research in materials advances is an appropriate use of DOE resources to fully establish the benefit and longevity of the product. The project would benefit from looking at cost-benefit for more modern products.

## Developing a Single Beam Ion Source Technology for Efficient Manufacturing of Transparent Conductive Thin Films – $800,000

Scion Plasma | East Lansing, MI | Principal Investigator: Maheshwar Shrestha

This project is developing a tool that rapidly deposits transparent conductive oxide onto heterojunction silicon with intrinsic thin layer solar cells, improving their performance. These cells are more efficient than other device structures but require a transparent conductive oxide. However, these oxides are costly and difficult to deposit quickly without altering the structure of the cell and lowering its efficiency. This technology will increase the oxide deposition rate, which will increase the manufacturing rate of these cells while reducing the cost, thereby increasing their market value.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 4 | 5 |
| Set critical challenges to overcome | 5 | 6 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 3 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** What is not clear is the impact this work will have on transferring to US equipment builders and ultimately promoting HIT cell manufacturing in the US. Working with the Fraunhofer group at MSU suggests a pathway to potential use outside of the US but it's difficult to assess this as the team did not describe their intended business model to sell their technology at the end of the 2 year performance period. As a result, other than increasing throughput by a factor of 2 for ITO sputtering systems (without discussion of O&M and OPEX considerations for a finished system) and whether this would be suitable for new systems (no retrofit) only it was difficult to assess the impact.

**Reviewer 2:** This project is one month old; appears to have a good team and the technological background to succeed. Development of the sputtering tool seems to be incremental.

**Reviewer 3:** The project's goal is to double the throughput of manufacturing HIT quality ITO with only 10% increase in cost over current technology using a unique ion beam enhanced sputtering technique. Improvements are also seen in roughness and operating voltage/energy. The technology would be useful to any technology that uses ITO.

**Reviewer 4:** This project is only one month after the start date. Its scope is narrow and focused on development of a linear ion source to assist in Magnetron sputtering of ITO for Si HIT cells: the innovation is in the ability of the ion source to double the deposition rate, at much lower temperatures than the customer magnetron alone sputtering. The challenges set in the narrative are also straight forward, except for the design of the linear source at that is long enough to process the ITO in a in-line system for 6 inch wafers and do so at 2X the throughput of state of the art. The PI indicates that the linear design has potential to be one meter wide, where the impact can be significant to industry and research outside the SETO program. This project, also has the potential to produce results on a fast pace because of its narrow but focused scope. Positive outcomes can attract industrial interest as soon as the results are validated. The project does address milestones/targets for the second year.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 4 | 4 | 5 |
| Collaborates with sufficient stakeholders | 3 | 4 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project started in 2020 so not possible to assess progress. One observation, the description of the metrics to come out of the project were inadequate to assess the impact. There were no comparisons to state of the art ITO techniques used by HIT cell manufacturers and no discussion of how cell performance bench marking would be performed during the project i.e. real cell measurements by a cell producer partner.

**Reviewer 2:** This project is only one month old--really need some history to provide an evaluation.

**Reviewer 3:** Project is just getting started so milestone results are generally yet to be achieved. The company is working with Fraunhofer and Michigan State but, with progress, will need to engage with manufacturing partners in order to construct production scale tools.

**Reviewer 4:** The project report was produced before the actual start date. Therefore, the comments here and the scores are place holders and are educated guess about the expectations from this project based on the narrative description. However, the project describes preliminary results that show promise toward achieving the expected results compared to the conventional sputtering of ITO. The milestones as written (1 to 3) are reasonable and most likely achievable. Milestones 4 and 5 are critical to the value and potential impact of the project: Capex and Opex cost analysis will validate the worthiness of the project. These milestones will also serve as given GO-NOGO decision point. The claimed impact/contribution to the HIT industry are reasonable, but needs to be validated by a third party.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: I think that the tasks as described in the document address what is needed for achieving the overall goals. I did not give a "6" rating because I did not see description for the fit, form and function (actual cell efficiency on a HIT cell versus the current SoA ITO process).

**Reviewer 2:** Score: 4. Comments: Let's see how they are doing next year--this project is only one month old; good team, good technology.

**Reviewer 3:** Score: 5. Comments: Task goals are naturally progressive early stage advancements. Currently missing the goals that would integrate the technology into a production scale system.

**Reviewer 4:** Score: 4. Comments: The value of the project derives from the fact that is focused on one task to produce a linear ion source assisted sputtering process faster than the conventional process used today, and has a potential lower CapEx.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** New build versus retrofit for sputter equipment. The latter would increase potential impact for sputter equipment ownership and process adoption. Engaging with HIT cell manufacturers for feedback of their process needs in ITO deposition. Validation of cell performance versus SoA cells that it is as good or exceeds current HIT performance. More work to determine the total cost of ownership for operating a ITO tool with their technology; equipment cost, O&M costs, materials cost and utilization, etc. These are all considered before new toolsets are procured and deployed.

**Reviewer 2:** What competing technologies are there?

**Reviewer 3:** The proposal appropriately focuses on the design and technological challenges. Value is only achieved after the technology achieves its goals in manufacturing of HIT devices. Further HIT may be limited by the amorphous layer deposition, not the ITO.

**Reviewer 4:** It is difficult to answer this question without examining the experiments approach progress and its challenges.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Definitive collaboration with a US manufacturer and HIT cell maker and sputter system owner/operator for process and equipment validation are the two main ones as these were not described in full in the documents supplied.

**Reviewer 2:** Might be good to connect to a company that fabricates solar cells.

**Reviewer 3:** After achieving the technical fundamentals, the PI will need to work with process equipment developers to move the technology into production.

**Reviewer 4:** The project needs to integrate an industrial partner to guide and validate the worthiness of the results, especially the impact of the cost to implement the findings.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Ensure the PI defines a material spec for the ITO that gives equal to or better HIT cell performance compared to SoA. Ensure that the equipment stakeholders described in the supporting document validate that the Scion equipment as meeting total ownership and operational needs for their cell customers. Develop a techno-economic analysis for the tool and associated project as a whole to quantify the value proposition for the technology.

**Reviewer 2:** 1) Good team, combination of academic and industry. 2) Might be good to connect to a company that fabricates solar cells. 3) Research may be incremental (what competing technologies are there?).

**Reviewer 3:** 1) Ion source is used to enhance sputtering of ITO. 2) Deliver twice the deposition rate with only 10% added costs for a significant cost reduction in the ITO film. 3) Project is just getting started and must prove technological results and cost results before then transferring to production.

**Reviewer 4:** It is early to give feedback this early in the project

## Field Factory for Cost Reduction and Deployment Acceleration of Photovoltaic Power Plants – $999,781

*Terabase Energy | Berkeley, CA | Principal Investigator: Dan Cohen*

This project is working to create a new field factory facility that delivers photovoltaic power plants and reduces soft costs. The team is designing and field-testing key subsystems of this approach to project construction before conducting an integrated field demonstration. This work will validate the cost, time, and levelized cost of energy targets that underpin the benefits of this facility and prepare the technology for broader commercialization within the industry. The goal is to enable better process control, lower costs, enhanced safety, and faster installation rates.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 3 | 5 | 5 |
| Set critical challenges to overcome | 3 | 4 | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 5 | 3 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** If the project is successful, the impact on the US industry will be significant, with a projected cost reduction of up to $0.07/Wp at the system level. This cost reduction will have a substantial impact on the PV industry, in US as well as worldwide. Reducing the cost of installed systems aligns directly with the SETO mission. The target cost reduction would be more credible if the project summary included a cost breakdown of a typical large scale PV installation and described specifically what part of those costs can be reduced using the proposed technology. The project work plan and methods are conceptual and doesn't include quantitative goals.

**Reviewer 2:** While this project aims to make a significant contribution to SETO's mission in PV, it is not well aligned with the goals of this topic. These state "The goal of these projects is to create technologies that have higher efficiencies, lower degradation rates, and lower productions costs to reach the goal of $0.03 per kilowatt-hour." The goal of this project is to reduce the cost of installing large fields of PV by up to $0.05 - $0.07/Wp, about half of the SETO goal to lower BOS from $0.67 to $0.54 /W by changing the way modules are assembled into systems. Although misplaced within the PV Track, the projects goals have clear significance for PV overall and thus advance the US solar industry. The focus of the study and plan to test at >100kW level, along with the large cost share, all demonstrate Terabase's skills and commitment. As this aims to explore a new paradigm for system installation, the unknowns are great and the statement of challenges is not well quantified.

**Reviewer 3:** The proposed work is meant to reduce assembly costs for utility scale power plants, and as such is very commendable. The concern is if the project is simply putting a roof over the heads of workers that would already be doing the assembly. How is this approach going to make a difference? When I think of a factory I think of a process flow with tasks that occur at various stations as the product moves through the factory. Is the program simply introducing 6 sigma, lean manufacturing, and better material flows? Once panels are assembled, what is the tracker transportation that is proposed to move the panels to the field, and properly locate them? Will that be rented, or will a new machine be procured and modified for this application? The project can have a large impact with a 10% reduction in LCOE, but the description is very high level with insufficient information as to how the end goal will actually be achieved.

**Reviewer 4:** Project is just beginning, but if successful will allow a more universal approach to installing PV in utility scale power plants. Approach adds elements of safety and modularity to installation process.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 3 | 5 |
| Collaborates with sufficient stakeholders | 3 | 2 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project hasn't started yet, so there are no performance to date available to evaluate those criteria, and I chose to enter average scores.

**Reviewer 2:** The project is just starting with no deliverables to date. It appears that their focus is primarily on their own business rather than delivering a new method to the entire industry. Thus, collaborators are not evident.

**Reviewer 3:** Since the project is just getting started it is difficult to make any assessments on performance to date. The idea behind the program is great, but there is not enough detail to understand if the program will be headed in the right direction to achieve the end goals. There are measurable milestones, but there is a lot of detail that is left out that would be helpful in better evaluating the project. The cost share shows that the company is serious about the effort. But the plan is very high level with not a lot of detail to provide an in-depth evaluation.

**Reviewer 4:** Since the project has not begun, it represents potential. However, group has done significant background work in preparation to the award that seems valuable - good thought process exercised.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: The project tasks follow a logical order of developing each part necessary for a successful completion, but is conceptual, superficial, non-specific and has no quantifiable goals or metrics and no timeline.

**Reviewer 2:** Score: 4. Comments: Each objective corresponds to a task - create the field factory, create equipment to move large assemblies, develop new foundations and analyze the process. In comparison to other projects in this topic, the project plan is much less quantitative.

**Reviewer 3:** Score: 4. Comments: The tasks are too vague (not concrete enough) to know if the overall project goals will be achieved. More detail (without giving any IP away) would be helpful in understanding the path that would be followed to achieve the overall project goal.

**Reviewer 4:** Score: 5. Comments: Approach to demonstration is a logical progression of steps, which if successful will enhance probability of success on a larger scale

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The development of a "large structure mover" that can move 4x30m structures seems challenging and potentially costly. The project summary doesn't include any specifics about how this can be addressed. In general, the methods and plans lack specificity (Employ rapid learning cycles, failing fast, engage expert network, modeling, managing risks through empirical testing simulation and analysis) are vague concepts that don't explain how, exactly, the team will approach the project development and manage the risks.

**Reviewer 2:** Many, as they indicate in their list of challenges, it is quite possible that anticipated savings cannot be realized and they may "fail fast."

**Reviewer 3:** I believe that the PI knows assembly and how they are going to achieve what they propose. That knowledge needs to be communicated better in the statement of work, with graded milestones to ensure overall project success.

**Reviewer 4:** Variation of field installation sites may be a significant factor. Some installation sites may be areal size constrained to allow installation of the assembly factory. What is cost impact of factory installation and infrastructure, such as electricity?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** While the project report states that the team will includes reaching out to external experts, stakeholders and prospective customers, it doesn't include specific information to evaluate if they are including the right partners. I also imagine that the development of the large structure mover must include the development of some kind of transportation system that will not be handled by the Terabase team, and no partners for that task are mentioned in the report.

**Reviewer 2:** The project does not provide quantitative evaluation of the time and cost analysis of current installation procedures nor to substantiate the projected savings. They identify retaining an expert project cost estimator as a mitigation strategy should the field trial results fall short of predictions. Brining that estimator on board now would be a useful addition.

**Reviewer 3:** Where is the tracker transportation & placement equipment coming from? Is that something that the PI is going to provide, or develop during this program? That tool seems to be very important to the success of the program, but there is little detail about how that will be achieved. Other than for the company itself, will the results be publicly presented to be of benefit to the wider US PV industry?

**Reviewer 4:** Too early in the program to tell, but hopefully awardee will bring in multiple large installation companies to review concepts and look at flexibility of approach.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The project needs further development before being launched. It must include specific tasks, milestones and quantifiable goals. 2) The PI should identify their partners (stakeholders, prospective customers, experts) and get from them a commitment to support this project. 3) The PI should add a more detailed and credible vision around the concept of the large structure mover.

**Reviewer 2:** These investigators, and the FOA reviewers who helped select the project, have identified a very creative potential path for significant savings in BOS. This review would score much higher if located in the correct topic area. This project should be relocated, potentially with reassignment of SETO management, to better integrate this investigation with the systems track of the PV program. The project needs to develop a more quantitative estimate of the anticipated benefits and may need to engage an expert estimator immediately.

**Reviewer 3:** Include quantitative go/no go milestones. Hold the PI to a more concrete plan as to how they will achieve the 10% LCOE cost reduction. If assembly is 50% of the total cost, then achieving a 10% LCOE cost reduction means achieving a 20% cost reduction in assembly costs. Is that reasonable?

**Reviewer 4:** Excellent in concept if achievable (i.e. high risk/high reward) Hardest part of project will be finding a “universal” transport machine to get “tables” from factory to installation point Other detail obstructions to setting up this “factory,” such as permitting or availability of infrastructure needs.

## Exploring Silicon Heterojunction Solar Cell Degradation: Bulk and Interface Processes Analyzed by Simulations and Experiments in Order to Develop Mitigation Strategies – $200,000

*University of California, Davis | Davis, CA | Principal Investigator: Gergely Zimanyi*

This project is working to determine whether hydrogen degrades two types of solar cells: heterojunction silicon cells, which consist of thin silicon layers on crystalline silicon wafers, and advanced passivated emitter rear contact cells, which are built to capture more light on the back surface of the cell. The team will identify what causes defects in heterojunction cells and at passivated emitter rear contact interfaces, to develop mitigation strategies and improve stability.

### 1. The project’s goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic’s goals and support SETO’s mission | 5 | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 3 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 3 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: This is project seeks to understand fundamental mechanisms of the relatively newly identified degradation mechanism in SHJ cells. The project description highlighted the challenges the team will need to address both in the modeling and experimental portion of the project, specifically the PECVD H processes challenges that may occur. If the model is validated by the corresponding experimental work the learnings will have a high impact on the SHJ cell field. Tasks that were described for this 1 year project match well with the level of SETO support. Understanding and mitigating the increased (over standard Si cells) degradation rate of SJH cells would be of significant value to research efforts in the same area outside of DoE. Weakness: The project description did not explain how this was a high risk approach and how different the teams approach is compared to other groups working on the same topic. There is not a clear pathway of how this project will help the solar industry in the USA. The team states that are in communication with Hanergy (China) and Meyer-Burger (Swiss).

**Reviewer 2:** The project goal is to reduce the degradation of SHJ cells and modules, which will improve module power and will improve the cost of PV-generated power. It focuses on hetero-junction technology, which is not a mainstream market today, but could become one in the future. The impact could be greatly increased by incorporating in this project PERC cell structures (PERC being the dominant cell technology today), or other upcoming cell technologies (such as other kinds of passivated contacts). Those other technologies would also benefit from a better understanding of hydrogen dynamics at their interfaces. I understand that this might increase the workload beyond the resources allocated within this project. Even if this cannot be done, I believe that the outcome of this project will be useful to other cell technologies. The impact on US industry is indirect. No commercial SHJ-cell manufacturers are US-based, but this project, if successful, will provide better panels available for the US PV market.

**Reviewer 3:** The project is extremely interesting and important, since SHJ is an important type of solar cell today. The degradation of SHJ solar cells evidently has an interfacial component that drives Voc loss over time and this project seeks to understand it at an atomistic level. The collaborating groups bring both theoretical and experimental strength to the problem. They have chosen their tools well and seem to have a good understanding of where the biggest challenges will lie. However, the scope of the work seems too much for the budget and timeframe. Development of appropriate a-Si:H structures (even without the c-Si interface) was studied for at least 30 years without a definitive match to a-Si:H experiments. Although the computational programs available have improved in the last decade since that effort was prioritized, the fundamental problem that a-Si and a-Si:H are non-equilibrium metastable structures likely remains. Still, I am glad that the group will bring the most current algorithms to the problem of understanding this key interface.

**Reviewer 4:** The project intends to explore the causes of Voc degradation in heterojunction devices and use the information to develop mitigation solutions. The work combines theoretical modeling with experimental analysis. The work could have a meaningful impact on the quality of HJ modules. There is substantial work to be done and the US does not currently have significant (any?) HJ module manufacturers.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 6 | 4 |
| Collaborates with sufficient stakeholders | 5 | 3 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has yet to start (acknowledged by the PI) but the key milestones were described along with budget and 1 year time frame. The physical properties of with be measured, e.g. SRV and interface defect density. It is less clear how this will be less clear how this will be related to the <0.5% SHJ degradation rate in a finished cell to validate the work as a whole. The partner in the project is ASU who will perform the experimental work. No description was given how the team will interact and communicate on a regular basis which will be important as the ASU team will validate the UC-D modeling work. The PI describes reaching out to Hanergy and Meyer-Burger to assess suitability of any mitigation process in their equipment/tool sets. There is no discussion on interacting with US entities to communicate the results and develop collaboration at any level of the supply chain.

**Reviewer 2:** The project hasn't started yet, so there is no performance to date available to evaluate those criteria, and I chose to enter average scores.

**Reviewer 3:** I remain concerned that the project is overly ambitious for the timeframe. Hopefully, I will be pleasantly surprised by the result. It is a great that the team is abreast of the NREL long-term stability results for SHJ module voltage and that they are in touch with M-B and Hanergy companies. SHJ modules are being sold in the US and we must have academic groups with models and experimental techniques prepared to deal with the unique issues they will present. The team hasn't really started work, but they do have a good grasp of the key challenges they will face in understanding the interface, its defects and the role of hydrogen thoroughly.

**Reviewer 4:** The project has not yet started so results and progress are not yet known. The PIs hope to engage with stakeholders once the first phase is completed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: It appears from the project description that the modeling objectives to be performed at UC Davis will help understand/define the experimental work that will be performed at ASU.

**Reviewer 2:** Score: 5. Comments: The tasks described in the report are well aligned with the project goal and the theoretical tasks (simulations) well aligned with the experimentation and characterization tasks.

**Reviewer 3:** Score: 6. Comments: The tight collaboration between theory and experiment will be helpful.

**Reviewer 4:** Score: 5. Comments: Tasks have been designed to combine modeling work with experimental work in order to draw conclusions and identify mitigation paths. Viability of solutions is yet to be understood. The solutions must be effective and applicable at production scale.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It wasn't clear the work would be related back to actual cell degradation i.e. beyond lifetime and SRV. The team plan to engage with equipment manufacturers but did not discuss plans to engage with SHJ cell manufacturers who would have degradation data and potentially have identified key process parameters that impact SHJ performance already.

**Reviewer 2:** The study limits itself to degradation, but could easily be extended to the relationship between the hydrogen dynamics and the cell initial performance.

**Reviewer 3:** I'm concerned that the structure of a-Si:H is changed in very complex ways by adding hydrogen in plasma deposition of the a-Si:H. It is not as simple as adding H to a theoretical structural model. Also, the question of what quasi-equilibration temperature the theoretical model (and the experimental samples) represent is a tough one. Clearly some features of the a-Si:H structure are equilibrated at a characteristic "quench" temperature, but others never reach equilibrium. This is hard to simulate, even with MD. The theorists should pay attention to the temperatures at which various kinds of atomic rearrangement freeze out during cooling of their models. The SHJ growers should be attentive to the interplay between growth temperature, H content and the structures (and Voc) they get.

**Reviewer 4:** The PIs did a good job of summarizing the technical challenges. Mitigating solutions will be the real challenge in the next phase. Finding a commercial partner will validate the benefit.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** More SHJ cell manufacturers.

**Reviewer 2:** I don't see, at this stage, the need to engage with additional partners. The collaboration with Meyer Burger and Hanergy already includes an equipment manufacturer and a cell manufacturer. Also, the participation of ASU/QESTT already brings best-of-class fabrication of SHJ devices.

**Reviewer 3:** The project is well conceived, though too small.

**Reviewer 4:** There is no connection with an existing HJ manufacturer. It would be helpful to find a US partner with active interests in the HJ space.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Prove any advances in an optimized process in an actual full size cell. 2) Communicate process changes and results with SHJ cell manufacturers to gauge feedback on viability. 3) Ensure close collaboration between modeling and experimental teams to ensure that the longer lead experimental validation of the modeling discoveries and be validated as efficiently as possible in the 12 month project.

**Reviewer 2:** 1) This is fundamental research that commercial companies typically don't fund.2) The mechanism under investigation is important (degradation of SHJ cells) and will likely bring insight to other important aspects (cell performance) and to other technologies (PERC, topCon). 3) Inclusion of ASU and experimental validation greatly improves the probability of success of this project.

**Reviewer 3:** 1) The connection between theory and experiment is important, to inform each. 2) The project is too short and poorly funded for its ambition. 3) As the project proceeds, it would be very useful to tap the experience reservoir about a-Si:H gained from 30 years of leading research in the US. Nearly all the experts are still working in science, but the field as a whole disbanded and it will be hard to meet them at conferences. Creative thinking about this will be useful.

**Reviewer 4:** 1) Modeling and experimental analysis that focused on on reducing Voc degradation in heterojunction devices. 2) The work is very early stage and needs to be started in order to understand mitigation plans. 3) US manufacturers are not currently focused on HJ technology but HJ could be a big player internationally if degradation and cost issues were improved.

## Microdroplet Electrospray Localized Laser Printing and Sintering of Nanoparticles for Passivated, Carrier-Selective Contacts – $200,000

*University of Central Florida | Orlando, FL | Principal Investigator: Kristopher Davis*

This project is working to enable the printing of silver contacts on silicon solar cells with very little thermal energy use, through a scalable technology called a nanoparticle electrospray laser deposition NELD. This technology will deposit silver microdroplets on the base of a silicon solar cell, then fuse the nanoparticles together with a laser, a process known as sintering. This project will lower costs and improve cell performance.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** If successful, this impact of this project can be considerable, as it would eliminate some of the most significant barriers to the adoption of the next si-based technologies (cost and performance of metallization for SHJ cells, possibility of using poly passivation on the front side for PERCPoly structures). The goals are very aggressive, considering the short duration of the project. The integration of this technology into finished modules passing some relevant reliability milestones would greatly increase the impact of this project - but completing those tasks would take longer than one year. Hopefully, the PI will be able to start another follow-up project after this one and bring this technology closer to being production ready. The impact on the US industry is indirect, since no substantial silicon cell production levels remain in the US; but this technology has the potential to make cheaper and better modules available to the US market. In addition, the processing equipment (NELD) can potentially be made domestically or by a US company.

**Reviewer 2:** Strengths: The PI has described the potential benefits of the innovative method for deposition carrier selective contacts to reduce contact resistance in both SHJ and PERC cells. They estimate efficiency improvements for both cell types which fit the SETO mission goals. The PI adequately described the 4 main challenges for the work in the project description. This is a high risk project as the team are developing a novel printing technology with associated laser annealing. There will be significant validation of the technology and its suitability for scaling. The high impact will be made if it is shown it can improve efficiency of 2 types of Si cells, SHJ and PERC, both forecast to continue to grow in market share over the coming years. This is an area of significant interest and activity outside of SETO funded efforts. Therefore it will add value. This will advance US PV R&D knowledge and standing if successful. Weakness: The project duration is 12 months and budget $250k. This seems inadequate for the work the team want to accomplish as described in the expected outcomes. It is not clear the work will directly impact the US PV industry beyond finished module with the technology would eventually be purchased by US EPC companies and installed int he field. Need a clearer path to incorporation in US cell and modules built onshore.

**Reviewer 3:** Project is still early stages. I'm looking forward to hearing how the project has initiated and any progress made. This is a unique, yet targeted focus on identifying a technical solution that would directly assist in reducing the cost of cell materials and processes. While this project could have a significant impact on material cost and overall help manufacturers reduce their overall cost, no industry stakeholders like a manufacturer is part of the project.

**Reviewer 4:** The prospect of using less silver in PV cells is intriguing and the proposal has strength because of the potential reduction in cost. I also like the fact it is investigating a novel manufacturing approach that could be scaled to change the PV cell making process substantially. However, this proposal has weakness because they don't appear to have an industrial partner, e.g. a cell manufacturer or tool maker. Also, the impact of the reduction on economics and cell efficiency is unclear.

Finally, it would be good to add an accelerated lifetime testing component to the project plan to demonstrate the reliability and durability of cells with the new technology over time.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 4 | 2 |
| Collaborates with sufficient stakeholders | 3 | 6 | 4 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has just started last month, so there are no performance to date available to evaluate those criteria, and I chose to enter average scores.

**Reviewer 2**: 2.1 The milestone breakdown looks reasonable although the budget to accomplish the number of experimentally based tasks appears modest ($250k). This is an early stage project and the PI is focusing on electrical resistivity, line width and print speed measurements as the main metrics to gauge success. Translation of these to comparative cell metrics including efficiency were not shown in the milestone goals for the 4 quarters. The PI did not adequately describe engagement with a partner in this project outside of UCF. The PI did describe the intention to publish in peer review journals. The intention to obtain LOIs from five industry stakeholders should help direct the team in future optimizations of their technology better aligning it to PV industry needs.

**Reviewer 3:** Fairly early stage to assess interaction so far; would like more information regarding journal publication targets and industry stakeholders they plan to contact.

**Reviewer 4:** This project is too new to assess performance, but the potential impact is unclear from an economic perspective, there are no industry partners mentioned and no method of information dissemination, e.g. Duramat, is discussed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The project milestones are very well quantified, and the metrics are very relevant not only to the overall goal of the project, but also to the needs of the cell manufacturing industry. It is unclear if the target of J0e of 50fA/cm2 for the n++ pc-Si contacts refers to the J0e after metallization (it should, otherwise it is not relevant). It would also be more relevant to use textured wafers instead of planar for this milestone.

**Reviewer 2:** Score: 5. Comments: This is an early stage project and the PI is focusing on electrical resistivity, line width and print speed measurements as the main metrics to gauge success. These should be adequate at this stage of the technology development to assess its potential/value.

**Reviewer 3:** Score: 4. Comments: Process and tasks appear to provide the appropriate rigor for the research and the scope of the project.

**Reviewer 4:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The project summary describes an option to integrate the P++ and N++ poly contacts to a PERCPoly process flow by firing through silver paste through the passivation layers, but doesn't explain how that can be done through the rear Al2O3 layer. The milestones for the polysilicon lines for the PERCPoly cells should include a target polysilicon thickness, since it is a critical point to prevent metal spiking (as explained in section 13). It should also be clear that the milestones should concurrently pass on the same or identically fabricated samples (not, for example, passing the line width criteria a sample that doesn't pass the tape test, and passing the tape test on another sample with a wider width).

**Reviewer 2:** Complexity of the equipment to print approx. 157mm x 157mm at the required industry rates and with the required equipment up-time could require more study/evaluation if the technology was should be successful that the lab scale. Cost, availability and shelf life of the chemical precursors needed for print the Carrier-Selective Contacts should also be considered in a technology total cost of ownership study.

**Reviewer 3:** Unknown at this time due to early stages of project.

**Reviewer 4:** No collaboration with industry partners, e.g. cell or cell manufacturing tool makers.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** At this stage, few stakeholders are needed. After feasibility is demonstrated, it would be useful to include cell manufacturers, material suppliers and equipment vendors.

**Reviewer 2:** Equipment manufacturers, for design for manufacturing feedback; Cell manufacturers for adoption requirements/needs for a new contact technology; Reliability test groups, e.g. Duramat, PVQAT, ASU group, etc. to help guide specific stress tests for the contact technology beyond simple peel tests.

**Reviewer 3:** Likely more information is available in the full SOPO regarding other stakeholders; however this is not in the current report. That information should be reviewed at the next stage.

**Reviewer 4:** Cell or cell manufacturing tool makers. Duramat to share results.

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** Very relevant to next-generation cell technologies; Relevant and well quantified milestones; Very aggressive schedule.

**Reviewer 2:** 1) Translate the electrical improvements to actual measured cell efficiencies in parallel. 2) Obtain equipment and cell manufacturers feedback early on to help focus research to maximize impact and proactively identify potential roadblock. 3) Start accelerated environmental stress tests at an early stage to identify potential failure mechanisms and start to address them to reduce the probability of needed to reformulate the contacts at a later stage and increase the value proposition for potential customers.

**Reviewer 3:** Certainly, the findings regarding the impact of the process approach will need to be evaluated and compared to the objectives. It's still too early to address at this point.

**Reviewer 4:** I recommend the project team add industry partners, quantify economic impact and add accelerated lifetime testing to prototype cells with new technology to assess reliability and durability. They should also plan a method to share results, e.g. Duramat.

## Novel and Effective Surface Passivation for High Efficiency n- and p-type Silicon Solar Cells – $800,000

*University of Delaware | Newark, DE | Principal Investigator: Ujjwal Das*

Passivation of surface defects is key to achieving high-efficiency silicon solar cells. This project aims to achieve superior surface and cell performance in silicon photovoltaics by using sulfur and selenium compounds to passivate the silicon surface and enable high open circuit voltage. The team is analyzing sulfur and selenium surface behavior using advanced X-ray and capacitive characterization methods for advanced cell design applications, such as p-type passivated emitter rear contact and n-type passivated emitter rear totally diffused structures, where voltage has traditionally been a major limiting parameter.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Timeline and requested funding levels appear reasonable for delivering the stated project objectives.

**Reviewer 2:** No comment.

**Reviewer 3:** If successful, this project will increase the performance of mainstream Si-PV modules, with the addition of one manufacturing step (which can be cost effective, though no target costs were included in the report summary). It is well aligned with existing research topics, because surface passivation is a critical part of all PV technologies, but the final milestone (22% on 20x20mm cell) would be more relevant if extended to a full-size cell. The risks are high since H2S or H2Se has never been used to passivate silicon solar cells at an industrial scale. The potential impact is improved by the fact that processing tools using H2S or H2Se have been used in the past for the PV industry. The impact on US solar industry is indirect, since there are no domestic Si-PV cell manufacturer; but it would improve the performance of the PV modules available for the US market.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 4 | 4 |
| Collaborates with sufficient stakeholders | 3 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Cost modeling appears to be a distinctly unique or disconnected effort given the early-stage of proposed technology readiness.

**Reviewer 2:** No comment.

Reviewer 3: The milestones have been met, with the exception of the passivation quality for p-type textured wafers. The proposed solution (re-visit the cleaning procedure) doesn't really explain why the passivation works on planar surfaces but not on textured surfaces. The milestones are well quantified and are relevant to a future successful integration of this technology in high volume manufacturing silicon cell lines. The summary report doesn't include any of the characterization and investigation lead by UNLV (photoelectron and sot X-ray spectroscopy, investigation of electronic structures, band edge positions, work functions, etc..). There's been sufficient device fabricated and results to start those investigations (unless those have been done, but were not included in the report).

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Access to materials and tool modifications rely on several external project partners, formalized coordination and collaboration agreements will be required for project to be completed in a timely manner.

**Reviewer 2:** Score: 5. Comments: No comment.

**Reviewer 3:** Score: 5. Comments: The characterization tasks complete the experimental part very well. At the conclusion of this project, more will be known about the relationship between the performance of the passivation and the underlying physical structures.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Long term stability of this passivation approach is one to watch, in addition to incidental contact corrosion mechanisms that might be introduced by the selection of these species.

**Reviewer 2:** The use of H2Se is so dangerous as the gas is extremely toxic. At the concentrations noted, is it safe to have in a facility?

**Reviewer 3:** The explanation for the milestone of low J0e on textured p-type surface being not met is based on the assumption of an oxide layer, from the observation that the surface is not hydrophobic. But heavily boron-doped silicon surfaces are typically not hydrophobic, even without oxide being present. It would be very interesting to extend this project to newer cell architectures, such as polysilicon/oxide passivated surfaces.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This group would benefit from working with NREL.

**Reviewer 2:** GIT substitutes for an industrial partner here, but if follow on funding is requested, should include an industrial partner.

**Reviewer 3:** Collaborating with an institution that is experienced with the fabrication of poly/oxide passivated surfaces would allow to extend this project to include next-generation cell technologies.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Adoption pathways of this technology are not identified, and no manufacturing partner is part of the project team.

**Reviewer 2:** No comment.

**Reviewer 3:** 1) This is a novel type of silicon passivation, requiring in-depth experimentation and characterization, well suited for an academic environment. 2) The results are impressive, even if, unfortunately, the milestone for P-textured surfaces has not been met. 3) The milestones and their associated metrics have direct relevance for transferring this technology to high volume manufacturing.

## Wide-Bandgap Polycrystalline III-Vs as Transparent, Carrier-Selective Heterojunction Contacts for Silicon Photovoltaics – $200,000

*University of Illinois at Urbana-Champaign | Champaign, IL | Principal Investigator: Minjoo Lee*

This project is testing visibly transparent III-V materials grown at low temperatures for use within the front contact of a silicon solar cell. The cell has heterojunction contacts, which are state-of-the-art contacts that can efficiently extract voltage from silicon solar cells at high rates. The team will then grow heavily doped layers of aluminum gallium phosphide and aluminum indium phosphide on textured silicon solar cells to explore the doping and defects within the cell. Finally, the team will characterize the surface passivation and contact resistance of the most promising layers and make complete photovoltaic cells with the heterojunction contacts.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 3 | 5 |
| Advance the U.S. solar industry substantially | 3 | 3 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The PI is taking a novel approach to developing concepts that can be used in next generation Si PV devices. The creativity in the approach is to be commended. The work is well thought out and the challenges are understood and are being addressed. The candor of the PI about the challenges is appreciated. There is concern about the deposition technology. Vacuum evaporation and sputtering do add cost, and with compound semiconductor materials controlling the composition is a challenge. In one of the tables the V/III ration is included, and it is mentioned that thermal evaporation/sublimation was used. How is the V/III ratio controlled in low cost deposition techniques like vacuum evaporation or sputtering? Was MBE used in this study? Other than this the work is very interesting and hopefully will lead to an improved Si PV cell. It is not clear that this approach will substantially advance the US PV industry.

**Reviewer 2:** Project is a high risk approach to improving Si solar cell efficiencies. It is early in process as it got to a delayed start. While technical feasibility is being evaluated, with difficulty in achieving reliable results on materials characterization, there is still significant work to make it a viable commercial approach.

**Reviewer 3:** This project is an early stage, fundamental material project, aimed at ultimately reducing the deposition cost of novel carrier selective contacts for SHJ cells with a pathway to >23% efficiency. The critical challenges the team have set are mostly based on electrical/electronic properties; measuring carrier concentrations and n-type conductivity. The was no high level discussion about adoption of the process in existing cells lines or deposition equipment re-purposing. This is a high risk project. The vision is for these poly 3-5 films to be deposited using low cost high throughput methods such as sputtering have lower optical losses that a:SiO2 and better reproducibleability than the MOx films. Impact will be dependent on the number of SHJ cell manufacturers that adopt the technology. Good match between the project funding and the planned duration. This will be of value to groups working on in the field outside of DoE funded efforts. The potential impact on the US PV industry was not adequately described by the PI. If successfully adopted, the technology would impact the US PV project development industry with increased availability of high efficiency modules (>20%).

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The program is of short duration, with limited funding, and the PI has done a good job of getting the program started and including a collaborator. The program is well organized with quantifiable metrics. There are plans to publish the results at an appropriate time.

**Reviewer 2:** Collaboration on this early stage is difficult, especially as the novel approach means there are not many experts on the technology. There still seem to be many uncertainties in basic material characterization for the project to be almost 50% complete.

**Reviewer 3:** The PI described the important milestones and when they would be met with in the 18-month project although there were contractual delays at the start of the project. The metrics illustrated in the document are quantitative, e.g. measurements of SPV, conductance, doping levels, cell parameters, etc. The PI did not discuss the dissemination of results. Engagement with and participation of the subcontractor ASU was described. The planned collaboration with stakeholders was insufficiently described. The PI mentions this in the supporting document but did not describe when even a high level of stakeholder engagement would occur.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the program is well thought out and planned.

**Reviewer 2:** Score: 4. Comments: While the proposed tasks seem appropriate in the approach, difficulty in the early stages make it difficult to move to future tasks. It appears that unanticipated material measurement difficulties need to be resolved.

**Reviewer 3:** Score: 5. Comments: This project involves early stage research for a new form of 3-5 compound carrier selective electrodes. The tasks described are complementary to each other and are unique in that aspect. They do add value to the goal of a new path towards carrier-selective contacts.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Think through the low cost deposition of the III-V materials and if you will be able to control the stoichiometry and doping of the poly layers. I think you need more control than vacuum evaporation or sputtering can provide.

**Reviewer 2:** Project needs strong support from a materials characterization team, can this be arranged? Is there precedence for incorporation of slower, more costly deposition methods in standard silicon cell processing. What is impact of process temperatures on basic cell performance - i.e. how to keep deposition temp low enough to not damage cell.

**Reviewer 3:** The team need to translate the innovation on to a functioning cell to prove the efficacy of the proposed technology. They should also assess the engineering challenges that may or may not exist associated with sputtering 3/5 compounds on industrial sputtering equipment.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Considering the budget and time frame I think that the PI is doing a great job. It would be good to engage US commercial industry, if it existed (no fault of the PI!).

**Reviewer 2:** It appears that planned material characterization has not been very successful. A strong team of characterization experts is appropriate.

**Reviewer 3:** High level early stage discussions with SHJ cell manufacturers and technologists. Equipment manufacturers relating to potential adoption challenges i.e. industrial sputter equipment manufacturers on modification for AlGaP and AlInp.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The approach is creative and ideas like this need to be supported. The question of added cost vs. the potential benefit from the performance improvement needs to be considered. Make sure that the results eventually get published in a refereed journal.

**Reviewer 2:** Can the project recover time to achieve future planned goals given initial difficulties. At what point does progress stall to point of looking at alternative approaches. Are there DOE/NREL/National lab experts that can support the measurement difficulties.

**Reviewer 3:** 1) Prove out the modeled efficiency on a real cell. 2) While early stage work, preliminary discussions with stakeholder can be very informative regarding future barriers for adoptions i.e. with cell manufacturers and equipment manufacturers. 3) As this is innovative and potentially impactful technology for industrial SHJ cell manufacturers ensure that, where appropriate, intellectual property is built up for the process.

## Research and Development of Architectures for Photovoltaic Cell-Level Power Balancing Using Diffusion Charge Redistribution – $800,000

*University of Michigan | Ann Arbor, MI | Principal Investigator: Al-Thaddeus Avestruz*

This project is conducting photovoltaic cell-level power balancing using diffusion charge redistribution to increase efficiency, lower manufacturing costs, and improve reliability. This work will examine the use of on-module power electronics to enable cell-level power optimization and transform the often complex current-voltage characteristics a string of solar cells into a well-behaved "super-cell" that eliminates cell power imbalances, mismatches, and partial failures.

1. **The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 |
| Set critical challenges to overcome | 3 | 2 |
| Implement a high-risk, high-impact approach | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 3 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 2 |
| Advance the U.S. solar industry substantially | 4 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project only had a poster to describe the work plan, objectives, deliverables etc. as well as difficult challenges to overcome. Therefore it was difficult to address most of the questions in section 1.

**Reviewer 2:** The focus of this project does adequately describe the issues attributed to module shading, and appears to characterize them reasonably well. The project team appears to be technically proficient to support the development of the product. It is positive that the intent is to integrate this into existing module technology and architecture and that is a strength. The most value lies in the increased reliability more so than the potential energy gain. Weaknesses: The PI did not provide a written report from which to review, only the poster was made available and that work product does not sufficiently detail the project. From review of the poster content, there is no mention of economic goals or improvements, there is not cited objective for energy gain values or increased reliability. Currently, the industry is not critically challenged by shaded module arrays, neither the financial or operational impact. The approach is difficult to understand based on the poster content.

2. **Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 1 |
| Measures impact appropriately (e.g. quantitative) | 2 | 1 |
| Disseminates results frequently and actively engages partners | 2 | 1 |
| Collaborates with sufficient stakeholders | 2 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** No milestones versus timeline and budget was described in the poster. There was no information to determine how to measure of impact. There was discussion on partners and how the information was (or is to be) distributed. No discussion on stakeholder outreach.

**Reviewer 2:** The poster content that was made available does not allow for reasonable judgement of the projects performance to date, or the qualifications of the project team.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The concept of addressing mis-match at the cell level is a compelling one for improved energy harvesting. However it was very difficult to match any task (as they were not listed in the poster) with how they will build to achieving the overall goal of the project.

**Reviewer 2:** Score: 1. Comments: The poster content that was made available does not allow for reasonable judgement of the project task schedule or key milestones.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Functionality, energy yield improvement, customer cost barrier, feasibility to incorporate into a module, system voltage tolerance.

**Reviewer 2:** The PI does not sufficiently address the cost component of the product, the cost of the product, or the blended price upon integration with a PV module. There is no mention of the challenges that exist in order to achieve acceptance and adoption by module manufacturers, and what the likelihood of commercial deployment may be. As important, is the rate in which this could occur, and how quickly it could actually realize an impact to the industry. Most importantly, there is no cited quantitative value or impact provided by the PI which is a key step in evaluating the purpose.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Module manufacturers, system designers, PE hardware manufacturers, code and standards groups.

**Reviewer 2:** Other valuable stakeholders would include module manufacturers, cell technology companies, testing agencies and national labs.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** Provide much more detail on the structure objectives and goals for the project for better assessment of its fit within SETO's portfolio.

**Reviewer 2:** 1) The PEER review did not include a review of a conventional project report; only the poster was made available, hence the review was limited in nature. 2) There is no cited measurable objective that can be utilized as determining the impact. 3) There is little evidence that a path towards commercial adoption can be achieved.

## Improving Energy Yield in Photovoltaic Modules with Photonic Structures – $147,163

*University of Minnesota | Minneapolis, MN | Principal Investigator: Vivian Ferry*

Silicon-based photovoltaic modules operate above ambient temperatures, which both decreases energy yield and reduces the lifetime of the module. One of the major sources of elevated temperature is the parasitic absorption of sub-bandgap radiation. This project is working to create photonic structures on the surface of a crystalline silicon cell that increase energy yield by simultaneously improving anti-reflection of above-bandgap light and reducing module temperature through reflection of infrared light. The structures will be deposited over the existing pyramids on the cell surface, and will be comprised of a small number of layers to be cost-effective. The structures will be created using a combination of opto-electrical-thermal modeling and experimental fabrication.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 3 |
| Implement a high-risk, high-impact approach | 5 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** Strengths: The topic of sub bandgap light management to improve module energy output is innovative and aligns well with SETO's mission. The challenges associated with determining the best surface to apply the photonic films and the variability of performance associated with cell type and surface impacts were well described. The challenges associated with applying the optimal films in a manufacturing setting (for maximal impact) and reliability of the films in finished devices were not discussed. This is a high risk project insofar as there are many variables (surface type, cell type, irradiance angle of incidence) that will affect the efficacy of the photonic films. The team appear to have narrowed down the optimal location to be the glass surface. If they can show the module temperature can be reduced effectively this will have a significant impact on energy over the lifetime of a system. This work is applicable to and would generate a lot of interest for groups researching methods to improve energy generation outside SETO funded efforts. This would advance the US solar industry especially if the team could find a method where films could be applied to the ARC coated surface of fabricated modules (not no description of the film itself in the document). Weakness: As this project involves both experimental measurements and modeling the budget and actual spend seems low. More resource would be needed to examine the challenges to move the technology into a manufacturing environment and also perform reliability testing.

**Reviewer 3:** The expected impact (lowering the module temperature by 2K) is in principle significant, but only if the proposed structures have no adverse impact and can be fabricated cheaply enough to justify the value (which is far from being obvious). The project summary doesn't outline any path toward that end, and without a credible path to be competitive, the impact won't be significant. Including different cell structures (Al-BSF, PERC and bifacial) increases the relevance of this project. Besides the cost, some obvious challenges are not mentioned in the challenge section of the report, such as parasitical absorption, potential reliability issues, dependence on angle of incidence, compatibility with existing ARC glass coatings.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** The team has only 3 months left to translate the reflection data shown in the document to measured energy improvements with measured module temperatures. This seems a short time to gain statistically significant results. The optical measurements (i.e. reflectivity from various cell and module surfaces) are appropriate. Discussion relating to translation to actual energy yield experimental validation was inadequately described. This will be a major challenge to build a compelling story for future adoption. The team described their approach to interacting with the NREL team adequately. There was inadequate discussion of potential stakeholder engagement to gauge interest in the technology.

**Reviewer 3:** The simulations are very relevant to the project goals and show an impressive match to the experimental results. The simulations were conclusive in choosing one type of structure versus the other (on cell or on glass mirrors). But time might be running out for the fabrication and characterization of experimental devices before the end of the project (June 2020), especially considering the fact that it involves energy yield measurements (which typically need to be performed for a long period of time to be conclusive).

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: No comment.

**Reviewer 2:** Score: 5. Comments: The tasks do adequately investigate performance of various cell types and modules through modeling and experimental validation.

**Reviewer 3:** Score: 6. Comments: The project is well planned, starting with study of existing devices (which provides validation of the simulations and characterization methods), continuing with using simulations to determine the best structure to develop, then fabrication and characterization of devices. The simulations are insightful and conclusive.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None noted.

**Reviewer 2:** As mentioned in the previous question, the PI should consider further energy performance/gain validation, assessment of manufacturability and determination the films are environmentally robust too.

**Reviewer 3:** The project summary doesn't mention potential negative impact of the mirrors (parasitic absorption, interference with module ARC, reliability, etc...) and how to mitigate them. It should be relatively easy to establish a cost target, knowing that the expected impact is an 1% increase in energy yield. Knowing that cost would help guiding the technology development.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None noted.

**Reviewer 2:** Cell and module manufacturers to assess compatibility with their manufacturing lines and to ensure that the photonic films do not impact the performance of passivation layers for cells and more importantly module ARCs. Reliability test groups to help determine suitable stress tests to determine the film would be robust in the field.

**Reviewer 3:** At this stage, it would be premature to involve more stakeholders. But a follow-up project that focuses in the fabrication of the proposed structures should involve module, coatings or glass manufacturers and PV developers, at least in an advisory role.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Useful module lifetime work.

**Reviewer 2:** 1) Quantify the efficacy of the films in the field by collecting energy yield data under various conditions. 2) Evaluate that the film is suitable for manufacturing. 3) Evaluate the film will be environmentally robust in a deployed PV module over the lifetime of the system, (25 years).

**Reviewer 3:** 1) Project is well designed and executed. 2) Substantial impact is uncertain unless a follow up project uses the outcome of this one and focuses on cost-effective ways to include the proposed structures in a manufacturing line. 3) I am doubtful that there is enough remaining time before the end of the project to fabricate modules and get good energy yield field measurements.

## Novel n-type Device Architectures to Achieve 1 Volt Voltage at Open Circuit in Thin Film Cadmium Telluride Cells – $645,000

*University of South Florida | Tampa, FL | Principal Investigator: Chris Ferekides*

Cadmium telluride solar cells are a low cost thin-film technology that has achieved commercial success in the solar market. To expand the opportunities for cadmium telluride technologies, this project is exploring a new cell design which starts with n-type cadmium telluride instead of the p-type that is commercially used today. This new approach could enable higher efficiency levels than those currently being mass produced. The team is using industrially relevant deposition techniques to demonstrate that the fabrication of n-cadmium telluride solar cells is possible at scale with efficiencies approaching 25 percent, an increase of two percent from current world record cadmium telluride solar cells.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Investigation of high risk approach to improve performance. May have significant impact.

**Reviewer 2:** Strength: the work is exploring a novel device structure to find a path for significant improvement in Voc for CdTe solar cells. The team has built certain capability in equipment and knowledge as the foundation for the project. They also developed a deposition method which provided them control to the sample concentration distribution. Weakness: The presentation was unclear on the plan to characterize not only the n-type carrier concentration, but also the total dopant concentration, as well as the activation ratio with the growth conditions. The results so far showed that the research is still in its early stage, would produce very limited impact to industry at this point.

**Reviewer 3:** Project aims at producing n-type CdTe solar cells with novel p-type contact layers. The approach focusses on previously developed elemental vapor transport deposition system, which is unique to USF. Strengths: 1) Leverage prior capability creation and experiences of PIs. 2) Field of study is interesting given that sx result indicate it may have merit. 3) Good mix of modeling, material and process development Weaknesses: 1) Reliance on EVT system, unlikely reproducible, possibly untransferable results. 2) No discussion how junction formation can be enabled, in CdTe passivation heavily depends on chlorine based anneal. 3) No consideration of alloyed absorbers.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is in early stages, not much information is available to judge success.

**Reviewer 2:** Some of above measurements scored lower was due to the project is young and no sufficient time to demonstrate. Since the team only achieved one of the goals at bare minimum, the project remains challenging. The measurement for milestones are quantitative with the key metrics: net n-type doping and minority carrier lifetimes; the final project milestones are: net n-type doping > 5E17 cm-3 ; and lifetime > 30 ns.

**Reviewer 3:** Too early to assess project progress, just started.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks are well defined to achieve the objectives

**Reviewer 2:** Score: 5. Comments: The material/device characterization, process optimization, and modeling of the devices are all critical parts of the projects.

**Reviewer 3:** Score: 4. Comments: Tasks are well laid out, but scope appears a bit narrow. A broader and structure study of the effects and interactions with chlorine passivation, alloy formation, etc. would not only be interesting, but likely necessary.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Investigator recognizes the possible challenges.

**Reviewer 2:** The starting device structure has lower quantum efficiency than its p-type reference. Could the team use a better device structure to start at higher ground?

**Reviewer 3:** Would like that the choice of deposition tool/method, absorber composition, and junction formation process would be considered in the tasks.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Existing collaborators appear to be sufficient.

**Reviewer 2:** Although it is too early to be used in manufacturable devices, some feedback from industry partners such as First Solar would be useful.

**Reviewer 3:** Other groups that have capability to form junctions or absorbers via other methods. Why does this project not also continue work done by Lynn et al. on n-type absorbers?

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** This is another hifi risk project for CdTe, for high risk projects supporting more than one group will spread the risk.

**Reviewer 2:** Start with some high efficiency n-type device structure, feedback from industry collaborators.

**Reviewer 3:** Good project and well organized. Project is a bit too focused on the preferences around methods and approaches. Targeted de-risking/evaluation of technology aspects that are common in current poly-CdTe technology would be desirable.

## Investigating Local Carrier Dynamics in PERC Patterned Cadmium Telluride Solar Cells – $214,904

*University of Utah | Salt Lake City, UT | Principal Investigator: Heayoung Yoon*

This project is developing a cadmium telluride passivated emitter rear contact solar cell that comprises a patterned aluminum oxide layer and small metal contacts defined on individual grains for greater cell efficiency and power output. Passivated emitter rear contact cells are designed to capture more light on the back surface of the cell. The team is using current generated by a concentrated stream of electrons to detect any defects in the passivated emitter rear contact design and quantify changes in physical parameters, such as the components' efficiencies, using 2- and 3-D numerical models.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 5 | 3 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Passivating and carrier selective contacts are the next frontier for performance improvements in CdTe thin film solar cells. This theme is consistent with the outcome of the working group at a recent 2019 CdTe workshop. The use of passivating oxides, especially Al2O3 is a well know opportunity demonstrated by various groups. It has proven difficult to form ohmic contacts on CdTe in general, and especially so, in the form of point contacts through a non-conductive passivation layer. Strengths: 1. The proposal is supporting of a primary initiative pursued by several in the academic and industrial community 2. A successful completion could shed some understanding on the transport limitations occuring in a PERC structure on low or heavily doped CdTe absorbers Weaknesses: 1. The proposal underlies the premise that Al2O3 will be effective to improve performance, this is not demonstrate and beyond the scope of this project 2. The proposal assumes that nano-fabricated contacts will be representative of a contact form through more practical ways, which is highly uncertain.

**Reviewer 2:** The US First Solar is the global leader in CdTe technology and it is very important to keep this competitive advatage through continuing supporting of this research area. The project if succesful will result in improved performance of CdTe and therefore, supports SETO's overall goals.

**Reviewer 3:** The project could lead to efficiency increases and lower LCOE for CdTe thin film modules and thereby supports SETO goals. The goals of the project contribute to the application of PERC device ideas to CdTe cell technology which may be one of the most promising paths for increased light absorption and Voc in CdTe cells. The project is high-risk and high-impact, with risks around PERC patterning not working, not reaching cost targets, or not behaving the same in the lab as in modules. The scope of the investigation is suited for SETO. The collaboration with First Solar is a critical stakeholder outside of the DOE. If successful, the project would contribute to the technology development of next generation CdTe modules and also improve the scientific literature around PERC patterning of thin film solar cells.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project has not started and cannot be evaluated for current performance.

**Reviewer 2:** This project has just started and I gave only 4 points for criteria 2.1-2.4 because it is not possible to predict how the team will perform. However, I strongly believe that this project has a well-rounded team which includes partners from academia (National Labs) and industry (First Solar).

**Reviewer 3:** The project initiation date is April 1, 2020 so the milestones do not have much progress, but the figures in the poster suggest the group can readily perform nano-probe analysis. The project would benefit from improved quantitative metrics including estimates for back surface reflective optical gain, back contact recombination reduction, and overall cell efficiency impact. The project team has a good publication record and active collaboration with project partner First Solar.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, all tasks are clear. it would help if task 1 would further clarify to what degree the patterned contacts will be evaluated for quality.

**Reviewer 2:** Score: 5. Comments: I agree that all tasks are unique and important for the overall success of the project.

**Reviewer 3:** Score: 4. Comments: The task to fabricate patterned contacts is important for evaluating PERC patterning for CdTe cells. This task would be strengthened by additional IV and EQ work on small 1 mm2 devices. The task of imaging local field distribution may be important. One of the risks of PERC patterning for CdTe cells is that contacts at grain boundaries may not function as well as contacts centered on grains. At full module scale it may be difficult to create a pattern that aligns with microscale structures, so the local field imaging may inform the lateral position constraints. The task to directly measure lateral carrier diffusion lengths does not seem to add value over other methods of studying recombination in thin film solar cells.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Thin film materials are very sensitive to handling in process and to subtle interactions with materials - it is unclear whether the necessary processes and handling will yield expected results. Forming meaningful contacts may prove much more difficult with the nano-techniques available.

**Reviewer 2:** I didn't identify any. If I could add something to the scope it would be some additional quantitative targets such as amount of measurements performed. This would ensure that results are reproducible and that methods is reliable.

**Reviewer 3:** The project team does not seem to have much experience with PV cell characterization, even with small <1 cm2 pixels. Regardless of the nano-scale device results, this project would benefit from quantitative measurements of Al2O3 reflectivity and Jsc gain (as is observed in c-Si PERC) as well as Voc gains by limiting contact recombination.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** A second and third collaborator that also form unpatterned substrates for comparative testing would be of value. It may be necessary to evaluate alternative methods to form contacts.

**Reviewer 2:** Team already works with partners from academia and solar industry (First Solar). I think, it would make sense to also engage utilities and potential investors so that they stay abreast of the newest achievements and impacts of this research on the future performance and cost of this technology.

**Reviewer 3:** The project has the key stakeholder of First Solar, but the level of engagement will be important. For this project to impact the First Solar's technology roadmap, First Solar will have to start investing in equipment design and its own internal pilot program. How that effort will interact with the project remains to be seen.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Place more emphasis on task 1, i.e., how to form meaningful contacts and ask the PI how a good contact will be "validated." If good contacts cannot be achieved, the results from task 2 are quickly eroding in value. Task 3 appears optional is opportunistic and not critical.

**Reviewer 2:** 1) Continue support advancement of CdTe technology. 2) Consider testing developed method on other inorganic PVs. 3) Strengthen collaboration with utilities and investors.

**Reviewer 3:** 1) Invest in device characterization. The nano-scale results will be much more compelling if combined with IV curve or EQE improvements - even if the device size is as small as ~1 mm^2. 2) Avoid polishing the samples if possible. Polishing removes the passivation and damages the surface and it may be difficult to compare the resulting material to that of pristine samples. 3) Invest in a model of device performance. You want to compare your nano-scale results to what would happen in idealized devices. For example how would a grain-matched pattern compare to a random pattern or a square array?

## Copper Indium Gallium Selenide Technology Advancement via Fundamental Modeling of Defect/Impurity Interactions – $691,014

*University of Washington | Seattle, WA | Principal Investigator: Scott Dunham*

Copper indium gallium selenide is a promising material for high performance, low-cost thin-film photovoltaics. In order to improve conversion efficiency and lower manufacturing costs, researchers need to better understand interactions between mineral impurities and native defects, as well as how both couple to alloy ordering and phase separation within these cells. This team is using density functional theory calculations to predict distributions of defects and defect complexes, estimate reaction and diffusion rates, and perform simulations to predict alloy, impurity, and defect ordering. The team will test the resulting model and process in order to optimize device performance, reliability, and cost.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 | 4 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 3 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a project build foundation for thin film solar advancement. It is not a high risk project. The impact of it is long range. The project is focused on CIGS, given the grim picture of CIGS solar industry in the US the benefit to US solar industry will be limited. Yet the developed models may be adapted to other thin film with additional effort.

**Reviewer 2:** The team has established methodology through previous work funded through BAPVC and NSF. The subjects of this research are suitable for using the method. The team's initial results showed the capability of the method. Weakness: With CIGS companies failing, the value to the results to US industry is questionable.

**Reviewer 3:** The ultimately project deliverable is to simulate from a material formation, through the simulation of a process, to a device performance. Thin film technologies are sensitive to intricate defect physics and this project may shed some light on some of the mechanisms involved. Strengths: 1) Challenging capability development, but also a strong list of key challenges to investigate. 2) If successful, mechanisms may enable future improvement. Weaknesses: 1) Unclear how steps in the model can be validated. 2) Lack of time domain simulation? May not capture many transient phenomena.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 2 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Good effort has been made to bring in additional partners to compensate for the exit of US CIGS industrial partners.

**Reviewer 2:** The team has achieved their planned milestones. They worked hard to collaborate with others when their industry partners stopped operation one by one.

**Reviewer 3:** Project with similar scope was pre-existing and it is not clear what the true starting point was. Some initial encouraging results. See very little about the feasibility of the next steps.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks are clearly defined. The multitude of partners and samples to validate the model may increase the work and the timeline.

**Reviewer 2:** Score: 5. Comments: Several modeling methods have been used to simulate different areas of device formation mechanism. They are all critical elements to gain overall understanding

**Reviewer 3:** Score: 5. Comments: If the model can be proven useful, the challenges called out under objectives are all value added activities.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** With multiple partners providing samples there will be more work to validate the model.

**Reviewer 2:** Instead of struggling looking for partners for CIGS research, should consider changing the direction to CdTe or other solar cells. It would provide more impact to the industry.

**Reviewer 3:** Validation of the proposed work is incredibly difficult and the project description spends very little time on this topic.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Good effort has been made to bring in additional partners to compensate for the exit of US CIGS industrial partners.

**Reviewer 2:** The team has enough collaborators.

**Reviewer 3:** Experimentalists that develop targeted test structures or design of experiments to provide validation opportunities.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Building good device models benefit industry and decreases timeline for improvements by narrowing the experimental window. For long term strength in the industry modeling is important. It is difficult work and given the diversity of thin film materials models may not be easily transferable. Funding this project may be important for long term but I consider it lower priority.

**Reviewer 2:** Suggest to re-direct the research to CdTe or other solar cell than CIGS. CIGS is proven to be hard to manufacture for both its complicated process and capital cost. Companies were failing. Should keep smaller amount of funding for CIGS device research. For this particular project which develops fundamental understanding of defect migration mechanism, it can be conducted on CdTe first and then applied to CIGS in the future when it becomes more promising.

**Reviewer 3:** This project is very high risk. Likely, the DFT work will either reproduce/correct or complement prior DFT work, which will be useful. The ability to predict structures and lastly interface is very high risk. Optimistic case, the project can provide some insight into selected issues.

## Developing a Low-Cost, High-Volume and Scalable Manufacturing Technology for Cadmium Telluride Feedstock Materials – $1,343,301

*Washington State University | Pullman, WA | Principal Investigator: Kelvin Lynn*

This project is developing low-cost, high-volume, scalable cadmium telluride feedstock production technology, which can be commercialized to deliver high quality feedstocks to industry at a reduced cost with rapid production rate. The material quality of feedstocks is optimized to the needs of high efficiency solar panel production. A novel cadmium telluride synthesis and growth process will be developed and scaled up, and the grown material will be evaluated with respect to defect structure, carrier lifetime, and unintentional impurities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Approach is being developed for compounding doped powders of CdTe through HPB. Project is potentially enabling, however, at best a necessary and not sufficient outcome to succeed. Strengths: 1) Leverage existing know-how. 2) Connected to NREL and FSLR for trials. 3) Project goals focused on end results (make a new type of device). Weaknesses: 1) The need of this project has not been clearly established against any plausible alternatives. 2) Commercial success is one of cost and academic player unlikely to have line of sight.

**Reviewer 2:** Based on the provided information, this project has achieved its milestones for the first three years. Cutting the cost of materials is an important part of cost reduction and this project could deliver a significant improvement for CdTe based photovoltaics. Thin film photovoltaics is a small percentage of solar manufacturing so the overall impact of this for US solar manufacturing may not be directly significant. But making CdTe thin film photovoltaics better competing with Si photovoltaics would have a beneficial impact. On aspect of the success is not covered by this project, that is related to performance of commercial modules using this feedstock. Changes in composition may have an impact on performance degradation of modules and this has to be tested. Commercial success will depend on this. I understand that this is outside the scope of this project.

**Reviewer 3:** Strengths: the project objective is an important for the CdTe technology, the leading thin film PV in efficiency and Market share. At the heart of this technology is the deposition of the absorber by essentially sublimation of the CdTe from bulk charge to thin film. So, unlike other PV technologies, it is important to ensure that the bulk source is close in its properties and has the correct dopant incorporated correctly and among other characteristics. This project is focused on doing just that. This is a challenging problem. However, it important to pursue this effort to fruition since successful results can produce higher efficiency and also serve as a uniform optimal source of CdTe for manufacturer. In the medium term, it can significantly impact the cost of the materials, and also increase yield. Good progress has been made, the team supporting the PI is exemplary and versatile. It has the skills and tools to test the concept, quick feedback, and validate in manufacturing setting. Weakness: Even though progress has been made, it relatively slow considering the importance of the objectives. It seems to me that the budget for the PI portion is relatively and consideration should be given to add some manpower to accelerate progress.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 3 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Powders have been fabricated and team has demonstrated p-type absorbers with high doping and lifetime. This is a noteworthy result. It is unclear to what degree the innovation around the powder manufacturing was the most critical step as alternatives were not explored.

**Reviewer 2:** I am not able to comment on the engagement with stakeholders and dissemination of the results. This is not sufficiently covered by the provided project summary. The results achieved are clearly presented.

**Reviewer 3:** The project is making good progress, showing important outcomes, and meeting the promised milestones. I believe that the progress can be faster, i.e. optimizing the characteristics of the bulk CdTe charge with different dopants and stoichiometry so that the project can demonstrate the values of the results to the final device product, and especially as it impacts First Solar. To that end the manpower in the PI lab could use a boost, and frequent interaction with the device fabricators and especially FS could be enhanced.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The goals and outcomes are clearly defined.

**Reviewer 2:** Score: 2. Comments: The milestones and tasks for the next period is not shown in the presentation.

**Reviewer 3:** Score: 5. Comments: See previous responses.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Not clear whether project team created enough engagement with industry participants to address the actual and allowable cost of feedstock manufacturing and practical limitations in a manufacturing process. Development of scalable production processes for raw materials may be somewhat premature for technologies where the device has not yet been proven.

**Reviewer 2:** One item I included above: On aspect of the success is not covered by this project, that is related to performance of commercial modules using this feedstock. Changes in composition may have an impact on performance degradation of modules and this has to be tested. Commercial success will depend on this. I understand that this is outside the scope of this project.

**Reviewer 3:** The importance of efficient co-ordination with all team members to test/ validate results, and quickly test the merits of the results in a working device, on a time schedule that allows a manufacturing entity like FS to validate the worthiness of the approach.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** An industrial representation with expertise in material processing.

**Reviewer 2:** It would have been good to have an industrial partner for this project that could validate the degradation aspect.

**Reviewer 3:** I believe this team is more that adequate to carry out the effort as described in the project. I think, again, the area for consideration is how to accelerate the translation of the results at each point in the investigations toward the critical point of validation in manufacturing setting, i.e. with FS.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Good progress made in the project. Yet to be determined how high impact this will be in the long run and also unclear that alternatives have been sufficiently evaluated.

**Reviewer 2:** Projects tasks and milestones to be listed. Industrial partner could have been required in the beginning of the project. Project summary could include a section describing how the information was or will be disseminated.

**Reviewer 3:** 1) Is the percentage of allocated time for each member in the project adequate and well defined in terms of responsibility. 2) Is the allocated level of effort at the PI lab optimized to drive the rest of the project activities so that the results can reach FS in a reasonable time. 3) Project to focus on advancing thin film deposition testing that is compatible with that of FS.

## Preparation and Evaluation of n-type Cadmium Selenium Telluride and Cadmium Telluride as an Absorber in Thin Film Photovoltaics – $188,561

*Washington State University | Pullman, WA | Principal Investigator: Kelvin Lynn*

The power-conversion efficiency of conventional p-type cadmium telluride absorbers is limited by relatively poor electronic properties, including low carrier lifetime, low doping levels, and challenges with back contact formation. This project aims to produce and evaluate n-type doped cadmium selenium telluride thin films that have the potential to exceed the performance of conventional absorber layers while maintaining the low manufacturing costs inherent to thin-film module architectures. The team will use close-space sublimation and newly developed feedstock materials, followed by heat treatments in the presence of carefully chosen gases to obtain high-quality n-type cadmium selenium telluride with the enhanced electronic properties needed to create high-efficiency thin-film solar cells.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a high risk project that may result in high impact.

**Reviewer 2:** The small scope project intends to evaluate the opportunity of n-type CdTe and CdSeTe to overcome the challenges in doping materials effectively p-type. N-type doping has been well established in single crystals, the initial phase of this work does not address areas of very high concerns. The later stage of actually demonstrating reasonable efficiency devices in poly cdte is much more daunting and unlikely to be fulfilled within the narrow scope of the project Strengths: 1) Work is well justified by prior sx experiences. 2) Thoughtful modest effort targeted at initial proof of concept. Weaknesses: 1) Not forward looking toward device integration. 2) Possibly to much effort spend on the material fabrication step, there are other ways to form n-type absorbers.

**Reviewer 3:** Strength: The project is exploring a method to significantly improve performance of CdTe-based solar cells. It is reasonable to first check the ultimate limit by studying bulk single crystals, gain substantial understanding of the material properties, then working on the thin film materials. The team built appropriate equipment for the former. Weakness: Although having collaborated with NREL on the thin film studies, the film growth was not under direct control of the core team. Only limited results were reported for much lower carrier density than bulk materials.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** No publications are mentioned for communication of results.

**Reviewer 2:** Good and predictable progress around forming n-type feedstock. Encouraging to see the bulk lifetimes are high. Many of the key challenges yet open, around how this could translate to a poly device.

**Reviewer 3:** As the team reported, the team suffered with some unfortunate changes and were doing their best to recover. There is a gap to the objective for thin films. Since the team relies on the collaborator for this part of the project for thin film growth, closer collaboration is needed.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks are aligned with the objectives.

**Reviewer 2:** Score: 5. Comments: Concur with the overall approach of forming feedstock and then in parallel perform some material analysis to understand limitations, while also attempt poly film/device fabrication.

**Reviewer 3:** Score: 5. Comments: The bulk crystal study establish a baseline and best-case scenario for the project. The thin film study would bridge to ultimate application for manufacturing if the approach is successful.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** They have identified the challenges.

**Reviewer 2:** Project is unlikely to achieve any significant device demonstration due to low funding. Project does not consider typical approaches for device fabrication and how this would need to change in an n-type structure. Example: is chlorine passivation still effective? how to form a junction with the n-type device?

**Reviewer 3:** The team has limited control to vary the parameter for thin film growth since it is done in another group. There is a big gap between the carrier densities measured in thin films and in bulks.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Existing collaborations are sufficient.

**Reviewer 2:** None recommend for this small exploratory project. Would need larger team if continued.

**Reviewer 3:** The team seemed to have sufficient collaborator for material study. For further evaluation, a collaborator with device fabrication and characterization would be helpful.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** This project aligns with couple of others for compositional changes for CdTe. I feel a couple of projects should be funded in similar high risk areas of investigation. Amount the CdTe composition changes this may be lower in priority. That said, the project has small budget and has already been started, it may be bast to fund for completion.

**Reviewer 2:** Good example of a SIPS project, high risk, small scope project. This is something worth doing and can get actionable demonstration that may help with decision in the future regards larger investments.

**Reviewer 3:** Closer collaboration for thin film growth, or building their own capability. Otherwise it is hard for them to conduct systematic studies by varying the growth conditions. The team planned to measure the dopant density of thin films using SIMS or GDMS. Should plan to see what parameters they can vary the dopant density in addition to that in feed-stock.

## Environmentally Sound One-Step Low-Cost Solar Silicon from Natural Quartzite – $200,000

*Worcester Polytechnic Institute | Worcester, MA | Principal Investigator: Adam Powell*

This project aims to produce pure silicon by developing a system that will electrochemically reduce natural quartzite to high-purity silicon in a molten salt bath. This process could significantly lower the cost of silicon.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 5 | 1 | 4 |
| Implement a high-risk, high-impact approach | 6 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a high impact project which thankfully is fairly short in duration and with a relatively low budget. The project should accept the material requirements of mono ingot manufacturers as this is rapidly becoming 100% of the wafer market. If these requirements can't be met with this unique process, there's little chance of Chinese wafer pullers introducing additional steps to accommodate this process.

**Reviewer 2:** At 4-5N, the projected silicon purity that would be produced with this approach is not sufficient to be competitive. This is barely at or above UMG, which has not been successful in the past at producing competitive cells and modules. Cell efficiencies have been improved so much since then than today, a solar cell made from 4-5N silicon would be even less competitive. The recent shift from multi to high-efficiency mono PERC, and the upcoming of even high efficiency cell structures (such as HJT or TOPCon) require even higher quality feedstock. Otherwise, if this project can produce good quality Si feedstock (at least 8N), it would be a cheaper, more environmentally friendly way, less power hungry technology that the baseline Siemens process and would be of great impact.

**Reviewer 3:** Strengths: The novel silicon purification process aligns well with SETO's goal for PV cost reduction.
The project describes the work to quantify the critical techno-economic challenges that will need to be understood before determining if a technology like this will become competitive. The work would potentially be over interest to other groups working in this or similar alternative Si purification research areas. This work may advance this area in the US solar industry as long as suitable US industrial partners with US based manufacturing are found in the discovery portion of the project.
Weaknesses: The approach appears to be focuses on cost and production plant modeling. It is not clear whether the key technical challenges will be identified and addressed before the end of the 1.5 year project. The total budget of approx. $250k over 1.5 years appears low to achieve the level of advancement proposed by the PI.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 | 4 |
| Disseminates results frequently and actively engage partners | 3 | 4 | 5 |
| Collaborates with sufficient stakeholders | 3 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team appears to be investigating a recent development to understand the possibility of applying this new science to silicon refinement.

**Reviewer 2:** The project hasn't started yet, so there are no performance to date available to evaluate those criteria, and I chose to enter average scores.

**Reviewer 3:** This project has just stated and no milestones were described beyond the two or three described in the text. No information was given to describe the levels of impurities in ppma/ppba and the potential mitigation strategies that would need to be introduced to manage them, especially for P and B which can be high but auto compensate. See comment above with respect to potential impurity issues and quantification. There was not quantification with respect to key throughput metrics for kg/hr/$capex or kWh/kgSi to benchmark the new technologies competitiveness. The teams would meet once/month and student teams coordinate on a weekly basis disseminating information. The project description indicates that a customer discover activity will be undertaken. There was no elaboration on what level of collaboration would occur.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The project appears to include tasks such as "preliminary business model" and "techno-economic cost model" with probably don't need to occur until the experiments are deemed successful or not.

**Reviewer 2:** Score: 2. Comments: The proposed tasks do not include quantitative milestones that would prove that the technology is viable: Si purity (most important), cost of producing the materials, and validation trough the fabrication of wafers and high efficiency cells.

**Reviewer 3:** Score: 4. Comments: There were no detailed task definition as the project has started very recently only high level objectives.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The only customers for this work are Chinese ingot pullers. Ribbon growth and vapor deposition are all technology failures at this point.

**Reviewer 2:** As sated above, the projected Si purity produced with this technology is not high enough. None of the proposed tasks directly address the basic proof-of-concept (which should be: produce silicon feedstock that can be used to make high efficiency solar cells).

**Reviewer 3:** The main ‘blind spots’ for a up stream silicon process like this is are 1) scale-ability beyond the lab “bench” especially for electrochemical processes which rely on complicated electrode and power supply design (touched on in the description). 2) The engineering and cost challenges should be determined up front as soon as possible. 3) Fit into existing supply chain is also an important blind spot (i.e. if material quality is adequate will it be suitable for only casting processes or CZ too). Fit with in future market needs and compatibility with emerging cell technologies e.g. PERC and next generation thermal budgets and purity requirements.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The PI should work with a mono silicon company to ensure that purity specifications are understood.

**Reviewer 2:** This project should include companies or institutions that grow silicon blocks; and institutions that can validate the possibility of fabricating good solar cells with wafers made from the feedstock produced by WPI.

**Reviewer 3:** Equipment manufacturers to determine the cost of design constraints (manufacturing materials, availability). Silicon growth companies for material specifications for incoming silicon feedstock. Cell manufacturers for the wafer specification and projected future silicon wafer quality needs.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project should focus on the areas of highest risk and remain pragmatically focused on a result which is interesting to the PV industry not academic peers.

**Reviewer 2:** 1) Re-assess possibility of reaching a higher level of purity, with a credible path to reaching those higher levels of purity. 2) Re-align goals and tasks to technical proof-of-concept, with quantitative milestones such as cell efficiency, feedstock purity, projected costs in high volume manufacturing. 3) Engage or collaborate with companies and institutes that have the capability of growing silicon blocks or ingots, and/or of making high efficiency solar cells and that are familiar with the current needs of the PV market and supply chain.

**Reviewer 3:** Silicon growers material specification needs to accept Si from the RPI process. Equipment manufacturers feedback to build/scale the equipment. Validate as must of the process as possible at the lab scale level to generate real data to fit into the production and TEA models they are developing from this project.

# New Cell and Module Structures/ Designs/Processes

## Quantum Energy and Sustainable Solar Technologies – $8,835,997

*Arizona State University | Tempe, AZ | Principal Investigator: Christiana Honsberg*

Quantum Energy and Sustainable Solar Technologies (QESST) is an engineering research center sponsored by the National Science Foundation and the Solar Energy Technologies Office. Launched in 2011 and based out of Arizona State University, QESST focuses on advancing photovoltaic science, technology, and education in order to transform the existing electricity generation system. The center's primary research areas are silicon cells and modules, tandem photovoltaic cell architectures on traditional silicon utilizing thin-film or III-V absorbers, and improving the performance of photovoltaics using test beds that can demonstrate manufacturability, integration, and sustainability of solar technologies. In addition to this research, QESST develops solar and photovoltaic education programs for graduate and undergraduate students, K-12 students and teachers, as well as outreach programs for the general public. QESST is designed to set the solar industry on a path to terawatt levels of installed photovoltaic generation in 15 to 20 years.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 5 |
| Advance the U.S. solar industry substantially | 6 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** QESST is a consortium directing research in several topics within the PV track. Thus, only some parts are aligned with the goals of the New Cell and Module Structures, Designs, and Processes topic. Similarly, special requirements of the co-sponsor, NSF, are of little impact on SETO's mission. That said, the benefits of the consortium structure make for a strong program. Industry involvement in both funding and advising the management has helped identify critical challenge in high risk investigations beyond the scope of their internal interests. Synergy among investigations and collaboration among investigators improves the productivity. NSF funding leverages the SETO budget. And, US industry members gain early access to the results and graduating students. One valuable aspect that is not emphasized in the SETO mission, perhaps do you an aversion from higher levels, is the education component. Usually university projects from SETO engage grad students and post docs. QESST taps into undergrads and high schools to promote awareness of solar technologies and potentially gain students aiming for the future solar energy workforce.

**Reviewer 2:** The results of QESST have been exceptional, with a considerable number of papers, patents, interested companies, and startups. They have a unique capability (Si fab) that is an exceptional place for development of Si PV. The goals and tasks of the program have been well thought out. The biggest question is if QESST has helped to further the US PV industry. This is not an indictment against QESST, but an indication of the economic realities in the world today. By QESST's own admission they are focusing on new, high value applications. Are any of the technologies QESST has been working on going to be used in utility scale applications (or even homeowner roof top applications), where they would have the most benefit for reducing global warming. It is hard to beat low cost Si PV. Again, there are larger forces at work, and this is not really a criticism of QESST, but it does need to be recognized.

**Reviewer 3:** Project provides a central point for many collaboration opportunities. It enhances technology and education. Technical leadership is outstanding, and projects driven by advisory groups is quite appropriate.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 6 |
| Collaborates with sufficient stakeholders | 6 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** In the 8th year of a 10 year multi-million dollar program, the performance of the program cannot be captured in the 5 page summary report. The 640 page, 2 volume 8th Annual Report delivered by the Director is more than adequate. Being founded as a consortium, collaboration has been ingrained in all participating investigators. Many of these now have multiple sources of funding, sometimes several through SETO. This strength of the program also lends confusion to considerations of who to credit for the accomplishments. Many of the more visible successes come from the work in commercial PV, particularly in silicon where ASU has established a complete pilot line for production from wafer to module with all major silicon technologies – Al-BSF, PERC, HIT. This capability supports numerous collaborations for tandem cell development. Within new cells and modules, QESST is exploring several families of materials at a very early stage of cell development where the bandgap-voltage offset (Woc) is a better metric than device efficiency.

**Reviewer 2:** QESST has done an excellent job of engaging multiple universities as well as reaching out to industry. They have an impressive track record of publications. It is well managed, well organized, and has clear goals and quantifiable evaluation metrics.

**Reviewer 3:** Project team effectively uses resources to meet clearly established objectives. Incorporation of Thrust and Test Bed approach seems successful in establishing milestones, providing educational opportunities, and reaching out to industry and academia.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: QESST is a large complex project. On the basis the reports and this limited review, it is very difficult to agree that each task is important. However, QESST is guided by an expert advisory board that performs on site assessments each year. The results and response to these reviews is captured in the Annual Report, providing evidence that this criterion is addressed

**Reviewer 2:** Score: 5. Comments: The program is well organized, with clear Thrusts and Testbeds.

**Reviewer 3:** Score: 5. Comments: Generally all tasks are appropriate for meeting thrust goals. Thrust sharing with the multiple collaborators provides an excellent use of capabilities perhaps not found at ASU directly. There seems sufficient startups indicating successful spin offs of technologies.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The weakened condition of the manufacturing segment of the U.S. PV industry may manifest similar deterioration in the quality of input the consortium receives from its industry members.

**Reviewer 2:** The leaders are aware of the concern about their impact on the US PV industry, and are working to address it. However, it is an issue beyond their control, and it is unclear how much of an impact they will have had by the end of the program. While there are startups, are those startups in a position to do anything beyond affect niche markets?

**Reviewer 3:** Potential blind spots are related to perhaps taking on too many activities. PI must make certain that capabilities, whether internal or with collaborating groups, meet those required to successfully take on projects.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** If QESST is to continue beyond 2021, the composition of university members needs to be more open. Some mechanism needs to be developed to phase out some partners and add new ones.

**Reviewer 2:** None, QESST has done an outstanding job of reaching out to multiple universities and commercial companies. They have helped startups get going.

**Reviewer 3:** PI has bases well covered. A look at the list of industrial participants and participating universities covers a wide range, and includes most successful teams in the field.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Engagement of industry in guiding university research and collaborating with the universities is priceless. Site reviews used at QESST promote a different type of interaction among participants than happens at a scientific conference. Collaborations seed creativity and need to be cultivated.

**Reviewer 2:** QESST has made a major impact of terms of technology developments, but the challenge again is if this is making any kind of significant difference in developing the US PV industry. I fear that the answer is "no." QESST is to be commended for the large number of publications and amount of outreach that they have done. A very positive part of the program.

**Reviewer 3:** This is important as it is one of the few truly collaborative activities in the US academia and research labs outside of National labs. Make sure focus does not become too divergent on activities that program cannot adequately support. Educational outreach offered through program is very important, as well as the opportunities this program provides college students.

## SonicWafering™ of III-V substrates for High Efficiency Cells: A Path to Less than $0.50 per Watt – $2,500,000

*Arizona State University | Tempe, AZ | Principal Investigator: Mariana Bertoni*

Creating the base, or substrate, of a solar cell typically requires sawing silicon blocks, but using sound waves instead of a metal saw results in less material waste and improves the lifetime of the substrate. This team is proving the viability of a sonic wafering process that uses low temperatures and intense sound waves to carefully and accurately remove completed gallium arsenide solar cells from the top surface of a thick wafer to reuse III-V substrates, so named for the semiconductor materials in groups III and V of the periodic table. This work aims to significantly reduce the cost of producing high-quality III-V substrates, which is one of the costliest components of this type of solar cell.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 6 |
| Set critical challenges to overcome | 2 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 4 |
| Advance the U.S. solar industry substantially | 3 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Sonic-induced substrate separation of III-V wafers seems novel and academically interesting, but problematic in terms of high-volume integration.

**Reviewer 2:** No comment.

**Reviewer 3:** Technoeconomic studies show that a low-cost method for forming a thin-film of III-V material is a key piece of the puzzle for improving efficiency of photovoltaics and lowering manufacturing costs, the primary goal of the New Cell and Module Structures, Designs, and Processes topic and in perfect alignment with SETO's mission. Assembling a team bringing the III-V experience of NREL and RIT performing the epitaxy by MOCVD makes the project's goals reasonable within the funding and duration shown and also engages the lower-cost potential growth technique of D-HVPE. The project also adds a new company to the U.S. PV industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 2 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project not started.

**Reviewer 2:** Not yet started.

**Reviewer 3:** Noting that the project is just starting, these scores reflect assumptions about the continued performance of the PI and her assembled collaborators. They all have excellent track records and outstanding publication and collaboration experience.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Possibly not in the handful of critical projects given the material set being employed (GaAs, even which cheaply separated substrates, is not a mass-market approach to solar).

**Reviewer 2:** Score: 4. Comments: No comment.

**Reviewer 3:** Score: 5. Comments: The PI provides one of the clearest descriptions (not requiring a request for the SOPO) of all projects. The assignment of work and objectives are quite clear. However, at the current state-of-the-art, some of the activities of the startup company, including evaluation of cost of ownership models, techno-economic analysis as well as interaction with key external stakeholders may not be of high priority for DOE funding.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The cost modeling of this effort appears too simplistic and assumptions do not align with SETO projections or stated goals. Needs more emphasis to ensure the right areas are being addressed for impact.

**Reviewer 2:** Since it hasn't started yet, hard to say.

**Reviewer 3:** The excitement over some early success in sonic wafering and assembling leaders in PV for other aspects of the investigation may be causing some blindness to the difficulty and duration of the effort needed to translate that success into a commercial success.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Suggest working with more than (1) GaAs cell builder - also include NREL III-V team for characterization/ validation of results.

**Reviewer 2:** No comment.

**Reviewer 3:** At this stage none others are needed. Some of the reviewers from SETO's PV Track Commercial technologies topic, individuals with substantial PV industry experience, could be of great help making the translation from laboratory success to the market.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Early stages look promising; however, no indication given on yield, TTV, defect incorporation rate, host wafer reuse…perhaps will improve as project continues.

**Reviewer 2:** Fund until go-no go point and evaluate. Looks novel and risky.

**Reviewer 3:** Mariana has assembled a great team to advance a promising technology. Success may need more than one option to mitigate more than desired level of residual wafer roughness. This team has the creativity to invent other options. Persevere. This will likely take longer than 2 years.

## Single-Source Vapor Deposition Equipment for High-Throughput Manufacturing of Thin Film Perovskite Solar Absorbers – $962,740

*BlueDot Photonics | Seattle, WA | Principal Investigator: Daniel Kroupa*

This project is developing modular, single-source vapor deposition hardware to enable high-throughput processing and manufacturing of thin-film perovskite solar absorbers. Single-source vapor deposition has the potential to be a rapid, cost-effective technique in which powder is turned directly to vapor and coated onto a substrate, the base of a solar cell. The team is working to design, build, and test a manufacturing platform that will improve the coating's uniformity on the cell, as well as its optical and electronic quality. This work will enable the next generation of solar manufacturing equipment for thin-film solar cell technology.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 |
| Set critical challenges to overcome | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 3 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Approach is straightforward and easy to follow; however, light on details and data, although the experimental plans are light on details and not well constructed for the level of funding requested.

**Reviewer 2:** This project has just started--looks like a good mix of technical development, aware of learning about manufacturing limitations, and developing a cost model.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 6 |
| Measures impact appropriately (e.g. quantitative) | 2 | 6 |
| Disseminates results frequently and actively engages partners | 3 | 6 |
| Collaborates with sufficient stakeholders | 3 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project not started.

**Reviewer 2:** This project has started a month ago--the plan looks great!

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The of VPD perovskite layers is not novel, but this method might compliment the many other solution deposition approaches that are limited by film uniformity and compositional variation - this project needs devices fabricated and studied ASAP to screen this technique for applicability. There is a lot of time and money expended on equipment and scale-up without that proof point being delivered.

**Reviewer 2:** Score: 6. Comments: Tasks are well defined and relate to one another.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Not many devices built/shown, need more characterization data and loss analysis and proposed remedies.

**Reviewer 2:** No obvious blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Proprietary limitations from a tool vendor exposing true cost of ownership data, obtaining process recipe details from manufactures and the myriad of combination and variants will likely obfuscate any detailed analysis the team wishes to perform within this project.

**Reviewer 2:** No obvious missing stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** It is unclear without a yield improvement estimate if the project's aims are in keeping with SETO cost targets.

**Reviewer 2:** Good project. Good team. Develop that cost model.

## Multi-Messenger in situ Tolerance Optimization of Mixed Perovskite Photovoltaics – $200,000

*Colorado School of Mines | Golden, CO | Principal Investigator: Xerxes Steirer*

This project is working to validate solutions to perovskite photovoltaic degradation mechanisms involving water and oxygen, electrical bias, light, and elevated temperature via in situ measurement of chemical reactions, volatile species, and electronic structure. Experiments are being performed on a new environmental X-ray photoelectron spectrometer (EXPS) that has opened up complex new directions in science, including real-time chemical information of interface reactions. State-of-the-art photovoltaic materials will be investigated including high efficiency mixed perovskites which will be provided by colleagues at the National Renewable Energy Laboratory and Hunt Energy Enterprises, LLC. Correlations among variables will be identified using multivariate methods. Mixed water and gas interactions with perovskite layers will be probed directly using EXPS in order to elucidate their surface bonding, activation energies and chemical pathways.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 3 | 6 |
| Set critical challenges to overcome | 6 | 4 | 6 |
| Implement a high-risk, high-impact approach | 5 | 1 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 3 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 2 | 6 |
| Advance the U.S. solar industry substantially | 5 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Development of tools for in-situ investigation of degradation mechanisms in perovskite PV materials is very important as it would accelerate development of optimal manufacturing conditions for perovskites and possibly different types of thin-film PV technologies.

**Reviewer 2:** This is a low-risk, low-reward project; the idea is to use laboratory equipment to understand the rate of perovskite failure due to temperature, humidity, light exposure, etc.

**Reviewer 3:** Perovskites hold substantial promise for their potential to increase inefficiencies and further lower the cost of solar electricity below SETO's goals. Device stability and durability are key roadblocks to commercializing perovskites. Analyzing and quantifying failures is often slow and is thus difficult to correlate to potential improvements. This work uses advanced Environmental XPS to shorten test time and provide useful information to researchers.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 2 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 3 | 6 |
| Collaborates with sufficient stakeholders | 6 | 3 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team effectively leverages the expertise and materials provided by NREL and industrial partners.

**Reviewer 2:** Right now the XPS spectra can be taken and analyzed using Python programs. The accelerated testing has barely begun. Moreover, it is not clear how changes in material properties will be related to device performance.

**Reviewer 3:** This project has thus far progressed steadily through its key milestones. It encountered a number of mundane equipment uptime challenges which slowed progress. Furthermore, additional coding resources were needed. However, the procedures are functional and being used for the next applied aspects of the final milestones. This is where significant physical modeling and correlation will need to be characterized in order to provide a pathway for rapid assessment. A paper on two-step degradation hypothesis is currently being prepared.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Expansion of capabilities for in-situ observation of processes that occur in perovskite materials and impact their degradation is very important. Such innovative tools will allow to draw important conclusions about relationship between manufacturing conditions and quality of produced modules. The knowledge gained from this project has the potential to benefit other groups conducting research related to perovskite PVs (potentially different thin-film PVs as well).

**Reviewer 2:** Score: 4. Comments: In this rather narrow project each the relationship of each task to another is clear.

**Reviewer 3:** Score: 6. Comments: The project was structured into 5 key milestones. The first three are focused on setting up the hardware and software for rapid testing and analysis. This work is largely completed. The final two milestones rely on using the test set-up to understand failure rates (activation energy) and mechanisms. This is where the value of the new procedure will be determined.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I didn't identify any 'blind spots' in this research project.

**Reviewer 2:** How changes in materials properties relate to device performance.

**Reviewer 3:** Given the complexity of PV devices and perovskites in particular, understanding failure modes and mechanisms is likely to be an extremely difficult challenge that will go well beyond the scope of this project. Furthermore the > 25 year deployment cycle of PV devices in bankable applications requires significant understanding of degradation trajectories.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** PI has a good working relationships with academia and industry. I think, that nothing is missing. Perhaps, other groups working on perovskite PVs could be interested in the results. A kind of national Perovskite Team would be something what DoE could consider. This way the results are exchanged between all research groups and it would also strengthen collaborations.

**Reviewer 2:** Need materials deposition and device fabrication and performance to be part of this team.

**Reviewer 3:** Given the collaboration with NREL and key industrial researchers, this work is exposed to some of the best thinking and resources in the industry. Real benefit will arise from broader dissemination of the capability to other researchers.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1. In-situ measurements tools are important to increase fundamental understanding of perovskite materials and associated reaction mechanisms. 2. In-situ tools measurement tools are typically expensive and they should be developed in a way, that they could be used on different materials as well. Perhaps integration of AI with in-situ observation could accelerate optimization of such tools. 3. Encourage collaboration between research groups working on perovskite PV technology.

**Reviewer 2:** 1. XPS acquisition and data analysis are in place. 2. Accelerated testing has barely begun. 3. How will changes in material properties be related to device performance?

**Reviewer 3:** 1. Perovskites have enormous potential but are significantly hindered by stability and durability issues which are very difficult to characterize and resolve. 2. This work dramatically reduces the lead time for stability tests and analysis. This permits faster information turns for ongoing work to resolve a variety of stability issues. 3. The test set-up and work could provide substantial benefits to most all perovskite research.

## Perovskite Solar Cells: Addressing Low Cost, High Efficiency, and Reliability through Novel Polymeric Hole Transport Materials – $200,000

*Colorado School of Mines | Golden, CO | Principal Investigator: Alan Sellinger*

This project is developing hole transport materials—layers in a solar cell that collect current—using polymers to enable thin-film perovskite tandem solar cells reaching efficiencies greater than 30 percent and lifetimes of more than 25 years. Polymers cost less than materials currently used for this purpose, and they will allow the team to manipulate their material properties to achieve greater compatibility with other layers of the device.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** Replacements for Spiro-OMETAD hole transport material are needed due to cost constraints. I believe that Spiro was taken into the perovskite field from the bulk heterojunction cells and it is not an ideal material for the perovskites. The first polymeric replacements from the Sellinger group look promising and it is good to have a followup project to optimize further by changing the chemistry. Close collaboration with NREL in measuring the devices is extremely important and must be maintained. The only question is whether perovskite cells will ever be able to displace the silicon incumbent. Attention should be paid to the development of these hole transport materials for silicon/perovskite tandems.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Not yet started.

**Reviewer 2:** Contacts and collaborations with the various perovskite cell companies should be established early to test promising HTMs. The NREL group's contacts should be leverage for this. IP should be well protected.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Not yet started.

**Reviewer 2:** Score: 6. Comments: They are testing all the relevant properties - including stability and compatibility with subsequent layer depositions in the device.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Not yet started.

**Reviewer 2:** Collaborative testing with the perovskite companies to ensure compatibility with their subsequent layer deposition and chemistries will be important. Companies are working on a wide variety of deposition techniques for high rate and early learning will be helpful.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Not started yet.

**Reviewer 2:** Joint testing with companies - see above.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Novel materials creation and testing. The kind of thing needed for advancing material science alternatives to Silicon.

**Reviewer 2:** 1) Continue working closely with NREL to validate. 2) Expand testing to perovskite companies developing high rate deposition. 3) Keep scientific focus on getting the HOMO level optimized and use the results to publish insightful scientific papers on this optimum and any other factors that help maximize voltage and hole collection together.

## Comparative Life Cycle Analysis of Scalable Single-Junction – $199,911

*Columbia University | New York, NY | Principal Investigator: Vasilis Fthenakis*

The project uses a Life Cycle Analysis framework to characterize, quantify, and compare the life cycle health and environmental impacts of the most salient emerging scalable single-junction and tandem perovskite solar cell architectures, which have shown potential for achieving high-level power conversion efficiency, stability at the cell level, and scalable and reproducible processes. The project will produce comparative evaluations of different perovskite designs and production pathways, as well as comparisons with other photovoltaic technologies and conventional power generation technologies that will inform decision makers and stakeholders.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 2 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goal of this project aims to take a first look at the life cycle assessment of perovskite solar cells to ensure that the technology is not blindsided by unforeseen hazards that negatively impact the environmental impact and limit the sustainability of particular perovskite options. An early challenge to the PV industry addressed removing lead-based solders from commercial silicon modules. Most of the perovskite compositions of interest incorporate lead in the absorber layer. Will this be a show-stopper or a manageable concern as for Cd in CdTe modules. Thus, the study has direct bearing on the value and affordability of future perovskite products. The investigator presents a realistic summary of the primary challenges, namely to identify which pathways are likely to be most relevant and what data exist to support the investigation. Obviously, both have many unknowns. As a first look at modest funding and single year duration the project is a reasonable investment for SETO. Cost share support from a solar energy industry gift supports the evaluation.

**Reviewer 2:** This program is well thought out and planned. The PI has done a good job in having an advisory board, although it would be good to have more people from industry engaged. The PI seems to have a good understanding of commercial manufacturing processes, as well as other issues associated with scaling up PSC technology (critical materials, concern about Pb, etc.), and is commended for doing the necessary background study. And while this has been addressed, there will be a concern about an academician evaluating a manufacturing process. As previously mentioned try to add more people from industry to the advisory board. It will add more credibility to the analysis. The results of the program need to be published in a high impact journal and widely read, as whatever the outcome they will be significant.

**Reviewer 3:** PSC (Perovskite Solar Cell) technology a critical aspect of DOE goals, at least potential is. Approach is well thought out and follows a clear logical path. Information dissemination to date is excellent, as are partnerships established. PSC technology rapidly evolving, may be a weakness to pin down existing approaches. However, system set up to evaluate is useful for any new structure.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The investigation has engaged several of the leading scientists developing perovskite PV. And collected process details on three promising structures. The only listed publication that is available, from the 46th PVSC, was somewhat disappointing in its focus on global warming potential and acidification producing the very unsurprising result that perovskites are more similar to other thin films than the bulkier commercial crystalline silicon. One reference in that publication was 8) P. Billen, E. Leccisi, S. Dastidar, S. Li, L. Lobaton, S. Spatari, A.T. Fafarman, V.M. Fthenakis, V.M. and J. Baxter. "Comparative evaluation of lead emissions and toxicity potential in the life cycle of lead halide perovskite photovoltaics," Energy, 166, 1089-1096, 2019. This works is apparently separate from the SETO funded effort.

**Reviewer 2:** The PI is to be commended for organizing this program, securing the funding, and getting it started. Having an advisory board is excellent, just add more people from industry.

**Reviewer 3:** Outstanding team of collaborators, although more industry participants would be useful. Not clear however the frequency of advisor inputs - regular contacts?

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The tasks are better suited to more mature technologies and appear aimed to collect data and perform analysis at a level well below current uncertainty bounds.

**Reviewer 2:** Score: 6. Comments: Yes, the program is well planned.

**Reviewer 3:** Score: 5. Comments: Well organized approach with one result leading usefully into next task. Success of goals will lead to suggested future direction, especially as it related to LCE involving use of Pb.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI seems to have lost focus on the critical concerns for perovskite development at this time. With the enthusiasm and expertise of the assembled experts on his ad hoc advisory panel, it is easy to see how the maturity of the technology may be overestimated.

**Reviewer 2:** There are no serious blind spots. The PI is to be commended for how well thought out the program is. Concerns have been previously noted.

**Reviewer 3:** Development of radically different advanced materials. Analysis method should be widely applicable as it is being developed. Incorporation of BOS in implementation of devices into systems would be good future work.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This investigation and the investigators are perfect for this study and well connected to all of the needed resources.

**Reviewer 2:** Previously mentioned.

**Reviewer 3:** PI has brought good group together, but additional industry participation would be useful - especially from existing Si technology producers.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** A life cycle assessment focused on potentially show stopping processes and materials for potential use in perovskite PV is an important contribution to SETO at this time. Development of perovskites are still in early stages, in spite of the excitingly high efficiencies. Uncertainties affecting LCA are still quite great. These investigators have the capabilities, reputation and connections to perform the analysis needed at this time.

**Reviewer 2:** This is a critical project and very important if PSCs are going to be commercially viable. Monitor to make sure that the people from industry have proper input to the program. They are critical to ensuring a viable result. The results of this study need to be widely published in a high impact journal.

**Reviewer 3:** 1) Make sure tools developed to study technology specifics are also applicable to newly developed material systems. 2) Encourage industry participation in this activity. 3) Continue to encourage dissemination of results to provide widespread comments and usage.

## Cross-Cutting Metrology Tools for In Operando Characterization of Carrier Dynamics in Photovoltaic Devices – $200,000

*Drexel University | Philadelphia, PA | Principal Investigator: Jason Baxter*

This project is developing cross-cutting measurement tools after exposing thin-film solar cells to infrared light with tremendously high terahertz frequencies. These methods enable the observation of how charge carriers move and recombine in the various photovoltaic device layers while the cell is operating. The team will obtain key parameters using noncontact probes and modeling in experiments.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: the project would provide a new way to characterize the recombination mechanism in thin film PV devices. Although the project just started, the team has done some work showing promising results. Weakness: the collaboration didn't include industry partners. It would be useful to get their feedback.

**Reviewer 2:** This project serves to develop a method for quantifying recombination mechanisms in photovoltaic devices. Initial work is done on CdTe but is applicable to CIGS and perovskite devices. As PV devices are becoming more advanced, it is becoming critical to understand underlying limiting mechanisms. This work could prove helpful to improving efficiencies further.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project is still at its very beginning, so it is understandable that not much results were reported. The team has done some initial work showing promising results for the feasibility of the method. However, the team could benefit by extending their base of collaborators including industrial partners. It would help them to tune the approaches to more practical issues and applicable methods.

**Reviewer 2:** The project is just getting started but has made good progress on the first two milestones. Clear, specific measurables have been outlined.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks were divided into initial device characterization, upgrading the measurement capability, modeling for interpretation, and further measurement to more devices and more complex systems. The arrangement is reasonable.

**Reviewer 2:** Score: 6. Comments: The project has been well scoped into logical sequential steps with clear deliverables.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Make the test vehicles closer to state-of-art devices.

**Reviewer 2:** Within the context of the project, the PI has done a good job outlining the key challenges.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Industrial partners.

**Reviewer 2:** Success seems imminent so it will not be long before additional applications will likely be desired. The team might benefit from having direct contact with device manufacturers either at research labs like NREL, other universities or perhaps a commercial facility like First Solar.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Develop a method with minimal difference with state-of-art CdTe solar cells. 2) Working with industrial partners to get input on how to adopt the test devices to be close to production devices, as well as the feasibility of techniques to help the PV devices.

**Reviewer 2:** 1) Advancement of PV efficiency are often limited by recombination mechanisms that can be difficult to quantify, characterize or resolve. 2) This work develops a novel and rapid platform for identifying recombination mechanisms. 3) The technique is likely applicable to CdTe, CIGS and perovskite technologies.

## High Speed, Roll-to-Roll Production of Durable, Low-Cost, Bifacial Perovskite Photovoltaic Modules – $4,000,000

*Energy Materials Corporation | Norcross, GA | Principal Investigator: Thomas Tombs*

This project is developing low-cost, high-efficiency, high-stability, bifacial, thin-film solar modules using roll-to-roll printers at the former Kodak manufacturing facility. The team and its partners are creating new methods to deposit layers of material to make the cell, develop a high-speed process using intense pulsed light to fuse the layers, resolve causes of degradation, and produce prototypes. The high-speed manufacturing process could eventually result in gigawatt-scale production.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project aims for 20% efficient stable perovskite mini-modules in three years, deposited and capped with roll-to-roll Willow glass on a huge Kodak coater at 80 feet per minute. Fortunately, the Kodak installation has enormous ovens and deposition areas - and has already demonstrated that Willow glass can be run through the machine roll-to-roll. The DOE investment of $4M over 3 years plus cost share comes to $5M, which is a very large SETO project and should be enough to demonstrate feasibility. The project will rely on perovskite and other layer recipes from Jinsong Huang and NREL but faces the hard problem of adapting them to industrial rates. With early 2020 silicon module prices already at about $0.28/W (and CdTe similar), any competitor faces a tough challenge; the team should not count on the $0.20/W "best case scenario" projected for silicon PV. Si PV has surprised us all many times by exceeding roadmap projections.

**Reviewer 2:** This is a very well proposed project, with a good team. The facilities and personnel are in place for a successful project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Milestones focused on progressive efficiency targets, along with stability testing, are wise. Several groups will be providing cost projections as the production recipes are developed - also a good thing. The project is just beginning (after the global COVID fever breaks, no doubt) and we won't really know the promise of this project for a year after that.

**Reviewer 2:** This is a very early stage project, so the plans look great. In 6 months, little has been documented. Let's wait and see.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The report shows reasonable awareness of the deposition and characterization challenges they will face. Glad to see a focus on diagnosing the problems that will inevitably arise.

**Reviewer 2:** Score: 5. Comments: I like the three tasks--we'll see how it ends up in implementation.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It is not clear that the team includes individuals with experience scaling other PV technologies onto RtR equipment.

**Reviewer 2:** No obvious blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I would like to see experienced CTO from one of the thin-film inorganic PV technologies consulted by the team. They are not the first to try to put a process onto roll to roll and should benefit from past lessons learned.

**Reviewer 2:** No obvious missing stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Learn from CdTe, CIGS and a-Si experience. 2) Keep collaborating with UNC and NREL - they know how to make good cells and can help guide improvement on the RtR equipment.

**Reviewer 2:** 1) Excellent proposed project. 2) It is too early on to make meaningful judgments. 3) A year from now, a serious look should be made to ascertain progress toward goals.

## Low Cap-Ex, High Speed Roll-to-Roll Perovskite Solar Module Development – $2,000,000

*Energy Materials Corporation | Norcross, GA | Principal Investigator: Stephan Deluca*

This project is developing a process to manufacture perovskite photovoltaic modules at unprecedentedly low cost and capital expense using high speed roll-to-roll printers. Unlike other thin-film technologies, perovskites combine the advantages of low-cost production with efficiencies on par with the dominant crystalline silicon technology. At this stage, the company is developing pilot production tools that will generate prototype modules demonstrating the module efficiency, stability, and cost structure needed to move into full production. Using existing production printers at Kodak, the company expects to produce modules at $0.30 per watt while utilizing U.S. manufacturing.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a very aggressive proposal looking at roll to roll fabrication of perovskite solar cells.

**Reviewer 2:** This project demonstrates the feasibility of RtR Perovskite manufacturing on a pilot scale. The produced modules have efficiencies lower than Si-modules, yet, they are printed on a flexible carrier and could cover a market segment that is inaccessible to Si-technology due to rigidity. Utilization of already existing manufacturing tools is another plus that would bring the overall costs of produced modules down. Successful demonstration will de-risk the technology and make potential investors feel more confident about perovskite-PVs.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 |
| Collaborates with sufficient stakeholders | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The performance is somewhat below the goals and milestones. Nevertheless, a great deal has been learned.

**Reviewer 2:** Project team has successfully demonstrate on a pilot scale manufacturing of perovskite PVs that pass IEC 61626 lifetime criteria. Research team has strong working relationships with industry partners, which is essential for moving a technology from lab to market.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: This project has 10 tasks and 17 milestones. It is clear that they are far behind their stated, aggresive objective: demonstrate 40 cm x 80 cm perovskite modules with cell arrays fabricated fully on RtR tools, demonstrating certified 17% efficiency and passing 1000 hours at 85 °C/85% RH with <5% power drop.

**Reviewer 2:** Score: 6. Comments: This project is important for reasons mentioned earlier - demonstration on a pilot-scale de-risks technology substantially.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** PI has no obvious blind spots, but may be overly optimistic in what can be reasonably accomplished.

**Reviewer 2:** I could not identify any ‘blind spots.’

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No missing stakeholders.

**Reviewer 2:** I think that the project deserves to be "advertised" to potential customers, off-takers. Therefore, PI and his team should develop few ideas on where their product could be used and strategically approach stakeholders in the identified markets.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Have demonstrated that roll to roll manufacture is a possible path to perovskite cell manufacture. 2) Have demonstrated high efficiency perovskite solar cells are possible. 3) Have not demonstrated high efficiency, scalable, perovskite solar cells fabricated using roll to roll processing are possible.

**Reviewer 2:** My main comment would be, that it is very important to continue supporting scaling-up of technologies that proved to be successful on a lab scale. This being said, SETO and researchers should carefully think about the potential market segments and applications and when funding such projects, emphasize establishment of relationships with stakeholders in identified markets.

## Low-Cost, High-Efficiency III-V Photovoltaics Enabled by Remote Epitaxy through Graphene– $977,483

*Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Jeehwan Kim*

This project is developing low-cost, high-throughput, and high-efficiency multi-junction photovoltaics by leveraging remote epitaxy and a two-dimensional layer transfer process that uses hybrid vapor phase epitaxy. This manufacturing method allows the growth of defect-free single-crystalline films that can be easily separated from the substrate. The substrate, which is expensive, can be reused by copying the crystalline information from the substrate through graphene. To validate the feasibility of this method, tandem photovoltaic cells will be grown and characterized to achieve maximum power conversion efficiency levels. In addition, the hybrid vapor phase epitaxy technique will enable high-throughput epitaxy at low costs, helping to produce photovoltaic cells at manufacturing scale.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Technoeconomic studies show that a low-cost method for forming a thin-film of III-V material is a key piece of the puzzle for improving efficiency of photovoltaics and lowering manufacturing costs, the primary goal of the New Cell and Module Structures, Designs, and Processes topic and in perfect alignment with SETO's mission. If "slippery" graphene delivers to the goal it will have a very high impact on the future of PV. Bringing the idea to PV from flexible electronics leverages DOE funding. Assembling a team with NREL performing the epitaxy – by potentially low-cost HVPE, another key piece – make the project's goals reasonable within the funding and duration shown.

**Reviewer 2:** Several excellent technical advances have been made during Year 1 of this program. The nucleation of graphene directly on GaAs is a major breakthrough, and avoids the layer transfer process. I think that is a game changer for this technology, as large scale transfer of a monolayer of graphene is incredibly problematic. The remote epitaxy by HVPE and subsequent exfoliation were also good accomplishments. There are still challenges associated with HVPE, and demonstration of a high areal throughput approach (not growth rate, but scale up to a large number of wafer throughput), either through a dynamic line or through a large area of wafers in a single batch, is still needed. That is beyond the scope of this program, but until that is demonstrated the LCOE cost targets will not be achieved. It is hard to beat Si PV! Another challenge that needs to be addressed is the remainder of the thin GaAs film processing. Somewhere in the process line the exfoliation will need to occur, and at that point what will the film carrier be? This will add cost. Can the pre-exfoliated wafer stand up to all of the front processing before the back processing is done? Again, terrific technical progress, but even if the substrate were free and the epi costs were zero (and they are not) will this approach be better than Si? Mention is made of the possible applications, which are great, but are they consistent with the SETO goals? So it is difficult to believe that a positive results will have a major impact on the US PV industry, especially for the terrestrial market.

**Reviewer 3:** While this is an interesting and challenging problem to tackle (lift off technique for III-V) it is difficult to understand the cost advantage. This could produce a higher efficiency terrestrial cell, the growth techniques do not seem to justify cost targets. The project seems better suited to a space program approach for extremely low mass PV panels.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 4 |
| Collaborates with sufficient stakeholders | 6 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The investigation hit a significant snag early on in that the preferred method to transfer the graphene film to the GaAs substrate failed and delivered a wrinkled film. The project quickly explored alternatives including growth of GaAs on graphene-coated Ge. That path did not work, as remote epitaxy does not occur for elemental semiconductor due to no existence of field penetration through graphene -- resulting in a Nature Materials publication. Direct CVD-growth on GaAs did work. The project is now back on course.

**Reviewer 2:** The program has met the goals, which were ambitious, and they are particularly to be commended for developing solutions to serious problems (direct deposition of graphene on GaAs as a solution to the issues associated with layer transfer). Since the project is early a significant number of publications is not expected. But they should have some in the upcoming year. They are working with several other organizations, but they should reach out to the US space industry (Solaero and Spectrolab) to see if there is interest. It would be good for them to make their results known to a wider audience, particularly for the graphene on GaAs.

**Reviewer 3:** The results to date are appropriate for the effort and cost. The characterization is not clearly covered to indicate proof of successful growth of films.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Key tasks are distributed to the best talent to fill the needs.

**Reviewer 2:** Score: 5. Comments: The project has tasks that build on one another, and it is well organized.

**Reviewer 3:** Score: 5. Comments: Approach adequately adds value from one step to the next, and use of partners for appropriate goals seems excellent. It is not clear the results of measurements that are taking them from one phase to the next. A cost analysis on each step would also be beneficial to assure end result is consistent with SETO goals.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Separation may not be a reliable as hoped. Add help from the ASU project on sonic wafering or NREL work on spalling could be of help if needed.

**Reviewer 2:** The technology is great, and they are making terrific progress, but that does not mean that it will result in a successful commercial product for terrestrial applications. The cost model for low cost III-V PV needs to be updated to ensure that the results will yield what is claimed for reducing III-V PV to a point where it will be used commercially and not in space or a niche market.

**Reviewer 3:** Program should look carefully at scalability of techniques used for growth of graphene and III-V compounds. This should also address cost benefits.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None are missing at this juncture.

**Reviewer 2:** Start working with the US space PV industry, and see if you can find an adopter of the technology for space PV. That may help to increase interest in this approach and lead to more investment.

**Reviewer 3:** Funded partners bring excellent skills to support the goals of the program. It is too early in the program to bring in a diverse group of stakeholders. If the project is successful, then manufacturing groups (cell and equipment makers) would be appropriate to add.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Excellent choice to fund a high impact potential benefiting from substantial prior development from other sources. The PI have other avenues for assistance within SETO's current investigations if film separation prove challenging.

**Reviewer 2:** The ability to deposit graphene directly on GaAs is a major breakthrough, and it has applicability to a much broader range of compound semiconductor devices than just PV. The cost model for III-V PV needs to be re-visited. For continued SETO investments in III-V PV there needs to be a compelling case that it can beat terrestrial Si PV, even if that includes III-V/Si tandem cells.

**Reviewer 3:** This is an exciting research project - lift-off techniques have been a long sought for method. Cost benefit may be better suited to spacecraft applications (i.e. power to weight importance.) Achievement of final outcome would still require a multi-year approach to achieve commercial viability. The industry is not well established in the US for this technology.

## Closing the Cell-to-Module Stability Testing Gap – $200,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joseph Berry*

This project targets the development of infrastructure to enable outdoor field testing for pre-commercial solar cell technologies. Nascent photovoltaics, such as perovskite solar cells, still have difficulty entering the market due to questions regarding reliability and environmental durability. While outdoor testing can provide valuable information, these tests are often conducted on laboratory demonstration modules with sub-optimal packaging. The lack of consistent packaging and module performance hinders the ability to separately assess the cell and package stability and makes it difficult to ascertain where failures originate. This project targets this problem through the development of a template module package for perovskite solar cells and building out of outdoor testing facilities and equipment. These capabilities will bridge lab scale experiments to module level questions addressing both packaging along with environmental impact to cells. This work will enable real world outdoor test required to de-risk perovskites and other innovations in photovoltaic modules.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 6 | 6 | 4 |
| Implement a high-risk, high-impact approach | 3 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a low risk, right-sized project located in the right place do deliver an important service to the burgeoning perovskite PV community.

**Reviewer 2:** The PI is to be commended for working to "fill in the gap". The program is well thought out and will be able to provide appropriate testing methodology for the stability of PSCs. The PI is also aware of the challenges and is working to mitigate them so that the program can be successful. It looks like outside entities are interested in the approach and would like to get devices on test. The only concern that I have is if accelerated testing could be done. Is the program just limited to on sun testing? Accelerated testing would help with learning cycles for PSC development and, if additional budget could be found, would be great to have implemented. The accelerated testing would be able to use the "standard packaging" but could obviously not be done in an outdoor test environment.

**Reviewer 3:** Strength of program is in the ability to do an intermediate environmental test on emerging material cells (specifically PSC) prior to module manufacturing commitment. Outdoor testing to allow this environmental impact provides the most realistic approach to technology viability. It's not clear, however, the intent of the cell enclosure. Also start date is unclear - i.e. Start date appears to be last October but no actual money against budget is included.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 4 |
| Collaborates with sufficient stakeholders | 6 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a new project just reaching its first milestone date. Milestones are tangible but could be more quantitative. The PI built a similar capability for the organics PV community approximately 8 years ago. The past performance; links to the NREL module and reliability group and NREL perovskites efforts (Joe Berry); and, gaining samples via Duramat all lend confidence to the probable value and success of the investigation.

**Reviewer 2:** It was not clear how the other stakeholders (entities providing samples for testing) would be engaged. The assumption is that a password protected web site will be set up where results can be monitored. How information would be disseminated was not clear. To the PIs credit the program is just getting started, so these comments are not meant to be a criticism.

**Reviewer 3:** Work in preparation to the project seems adequate. Issues of electronics and materials have been identified, but not clear differentiation of devices on encapsulation requirements vis-a-vis cell structure and chamber encapsulation.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Two tasks: develop and outdoor test platform and create standard packaging to give novel technologies a level playing field. The first task is unique and valuable because of the location at NREL. The second permits leading teams to focus their strengths on advancing cell technology, undistracted by the great challenge of reliable encapsulation.

**Reviewer 2:** Score: 5. Comments: Yes, the PI has a great plan to implement the overall program

**Reviewer 3:** Score: 5. Comments: This is a critical task to help move from cell to module technology. Approach seems logical and well thought out, but may underestimate complexity of designing desired environmental chamber.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No blind spots.

**Reviewer 2:** No major "blind spots" are evident. Two concerns previously mentioned are possible acceleration of testing, and making sure that testing results are available in real time.

**Reviewer 3:** Complexity of desired environmental fixture. Not sure specifications other than desired thermal budget.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** At this stage, none.

**Reviewer 2:** None obvious.

**Reviewer 3:** Good collaboration with internal NREL researchers is clear. Collaboration with Duramat and MHPSC team critical to define next steps in collaboration, as they are directly involved in outreach to university and manufacturing groups.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is similar to NREL's facility for outdoor testing of organic PV. Hybrid perovskites solar cells have many ways to degrade from mechanisms similar to all other PV device, e.g. contacts, H2O, corrosion, encapsulant failure, etc., and ways that are unique, e.g. ion migration, phase change, delamination. There are very little useful outdoor test results for this promising technology.

**Reviewer 2:** Testing such as this needs to be funded at a higher level. Having NREL as the test location adds credibility to the results, and so work such as this needs more support.

**Reviewer 3:** Project is important, if not critical, to the successful movement of cell technologies to market. It is not clear how differentiation will be made for cells vs. mini-modules when decision is made for environmental chamber. Encourage this integration with other material research groups.

## Flexible Perovskite-Perovskite Photovoltaics for Mobile Power Applications – $745,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: David Moore*

The National Renewable Energy Laboratory and Swift Solar are collaborating to commercialize the lab's novel solar cell device design that enables the manufacturing of lightweight, flexible, and highly efficient multijunction perovskite solar cells.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project focuses on developing scalable processes for making flexible perovskite PV devices. The goal is to produce 10x10cm flexible, functional mini-modules using processes that have the yield and reproducibility for production. While the long-term market may be mainstream solar applications, initial focus is on niche, portable power applications. This project is therefore an early stage steppingstone to SETO's mission.

**Reviewer 2:** The NREL/Swift collaboration is working toward scalably-produced flexible tandem perovskite cells. The project tackles moving to industrial-type vapor deposition for the wide gap material incorporating DMA to limit the Br needed. They also seek an industrial recombination layer. Before the project and during the first months, the team has had some successes in making wide gap materials and cells with the vapor process and have a better understanding of the gap widening mechanism. They have important milestones around stability, but early results are promising. The close collaboration between Swift and NREL is excellent for technology transfer and the 50% cost share from Swift means they are serious about collaborating. Swift has wisely chosen to entire the field through the niche markets of drone power and on-board EV charging; they are wise to not go head-to-head with the Si PV manufacturing behemoth initially even those these markets raise the pressure to obtain efficiencies about 25% on a flexible substrate. This seems a good use of SETO money with the possibility of launching a US perovskite cell industry.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The work is appropriately structured and has good criteria. The focus on portable power applications is not directly in line with SETO objectives, however. Although the PIs are connected to NREL, they are not working with established industry players which would likely speed work and ultimately deployment of a successful technology.

**Reviewer 2:** The project began in November and already has results. For example, they have bent flexible tandems and find little or no efficiency change. Those milestones I know about are directed toward the things Swift needs to begin manufacturing. They have chosen to stay close to layer formulations that NREL has already proven. These all improve the chance of success.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The work is appropriately gated. The PIs claim that the fundamental PV materials have already demonstrated capability (efficiency, stability, etc). The current focus is on depositing the films using high yielding and reproducible process technologies that can scale to larger size and higher volumes.

**Reviewer 2:** Score: 6. Comments: The only potential weakness is if they cannot improve upon single junction efficiencies by going to the tandem structure. This was not mentioned in the writeup. They do need high efficiency to compete with III-V's in the UAV market and presumably also for on-board EV charging.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PIs have presented a thoughtful plan for exploring scalable processes while addressing key composition and atomic structural challenges of the materials. The efficiency and cost potential of perovskites is significant. However, perovskite challenges are also formidable including: Material stability in real world applications; Integration of the tandem device and the associated electrical circuitry; Acceptance of heavy metal materials in the marketplace.

**Reviewer 2:** I hope the PI understands the UAV power competition from III-V companies like Microlink, which sells flexible PV with over 30% efficiency. As the project report says, this market is not very price sensitive, so they'll need to get efficiencies over 25% for sure.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Commercializing the technology will require substantial resources (financial, technological and commercial). Today's PV market has a higher entry barrier compared to the past. Collaboration with established players would likely improve results in a shorter period of time.

**Reviewer 2:** As this project develops, they should try to hire some ex-Microlink business types who know the UAV market well.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) PIs claim that core PV milestones have been achieved using flexible perovskite devices. This project focuses on developing processes that could scale. 2) Initial market/product is targeted for mobile applications (not low cost power generation). 3) Perovskites hold substantial promise for longterm advancement of high efficiency, low cost solar electricity. This initial step could prove value in that effort.

**Reviewer 2:** 1) Get the efficiency to near 30% quickly with vapor deposition, since that is the only good reason to make a tandem and the key to entering their chosen markets. 2) Flexibility is good enough already, don't worry about that. I suppose that cost is also less important once reasonably fast deposition techniques are established. 3) Transfer to the moving line at Swift as soon as possible and/or work in parallel with NREL.

## Halide Perovskite Solar Cells – $5,547,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joseph Berry*

This core photovoltaic support project examines critical materials, integration, and device issues required to propel the development of halide perovskite solar cell technologies. This project uses a scientific approach to understand the roadblocks and risks associated with commercializing halide perovskite solar cell technologies, including any challenges to fully scalable manufacturing and long lifetime field operation. This project focuses on stability research to better understand mechanisms that cause degradation and failure in halide perovskite solar cells and develop device stability acceleration factors that can be applied across relevant halide perovskite materials for photovoltaics and associated device architectures. This work is device focused but has a materials-driven emphasis in order to overcome the efficiency, stability, and scalability challenges preventing halide perovskite solar cells from reaching $0.03 per kilowatt-hour by 2030.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 | 6 |
| Implement a high-risk, high-impact approach | 2 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 1 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** While perovskites could certainly move PV performance up and lower cost, this "project" sounds more like a broad program to address all perovskite issues. As a result, the high risk technology challenges appear to be compounded by high risk management challenges.

**Reviewer 2:** This project addressed the three most pressing challenges faced by perovskite PV technology: stability, scalability, and efficiency. The team studies the fundamental processes behind some of the physical or chemical characteristics of photovoltaic materials that have large impact on the performance, price, and competitiveness of this emerging technology. There are many strengths to this proposal and no significant weaknesses. I really like that the team closely collaborates with industrial partners and addresses the real-life problems. Also, in general, this is great project as it will allow smaller startups to cost-effectively implement identified strategies that would make perovskite-based PV commercially viable without the need to invest own resources. Hence, the results will benefit the entire industry and will accelerate technology transition from lab to market.

**Reviewer 3:** This is a very challenging project--a lot of work has been done but mostly "around" the project goals.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 5 | 2 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 4 |
| Collaborates with sufficient stakeholders | 6 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Numerous accomplishments have been documented in 27 published papers. It is difficult, however, to tell how close the research is to informing a high performing, scalable device that satisfies industry standard durability requirements at requisite costs. Furthermore, no budget or timeline update were included in the prepared report.

**Reviewer 2:** Project has only started in October 2019 and not many milestones has been achieved so far, but team has a clear understanding of potential challenges and is being proactive in anticipation of such. This provides the confidence in team's ability to complete the project on time and with good results.

**Reviewer 3:** This is an ambitious project, and as a result is having difficulty getting running.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: From the prepared paper, it is very difficult to understand what the deliverables are for each task or how much progress has really been made.

**Reviewer 2:** Score: 5. Comments: As mentioned earlier in this review, performance of perovskite-based PVs is an important factor determining how successful they can be in the area that is currently dominated by Silicon-based PVs. Team looks particularly at the stability and efficiency. On the top of it, team also studies factors affecting the scalability of the technology - which allows to translate research results into real life applications. I don't know in what form the results will be delivers - reports for each task or combined final report, but it would be great to see the results ordered into a sort of matrix showing the interdependency between factors affecting performance and factors affecting scalability. Maybe something what would increase efficiency doesn't necessarily makes sense for scalability. This type of analysis would be really great and unique.

**Reviewer 3:** Score: 3. Comments: Well chosen tasks.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** From a technical perspective, the PIs clearly understand the breadth of their challenges. Despite claiming many successes, the list of risks remains large. However, the scope of the proposal is essentially to invent and commercialize perovskites which is broader than a typical project of this type. Given the number of non-technical challenges mentioned or implied by the paper, it seems that there is need for additional managerial over-sight.

**Reviewer 2:** Perhaps this is already part of the project, but under scalability I would recommend that PI looks at toxicity and environmental impacts stemming from large-scale integration of this technology.

**Reviewer 3:** PI is aware of the difficulties.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It appears that most everyone in the US that is working on perovskites is connected with this team. Again, better management oversight and coordination may be warranted.

**Reviewer 2:** I think the project covers this pretty well.

**Reviewer 3:** None--might be better to focus on one of the tasks at this point.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Perovskites, if commercialized, could move the PV industry to the next level of efficiency and lower LCOE. However, perovskites are currently limited by numerous technical challenges such as stability, durability and processing. 2) The goals of this project are essentially to solve all the technical challenges associated with perovskites: material formulation, stability, accelerated life tests, device structure, processing, etc. 3) The poorly crafted document fails to report on funding or schedule progress.

**Reviewer 2:** 1) Great job prioritizing scalability issues. This is one of the areas that is often overlooked. 2) Team's engagement with stakeholders - this feedback is critical to make results actionable and applicable in real-life. 3) I don't know how much the licensing of project results may cost, but hope this is not cost-prohibitive for smaller companies.

**Reviewer 3:** 1) Ambitious project with large team. 2) Getting results "around "the objectives. 3) Having difficulty getting going.

## High-Efficiency, Low-Cost III-V Solar Cells by Dynamic Hydride Vapor Phase Epitaxy Coupled with Rapid, Polishing-Free Wafer Reuse through Orientation-Optimized Spalling – $200,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kevin Schulte*

Low-cost III-V photovoltaics have the potential to lower the levelized cost of energy because III-V cells outperform silicon in terms of efficiency and annual energy harvesting efficiency. In this project, researchers address both the high costs of III-V epitaxy and single crystal substrates. Hydride vapor phase epitaxy is the most promising inexpensive, rapid-growth technique for high efficiency, III-V materials. The continued development of high-throughput hydride vapor phase epitaxy is coupled with novel epitaxial liftoff strategies to enable III-V solar cells that are cost-competitive under one-sun conditions.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 5 |
| Set critical challenges to overcome | 6 | 6 | 6 |
| Implement a high-risk, high-impact approach | 6 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** After a lapse of 30 years, growth on 110 surfaces returns to take advantage of the preferred cleavage plane. Work at MIT and Kopin funded by DOE, developed a separated GaAs thin-film process that produced cells with efficiency of 22% single junction and 24% thin-film tandem. This current investigation is well aware of this work and have captured many of the challenges and opportunities in their discussion. Work on orientation dependent growth rates and dopant incorporation has also experienced a period of dormancy. HVPE has competing growth and etch reactions such that the vertical growth rate on the (110) surface may be far slower than on (100). With the current awareness of the importance of achieving both low cost and high efficiency, the subject investigation stand a better chance of realizing the high impact goal. The challenges of optimizing growth on an orientation other than 100 are great and fully appreciated by the team. While the task of spalling may be simplified by the chosen orientation, the demands on residual surface roughness make this an equally challenging objective. The project would not be completed within the funding and duration planned in any other organization, as it benefits from the core program in III-Vs and experience in D-HVPE. Of course, techno-economic studies show that a low-cost method for forming a thin-film of III-V material is a key piece of the puzzle for improving efficiency of photovoltaics and lowering manufacturing costs, the primary goal of the New Cell and Module Structures, Designs, and Processes topic and in perfect alignment with SETO's mission. Doing so with D-HVPE's low cost potential addresses a second and equally important process component.

**Reviewer 2:** The project has two very difficult challenges to overcome, demonstration of DHVPE growth of multi-junction cells on (110) GaAs and rapid, polish free re-use of GaAs substrates. The level of funding and the planned project duration are inadequate for these goals. Realistically the project should be for 3 years and the level of funding for each year should be at least $500k, so that is why I give that question a lower ranking. No fault of the PI! Considering the level of funding great progress is being made. The solution to use a different substrate plane is creative and an excellent solution to some of the spalling challenges. Technically, there are a number of concerns of which the PI is well aware and is trying to address, including adding the metal to create the mechanical stress for the spall, initiating the spall at the wafer edge, developing an edge release mechanism so that the spalled layer does not "hang up" due to the edge. A concern is all of these add cost to the process, and in the end do we have a cheaper process than a new substrate? A host of other questions need to be asked about the DHVPE. What are the capital equipment costs associated with developing such a tool? How much lower will the run costs be compared to MOCVD? There are also a lot of other costs associated with processing III-V solar cells. If the substrate costs and growth costs are eliminated, this would probably only reduce the cost of III-V cells by 50% due to the other processing costs. And, for spalled material, there will be addition costs due to the need to attach the spalled layer to a carrier for processing. Will the metal stress layer become part of the final processed cell? Again, great technical/scientific progress is being made, but the overall view of using III-V for terrestrial PV needs to be seriously re-evaluated.

**Reviewer 3:** Project has significant potential to reduce cost for III-V solar cells. While this is presently a niche market, success could move this to more mainstream terrestrial use. High risk program that is appropriately funded with good partner. Success would support one of the few solar technologies that US leads in.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has just started and already achieved its first milestone to grow high quality GaAs on (110) substrates. Milestones for the remainder of the project are quantitative and realistic. The partnership with the very capable team at CSM benefits from the proximity of the two organization.

**Reviewer 2:** Despite being critical of the overall approach in terms of achieving the SETO goals, the PI has done an excellent job for the technical work considering the budget and schedule. Do reach out to the US space PV industry to see if there is interest in this approach.

**Reviewer 3:** Project is well thought out, with clear analytics to determine progress and appropriate direction of research. Still too early in the program to determine if partnerships and information dissemination is appropriately achieved.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Two Tasks. Learn to grow and make solar cells on (110) substrates. Learn to separate then and leave an epi-ready surface. As a relatively small project this is all that can be done and all that is needed.

**Reviewer 2:** Score: 5. Comments: In the light of the project goals the tasks are important and are moving technical and scientific understanding forward.

**Reviewer 3:** Score: 5. Comments: Goals are clear, analytics are excellent, and goal progress is clearly formulated.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1**: The PI has carefully researched prior work in this field and has been informed of unforeseen barriers those investigators were unable to overcome. There may be no more blind spots.

**Reviewer 2:** The PI is aware of the technical issues, the concern is that the solutions to the technical issues will increase the cost of the approach will increase the LCOE and thereby make the overall approach impractical to implement. The best application of the technology may be in the space PV market. The PI should continue discussions with the companies that are mentioned in the summary.

**Reviewer 3:** Still too early to tell, but seems that so far approach and data acquisition and evaluation are appropriate.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** As mentioned, as work progresses each of the 3 thin-film III-V concept investigations may benefit from collaboration and shared technology.

**Reviewer 2:** The PI is well aware of interested organizations and stakeholders.

**Reviewer 3:** Project team has identified potential interested parties that could take this commercial. It's a small universe of active III-V solar cell producers in the world. Are there other industries in III-V device fabricate that might also benefit from this technology if successful?

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Lift-off technology for producing high efficiency solar cells affordably requires a technology lower in cost that the lateral etch processes and one that can reuse the substrate with minimal work to return it to epi-ready. This is one option that may achieve this goal. While very promising, it will probably take long than the investigators think. Persevere.

**Reviewer 2:** First, scope projects to the budget or provide adequate budget for the project. The budget and schedule are inadequate for the tasks. Secondly, keep the critical metric, LCOE, always in mind when funding projects and make sure that recipients are always considering that as the programs progress. If developments that add considerable cost are added during a program, while resulting in technological advance, will the additional cost preclude the technology from ever being adopted for terrestrial PV applications? Will III-Vs ever be viable for terrestrial PV applications?

**Reviewer 3:** Program is well constructed and dollar value seems very good. NREL capabilities to support evaluation and data acquisition is excellent. Collaboration is early but well thought out by PI.

## Hybrid Tandem Photovoltaics – $955,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Adele Tamboli*

Tandem or multijunction solar cells are able to convert sunlight to electricity with greater efficiency than single junction solar cells by splitting the solar spectrum across sub-cells with different bandgaps. Combining well-established photovoltaic technologies into a single tandem architecture holds promise for dramatically increasing total cell efficiency, but substantial development is needed to address the challenges of scaling hybrid tandems from lab "hero cells" to interconnected large modules. This project seeks to demonstrate high efficiency III-V/silicon tandem solar cells, strings, and modules with a primary focus on benchmarking the three-terminal tandem in relation to state-of-the-art two- and four-terminal configurations. This includes robust device and string simulations, experimental cell and string demonstrations, and reliability testing of cells and novel components.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 6 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The primary and unique benefit of this project to the New Cell and Module Structures, Designs, and Processes topic is the exploration of module designs incorporating mechanically stacked multijunction cell structures including circuits using 3 and 4 terminal cell configurations. The major goals and challenges address this key issue. The four listed challenges are all on point. Later in the report, some milestone descriptions suggest the scope does veer into less important issues. For example, it is not clear that the producing and testing GaInP top cells will deliver commensurate new information relative to GaAs, although the higher efficiencies may generate added excitement. This is one of very few early-stage research and development projects with sufficient promise to have industry participation. The first reports of experimental Si-based 3T tandems only appeared in the last year. Three terminal tandem cells over the IBC silicon have clear advantages for energy yield and production simplicity versus the 2T or 4T devices as described in the report. The high impact carries a high risk in challenges related to user acceptance of the 3 terminal cell. The team's recent publication of a 10-page ACS Energy Letters addresses the complexity, introducing a standard taxonomy to discuss variants of the device structure, how to measure the performance and loading topology. This approach to addressing the risk is an excellent demonstration of the role of a National Lab in the nation's interest. The project leverages research support and industry participation from the space PV applications, an early high value market for product introduction. With the closing of Alta Devices and loss of significant manufacturing capacity, advancing III-V solar manufacturing for terrestrial application has a greater barrier.

**Reviewer 2:** The PIs have done a terrific job of developing the 3T approach and demonstrating feasibility and proof of concept for a number of configurations. They have done a great job of thinking through all of the possible configurations. The project is also adequately funded and given adequate schedule for the work. The approach and tandem architectures are what are most important about this project. The TCA demonstration and initial qualification are also to be commended. They have developed a solution to one of the challenges with tandems, i.e. the need for current matching. In terms of concerns, can III-V cells be incorporated into a tandem cell with Si and be cost feasible, even with HVPE and growth substrate re-use? The additional costs of III-V processing are still too high to make it cost competitive with Si. However, the approach demonstrated in this project may be applicable to perovskite/Si or thin film/Si, and that is where the terrestrial application may be. Of course, the III-V/Si 3T approach may be suitable for space or niche applications. One other concern, which the PIs are aware of and have worked on addressing at the module level, is the wiring and power management required for 3T devices. What are all of the options, and what is the added cost? The Si cell processing adds complexity and cost, and obviously needs to be factored into final LCOE determination. BTW, this approach also provides an advantage if the cells in the stack degrade during their lifetime. The overall reduction in power will be less than that for a 2T device. Great job on the technical work, do think about cost implications for solutions that are developed to solve technical challenges.

**Reviewer 3:** The project addresses an interesting approach to enhancing cell efficiency. Use of TCA is key to success, and early field testing is appropriate for proof of concept. While this work, if successful, will be important, is there a strong enough US base of manufacturing to implement the results?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The very clear description of the organization of this work highlights the focus on understanding the implications of new module designs. "The majority of the work described here physically takes place at NREL. Collaborators at CSM work in the NREL labs. ISFH fabricates 3T Si bottom cells for this project in Germany and provides them to NREL for integration into tandems. SolAero provides large-area growth of III-V cells to NREL, where the material is processed and integrated into tandems." Obviously, NREL has the capability to produce all aspects of this work, but this investigation has been designed to tap the skills and collaboration of important stakeholders.

**Reviewer 2:** The team has set challenging, quantitative goals, and they are making progress towards achieving them. They have also done an excellent job in reaching out to others, and approaching this program from a team perspective. They have an impressive list of publications and patents. The team is a very bright group of people that works together very well.

**Reviewer 3:** Biggest issue is with measuring quantitative results. Most important to success of this work is to demonstrate cost effectiveness for terrestrial applications. While outdoor testing early on is an excellent activity there does not appear to be cost evaluations. Milestones met to date are excellent.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The focus on technology and performance of mechanically stacked tandems and associated emphasis on the enabling transparent conducting adhesive layer are the primary value of this investigations.

**Reviewer 2:** Score: 5. Comments: They have a “graded” approach towards achieving the overall program goal. While the final application, in my opinion, will not be III/Vs w/Si, they have demonstrated feasibility with that system, and hopefully the work will be extended to include perovskite/Si and/or thin films/Si.

**Reviewer 3:** Score: 6. Comments: Technical goals are excellent and have been met nicely. Value of trying approach on too many materials seems marginal until full up testing has been accomplished. Proof of stability of TCA layer is valuable for many other applications.

### 4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Clearly, the focus on understanding the performance of this type of solar cell is a major strength of the investigation. They know they will need low cost deposition, such as HVPE, and a low-cost method for making thin top cells. Both are beyond the scope possible for the funds and duration of this investigation, and these topics are supported elsewhere in the SETO program. The mechanically stacked tandem cell approach requires careful control of reflection at three times as many interfaces as a conventional module. The investigators are well aware of this, but may lack an appreciation of the added process cost this control will require.

**Reviewer 2:** Be aware of the added cost of Si processing, power management with a 3T device, as well as the added cost due to inclusion of the III-V device. The cell architecture needs to be implemented in a low-cost way. The III-V/Si 3T device is the exemplar. Take this the next step by integrating other low-cost devices.

**Reviewer 3:** Care should be taken to not “try” to many different materials until goals on typical (Si and III-V) are met. Models of LCOE on the devices should be exercised - will end result (beyond space applications) be less expensive than either high efficiency silicon structures or conventional tandem III-V cells?

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** At this stage of the investigation, the project has engages all of the needed organizations.

**Reviewer 2:** They have already engaged the relevant parties and are to be commended for that.

**Reviewer 3:** Project has accumulated an excellent internal team, and appropriately tapping outside resources for materials and evaluations. Because of outreach efforts by PI it appears that important stakeholders are being involved at this point.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** These investigators have established a tight focus on the issues of key importance to eventual application of tandem solar cells and need to be able to continue the investigation without distraction of the future cost potential implications of test structures they employ. The investigators recent paper presenting a taxonomy for discussion, measuring and application of 3 terminal tandem cells was long overdue and a very valuable contribution from SETO funding. Three terminal devices are complicated with significant potential value.

**Reviewer 2:** The PIs have done an excellent job! Secondly, consider ways that this approach can be implemented with perovskite/Si and/or thin film/Si devices. A follow-on project in that area with this team would be a good investment and should be seriously considered.

**Reviewer 3:** LCOE should be continuously evaluated with respect to falling Si module costs. Work is well thought out and goals clear but involving too many material combinations may dilute effort and success. Development of the TCA component and proof of stability is important. Information dissemination through publications is outstanding.

## III-V Photovoltaic Cell Core Capability – $8,100,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Myles Steiner*

This project creates a path toward cost-effective III-V solar cells. The materials used to create these cells offer many advantages, including the potential for high solar cell efficiencies, relatively low sensitivity to changing temperatures, environmental stability, and their light weight and flexibility. This project is researching materials and device architectures that can lead to high solar cell efficiencies and develop a low-cost substrate growth technique called hydride vapor-phase epitaxy. The team is also researching substrates, including silicon, that are inexpensive or able to be removed and reused will be investigated to create these low-cost III-V solar cells.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 6 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a large, multi-faceted project that is well aligned with The New Cell and Module Structures, Designs, and Processes topic's first two objectives to improve efficiency of photovoltaics and lower manufacturing costs and comparably aligned with SETO's mission. It is composed of three thrusts – practical high efficiency cell architectures, low cost epitaxy by D-HVPE, low-cost crystalline film processes. While some groups pursue the limits of efficiency, using up to 6 junctions, this team aims for the best one sum solution with efficiency >40%. HVPE was abandoned 30 years ago, in spite of its many superior capabilities, because it was incapable of producing Al bearing layers needed for the best solar cells. Solution was an achieved goal of the group this year. Finally, in thin-films they are working on four of their own unique ideas and collaborating with at least three other groups working on other inventions. The exclusive focus on high performance photovoltaics has produced some clear leading strengths. Through their numerous collaborations with groups having more diverse interest, they also leverage non-DOE funded research.

**Reviewer 2:** The scientific and technological developments on the program have been very good to date. The HVPE work with Al compounds (developing the precursors and the Al containing semiconductor material) has solved a long term, lingering issue with the approach. The cell performance improvements, particularly with the strain balanced QWs is also very good, and the goal to improve metamorphic cells with thin buffers is also to be commended. The technical team is excellent and have done excellent work. The concern with the program is if III-V cells can ever be cost competitive compared to Si for terrestrial applications. If the substrate was free and the epi costs were zero, the processing costs of III-V cells would have to drastically change to get the LCOE down to that for Si or CdTe. But substrate costs are not zero, and most efforts to re-use substrates end up with processes that add cost and end up close to the cost for a new SX polished substrate. For example, a thin film released from a substrate requires additional cost to attach to a carrier or holder to finish processing. The substrate needs to be cleaned if not polished again. The example of Alta Devices, the company that tried to commercialize III-V cells in the past decade using ELO, high throughput MOCVD, and low cost processing yet is now bankrupt is sobering. While HVPE has made great progress in the past 10 years, there are significant capitalization costs as well as design work that needs to be done to achieve the kind of throughput that a large MOCVD tool can achieve. So, while scientific/technological progress has been excellent, the underlying cost structure of III-V multi-junction cells is still too high to make the technology cost competitive with Si for terrestrial applications. There may be applications for space or niche markets, and that is probably the best approach to commercializing this technology.

**Reviewer 3:** Project brings together some of the brightest investigators to tackle the issue of a reduced cost, high efficiency III-V structure. Approach is excellent to take a low-cost growth technique and address most critical issue (i.e. incorporation of Al into the technique). However, there is a lack of developed industry outside of research organizations to implement successful results from project.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Techno-economic studies show that III-V cells can compete in terrestrial PV markets. After efficiency, the two biggest cost drivers are the cost of epitaxy and a low-cost method for forming a thin, single-crystal film. At present D-HVPE is the only chemistry that has the growth rate and material quality to hit the targets for low-cost epitaxy. All of the innovation bringing it back to the fore has come from this group's work, most recently with creation of a source for aluminum. The projects milestones in these areas are quantitative, appropriate and achieved. The short report may have short changed listing publications, but the direct output is adequate. Much of the work also appears in publications of their numerous collaborators.

**Reviewer 2:** The team is doing an excellent job in creating quantitative performance milestones and achieving them. They could collaborate with more stakeholders that would be first adopters of the results, e.g., Spectrolab & Solaero. The program is doing a good job of publishing.

**Reviewer 3:** Project accurately measures progress of technical results. However, like many (most?) projects of this kind it appears the focus is on highest efficiency achieved. What are the ongoing cost evaluations of different approaches made - are they being analyzed real time? Budget seems appropriate for level of work (contract budget quite a bit higher than original??) and collaboration. Information dissemination via Journal publications appropriate.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The three primary thrusts, as mentioned above, are each unique and hit the three most important developments needed to realize affordable, high performance and high value solar technologies on the grid. Within these thrusts there may be finer structure in tasks although these were not reported in the short Peer Review Report.

**Reviewer 2:** Score: 5. Comments: While there are serious concerns about the ability of III-V MJ cells to achieve cost parity for terrestrial applications, the program tasks are unique and are addressing costs aspects of III-V cells. They are working on important things within the context of the program.

**Reviewer 3:** Score: 6. Comments: Project is well laid out with effective goals to build on either the next step forward, or incorporation of external project success into the main goals of this project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI benefits from the active collaboration, regular meetings and frequent sample exchanges with numerous other leading PV groups around the world. This certainly contributes to better vision and lower risk of blind spots. Physically located in the same building with leaders in other PV topics - silicon, thin-films, perovskites - similarly helps the vision. The only concern is the current lack of terrestrial products and ability to initiate durability testing, although some of this will start in the related project with Tamboli.

**Reviewer 2:** While trying to develop technology to reduce costs in one area, be careful that you are not adding costs that offset the original improvement. Scientific & technological progress has been great, but a serious consideration of ultimate costs needs to be made or revisited.

**Reviewer 3:** There should be a continuous consideration of cost implications on decisions made regarding path forward.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The closure of Alta Devices removed the most visible industrial partner with clear intent for the terrestrial PV market. This is a major loss, but not necessarily critical. The remaining companies can still advise on production issues.

**Reviewer 2:** Please have more engagement with the US space cell suppliers, ie., Spectrolab and Solaero. They would probably be the first ones to implement the technology that is being developed.

**Reviewer 3:** This is a base research program, and necessary external and internal resources are appropriate. Unfortunately, there is not a strong outside commercial industry to actively participate beyond those partners already enlisted.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The NREL team is focused on the 3 key issues for advancement of high-efficiency, one-sun cells -- practical high efficiency, low-cost epitaxy, and single-crystal thin-film handling. Their leadership in each of these three areas makes them a sought-after collaborator for many other innovators. They are a key contributor to most of the best high efficiency projects in the New Cell and Module Structures, Designs, and Processes topic.

**Reviewer 2:** Please be more careful about cost models that are developed that indicate III-V MHJ cells can be cost competitive with Si for terrestrial applications. The technological advances on this program are great, particularly the development of Al compounds for HVPE and the subsequent demonstration of the growth of Al containing semiconductor material. Cell performance improvements have also been very good.

**Reviewer 3:** This is a critical component of the US development activities in high efficiency PV conversion. It is high risk, but high reward programs like this one that may make a significant impact in continued energy production cost decreases from PV. Program goals should align both with improved efficiency and reduced cost - it appears goals are most heavily driven by efficiency.

## Vapor-Phase Growth of Low-Dimensional Perovskite Interfacial Layer for Stable and Efficient Perovskite Solar Cells – $200,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kai Zhu*

Low-dimensional perovskites have shown promise for improving the stability of perovskite solar cells. The challenge has been the lack of control on the structural/chemical/electronic properties of new materials/structures induced by the bulky cations. This project aims to develop a vapor-phase approach to coat a uniform compact low-dimensional perovskite contact layer with improved barrier properties on top of a state-of-the-art three-dimensional perovskite absorber to enhance perovskite solar cell stability. This approach allows control to tailor the low-dimensional perovskite interfacial layer so that one can obtain proper energetics and out-of-plane transport for effective/selective charge extraction for higher perovskite solar cell efficiency and stability. The goal is to establish a new technical approach that can be added to the state-of-the-art technology platform to accelerate the development of stable and efficient perovskite solar cells.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This small ($200k) 1-year SIPS projects aims to develop and test 2d perovskite layers atop 3d perovskites that can enhance their long-term stability. The first quarter of project work has enabled to the team to demonstrate the vapor conversion of 3d to a 2d top layer for which was one of their key goals. These 2d perovskite materials are a frontier topic in global perovskite research so it is good that NREL has its hands in. In keeping with SIPS, this is a rather speculative project, since it is not certain that success will actually produce a more stable 3d perovskite cell.

**Reviewer 2:** If commercialized, perovskites could significantly increase efficiency and lower LCOE. Stability and durability, however, are key challenges. This work hopes to incorporate 2D structures with 3D structures to improve stability. The team intends to develop the processes for the depositions without adversely affecting the device.

**Reviewer 3:** I understand that this project is relatively small (funding amount) and has a very narrow objective - to investigate what happens to the precursors molecules that form a 2D perovskite layer when they are transfered from a vapor phase to the surface of 3D perovskite layer. This is an important and rather fundamental question that is useful when developing a manufacturing processes based on vapor deposition technique. From project description it also sounds like the end product would be a perovskite-on-perovskite tandem module on a glass substrate. This product would directly compete with Silicon-PVs. I am not convinced that this is the best path to commercialize perovskite technology. I think they have more chances to be successful in the products would at least at first target niche markets where Si-PVs have their limitations (rigidity, weight).

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 4 | 5 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** While the materials science goals for the 2d layers are clear, it is less clear how much additional work after this project would be required to demonstrate improved perovskite cells.

**Reviewer 2:** The project has clear goals and success criteria both at the device level and the chemical/morphological levels. The team is currently not working with experts outside NREL. The project is only about one-third completed and has not yet published results.

**Reviewer 3:** Project team has a very clear goal that they are capable of meeting. If the team will encounter challenges, there is no doubt they can tap into NREL's experience with perovskite technology and resilve them in timely manner.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The chemistry and materials science parts of this project are well defined. The team hasn't got evident milestones for out of plane conductance of the layers - which should probably guide their search even in a short SIPS project. I don't see the metrics for transport measurements. I also don't see milestones for the promised improvements in stability through 2d perovskite barrier functionality.

**Reviewer 2:** Score: 6. Comments: The PI has clearly outlined a step-wise plan for formulating 2D structures and then incorporating them with 3D structures.

**Reviewer 3:** Score: 5. Comments: I think this project in general addresses one task (vapor deposition of 2D perovskite on 3D perovskite layer) that team has divided into a reasonable amount of subtasks.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** 1) Well-defined barrier property measurements for the 2d layers. 2) Well-defined transport property measurements for the 2d layers.

**Reviewer 2:** The PI has done a good job of thinking through potential roadblocks not only within the material science aspects but also in the process technology needed to formulate the materials.

**Reviewer 3:** Perhaps, PI did not consider what potential market and applications for 2D perovskite-on-3D perovskite could be and how they would compete against the dominant technology (Si).

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No need for an extensive network at this early stage

**Reviewer 2:** Rather than being exclusively dependent on expertise within NREL, the PI should explore whether similar work is being or could be done at academic facilities.

**Reviewer 3:** Other research teams that are using vapor deposition technique for manufacturing of perovskite cells/modules.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This kind of exploratory work alongside the NREL core work is beneficial in seeding future technologies.

**Reviewer 2:** 1) Perovskites could improve solar performance at low cost but are currently limited by stability and durability issues. 2) This work explores the possibility of incorporating 2D perovskites with 3D perovskites to stabilize the materials without muting performance. 3) The work addresses material and process technology issues needed to formulate the structures.

**Reviewer 3:** Just one general recommendation for SETO's research on perovskites: perovskite PV materials are in a way just anoher photovoltaic material like silicon, that uses the energy of the sun to produce electricity. On the other hand, this material is so different - it is light, transparent, and flexible. SETO should focus a little bit more on the perovskite qualities that make it different from perovskite and strategically fund research that would help to create products and new applications for perovskite PVs in niche markets that are inaccessible to silicon PVs.

## Building Windows with Transparent Photovoltaics to Lower Costs – $2,500,000

*Next Energy Technologies | Santa Barbara, CA | Principal Investigator: Corey Hoven*

Next Energy Technologies Inc. has developed transparent photovoltaic coatings for integration into commercial windows. These low-cost, wet-coated materials selectively absorb and convert light in the infrared and ultraviolet spectrum while allowing significant visible light transmission with colors that are desirable to the window market. This approach uniquely allows the photovoltaic windows to look like conventional windows, but also allows for reduced module and balance of system costs by leveraging existing window costs. This project enables the project team to transition from small-scale 3.5 inch units produced using laboratory processes to larger format devices utilizing manufacturing-relevant processes.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 |
| Advance the U.S. solar industry substantially | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project serves to utilize existing window infrastructure as a platform for inserting an active PV device. In doing so, many of the traditional costs of a module (glass, frame, support structure, etc) are already in place. The incremental cost is proposed to be relatively low thus achieving the $.04/kWh LCOE target. The project seems to be well-scoped with appropriately prioritized metrics, timeline and budget. Many of the more difficult challenges of this technology are outside traditional PV issues. Specifically, these include visual clarify, uniformity and their relevant uniform degradation characteristics. Additionally, building owners will need to incorporate electrical (hardware, software and labor) into the window framing process. It is not clear the impact of this technology given the relatively low efficiency and small amount of exposed area on a structure that is likely to have high electrical demands. Further, there is much work to do to meet standards at full architectural scale.

**Reviewer 2:** NEXT is aiming to commercialize window glazing units incorporation bulk heterojunction (polymer-fullerene) PV that are transparent to UV and visible light and generate electricity at $0.04 cent/kWh. Prototypes have reached 7.2% efficiency and similar units are passing the IEC 61646 degradation tests and other IEC and ASTM window standards. The NEXT windows have a good likelihood of getting product to market through their Viracon partner (a huge glass supplier) if they can pass all the tests, without compromising efficiency. It is concerning that the windows are only 10% transparent in the visible, which will limit their use, but there are enormous commercial building areas using transparencies in that range. It would be important to know what fraction of commercial windows have comparable transparency today. Success would represent an important first step in deployment of BIPV windows widely and is worth the large SETO investment. It's good to see a US company in this space.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Reported progress appears essentially on schedule. The key partner remains engaged in the work. Goals are appropriately necessary and progressively advanced.

**Reviewer 2:** The focus on passing both windows and PV standards is important. After a delay caused by the damp heat tests, they seem to be on track. Hopefully, Viracon is active in proposing and carrying out the tests they would need to participate in commercialization.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: All required tasks are appropriate and demonstrate ongoing advanced of the work. Nevertheless, there will be substantial additional tests to not only validate the PV part of the device but the integrated and long-term visual characteristics. This all needs to be done on units that are much larger than the current test samples.

**Reviewer 2:** Score: 6. Comments: The stability testing is very important. They have accelerated tests predicting less than 10% efficiency loss over 30 years. A strenuous testing program will be essential, as the formulations change to reach different efficiencies and transparencies.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Architectural issues are likely more challenging than PV device issues. While the PI has clearly considered these challenges, they remain very difficult issues: color and clarity throughout the life cycle of the device and uniformly between devices at all points in time. Building owners and architects have very high standards while building constructors often want simple solutions. This product may encounter adoption challenges beyond the technical challenges.

**Reviewer 2:** It remains to be seen whether PV can penetrate deeply or if the builders will find too much risk in putting these onto new buildings. Also, wiring adds complexity to building fabrication and this could deter all but those seeking the highest LEED ratings. It will be interesting to see how this goes over the next few years.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** None are missing. Having an established and respected stakeholder like Viracon is critical.

**Reviewer 2:** Has NEXT engaged with the engineering/construction firms like Black & Veatch that provide evaluations of PV system bankability? Given the cost premium for these windows in buildings that require financing, I would think they should get an evaluation.

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) The PI has made steady progress and developing a PV device that can be inserted into an IGU structure. The reported cost of the electricity is believed to be consistent with SETO's $.04/kWh target. However, it is not clear how much energy could be generated in a practical application. 2) Devices to date have been relatively small demo units to prove the capability. The PI is using scalable technologies that presumably will enable larger devices at high volume. 3) Satisfying the visual demands of the architectural and building industries will remain an ongoing challenge that is yet to be proven on full size modules across many units.

**Reviewer 2:** 1) Test carefully for discoloration under sunlight with high UV content. 2) Engage with Black and Veatch or other independent engineering consultants early regarding bankability. 3) Continue to work to meet all available standards tests.

### On-Device Lead Detention for Perovskite Solar Cells – $198,112

*Northern Illinois University | DeKalb, IL | Principal Investigator: Tao Xu*

Perovskite solar cells face major obstacles including toxicity of lead, a key active component, which remains relatively unexplored because of the lack of effective solutions. This project is developing an innovative, simple, low-cost, add-on approach for in-situ on-device sequestration of leaked aqueous lead for severely damaged perovskites. The goal is to capture more than 99.9 percent of lead leakage from perovskites soaked in water by using low-cost, high-efficiency metal ion-exchange resins as lead-trapping layers on both sides of the devices.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 5 |
| Set critical challenges to overcome | 6 | 4 | 6 |
| Implement a high-risk, high-impact approach | 6 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 6 |
| Advance the U.S. solar industry substantially | 6 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Today, Pb is an essential component element in all the best perovskite solar cells. This project provides a hazard mitigation approach that would undoubtedly be adopted by manufacturers if both the project and Pb-based perovskites are successful. The project starts once COVID is mitigated, but pre-project results are promising. They demonstrated a highly transparent DMDP film that scavenges and binds Pb in water solutions and demonstrate 96% sequestration from a water bath containing smashed and cut perovskite cells. The target for this project is 99% sequestration and retention for 7 days to allow time for field remediation of broken modules. The only weakness I see is the need for recognition in the field that Pb has leaked. It would be great to incorporate a breakage sensor in the modules also, but that's not the goal of this small project. They collaborate with NREL who will fabricate and test the cells incorporating the N. Illinois films. The project is very important piece of SETO's perovskite portfolio and a great bargain if the PI actually starts a company or licenses the formulations. However, there is no sign that the PI is thinking about how to incorporate these films in perovskite/Si tandem modules. The project should look at how these films will perform in Si/perovskite tandems, since they are likely to be the first widely deployed perovskite devices.

**Reviewer 2:** Perovskites hold potential significance for improving PV efficiency and further reducing the cost of solar electricity. Perovskites are limited by their thus far inherent lack of durability as well as the fact that most all contain lead. This work explores a method to capture 99.9% Pb leakage from severely damaged modules soaked in water for 7 days. The work is just getting started.

**Reviewer 3:** Although the perovskite PVs don't contain large quantities of lead, this technology is still perceived at "toxic" by many due to the very soluble form of lead being part of the technology. Hence, it is very important to demonstrate that this technology can perform well without causing harm to public health and environment.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The team seems cognizant of the value of the product they are trying to make. However, the team emphasizes that they will talk with insurers. More importantly, they need to talk to entities like Black and Veatch who would ultimately need to certify safety and performance of PV modules for developers, insurers, and banks. The other missing partner is the film or chemical company who will license and partner to bring this to market when the time comes. There are still 2 to 10 years before perovskite really impacts the market, so the timing is good.

**Reviewer 2:** This work is just getting started so it is difficult to assess progress. Nevertheless, the PI is working closely with NREL where significant perovskite work is ongoing. While the identified milestones represent good progress, they may not be sufficient to satisfy regulators or the solar PV market.

**Reviewer 3:** This project just started recently, and the "4" points that I gave under categories 2.1-2.5 don't specifically reflect upon team's performance.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: They have a plan that seems to wisely focus on the durability of their films over years and on the performance.

**Reviewer 2:** Score: 4. Comments: The outlined goals of 99% capture without adversely impacting PV performance represents a modest first step in addressing lead content. The project is reasonably well scoped for this early work.

**Reviewer 3:** Score: 6. Comments: Studies like this, that develop methods to mitigate potential hazards and risks stemming from a new technology are very important and the timing is perfect. I am very glad to see that SETO sees the value in this type of research.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project should look at how these films will perform in Si/perovskite tandems, since they are likely to be the first widely deployed perovskite devices. The entities that contribute to the establishment of "bankability" for PV systems should be engaged early in the project. These include Black and Veatch, but there are others. It will be essential to test the films through typical PV cycles of light and dark, hot, cold, humidity and especially within a sealed module facsimile. Transparency after UV exposure will be important to module manufacturers too. The team should best testing procedures this with the NREL Reliability group. Also, compatibility of the bottom film with the various solvents used in perovskite manufacture should be examined.

**Reviewer 2:** While lead contamination may prove to be a show-stopper issue for broad perovskite deployment, this work is unlikely to assuage the concerns of regulators or customers. The solar industry spent years working to eliminate lead from its products. 99.9% is not a sufficient level of containment and the experimental definition of "severely damaged" would not be consistent with existing fire and disaster tests. Furthermore, the added cost of the containment material creates added impediment to achieving SETO's cost goals.

**Reviewer 3:** It is difficult to speak to 'blind spots' at this stage of the project development. Something to watch out for is how effective the research team communicates results from the project to stakeholders.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** NREL's Reliability Group should be engaged, in addition to their collaborators on the cells themselves.

**Reviewer 2:** The PIs should collect legitimate regulatory and market validation of the goals both in the US and abroad (notably in Europe). A professionally prepared preliminary cost model could also help elucidate the magnitude of the adverse cost effects.

**Reviewer 3:** I think PI should seek to develop collaborations with potential offtakers of the technology (BIPV) and with environmental agencies. In California it would be CalRecycle, Department of toxic and hazardous materials, utilities, but also non-profit organizations such as Sierra Club.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Talk to the guarantors of bankability and insurability before talking to the banks and insurers. 2) Focus on the 99%, 7-day targets, but don't forget the durability/reliability testing for cells containing these films. 3) Demo in a really great (near-record) perovskite cell because no one will read your detailed data and the caveats about why the cell efficiency wasn't that high.

**Reviewer 2:** 1) Perovskites hold significant promise for the industry but are hindered by poor durability and the inclusion of the heavy metal, lead. 2) This work focuses on a containment methodology to capture 99.9% of PB leakage while soaked in water for seven days. 3) The goals of the project need to be validated against market acceptance criteria and cost entitlement.

**Reviewer 3:** 1) Continue improving sustainability of emerging energy technologies. 2) Consider funding projects that develop solutions for recycling of new technology, this includes circular design of the modules. 3) Ensure that results from such research are "visible" to public as well to improve the "image" of perovskite PVs.

## Investigation of Gallium Oxide as a New Transparent Conductive Oxide for Photovoltaics Applications – $200,000

*Ohio State University | Columbus, OH | Principal Investigator: Tyler Grassman*

This project explores the use of a new material, gallium oxide, as a transparent conducting oxide layer for solar cells. Transparent conducting oxides are a layer within a solar cell that conducts electricity on top of the light-absorbing material in the solar cell, such as cadmium telluride. As a result, the conductivity of the transparent conducting oxide and its transparency to the full solar spectrum are critical properties for creating a transparent conducting oxide that's effective. Gallium oxide has a wide bandgap, which enables more light to pass through the transparent conducting oxide and be absorbed by the absorbing layer that converts the photonic energy into electrical potential. To determine the applicability of gallium oxide as a transparent conducting oxide for photovoltaic technologies, this team is studying the deposition of this material in solar cells using tools that are commonly used in the solar industry. The team will then test the resulting optical and electronic properties of the solar cell and analyze the performance of the prototype transparent conducting oxide.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 6 | 4 | 6 |
| Implement a high-risk, high-impact approach | 6 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 3 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Development of GaOx as a superior TCO is well aligned with the goals of the New Cell and Module Structures, Designs, and Processes topic. With a much larger bandgap and smaller index of refraction than any of the conventional PV TCOs, GaOx can not only be seen as an improved material to replace conventional TCOs for increased efficiency (blue response), improved affordability due to sustainability advantages and also holds potential for use within an integrated antireflection coating (ARC) strategy. The investigation has sound plans for reaching needed conductivities without creating adverse free carrier absorption in PV relevant thin films, although the milestone for this phase would seem modest. While GaOx is new to PV it is used in high power electronics, leveraging non-DOE support (possibly more than any other SETO project) such that the high impact objectives are also reasonable for the small funding and short duration of the SIPS award.

**Reviewer 2:** The study of Ga2O3 is a hot topic right now, so work in this area can have a significant impact to the broader scientific/engineering community. It would be good if modeling would be done on the effect of the Ga2O3 on hetero-junction Si cell and with thin film CdTe, to determine the value of the approach. As a replacement or improvement on the front metal grid, it is very hard to improve on the metal grid model (with minimal grid obscuration and sheet resistance) for extracting current. The sheet rho of the TCO needs to be very low for any kind of improvement, and also must not interfere with AR coatings. For III-V cells it is not a good match with current dual layer AR technology, which is well optimized. For thin film and Si cell technology it may make a performance improvement as a heterojunction. Can that improvement be quantified? The challenge is also to grow the material in a way that keeps cost low but also improves performance. The program has done a great job of characterizing the material that they have grown, using standard deposition technology.

**Reviewer 3:** While the impact of this project may not make a significant impact on the bulk of the Si solar industry, it's impact on thin film and new materials may be substantial. This is truly a high-risk research program which may be low in probability of success but high in value. Findings to date have indicated how high risk this is, given lack of ability to achieve levels of growth rate and conductivity as otherwise reported in the literature.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project only started in August of 2918 and has encountered usual start up issues as they attempt to translate knowledge developed for high power electronics in MBE single crystal material to films of PV relevance. Performance is typical of the short duration of SIPS awards. @ of three key milestones have been achieved. Resistivities of the films are still high. Single crystal $Ga_2O_3$ has demonstrated mobilities at 200 cm2/V s and very low resistivities. The plans to explore amorphous morphologies, initial data (Eg 5.1 eV versus 4.8 eV for crystalline) and schedule bode well for successfully reaching a reasonable level of <10-2 Ω-cm. The excellent assessment of the likely performance in dissemination of results and collaborations relies on past performance of this team.

**Reviewer 2:** The program has quantitative goals, and they have been able to achieve these. The program is a yearlong, so they have not had time to publish results or reach out to collaborators. There are US thin film manufacturers that may be interested, and perhaps some Si ones as well. It would be interesting to see if there is much industrial interest in finding a replacement to current TCOs. As mentioned previously, the materials should be considered for use in a Si HJ cell. If that can be demonstrated via modeling, then the project should expand to experimentally verify this improvement.

**Reviewer 3:** Since this is a relatively small project, and still in its early stages, it is not surprising that a large collaboration and information dissemination process has not occurred. Note that capabilities in other locations may be appropriate to review issues encountered to date.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Tasks appear to be to evaluate growth by ALD, evaluate growth by rf sputtering and film characterization. Each is clearly unique and essential to establishing viable PV relevant processes and materials for improved PV modules.

**Reviewer 2:** Score: 5. Comments: Yes, the tasks are consistent with the overall program goal, and they complement each other well.

**Reviewer 3:** Score: 5. Comments: Approach appears to be logically laid out, with goals cascading onto the next task after success.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** There are no apparent blind spots.

**Reviewer 2:** It would be interesting to do performance models of cells that have incorporated Ga2O3 and compare with standard designs, to quantify the performance improvement. Particularly with CdTe, perhaps a hetero-junction of n-Ga2O3/p-CdTe may have a more significant performance improvement than I consider possible.

**Reviewer 3:** PI should actively solicit advice or inputs from other organizations that may have expertise in growth of these categories of films.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** At this stage of investigation the project needs no other stakeholders or collaborations. In the event he has further difficulty achieving his resistivity target, NREL has many resources that could help.

**Reviewer 2:** Are there any Si or thin film solar cell manufacturers that are interested?

**Reviewer 3:** Other groups, such as NREL and universities, may be able to provide some advice related to issues in growth and conductivity challenges the program has seen.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is exactly the type of research the SIPS program is intended to find. SIPS funding should be continued. Semiconducting oxides are an important class of materials for ongoing PV and basis sciences research.

**Reviewer 2:** What are the actual performance improvements that would be expected (as determined by modeling) if Ga2O3 were incorporated into either a Si or thin film solar cell? Are there any US PV industry organizations interested in this approach?

**Reviewer 3:** Project is indeed a high-risk program, but if successful would add value to industry, especially thin film cell envelopment. Is PI soliciting other organization support and guidance in solving some of the initial issues encountered. Not clear to me that the institute has necessary tools to fully evaluate and maximize potential for program success?

## Identifying Impacts of Process, Precursors and Defects in Metal Halide Perovskite Solar Cells – $1,500,000

*Princeton University | Princeton, NJ | Principal Investigator: Barry Rand*

In an effort to improve the energy yield and stability of metal halide perovskite photovoltaic solar cells, this project aims to improve material selection and fabrication techniques for producing these cells. The team is working to identify interactions that can occur in precursor solutions or at solid interfaces that result in defects, either spontaneously or under solar cell-relevant stresses such as light, heat, atmosphere, and voltage. The team will then establish targeted strategies and processes to mitigate perovskite cell degradation by selecting optimal precursor solutions and creating robust absorbers needed to make these high-efficiency solar cells.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 6 | 6 |
| Set critical challenges to overcome | 3 | 5 | 6 |
| Implement a high-risk, high-impact approach | 1 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 6 | 5 |
| Advance the U.S. solar industry substantially | 2 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project seems incremental at best. They really need an industrial partner if this program is going to succeed. The relationship between reaction by-products and electrical defects seems tenuous at best.

**Reviewer 2:** Strengths: Study of fundamental reaction mechanisms involved in the formation of perovskite ink including identification of side products, reaction rates is perhaps the most important question that scientists need to tackle to enable a controlled formation of photovoltaic material. This research aims to benefit not only one particular perovskite processing step but could potentially have a positive and cost-reducing effect on any of the following manufacturing steps, thus, benefiting many teams working on perovskite technology. Weakness: none identified.

**Reviewer 3:** Perovskites hold the promise of advancing the efficiency of solar devices at low cost. However, there are a number of challenges with the technology. This work focuses on addressing unintentional side reactions that alter the composition, performance and stability of the absorber layer. The project focuses on understanding the side reactions and preventing them so that defects are never created. The goal is to develop T80 lifetimes of >5000 hours.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 2 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 2 | 6 | 5 |
| Collaborates with sufficient stakeholders | 1 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project looks like Princeton University is engaged in a project in isolation. They really need active partners to push the technology in this project. Publishing of only one paper, partly supported by this grant, is disturbing.

**Reviewer 2:** This is a well-rounded project with a clear goal to identify and quantify the relationship between defect formation in perovskites and solvents used during the formation step. Team also collaborates with NREL team and utilizes NREL's experience in this area. The results from this research project will be of importance for the entire perovskite-researchers community, and perhaps, dissemination of results and transfer of knowledge should be emphasized a little bit more.

**Reviewer 3:** The team has established clear milestones and has a working network of researchers at NREL and Princeton to support the efforts. The goals are formidable and will require substantial, detailed experimentation and analysis. The team claims to be recovering on the milestone by utilizing what sounds like best known methods from NREL.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: They have performed mechanistic experiments, but it is not clear to this reviewer how these results pertain to improved perovskite inks and defects in cells

**Reviewer 2:** Score: 5. Comments: I find that tasks for this project are clear and reasonable and each of them is important to the achievement of project goals.

**Reviewer 3:** Score: 6. Comments: The tasks appear very challenging. Identifying all the side reactions and their ability to catalyze defects will require painstaking detail and a large number of samples.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I would encourage the project team to engage an industry partner.

**Reviewer 2:** I could not identify any critical blind points.

**Reviewer 3:** The PIs seem to have effectively scoped out the project and structured the relevant project phases. As anyone that has ever worked in the electrochemical or pharmaceutical business knows, characterizing and eliminating side reactions (especially when dealing with highly reactive halides) can be a very difficult task. These other industries often use combinatorial techniques to deal with the vast experimental space. This might be worthy of consideration for this work.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** They are missing an industry partner.

**Reviewer 2:** This project addresses one of the fundamental questions related to the prevoskite PV technology, and the results should be disseminated very broadly. The team is already collaborating with NREL and publishes results in scientific literature. However, the gained knowledge may not reach smaller startups fast enough. Perhaps, given the overall importance and amount of funding going to pervskite research, it would make sense to organize a kind of nationwide Perovskite team that would meet regularly and exchage updates and lessons learned.

**Reviewer 3:** If the PIs believe they have the capacity to handle the quantity of samples in a high-quality manner, then they may have the resources needed. Their relations with NREL and other researchers should serve as a good community for ongoing discussion of both failure modes and experimental techniques.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Mechanistic studies are nice. 2) Impact on technology is not clear. 3) Need an industry partner.

**Reviewer 2:** 1) Fundamental research of perovskite PV could help to close knowledge gaps pertaining to this emerging technology and accelerate the overall development of high performing low-cost perovskite PVs. 2) Collaboration with other groups is very important for this type of research. 3) Better understanding and control over the perovskite formation reactions benefits all manufacturing steps.

**Reviewer 3:** 1) Perovskites hold the promise of delivering higher efficiency and lower costs. However, their instability and durability problems are limiting their integration into commercial devices. 2) This work explores the side reactions that occur within the halide perovskite absorber layer with a goal of ultimately eliminating these parasitic processes. 3) Thus far, the PIs have proven the existence of several defect generating modes. The next phase focuses on detail quantification of the work. Success requires the team to identify solutions to eliminate the reactions altogether.

## Accelerated Scaling to Rapid Open-Air Fabrication of Durable – $1,496,069

*Stanford University | Stanford, CA | Principal Investigator: Reinhold Dauskardt*

This project is working to fabricate and encapsulate large-area and durable perovskite solar modules using a scalable open-air processing route that validates the reliability of the cell by using accelerated testing and thin-film metrics. The team's scalable processing of durable perovskite and inorganic transport layers provides a platform to make series-integrated high-voltage perovskite solar modules entirely in open air, eliminating unstable organic transport layers. The work will mitigate barriers to wide-scale deployment of perovskite technology, namely module manufacturing and reliability, and eventually allow photovoltaic-generated electricity to reach costs as low as $0.02 per kilowatt-hour.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 6 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** While I agree that it is important to develop manufacturing methods that are "simple" (aren't limited by environmental factors, such as temperature, moisture, air constituents), I am a little bit concerned that the targeted efficiencies are just above 16%. Especially when the project description mentions "curved surfaces" (of vehicles), I think this could be problem that would make commercial applications difficult. The surfaces on vehicles are limited by vehicle size and here more expensive panels with higher efficiency possibly make more sense than low-efficient panels that possibly cost less.

**Reviewer 2:** The project undertakes to demonstrate high throughput scalable demonstration of 100 cm2 perovskite modules. The project targets certified efficiencies of >16% and completing indoor and outdoor accelerated lifetime studies. If successful this demonstration would be an important step along the path toward commercial perovskite product development.

**Reviewer 3:** Perovskites could potentially lead to higher efficiency PV modules that deliver lower LCOE. This work focuses on using a productive open-air-fabrication technique to deliver thermomechanically stable 10x10cm perovskite devices with efficiencies >16%.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Team collaborates with partners from industry. Perhaps, team also should consider engagement with business analysts that evaluate niche markets, such as solar for automotive applications.

**Reviewer 2:** Multiple peer reviewed papers have already been published on 2 cm2 devices, approximately 1 year into the 3-year project. The tasks are on schedule and budget. The project undertakes to perform validated efficiency testing at NREL. Accelerated life testing is also in the plan.

**Reviewer 3:** Reported progress is slightly ahead on key milestone. Several papers have been written and information has been shared amongst the project collaborators.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: I think that team tackles many unique tasks. One of them - cost modeling is a bit premature. I think at this point it would make sense to focus more on the manufacturing tool and characterization of produced PVs under real-life conditions (outdoor, different temperature profiles, different air moisture).

**Reviewer 2:** Score: 5. Comments: Production of smaller scale cells with reproducible power conversion efficiencies have been completed. Scaling to 100 cm2 is still in the future goals.

**Reviewer 3:** Score: 6. Comments: The project tasks seem to be thoughtfully planned in order to ultimately deliver the committed devices.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I think that PI should think of additional potential applications. PV panels with 16% efficiency may not be suitable for automative applications. I actually rather like the idea of using spray method to manufacture tandem PV cells.

**Reviewer 2:** None at the moment.

**Reviewer 3:** In their area of focus, the PIs seem to have done a good job of scoping their challenges.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I strongly believe that team will successfully develop the spray-tool that works in ambient air. I am more concerned about the targeted market. I think PI could engage stakeholders from construction industry and explore opportunities to test his manufacturing approach for development of BIPVs.

**Reviewer 2:** Private companies, National labs and other universities are involved in the project currently. No additions are suggested.

**Reviewer 3:** They seem to have good partnerships that can support hardware and processing advancements. They will eventually need to expand to more sophisticated materials and structures so additional connections will likely be needed.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Test developed tools in tandem PV manufacturing. 2) Identify most suitable applications for cheap/low efficiency PVs, moderate priced high efficiency PVs - they will likely occupy different markets. 3) What about building integrated applications (BIPV)? Available surface on buildings is not as limited as the available surface on vehicles.

**Reviewer 2:** The project sets aggressive goals that, if successful, will demonstrate significant progress to commercialization of an emerging technology. The project is currently on schedule and budget. The project appears to have the appropriate stakeholders and third party testing engaged.

**Reviewer 3:** 1) Perovskites could lower LCOE if the key materials, device, durability and processing challenges can be addressed. 2) This work takes an early but significant step to develop an open air processing system to make >16% fully assembled devices that address thermo-mechanical structure challenges.

## Perovskite on Silicon Tandem Solar Cells – $1,365,306

*Stanford University | Stanford, CA | Principal Investigator: Alberto Salleo*

This project is studying newly developed perovskite on silicon tandem modules to determine the best interconnection design and material properties for each module component. The perovskite material will be characterized and modified to produce a top cell with an ideal band gap and few structural and electronic defects. Modeling will be used to predict outdoor panel performance under realistic spectral variations, which affects how well the electrical current is balanced between the two types of cells.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This investigation draws together a strong team needed to create the new materials, perovskites and device component layers, needed to improve the efficiency and reliability of potential PV products. The team has consistently placed heavy emphasis on the reliability and, with one of the longest track record of leading perovskite research, has done long term degradation experiments. These show considerable promise for the future of the technology. Proving the efficiency potential and reliability of perovskites are the number 1 and 2 priorities for this area of research and provide the primary focus of research by this team. Work to model energy yield of tandem devices and module designs is of less significance, though likely driven to answer attacks on the efficacy of perovskite/silicon products. Translating success from this investigation to advancing the U.S. solar industry will require substantial research to develop technologies needed for cost effective production – such as reducing annealing times, scaling to relevant areas and suitable low-cost encapsulation. As they observed in support of seeking higher efficiencies "installing solar panels costs more than the panels themselves." In a similar vein, cell costs are a small portion of the solar panel cost. The current balance of effort in this project is appropriate and consistent with a pathway to achieve the 2030 SETO goals for industry production and associated reduction in LCOE.

**Reviewer 2:** The strengths of the program include the technical developments and the overcoming of a number of technical challenges. They are making great progress, building on past results. They have well defined, quantifiable metrics, and they have made progress to achieve them. They have also done an excellent job of publishing results and reaching out to the PV industry to try and transition the results into products. The concerns are that, in order to overcome the technical challenges, they have implemented a number of approaches that have added cost. At what point are performance improvements moot due to the added cost? Vapor deposition, ALD, and evaporated metal contacts are all mentioned as being implemented to overcome certain technical challenges. While an argument is made for the value of increased efficiency (installation costs being more than the cost of the current Si cells, I assume on a $/Wpk basis), at a certain point the increased cost of the tandem cell makes the LCOE greater than that of Si. The tandem cell is then relegated to niche markets. Technically the program is excellent. It would be great to see a cost analysis done on a tandem cell manufactured with all of the processes required to have the improved cell efficiency. One other comment...to their credit, the PIs recognize the issue with variable performance degradation on junctions in a tandem cell and the effect on overall performance. They are taking steps to evaluate this issue.

**Reviewer 3:** Program is extremely timely and brings three world class institutions into a collaboration. All have strengths in appropriate areas, and advances demonstrate the efficacy of the partnerships established.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** One might argue that the team has actually failed under the criterion for "Meets important milestones within reasonable timeframes and budgets" in that the milestones they met – >26% year 1, >28% year 2 and >30% year 3 – seemed unreasonably aggressive under any budget from the just-demonstrated 23.6% result at the start in 2017. Yet, this is the reality of research in perovskites. Their milestones are quantitative, important and set at levels necessary to continue to lead this field. The team engages 3 universities with leading scientists from each. They have many excellent publications. The authors lists on many of these publications show contributions from many other organizations not immediately funded by this award. While collaborations with stakeholders is not highlighted in their reports, McGehee is on the board or advisor to several PV companies due in part to their having been founded by past grad students from his group.

**Reviewer 2:** The PIs have done a very good job of organizing the program, setting challenging and quantifiable goals, and disseminating the results.

**Reviewer 3:** Project team collaboration effectiveness is demonstrated by meeting milestones. Budgeted amount seems to be used wisely to achieve milestones. Information dissemination through multiple (>20) peer reviewed publications and presentations.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The SOPO for this project is organized by tasks needed to achieve specific performance levels - efficiency and degradation - with specific targets and pathways to systematically improve each region of the device. Not all of the technologies are new in PV, e.g. developing screen printed gridlines, but in new in application to these films and essential capabilities for the ongoing research of the team.

**Reviewer 2:** Score: 5. Comments: Again, a well-organized program that builds on itself.

**Reviewer 3:** Score: 5. Comments: Project requires multiple stages to be coordinated by multiple facilities that have been successful. Each task builds on previous, with constant evaluation testing during the process.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** McGehee has assembled a strong team with Zach Holman and Stacey Bent. He may have lost significant interaction with investigators like Reinhold Dauskardt and Alberto Solleo when he left Stanford. CU does not offer the breadth in PV materials that Stanford has. He can compensate to some extent with frequent trips to NREL. Authorship of publications of this work clearly shows the NREL connection is happening.

**Reviewer 2:** As mentioned previously a manufacturing cost analysis needs to be done on the approach. At what point does the additional cost of adding a cell to increase a SJ Si cell efficiency from ~25% to a tandem efficiency of 30% no longer make sense? Solutions are being developed to address problems, but at what additional cost? Have the cost advantage of low cost PSCs been eclipsed in integrating them with Si cells?

**Reviewer 3:** Perovskites may be particularly susceptible to degradation by combined stress factors. In the interest of achieving a truly stable compound this approach should be considered - see work by NREL on combined stress testing.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The team is exceedingly capable in developing advances cell designs and associated materials. The reliability testing, previously performed in collaboration with Dauskardt, may be an area for added support.

**Reviewer 2:** I don't see any. The PIs have done an excellent job of publishing results and reaching out to industry.

**Reviewer 3:** Teams seem appropriate, but additional stress testing capabilities may be appropriate.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** These are three powerful investigators who work well together. Joe Berry from NREL and others from the NREL team appear on many of the numerous publications from this work. This should be cultivated. The allocation of effort of this project hits the top 2 priorities for perovskites with the right emphasis. Analysis of energy yield and module design is still important and addressed at the appropriate level. With HZB now hitting 29.1% efficiency and this team already over 28% with a 30% target for October, SETO should have a plan for a celebration and follow-on initiate when perovskite break 30%.

**Reviewer 2:** Consider the economic implications (LCOE) of trying to improve on the Si SJ cell. At what cost point does it no longer make sense to improve cell efficiency? Other than the economic issue, the program has made excellent progress and done a terrific job of overcoming several technical barriers.

**Reviewer 3:** of material combinations on Si is impressive. Further testing will be necessary to really identify material, cell, and module stability to assure usefulness in commercial space.

## High-Throughput Vapor Deposition for Perovskite-Perovskite Tandem Modules – $660,000

*Swift Solar Inc. | Golden, CO | Principal Investigator: Joel Jean*

Perovskite-perovskite tandem photovoltaic solar cells offer an opportunity to obtain high efficiency levels while maintaining the low-cost and high-throughput manufacturing potential enabled by thin-film perovskite materials. This team will adapt an already commercially proven vapor deposition technique and test its use with perovskites at industrial scale for the first time. This technique could be an alternative to the widely used solution-based perovskite growth methods. The team aims to validate the vapor deposition method and produce a tandem module with an efficiency that's greater than 25 percent.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project aims to develop high-rate scalable vapor transport deposition technique for efficient, durable, inexpensive perovskite single-junction PV cells. This is a very ambitious project for 3 years and $1.2M. It is very concerning that between July 2019 and February (2020) the team was only able to reach about 5% cell efficiency on the new tool. Hopefully, this was caused mainly by a delay in getting the tool installed and working. The team has succeeded in making the desired structures and beginning a program of device and layer characterizations. My other concern is that the 3-year goal of 17.5% mini-modules will still be insufficient to enable market entry. Will Si and CdTe efficiencies ever-rising and their costs declining, I doubt that any rigid module with efficiency below 20% can compete, regardless of price.

**Reviewer 2:** Early on project--have started to make progress toward goals; quick vapor deposition of perovskite films is a big plus.

**Reviewer 3:** This project attempts to scale up a manufacturing process to produce tandem perovskite-on-perovskite flexible modules. This could address one of the limitations of Si-based PVs - their rigidity. The flexible PV panels don't compete with the leading technology (Si)Â in niche market, where flexibility of panels is required. Therefore, I think this research deserves support as it could help US solar industry to become a global leader in a solar market segment for i.g. wearable photovoltaics.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** If diffusion length is the key parameter (and needs to be 600 to 700 nm for successful solar cells) the milestone should be for a measurement of diffusion length. Why was the tau milestone downgraded based on literature ambiguity, instead of simply changing to a different measurement milestone? Actually, for such an industrial project, it seems that progressive efficiency and stability milestones would be most appropriate. It is good that the team is closely involved with NREL to share recipes and help diagnose cell problems.

**Reviewer 2:** This project is approximately 9 months old; and the team has started to make progress on all of their goals. Changing their goal on carrier lifetime seems to be acceptable at this time.

**Reviewer 3:** The project advances a manufacturing method, that has been proven on a smaller scale and sets realistic goals and objectives. Collaboration with NREL, which has a lot of experience evaluating performance of perovskite modules is important and will likely shorten the time needed to analyze data and optimize manufacturing parameters

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: My concerns about using/changing the tau milestone instead of efficiency or diffusion length are expressed above. Also, I'm wondering how much the throughput is sped up using the combinatorial deposition approach the team uses. They avoid load/unload time --- how many more experiments per day do they achieve that way.

**Reviewer 2:** Score: 6. Comments: Rapid deposition and characterization of perovskite films is very important and they are making progress on all aspects of this. Progress on Monte Carlo cost model is important, and good.

**Reviewer 3:** Score: 4. Comments: I slightly disagree that each of the tasks is important for overall success of this project. For example, development of a model calculating material input and manufacturing costs is premature, as the team first needs to prove that the method works first and should instead prioritize investigating of relationship between tool parameters on efficiency and durability of manufactured modules.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** It's good to have a combinatorial approach to optimization, but the team should be certain that there is not bleed of contaminating impurities with their deposition through a single hole mask.

**Reviewer 2:** I always worry about reliability of perovskite cells.

**Reviewer 3:** PI and his team envision that this manufacturing method could be widely adopted and therefore, it would be recommendable to think how modules produces using this method can be recycled at the end of their useful life. It should not be a major task, but I think, thinking ahead in terms of circular design is a good exercise for any team that aims to reach large-scale manufacturing volumes.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Glad to see the work with strong modelers of the cost structure and other aspects of technoeconomic analysis. The weekly meetings with NREL and Cambridge are important.

**Reviewer 2:** All stakeholders are included.

**Reviewer 3:** I think team has already established good collaborations with research facilities. Perhaps, team could try to establish collaborations with stakeholders from industry, who, i.e. use similar manufacturing method for a different product to learn about their experiences and things to consider.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Look at the value of the combinatorial deposition and have the team ensure there is no contamination if they haven't done that already. Is there corresponding combinatorial sample measurement (simultaneous, time saving) equipment available? 2) Ensure the milestones involve a steady increase in efficiency coupled to stability testing. 3) Give the team a break for the COVID slowdown.

**Reviewer 2:** 1) Making progress on rapid deposition and characterization of perovskite films. 2) Good Monte Carlo cost model. 3) What about cell reliability?

**Reviewer 3:** 1) Detailed cost analysis should not have a high priority for projects that are still trying to figure out whether the method will work. 2) Any project aiming to develop a large-scale manufacturing process should have at least a small subtask to conduct a sustainability exercise. 3) Whenever possible, it is good for teams to collaborate with industry stakeholders that already have experience with certain tools/processes even when for a different product.

## Investigation of Defect Physics for Efficient, Durable and Ubiquitous Perovskite Solar Modules – $1,000,000

*University of California, Los Angeles | Los Angeles, CA | Principal Investigator: Yang Yang*

In order to push perovskite solar cells closer to their theoretical limit of efficiency and durability, researchers need to better understand and control defects in the perovskite material and at the surface of the layers in the cell. These defects are the source of losses in the cell's open circuit voltage and can cause degradation in the solar cell over time. This project is developing physical models of defect-induced types of degradation, both on the surface and in the bulk perovskite material. The team will conduct a blend of computational and experimental studies on critical defect types and densities within the perovskite material when there's heat, light, increased voltage, or moisture present. The team will then use in-depth characterization techniques to quantify the chemical and electronic properties of defects in order to improve defect manipulation techniques that could increase perovskite cell efficiency.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 3 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** I believe it is critical to continue to fund research into emerging technologies. From efficiency alone, perovskites have a potential to be disruptive if a large scale, long-lived cells can be demonstrated. Exploring causes of efficiency loss and degradation (including characterizing deep trap states) has value in adding to the body of work that is needed to open possibilities of a commercial product. Still, for this work in particular, a clear tie between defect density, device efficiency and reproducibility were not established. Therefore, it is hard to tell how much impact this work will have on improving device performance.

**Reviewer 2:** This large project is working to understand and control defects in perovskite materials and solar cells. While the perovskite materials are remarkably defect-tolerant, increasing initial efficiency and reducing degradation of solar cells will require a strong understanding of defects that impact carrier mobility, carrier lifetime, band bending and even atomic migration.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Collaboration with 2 additional universities and NREL is established. The work has resulted in two major journal publications in highly selective peer reviewed journals (Science and Advanced Materials). So far, measurable crystal growth gain size improvements, innovative spectroscopy techniques have been applied, and identification of location of two trap state densities has been achieved.

**Reviewer 2:** This is a major collaboration among excellent academic research groups, with frequent meetings. They also look at samples from NREL, which is important since so many other groups study NREL materials and this allows rapid learning about the physics. The ability to make and manipulate defects through original chemistries is useful but should not become the focus of the work. Rather, such manipulations of the material structure can help reveal the meaning of the characterizations. The PAS has already given great insights into the depth dependence of several defects. Hopefully, the group is making the more standard measurements of TRPL and others as a baseline for this more difficult technique. It would be good also to get the EPR work underway, as it may give insight into the actual structures of the key defects. Still, this is a huge and open field being addressed and the team has a good plan and good results already in the first year of three.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project is still early in execution. Year 1 consists of subtasks to establish baselines, whereas year 2 is devoted to defect characterization and year 3 is devoted to physical models and mitigation. In preparation for work in years 2 and 3, some defect characterization has occurred and candidate materials for passivating surface defects have been identified.

**Reviewer 2:** Score: 6. Comments: The team is quite ambitious in trying to integrate many characterization techniques for defects in perovskites. This is a key endeavor for understanding new semiconductors and should bear fruit in improving solar cells -- even if there is no one-to-one correspondence between their results and altered device structures and compositions.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Identifying clear and quantified ways this work will accelerate product development would strengthen it. Ideally one would know the potential improvement(s) expected as a motivating factor before funding/undertaking the work.

**Reviewer 2:** The team plans to get working on full solar cell devices but as they near the end of Year 1, they are not showing results comparing the films to the cells. In such thin devices as the perovskite solar cells, the near interface regions are extremely important and their defect structure may depend upon built-in fields, near surface chemical contamination from the selective contacts and other effects that can only be studied in full devices. Film studies are also important because they should be simpler, but a good understanding of the solar cells depends on a robust study of devices.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Other universities and NREL are involved. The project could benefit from industry/manufacturing experience targeted to emerging technology.

**Reviewer 2:** The academic collaborations and copious publication history of this team bodes well for dissemination of results.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** It is not clear how much improvement and where (lifetime, efficiency) is expected from the work. It is important to fund early stage research investigating new technologies to keep the US at the forefront of PV progress. Early stage researchers often have fantastic contributions to materials science but are not well calibrated to manufacturing/product development challenges and mindsets.

**Reviewer 2:** 1) Move the team toward studying devices in parallel with films. 2) Ensure adequate sample exchange with other groups. 3) Set up the quick standard characterization in addition to the more time-consuming ones the group seems to be focused on now.

## Mini-Modules Made with Monolithically Integrated All-Perovskite Tandems – $1,461,640

*University of Colorado Boulder | Boulder, CO | Principal Investigator: Michael McGehee*

In collaboration with perovskite researchers at the National Renewable Energy Laboratory, this team aims to make monolithic two-terminal tandem solar cells that have a 27 percent efficiency level and are constructed entirely from thin-film perovskite light absorbers. The project uses scalable deposition methods such as slot-die coating, sputtering, chemical vapor deposition and thermal evaporation to fabricate perovskite solar cells that degrade by less than 10 percent after 1,000 hours of use.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a strong project addressing a real need. The challenges have been well articulated and mitigation strategies are in place.

**Reviewer 2:** Perovskites present a substantial opportunity to advance solar efficiency and lower costs. However, devices remain unstable and weakly demonstrated except at small scale. This project has scoped a wide set of milestones from creating individual cells to making individual devices, to making tandems and eventually making mini-modules. If these devices could be developed into commercial products with appropriate stability, they would have a significant impact on the solar industry. The paper claims benefit for a set of representative companies that are no longer in business.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 |
| Collaborates with sufficient stakeholders | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a high risk-high reward project--because of challenges some of the milestones have had to be revisited. Might be good if they were in early stage conversation with potential industrial partners.

**Reviewer 2:** The team has made steady progress on its milestones. They have achieved the fundamental efficiency and cell formation milestones and have published results. The modest stability goals are not fully satisfied and appear to be hindered by more mundane lab issues like equipment availability and resourcing.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks have been well-described. It is easy to see progress against these milestones. It makes challenge mitigation possible.

**Reviewer 2:** Score: 5. Comments: Individual tasks are significant and appropriate. The scope of the overall project is far-reaching but still only achieves modest stability improvements on very small devices. Nevertheless, this is an important foundational step to more advanced devices. The team has restructured its target market to initially focus on mobile power applications (UAVs).

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The team might start to have discussions with potential industrial partners to plan a path to market.

**Reviewer 2:** Technically, the researchers are encountering and addressing the key materials challenges associated with perovskites. It is not clear how many of the solutions are well understood from a materials science perspective vs empirical advantages. Further, there is much work to be done beyond these small proto-type devices.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Perhaps a manufacturing partner.

**Reviewer 2:** The PIs cannot depend on relationships with the list of out-of-business PV companies in the paper. Validation and commercialization will likely require partnering with a more established PV industry company. For now, however, the focus on materials, processes and devices is well scoped amongst NREL and UC.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) High-risk, high-reward project. 2) Good team. 3) Might include discussions with potential manufacturing partner to anticipate path to market roadblocks.

**Reviewer 2:** 1) Perovskites are an important technology with the potential to significantly advance the PV landscape and drive down costs further. 2) The PIs have developed a broad, progressively advancing methodology to first explore films, then processes, then devices and ultimately mini-modules. They are about halfway through the program and generally making progress despite varying technical and more frequent logistical challenges. 3) Current focus is on small demo devices. Substantial work will be required with yet-to-be-identified viable partners to develop the technology into something that could be commercialized.

## II-V Solar Cells with Novel Epitaxial Lift-off Architectures for Extended Substrate Reuse for Low-cost Manufacturing – $200,000

*University of Houston | Houston, TX | Principal Investigator: Venkat Selvamanickam*

The highest solar cell efficiencies have been achieved with costly III-V photovoltaics— so named for the semiconductor materials in groups III and V of the periodic table—but reusing the base of the solar cell, called the substrate, can lower costs. The team is developing an architecture based on novel layers so that polishing the substrate after old layers of material are removed won't be required for reuse.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 6 | 5 |
| Set critical challenges to overcome | 4 | 4 | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 3 | 6 | 3 |
| Match well with the level of DOE funding and planned project duration | 4 | 3 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 3 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** GaAs based PV offer many advantages over Si-based devices, but have failed to reach commercial success for terrestrial applications due to the high cost of wafers. Several companies have tried in the past to solve this problem through ELO techniques, most notably Alta Devices, but they ran into challenges with being about to actually re-use the carrier wafer more than once or twice. Achieving a reusability of 100 times could help GaAs-based devices compete with the high efficiency PV market. This is a 1 year proof-of-concept project. They have achieved a "60 times reduction in surface roughness of GaAs wafer … with ELO with NaCl layer" already. First test will be if they can make PV cells out of the ELO layer. If successful, the project could build on what Alta devices achieved in 2012/2013, but at potentially lower costs. However, most of the PV industry is focused on Si due to the cost-effective nature and ability to mass produce with high reproducibility. This research is focused on GaAs specific issues, which will limit the impact.

**Reviewer 2:** This is certainly a high-risk project. To be able to grow from a GaAs crystal using a NaCl buffer layer repeatedly is an interesting idea. The project summary does not really discuss many of the potential issues that could occur. One that is totally ignored is whether the Na or Cl will contaminate the solar cell and reduce efficiency. (I asked the PI about this in an e-mail but never received an answer).

**Reviewer 3:** Strengths include the value in supporting mass production of high efficiency multijunction cells, which would be a gamechanger, but the weakness is there are no industrial partners.

**Reviewer 4:** This is a very creative approach and the PI has done a great job in doing background work for this effort. If successful it will create a new technology area for III-V devices in general. For the stated goals the project needs to be funded at a higher level for a longer period of time. I do question the notion of III-V cells being viable for terrestrial applications, even with this substrate re-use technology demonstrated and a lower cost method of III-V deposition developed.

For that reason I do not see this as having a major impact or having a high payoff on the US solar industry. It may be of interest for other III-V device areas that have to sue substrate thinning or removal.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 0 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 0 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 0 | 3 | 5 |
| Collaborates with sufficient stakeholders | 4 | 0 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** As this project is just beginning, it is not possible to judge the team's ability to meet milestones and to disseminate results frequently. No plan mentioned in report to collaborate with stakeholders. PV needs scale to be successful. Therefore, the recipient should begin investigating resources that would enable scalability.

**Reviewer 2:** Project not started yet. Tasks and milestones are fairly simplistic. A detailed plan was not included.

**Reviewer 3:** The project has not yet started.

**Reviewer 4:** The program is just getting started, so it is hard to evaluate some of the criteria. I do believe that the PI will publish results. It is unclear who the beneficiaries would be for the technology, but the PI should engage with SolAero and Spectrolab, perhaps they would be interested in the approach.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: A re-usable wafer that can seed 100 20% GaAs solar cells is only achievable if the recipient succeeds in their quarterly goals/milestones.

**Reviewer 2:** Score: 3. Comments: It is a unique project and very short (1 year) with modest budget. So it is just a quick evaluation to see if the idea works. There are likely to be many technical issues to solve in that year any one of which could kill the economics of the proposal. The main issue I have is whether it will be economic even if the project is 100% successful. The project summary says "Combining with 10X lower III-V growth costs, the overall cost of III-V PV could be reduced to \$0.30/W". This is where Si is today. If your target is not a lot better than the present technology you are unlikely to be successful. This has been demonstrated in PV many times. The cost of commercial start-up is staggering. It can only be justified if the goal is a significant advancement over the present.

**Reviewer 3:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 4:** Score: 5. Comments: The program is systematic and is planned well, and the PI has measurable, reasonable metrics for success.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Commercialization is the biggest blind spot that is not mentioned in the available documents. A lack of a plan could make even a successful execution irrelevant to the PV industry.

**Reviewer 2:** Very little is said about solar cell processing. It is one thing to make layers of GaAs. It is something completely different to turn those layers into efficient solar cells. What about contamination from the barrier layer? What about stresses in the material due to lattice mismatch?

**Reviewer 3:** Industry partners, e.g. Spectrolab (Boeing).

**Reviewer 4:** Be careful of the viewpoint that III-V PV can compete in the terrestrial marketplace. There is stiff competition from Si, probably too much to overcome. However, the technical approach is fascinating and the PI has been very creative to develop (if successful) an easier and lower cost way to re-use GaAs substrates.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Module manufacturers and high volume MOCVD tool vendors.

**Reviewer 2:** Being able to grow GaAs films with a particular barrier layer is only the first step. The University is unlikely to commercialize such a process so they would have to interest a company, presumably one that is already involved in the manufacturer of GaAs solar cells, which doesn't leave many options.

**Reviewer 3:** Multi-junction cell manufacturers, e.g. Spectrolab (Boeing). They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 4:** As mentioned previously, try to engage the space PV manufacturers. They may be interested in implementing the technology iof successful.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) A commercialization plan is needed that is coupled with technoeconomic analysis and forecasts. 2) As far as I am aware, this is a unique approach to GaAs ELO. 3) The industry does eventually need a post-Si technology. At the moment, GaAs is the only technology that has exhibited durability.

**Reviewer 2:** Small highly speculative programs do have a place in the portfolio. When evaluating high risk programs, the ultimate reward needs to be better defined. If it takes a win in a high-risk program the goal or target should be a step function better than the present technology especially if the figure of merit is LCOE. The cost for a new commercial technology to enter PV is huge. This can only be justified if the potential gain is also large.

**Reviewer 3:** Find an industrial partner, get feedback from that partner and work on a prototype in their factory to demonstrate the technique. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 4:** Again, reconsider the economic viability of III-V cells for terrestrial applications. The program is very creative and brings a novel idea to substrate re-use.

## Controlling the Recombination Activity of Dislocations in III-V Solar Cells – $200,000

*University of Illinois at Urbana-Champaign | Champaign, IL | Principal Investigator: Minjoo Lee*

Existing III-V manufacturing methods, such as epitaxial liftoff, that attempt to reuse costly III-V and germanium substrates over many growth cycles are too expensive to enable manufacturing at large scale. One way to overcome this issue is to grow the cells on low-cost substrates such as silicon. This team is performing a systematic study of III-V solar cells grown on silicon surfaces decorated with beryllium, carbon, germanium, tellurium, and other impurities in order to identify conditions that will render dislocations and other structural defects less harmful to solar cell performance. Reducing the impact of defects would improve device performance and enable the use of low-cost growth substrates in the fabrication of high-performance III-V cells and modules.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 1 |
| Set critical challenges to overcome | 5 | 4 | 1 |
| Implement a high-risk, high-impact approach | 4 | 4 | 1 |
| Match well with the level of DOE funding and planned project duration | 3 | 3 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 1 |
| Advance the U.S. solar industry substantially | 3 | 3 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The program is creative and if successful, will significantly improve hetero-epitaxial growth. The right partner has been included. Good experimental work is being done. The scientific/technological work is excellent. There is a concern that the program is too ambitious for the level of funding and duration. However, the concept of the growth of tandems on Si, either as a substrate or an active junction, needs to be re-evaluated. Even if a Si substrate could be used to provide a reasonable efficiency, and the growth costs of the III-V cells is reduced significantly, there are still the processing costs associated with the tandem cell, higher than what they would be for just a Si cell. A marginal performance improvement may be achieved, but at what additional cost? Will the LCOE of the tandem be lower than that of a Si SJ cell, even with all of the other system costs included? While high risk, the payoff is a concern. Keep the technical work moving forward, but be aware of the cost implications and if the approach is viable for commercial application.

**Reviewer 2:** Strength of this work lies in the significant impact on reduced cell cost using III-V high efficiency compounds on low cost Si substrate. One might envision a cost adder of 20% thin III-V layer on Si which could increase cell efficiency by at least the same amount. Use of these materials are inherently more stable than perovskite layers, which would lead to lower risk commercialization. There is definitely a niche market only for the successful end result, which would reduce strong commercialization drive. Measurement techniques require many samples for a statistically significant finding - this becomes very expensive in research.

**Reviewer 3:** This report omits so much important information that it is not possible to identify meaningful findings, let alone agree with them. The pseudobinary alloy composed of In, Ga and P has properties anywhere between the binaries InP and GaP. The investigators refer to their material as GaInP with no indication of composition or other indicator (Eg?) that might help the reviewer evaluate the work.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 3 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 3 |
| Disseminates results frequently and actively engage partners | 5 | 3 | 2 |
| Collaborates with sufficient stakeholders | 5 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The budget is too low and the schedule is too short for the work. Projects such as this need to be funded at a higher level. The appropriate partner has been chosen, although it took a long time to get UCSB on contract. There are good quantitative metrics for the program success.

**Reviewer 2:** There is insufficient information in the report to determine the stakeholder interaction. Who is on the advisory group, and when are their inputs solicited? Measurement and data analysis seems excellent, but time consuming. I understand that delay on some tasks was due to contract finalization with partners, but can the time be made up?

**Reviewer 3:** The strength of the investigators and collaboration built in between Illinois and UCSB should make this a strong program. However, the primary finding "remarkable dislocation tolerance in n-InGaP" is explained as follows: "materials with low minority carrier diffusivity have better dislocation tolerance than those with higher diffusivity." The low minority carrier diffusivity that keeps the minority carriers from reaching the dislocation to recombine will very likely also keep those minority carriers from reaching the junction of the solar cell to become useful current. The III-V solar cell delivers 2/3's of the power in a monolithic tandem on silicon. This cell must be more than good. 25% should be the target. The chosen path is not likely to reach such high efficiency.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the program is well thought out.

**Reviewer 2:** Score: 5. Comments: Tasks seem to be appropriate, but comparing budget spent to date versus progress will it be possible to down-select different candidate materials?

**Reviewer 3:** Score: 4. Comments: Work using APT to examine the doping on dislocations could be of substantial interest, if performed in material with better diffusivity.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Be aware of the tenuousness of the economic argument for the use of III-V cells for terrestrial applications.

**Reviewer 2:** PI should interact with commercial and industrial resources to enhance transfer success if project succeeds. National Labs have studied for many years different material combinations, is this being taken advantage of by the PI?

**Reviewer 3:** There are no publications from this work. All I can see is this report from which I would conclude they have many blind spots. This is not consistent with past work from this investigator.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The right stakeholder is involved, and the results will be published at the appropriate time.

**Reviewer 2:** It is hard to determine from this summary what the interaction with outside groups is. For instance, what industrial and National Lab players are contributing in thought or dollars. This collaboration is critical for making sure any advances are relevant to potential use.

**Reviewer 3:** Include some PV experts currently working to improve III-V/Si monolithic tandems -- Steve Ringel, Frank Dimroth.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Reconsider the tandem cell approach where Si is one of the junctions. Can you really cost effectively add a junction to Si and get a better LCOE, even when the system costs are included? From a technical point of view the program is creative and of great value, just not convinced that this will lead to a significant impact on the US PV industry.

**Reviewer 2:** 1) Project is valuable to move forward enhances to Silicon/III-V integration. But with such a low cost of Si cells with good efficiencies does it still make sense? 2) Enhance project collaboration outside of directly funded groups. 3) Measurement techniques are valuable, and could also be moved to other programs to enhance their work.

**Reviewer 3:** This appears to be misguided work. Appearances can be deceiving. This project needed more than the 5 page report for a better review, although they did not make the best use of the 5 pages.

## Roll-to-Roll Manufacturing of Continuous Perovskite Modules – $849,216

*University of Louisville | Louisville, KY | Principal Investigator: Thad Druffel*

This project investigates the applicability of low-cost, roll-to-roll manufacturing techniques for perovskite modules. The team employs rapid deposition and annealing techniques, which are the processes used to deposit the absorber layer onto a substrate and then heating and cooling it to toughen the absorber. The team is then studying the performance of the absorber layer and use the same techniques on the remainder of the device layers. The team aims to use these techniques to create a high throughput manufacturing process for perovskite modules in a commercial roll-to-roll facility.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 3 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project using radiative heating in conjunction with roll to roll processing to form perovskite solar cells is an important step. The results of this project may impact other thick film solar cell technologies.

**Reviewer 2:** The first 8 months of work have brought the team to a 5% 1 cm2 perovskite cell annealed (I think) with rather long dwell times. Also, they have made a 14.5% cell using RTA. Making high efficiency perovskite cells is not easy, but the clock is running for this project. It is not clear what the milestones are, but these baselines will not be sufficient to enable progress on the novel processing. Unless they demonstrate competitive (with Si) cells by some technique and use their on-line optical processing to make reasonable cells, this project will not make an impact. It is a very difficult job to optimize so many layers for a new anneal process during 3 years and for $1M plus cost share. Their weakness is that the current results are not very compelling.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 2 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is already showing results presented at scientific meetings. It would be nice if the cost model were further along, and the researchers had begun conversation with solar cell fabricators.

**Reviewer 2:** The collaboration with NREL is useful, but it is not clear that the students have actually begun work there. Certainly, they don't seem to have come back yet with the tricks of making a good cell. The industrial forum they plan will only go off well if they have competitive results.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Each task in this proposal is important and relates well to the other tasks.

**Reviewer 2:** Score: 6. Comments: The plan is fine. But it appears they will need to separately illuminate each layer instead of doing the entire stack. And that means many anneals and much to optimize.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** They should be working with others in the industry. See what potential roadblocks there are in the PV fabrication industry. They should also query other technologies to see what is in place.

**Reviewer 2:** As results on each layer come in, the PI should consider a cost/benefit of treating several layers together. How much can be done and how much does it cost to does each layer separately.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Industry partners, in both PV, and in the roll-to-roll business.

**Reviewer 2:** They will need to establish good relations with each of the perovskite companies, but this will be tough since each has their own annealing technology.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This is a solid project. 2) It is low risk-low reward. 3) PIs should be contact with others in the PV business and in the roll-to-roll business.

**Reviewer 2:** 1) Transfer recipes from NREL and master them in-house. Send students as soon as COVID is over and have the PI visit also. 2) Work anneal of each layer separately, then look at the possibility of combining, with cost of manufacturing in mind.

## Semitransparent, Reliable and Efficient Scalable Organic Solar Cells for Building Integrated Applications – $1,300,000

*University of Michigan | Ann Arbor, MI | Principal Investigator: Stephen Forrest*

Organic photovoltaics are an ideal solution for semi-transparent building integrated photovoltaics for windows, building facades, and rooftops. This project aims to produce organic solar cells with a 15 percent power conversion efficiency that are 50 percent transparent and have a projected 20-year lifetime for building-integrated photovoltaics. This would nearly double the increase in performance compared to typical power-conversion-efficiency values at similar levels of optical transparency. The team will also use its roll-to-roll film-growth technology to continue to improve manufacturing yields and the scalability of organic photovoltaics.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The Forrest group does world leading and cutting-edge research on organic photovoltaics. They have pioneered a variety of very stable small molecule PV cells. In this work they are continuing to make progress in efficiency and stability of semitransparent cells. However, the cost of $1.12/Wp is quite high compared with the roughly $0.35/W silicon modules now being sold and is above the projected system cost targets of SETO. There is high commercial risk in expecting that buildings will spend more to add PV to their windows than it would cost to install a PV field. They have shown rather impressive stability results for their cells packaged under inert atmosphere, however, real field conditions may reduce stability by compromising the inorganic capping layers they use. This project aims a extremely high efficiency and transparency which could actually open the BIPV window market.

**Reviewer 2:** This is a great project and I am glad to see that SETO supports OPV technology. I think semitransparent OPVs are best suitable for applications in greenhouses: they are more stable than perovskites, the transparency is adjustable, and they definitely have the lowest environmental impact.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** LUE seems a reasonable measure and by this measure, the team's solar cells are doing better than the inorganic or organic competition in this space. However, the team should be asked to account for the added grid lines they will need when deploying in larger sizes than the lab-scale cells they have made to date. Measurements of the transmission of relevant grids should be made and corrections to transparency applied. Some of this learning will occur as they transition to 10x10 cm2 modules.

**Reviewer 2:** I like that PI sets clear quantifiable goals and explains the steps his team is going to take to achieve them. However, from the project description I could not conclude that research team collaborates with any specific stakeholders. Also, one things that I was missing in the description of the project goals: the targeted size for OPVs that will be developed under this grant.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The challenge the team has taken on is well-defined: to improve the LUE. As this is relatively far from commercialization, it is good that they are trying different active layer formulations and making impressive progress in each.

**Reviewer 2:** Score: 5. Comments: Yes, all tasks are unique and important. I also think, that one of the produced cells could be tested in real life conditions (outdoors) for at least few months to see how they perform in real life.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI should calculate the loss of transparency and questions of appearance when grid lines are applied to make up for relatively poor TCO conductivity.

**Reviewer 2:** Only one, PI mentions that OPVs can be easily applied to any glass surface but doesn't discuss potential challenges.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Consultations with architects will be important. Perhaps they have already taken place.

**Reviewer 2:** Solar industry, perhaps agricultural companies as potential off takers. California Energy Commission has funded a similar project, I think that PIs could collaborate and exchange their "lessons learned."

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Continue accelerated light-soak tests of the new formulations. 2) Consider loss of transparency due to grid lines. 3) Engage with architects to see which colors and transparency levels are the most desirable.

**Reviewer 2:** 1) Strategically target a market for applications based on unique qualities of OPVs and engage with stakeholders from that market segment. 2) Size matters - I didn't have the feeling that PI was too concerned about the scalabilty. 3) Recyclability of OPVs is one of the advantages that makes them different from perovskite PVs and other commercialized technologies. Whilst PI mentions it in the beginning, I think it won't hurt to emphasize this more and communicate the message to other stakeholders.

## Scalable Manufacturing of Efficient Perovskite/Silicon Tandem Modules – $1,350,000

*University of North Carolina at Chapel Hill | Chapel Hill, NC | Principal Investigator: Jinsong Huang*

This project focuses on increasing solar cell efficiencies by using both perovskite and silicon as the semiconductors in a photovoltaic cell. This team is designing and testing a six-inch by six-inch silicon perovskite tandem cell using an inexpensive high-throughput process capable of producing 5,000 wafers per hour in a solar cell fabrication facility. This process uses a low-cost blade coating process to apply the relevant perovskite layers to make the tandem cells, leading to a lower capital expenditure required to implement this process in existing or new solar cell fabrication facilities. The resulting tandem solar cell could reach an efficiency over 30 percent.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Project proposes to fabricate perovskite/Si tandems with high efficiency using scaleable fabrication techniques.

**Reviewer 2:** Integration of emerging PV technology with widely commercialized Si-PVs is a good strategy to bring the perovskite-PVs into commercial applications. The efficiency goal and the target size of 6” are realistic. Nothing said about stability of the perovskite layer. Also, PI wants to use $CsPbI_3$ as a precursor for perovskite. Cs is a relatively scarce and expensive metal, I am a bit concerned that on a large scale the availability of Cs could be a bottleneck in the supply chain.

**Reviewer 3:** Perovskites present an opportunity to extend efficiencies upward while lowering LCOE further. This team’s work appears very aggressive yet highly practical in mapping out a pathway to early demonstration of a commercially viable product. The focus is on efficiency, scalable processes and silicon-perovskite integration. The work appears to mostly leave durability to others.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 5 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** A very strong team has just initiated this project. The tasks have been clearly defined, and the challenges articulated. Progress is being made.

**Reviewer 2:** I feel that this project doesn’t have strong working relationships outside academia. It is very important to have feedback from solar industry for this type of project.

**Reviewer 3:** Thus far, the project is on or ahead of its individual milestones. Each has demonstrated an ability to advance the work to the next stage. This report and poster showed good results where available. The work stresses the use of low cost, scalable coating technology and is therefore practical. The team also developed novel device designs that go beyond the original scope. It is not clear whether results have been published beyond this report. The collaboration between UNC, ASU and NREL appears to be very good and should leverage the substantial knowledge and capabilities at these labs.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks are well defined and speak to each other. The outputs are measurable.

**Reviewer 2:** Score: 5. Comments: This project is important because it combines already commercially proven Si-PV technology (low risk) with emerging thin-film PV technology in order to develop PV modules outperforming Si-PV in terms of efficiencies. Such approach is a strategically good path for perovskites from lab to market.

**Reviewer 3:** Score: 6. Comments: The experimental approach appears to be well considered and builds upon earlier successes. The use of scalable process techniques reflects the practical need to develop devices and procedures that would ultimately be usable.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It would be nice to see some cost analysis going along with the technical aspects.

**Reviewer 2:** PI doesn’t discuss the stability of perovskite layer - this is important to ensure that both layers have comparable stability and durability. I understand that this could not be studied under this project, as it would make it too complex, however, I was missing such discussion in the project description. Also, again, usage of Cs in perovskite layer could create potential supply chain bottlenecks in case of potential large-scale manufacturing. I would like to see a discussion about how Cs could be replaced with more abundant and inexpensive materials.

**Reviewer 3:** The report does not discuss two of the bigger challenges with perovskites: durability and lead content.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** PIs should work to make sure that industry is involved--they have a good understanding of what is scalable.

**Reviewer 2:** Project team has good relationship with partners from academia and has presented results in scientific magazines. I would in addition recommend that team reaches out to stakeholders from solar industry, who could be potential adopters of the technology.

**Reviewer 3:** Collaboration amongst UNC, ASU and NREL appears to be working well. Eventually, there will be a need to enroll commercial entities which, unfortunately, are limited within the US solar space.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Good project with strong team. 2) Project is early on, but progress is being made. 3) This reviewer would like some kind of cost analysis.

**Reviewer 2:** 1) Development of tandem PVs with perovskite on silicon photovoltaic materials is a good strategy for bringing perovskite closer to commercialization and continued funding for this research area is important. 2) Efficiency of tandem cells is important, yet, the stability of both layers is just as important. Additional research is needed for this area. 3) High-performance PV cells will likely find initial applications in areas where available space for PV installations is limited (rooftops), therefore, research should in addition prioritize encapsulation techniques to minimize potential environmental and health impacts. 4) Tandem PVs will be even more difficult to recycle due to their complex architecture - something that needs attention from the early steps of development. Consider funding projects looking into more circular designs of modules.

**Reviewer 3:** 1) Perovskite promised higher efficiency and low cost. 2) This work focuses on practical methods for integrating perovskites with silicon using low-cost, scalable techniques. The researchers have met or exceeded their original plans and have expanded the scope to novel device work. 3) The work avoids critical perovskite issues notably related to durability and stability.

## Higher Throughput, Lower Cost Processing of Flexible Perovskite Solar Cells by Photonic Curing – $200,000

*University of Texas at Dallas | Dallas, TX | Principal Investigator: Julia Hsu*

The University of Texas at Dallas is working closely with NovaCentrix, a company that pioneered the process of photonic curing and has already integrated it in roll-to-roll manufacturing of printed electronics. In this photonic curing approach, short pulses of broadband light quickly raise the temperature of a film high enough to initiate phase transformation, grain growth/coalescence, and chemical reactions, while the substrate remains below its decomposition/deformation temperature, something not possible with conventional methods. The team is applying photonic curing to replace the lengthy thermal annealing steps in perovskite solar cell processing, reducing time and energy cost and enabling flexible substrates. The physical proximity and the complementary expertise of the two teams will facilitate developing this new tool to produce large-area flexible photovoltaic devices with high throughput.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 |
| Set critical challenges to overcome | 4 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 3 |
| Advance the U.S. solar industry substantially | 3 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Weakness: it is not clear why PI has chosen nickel oxide (NiO) as a hole-transport molecule (HTM). The results achieved so far show that new instrument is not compatible with NiO, it bids the question, why team at least try how their method would work with any of known polymer HTM or small molecule HTM? In terms of potential benefits, it is not clear from the provided documents how the new manufacturing method would affect the performance of perovskite-based PV materials? Perhaps the benefits of lower energy input are less than the drawbacks stemming from decreased efficiency? Strength: New method has the potential to dramatically increase the manufacturing throughput (given the suitable HTM is identified) and it could benefit US PV industry and give the emerging perovskite technology much needed boost.

**Reviewer 2:** This method to reduce annealing time for roll-to-roll perovskite processing may produce a useful tool for future production. At the present time, and within the constraints of funding for PV R&D, the investigation would appear to be somewhat lower priority. At this stage of research in perovskites, it is not clear which materials and configurations will require a faster anneal. For example, it may not be important to solve the challenges addressed in processing NiO and PET/ITO substrates.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 5 |
| Collaborates with sufficient stakeholders | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** From the project description I wasn't able to identify with who the Recipient is working/collaborating. I also think that scientific papers are great for dissemination of results in academia, but active engagement with stakeholders and PV industry partners is just as important.

**Reviewer 2:** The investigation is well guided toward its goals with quantitative milestones and well-chosen measures of the impact. For example the use of SPV for characterization of the conversion of NiO is described well. For a small project without much operating history, the publication output has been quite good.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: This is in my understanding a small project and the major task is to test the new roll-to-roll process that uses light instead of heat. I think this task is important, but it would be even better if it would be performed in the context of evaluation of tradeoffs between performance and manufacturing cost.

**Reviewer 2:** Score: 5. Comments: Again the project is well designed to achieve its objectives. The outcomes have not been as desired, but at this size there isn't much room to support mitigation strategies.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** PI didn't consider testing the new method on any other HTM. Also, PI doesn't seem to look holistically at the overall costs of the proposed new process which would account for changes to the cell efficiency and complexity of new tool. Can it be scalable given all extra adjustments that needed for even a small-scale production?

**Reviewer 2:** The reports does not demonstrate the role of the photon in changing the materials. It is not clear how photonic processing differs from rapid thermal annealing.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** PI is collaborating with peers from academia and company that provided the tool. I think they should also disseminate results to PV startups and see what those startups think of their approach and material choice.

**Reviewer 2:** As a small investigation of the potential for photonic processing, and recognizing the breadth of capability at UTD, this project was adequately supported without engaging other organizations.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** It is pretty much summarized in previous sections.

**Reviewer 2:** It is not yet clear what configurations of perovskite cells will move into production. Exploration of advanced tools for a future factory is thus somewhat premature. Investigation of new processing regimes that may create or enable new materials delivering superior properties is always an important area for innovation. Photonic processing may have some as yet unknown interaction with one or more layers of a perovskite cell that could deliver a unique and superior property.

## Toward Low-Cost, Efficient and Stable Perovskite Thin-Film Modules – $4,500,000

*University of Toledo | Toledo, OH | Principal Investigator: Yanfa Yan*

This project is developing high-efficiency perovskite mini modules and investigating deposition techniques that can be scaled up for high-speed manufacturing. The team is working with First Solar, which has world-leading expertise in industrial thin-film photovoltaic manufacturing, degradation testing, and predictive lifetime modeling. To test reliability, the team is developing accelerated stress-testing methods that can detect what degrades perovskite modules outdoors.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 4 | 6 |
| Set critical challenges to overcome | 4 | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 6 | 4 | 6 |
| Advance the U.S. solar industry substantially | 2 | 6 | 3 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** There is a lot of excitement outside the industry in the potential for Perovskite PV, but all attempts to make functional minimodules that can get anywhere near Si module efficiency, let alone reliability, have failed. There are many challenges in Perovskite solar modules that are being addressed in this project: cell to module loss reduction, operational stability, and accelerated life testing. All three have evaded researchers to date. There are many risks to a successful completion of this project. This 3-year study will have a high impact if at the end they have demonstrated a minimodule with an efficiency above 20% that can operate in real-world conditions and a set of tests that simulate IEC 61215 for Perovskites. This would be a major step in proving if Perovskites have a chance at taking market share from Si This is a substantial grant that could be good for our understanding of Perovskite minimodules, but is not expected to impact the US solar industry for the foreseeable future. However, it will be good to inform the industry on what technologies to consider when Si-based PV starts to approach the Shockley Queisser limit. Open question is still whether or not Perovskites will be able to compete with Si at sub 20¢/W (where they will be by the end of this project period).

**Reviewer 2:** The promise of higher efficiency thin-film cells using perovskite is intriguing and could be a gamechanger. I like the fact this is looking into a novel technology and striving to answer some of the core questions about perovskite viability and setting up an accelerated lifetime test protocol for other perovskite researchers to use. Having First Solar as a partner is a major strength. I think the only weakness is that perovskite solar cells have been shown to be unstable, so I wonder if this work may not be needed. It would be good if this project could help conclusively answer the questions of perovskite reliability across multiple projects working on the material.

**Reviewer 3:** The project generally aligns well with SETO goals by advancing an emerging cell technology with potential for lower manufacturing costs and lower solar LCOE. The goals to identify appropriate accelerated lifetime tests and demonstrate good stability are critical for perovskite solar cells. The project is high risk because of the early stage of perovskite solar cells as a viable PV technology and more specific risks of process nonuniformity, lead content, and poor stability. The project mostly adds value to DOE member NREL's and UT's existing perovskite research efforts. The focus on large area encapsulated devices is needed for perovskite solar cells to advance the PV industry.

**Reviewer 4:** Perovskites could potentially enhance solar module efficiency substantially while bringing down costs further. To date, the technologies have struggled with durability and have not yet been integrated into commercially viable devices. This work focuses on developing accelerated life tests tailored for perovskite mini-modules. The researchers hope to identify devices with >20% efficiency and 25-year lifetimes.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 3 | 4 | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 6 | 2 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is just beginning, but the goals, timeframe and budget seem appropriate for the scope. If the final product is a report of "industry acceptable stability test protocol for perovskite cells and modules" and a demonstration of a correlation between tests and outdoor performance would have a high impact. The team represents research and module manufacturing. I think the team would benefit from input from the finance and development community.

**Reviewer 2:** The project has not yet started. The report does not mention information dissemination, e.g. through Duramat. First Solar as a partner is a major benefit.

**Reviewer 3:** The project has just launched so evaluating milestones is premature, but the champion efficiency >23% on small area devices shows that project team is experienced in perovskite solar cell fabrication. The project's metrics for impact are focused on stabilized and long-term efficiency which are a great place to start.

**Reviewer 4:** The project is just beginning so there are no results to report at this time. The collaboration between experts at University of Toledo, NREL and First Solar should yield industry-relevant results.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Reducing discrepancy between cell and module efficiencies is required to make meaningful minimodules to measure stability. The test regime that they are developing is only effective if it is coupled to commercially "viable" minimodules.

**Reviewer 2:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 3:** Score: 4. Comments: The focus on heat, light, and bias testing for perovskite minimodules is important for evaluating the commercial prospects. The project's effort to develop mitigation strategies for any observed failures directly addresses some of the major blockers for deployed of perovskite PV modules.

**Reviewer 4:** Score: 6. Comments: The report outlines four key goals of this work all of which are related to the especially difficult challenge of understanding and mitigating perovskite stability and lifetime issues.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Biggest blind spot is if the team can make minimodules that accurately represent commercially viable products. If the module stability and associated tests are not relevant it could hinder the impacts of the project.

**Reviewer 2:** None apparent except for possibly information dissemination -- upload data to Duramat.

**Reviewer 3:** The project plan does not directly address known issues with UV degradation, moisture corrosion and thin film delamination in perovskite solar cells. Managing these issues should be built into the project plan. The proposal would benefit from a discussion of which module materials are expected to be most appropriate.

**Reviewer 4:** The project objectives intend to perform lifetime tests on perovskite devices that were produced using scalable techniques. The paper does not talk about the structure of the films. Substantial additional materials work will be needed beyond the scope outlined in the paper. The report also does not address concerns related to deploying lead into production devices.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** This team represents academia and producers but could benefit from some downstream stakeholders (financial and/or developers) to understand what it would take to get the broader industry engaged.

**Reviewer 2:** Duramat for information sharing.

**Reviewer 3:** The project would benefit from additional discussion of First Solar's role as a partner. Having a commercial entity to guide the prototyping phase and pilot a new technology would strengthen the project.

**Reviewer 4:** The collaboration of UT, NREL and First Solar provides a broad set of expertise and resources to work on all aspects of perovskites. Of notable importance is the long-term view towards commercialization.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Perovskite minimodules need to be commercially relevant for the reliability data to be useful. 2) Cost implications of the modules needs to be tracked and evaluated throughout the project. 3) This is a large grant that may not be impactful for years to come.

**Reviewer 2:** I like the fact this work can be used by First Solar and many other research teams to test the long-term performance of perovskite solar cells. Hopefully it will help expedite the progress of perovskite development by answering some of the core questions about the technology's long-term performance. Having First Solar as a partner is a key benefit. It would be good if they shared their results publicly using the Duramat archive.

**Reviewer 3:** 1) The project team would benefit from additional support in minimodule fabrication and BOM selection. PV packaging materials for c-Si may not be appropriate for perovskite solar cells.2) Make sure to discuss your failures as much as you celebrate your successes. Building a new large-area thin film technology is hard and sharing your problems and attempted solutions with the community is important. 3) Consider mechanical scribing techniques and masked deposition in addition to laser scribing. Make sure to publish on scribing failure mode and process development because the perovskite community needs more public materials on this topic.

**Reviewer 4:** 1) Perovskites present an opportunity to increase efficiency while reducing LCOE. 2) Commercialized perovskite devices are limited by stability and durability issues. This paper focuses on evaluating these parameters for a variety of thin film devices that are prepared using scalable processes. 3) The collaboration of UT, NREL and FSLR presents and excellent opportunity to leverage broad expertise in the field.

## Ultra-High Efficiency and Stable All-Perovskite Tandem Solar Cells – $850,001

*University of Toledo | Toledo, OH | Principal Investigator: Yanfa Yan*

This project is developing processes and strategies to fabricate high efficiency and stable perovskite-perovskite thin-film tandem solar cells. The team aims to develop efficient wide-bandgap perovskite cells with high open circuit voltages for the top layer of the tandem while also developing efficient low-bandgap cells for the bottom layer. The team will then develop efficient interconnecting semiconductor layers with low optical and electrical losses and study potential ways that these perovskite-perovskite tandem cells could degrade over time. The team will use this information to develop approaches to mitigate instability issues in perovskite-perovskite tandem cells in order to increase lifetime and lower costs, with the aim of developing a cell with greater than 25 percent efficiency.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Perovskite/perovskite tandem cells are very attractive. Yan has put a good proposal in place.

**Reviewer 2:** I think that research team is aiming to address too many questions at once, perhaps rushing the results. The major issue with perovskite-on-perovskite tandems is their stability and performance over time. I think, team should be rather focusing entirely on this issue and study on fundamental level degradation processes in tandem cells.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a young project and Yan is making good progress on it. He has reached early milestones.

**Reviewer 2:** As mentioned previously, I think that team aims to address too many problems at once, hence, scattering a relatively low budget and other resources. I think that more targeted approach focused on a thorough investigation of one or two fundamental questions pertaining to the efficiency and degradation mechanisms in all perovskite tandem cells would have a larger impact.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Tasks are well described, and all are important in reaching goals in this project.

**Reviewer 2:** Score: 3. Comments: Although all of the tasks are important, I think they are too much for a university team. Universities are typically good at fundamental research, but fundamental research requires time and focus to ensure that results are reproducible and well understood. In my opinion, team will not have enough time to thoroughly investigate all of the tasks.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No obvious blind spots; this is a fairly academic project and contacts at NREL will, I hope, ensure that results end up in the hands of fabricators.

**Reviewer 2:** I think PI understands the area of research well and the challenges that come with it. But perhaps he underestimates what it takes to tackle those challenges (in terms of time and resources).

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None, at this stage of research.

**Reviewer 2:** I provided similar comment to another project that looks into some fundamental research questions - I think the results should be shared very broadly with the entire "perovskite community," and maybe the best way to do so, to establish a nationwide perovskite committee/team that would convene a few times a year and provide the opportunity for researchers and companies to exchange their experiences.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Good project, academically orientation. 2) Good team, keep NREL in the loop. 3) Project is early on, so let's wait and see.

**Reviewer 2:** My only one major comment: Fundamental research cannot be rushed. Results should be tested and questioned until they are reproducible. Less is oftentimes more when it comes to new materials and understanding of their properties.

## In-situ Characterizations of Microstructural Degradation of Perovskite Solar Cells – $201,015

*University of Utah | Salt Lake City, UT | Principal Investigator: Heayoung Yoon*

To understand how perovskite solar cells degrade, this project team is developing methods to measure the electronic properties in perovskite absorbers while the device is exposed to high temperature, bright light, and other potential causes of damage. The surface of the perovskite layer as well as the grain bulk and grain interfaces will be monitored to gain insight into how the materials evolve and degrade.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 3 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 6 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 3 |
| Advance the U.S. solar industry substantially | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Perovskite PV is very promising but not well understood. This research appears to be a novel exploration of this technology which may broadly support development of reliable perovskite PV.

**Reviewer 2:** This project is just beginning, so has no results. I have the following concerns: 1) There are many studies outside of DOE looking at microstructural degradation of perovskites under environmental stressors; this is does not seem to be competitive. 2) Electron beams are very destructive to perovskite films. Will the degradation be due to the probe or the environment. 3) SEM/EBIC are not scalable.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 6 |
| Collaborates with sufficient stakeholders | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is just starting.

**Reviewer 2:** This is a very early project, so there are no results. The team might partner with a manufacturing company to understand constraints.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

Reviewer 1: Score: 4. Comments: There are limited tasks for this project, but this appears appropriate for the narrow scope of the effort

Reviewer 2: Score: 1. Comments: 1) There are many studies outside of DOE looking at microstructural degradation of perovskites under environmental stressors; this is does not seem to be competitive. 2) Electron beams are very destructive to perovskite films. Will the degradation be due to the probe or the environment? 3) SEM/EBIC are not scalable.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** They should have a manufacturing partner and study the literature on perovskite characterization.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No comment.

**Reviewer 2:** Need a manufacturing partner.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** 1) There are many studies outside of DOE looking at microstructural degradation of perovskites under environmental stressors; this is does not seem to be competitive. 2) Electron beams are very destructive to perovskite films. Will the degradation be due to the probe or the environment? 3) SEM/EBIC are not scalable.

## Approaching the Radiative Efficiency Limit in Perovskite Solar Cells with Scalable Defect Passivation and Selective Contacts – $1,249,997

*University of Washington | Seattle, WA | Principal Investigator: David Ginger*

This project focuses on using low-cost techniques to develop perovskite solar cells that approach their theoretical efficiency limit in order to reach the maximum possible performance for these cells. In order to achieve this goal, researchers must better understand defects in the perovskite material and invent new ways to passivate, or deactivate, these defects. In order to improve the efficiency and lifetimes of perovskite solar cells, it's important to be able to passivate defects that arise in low-cost manufacturing environments. The team is using novel optical and microscopic probes to provide insight into the defects currently produced during perovskite cell production and then develop scalable layers to add to the solar cell to passivate these defects.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is an excellent team looking at the problem of surface recombination of perovskites. They also plan to develop ETL and HTL films to contact the perovskite. The only issue is that the search for ETL and HTL layers looks "Edisonian."

**Reviewer 2:** With the development and demonstration of several different high-performance perovskite active material layers, attention must turn toward their surfaces, hole- and electron-transport (HTL, ETL) partners and stability. This project is testing a wide variety of surface passivants that are also suitable as charge-extracting interfaces to the HTL and ETL layers. As the perovskite solar field develops, this large library of such surface passivants will be needed to provide options in the design of high-efficiency and stable cells. The UW team has good experience, good ideas and has partner with Marder (GaTech) who will do some of the synthetic chemistry and others for optical characterization. This is an important project to complement the industrial and device work in the SETO perovskite portfolio. The team has an early success, demonstrating a surface coating to Cs17/Br15 mixed halide perovskite that enables 2.7 microsecond lifetime. The main thing unclear from the writeup is how the 2-photon cross-correlation measurements will contribute to project goals.

**Reviewer 3:** Perovskites present an opportunity to improve solar efficiency and further lower LCOE. This work focuses on efficiency improvements by improving lifetimes and reducing surface recombination. The researchers are screening for material families that satisfy a set of requisite characteristics that would reduce surface recombination.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 3 |
| Collaborates with sufficient stakeholders | 6 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This team is off to a great start. They have developed a perovskite film with minimal bulk recombination so that it will be easy to compare surfaces and interfaces.

**Reviewer 2:** It is not entirely clear to me that lifetime is the only good measure for these passivation layers. Perhaps a diffusion length measurement (also sensitive to surface quality) should be developed. It's not clear how the SRV is extracted from TRPL alone since the quality of the unpassivated surface may vary.

**Reviewer 3:** The project is roughly half completed and the team has made steady progress. They are on schedule and ahead of budget at this time. They have collaborated with the University of Arizona to measure band gaps. They might benefit through conversations with NREL or other research teams.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Both tasks are crucial to success. Developing a bulk film with little recombination is great.

**Reviewer 2:** Score: 5. Comments: I would like to understand the 2-photon correlation measurements.

**Reviewer 3:** Score: 6. Comments: The project is designed in natural, modular, sequential steps of identifying potential materials, integrating them into structures and then evaluating their effectiveness using advanced PL techniques. The data published in the poster appears promising.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I worry about the Edisonian search for ETL and HTL.

**Reviewer 2:** Trying these molecular layers on a number of industrial solar cell perovskites would be helpful to the industry and help them see if their results are universal in application.

**Reviewer 3:** The PI has done a good job of laying out the challenges. The process of identifying an appropriate material is likely to be painstaking and tedious. Having the capacity and patience to steadfastly move forward will be necessary to complete the work on schedule.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None--the team seems smart enough to seek out collaborators where necessary (e.g. Neil Armstrong U of Arizona)

**Reviewer 2:** There should be active collaboration with all the groups that make high performing perovskite layers coupled to excellent (and new) HTL and ETL layers, so that the charge extraction properties of these molecular layers is well tested.

**Reviewer 3:** This work seems highly complementary to efforts at NREL. Bilateral conversations may prove useful

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Great team with a great start. 2) Continue to seek collaborators where necessary. 3) Is search for ETL and HTL really Edisonian?

**Reviewer 2:** 1) This work is important since it provides a library of candidate interface materials between the active layer and the HTL and ETL layers. 2) The team should be patenting their promising materials.

**Reviewer 3:** 1) Perovskites hold promise to improve PV efficiency and lower LCOE. 2) This necessary work focuses on formulating and integrating materials that will reduce surface recombination and hence improve efficiency beyond other work that is mostly focused on bulk properties.

## In-situ Photophysical Monitors and Corrective Algorithms for Photovoltaic Film Deposition and Rapid Thermal Processing in Scalable Roll-to-Roll Manufacturing – $199,992

*University of Washington | Seattle, WA | Principal Investigator: Devin MacKenzie*

Low-cost, high-throughput solution processing could substantially reduce thin-film photovoltaic costs, but it requires new photovoltaic manufacturing lines using roll-to-roll processing. This project is developing gas flow-stabilized slot-die deposition heads and in-situ, real-time optical tools to characterize the roll-to-roll deposition process used to create these cells. The team is using fiber-based optical probes, time-resolved photoluminescence, and light-scattering probes to better understand, for the first time, the critical phase transformations and sintering processes needed to create perovskites with roll-to-roll processing. The team plans to develop real-time corrective algorithms for the deposition process and use these tools to optimize roll-to-roll deposition methods for perovskites and other thin-film photovoltaic materials.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 6 | 4 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Development of tool that enable in-situ measurements is very important as it would allow to accelerate development of optimal manufacturing conditions for perovskites and possibly different types of thin-film PV technologies.

**Reviewer 2:** This work is focused on developing methods for understanding the quality of perovskites during roll-to-roll processing. The test platform (hardware and software) are used to analyze films and to characterize changes due to process conditions.

**Reviewer 3:** In-line diagnostics that follow crystallinity and carrier lifetime should be beneficial to the entire perovskite manufacturing community. This team is attacking some of the hard problems associated with perovskite in-line measurement to get something useful out. Their focus on the environment conditions for solvent evaporation makes sense, as does the focus on improving the signal to noise of the Raman and TRPL measurements. My sole concern is that their new ("high") coating sample speed of 1 m/min that they aim for is an order of magnitude below the targets of industry for low cost/W of the cells. So the degradation they observe when the obtain reasonable signal to noise may not actually be a problem at eventual industrial web or sample speed. Journal publication of results is entirely appropriate for this work. The attempt to replicate NREL results is wise since their recipes are public, but the achieved efficiency below 9% is troubling for the relevance of the actual data.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 6 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team effectively leverages the expertise provided by NREL and also uses feedback from industry partners to make the product most useful to potential off-takers.

**Reviewer 2:** The platform has been developed and used to evaluate grain size using variations on NREL recipes. Difficulties have been encountered with material stability during the processing which required the team to adapt. Device optimization has been slow as current efficiencies are at 8.6% against a relatively modest goal of >15%.

**Reviewer 3:** In this short, lean project, the team should focus its work on demonstrating the efficacy of these in-situ diagnostics rather than optimizing their solar cells. It seems that they have defined several key problems and have a good chance of contributing significantly to future manufacturing diagnostics if perovskites have success either in standalone form or as part of Si/perovskite tandems.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: I believe that in-situ observation of processes that occur during manufacturing is very important and allows to draw important conclusions about relationship between manufacturing conditions and quality of produced modules. It leads to a better control over the manufacturing process.

**Reviewer 2:** Score: 4. Comments: Each task is scoped reasonably but the challenges of dealing with complex and typically unstable perovskite PV materials makes progress very difficult.

**Reviewer 3:** Score: 5. Comments: The team has selected TRPL and Raman as key probes. Both seem like good choices.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** I didn't identify any critical blind spots. One suggestion for PI is to consider how this tool could be modified to be used for different manufacturing techniques.

**Reviewer 2:** The researchers noted difficulties with perovskite instability and also report slow progress on yielding higher quality films.

**Reviewer 3:** I think the development of a third test, rather than optimization of the solar cells should be the priority of the remaining project time. Many other groups have enough money (SETO and private) to do the perovskite solar cell optimization. Diagnostics are the best focus for this project.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** PI has a good working relationship with academia and industry. I think that nothing is missing. Perhaps, other groups working on perovskite PVs could be interested in the results. A kind of national Perovskite Team would be something what DoE could consider. This way the results are exchanged between all research groups and it would also strengthen collaborations.

**Reviewer 2:** Until more stable and durable perovskites are developed, in situ analytic methodologies may be difficult to develop.

**Reviewer 3:** Hopefully they are presenting at conferences.

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) In-situ tools are important. 2) Versatile in-situ tools that can be used for different manufacturing methods could be the next step. 3) Encourage collaboration between research groups working on perovskite technology.

**Reviewer 2:** 1) Improving perovskite efficiency will be important but stability and durability are more critical issues. 2) This project focuses on developing in situ probes and software to analyze film quality. However, the films' natural instability have hindered progress. 3) Current performance is lagging eventual goals.

**Reviewer 3:** Emphasize diagnostics development and debugging over solar cell efficiency.

Attend perovskite solar cell conferences and present results. Use a realistic growth rate that is high enough to represent the rates that the startup's economic modeling has shown is necessary to achieve cost goals that allow perovskites to compete with (or augment as a tandem) future c-Si PV (say, below $0.20/W).

## Machine Learning Assisted Enhancement of Perovskite Stability and Performance – $1,500,000

*University of Washington | Seattle, WA | Principal Investigator: Hugh Hillhouse*

High photovoltaic power conversion efficiency devices with low year-over-year degradation rates, like hybrid perovskites, have the potential to lower costs if their stability and phase segregation can be improved. In order to better determine the maximum open-circuit voltage and photocurrent a hybrid perovskite solar cell is capable of generating, this team is developing photoluminescence video methods that reveal the role of micron-scale spatial photoluminescence heterogeneity and millisecond-time-scale photoluminescence intensity flickering in material degradation and phase segregation. When combined with large composition libraries and different testing environments, the videos yield enormous data sets. The team plans to mine this data with advanced machine-learning algorithms in order to generate a predictive model of degradation for perovskite solar cells.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 2 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project reports states "The goal of the project is to develop predictive models of perovskite material and device degradation." Given the fluid state of development and ongoing changes in the structures of leading perovskite materials, achieving this goal would likely generate interesting information of limited long-term value. It will be very important to observe what types of devices and materials are evaluated. In the referenced publication from this group (RJ Stoddard, WA Dunlap-Shohl, H Qiao, Y Meng, WF Kau, and HW Hillhouse, "Forecasting the Decay of Hybrid Perovskite Performance using Optical Transmittance or Reflected Dark Field Imaging," ACS Energy Letters 2020), they cite the motivation for the study is that several studies have shown that perovskites that pass conventional PV stability tests, degrade under outdoor conditions. Citing the work of Duong et al at ANU where after passing 85-85 in dark, the devices failed under illumination. Photocatalytic reactions at the TiO2 contact might be the cause, but would not justify the large effort to develop this prediction. The greater value of this project is in developing tools that can be applied to each new generation of perovskite materials and devices. Here the benefits of the machine learning assistance and other tasks may be important. Overall, this is a large project ($1.8M) with a narrow focus, fortunately focused on an important and challenging problem. The leverage of pulling expertise from the machine learning community is a significant plus.

**Reviewer 2:** The project is addressing the serious degradation issues with perovskite solar cells. What they are working on should have a long-term impact on the development of stable perovskite cells. The approach is sound, and the use of machine learning to develop a model for degradation using data is, as far as is known, unique to photovoltaics. The challenges have been recognized (slow rate of degradation for encapsulated cells) and it appears that a work around has been demonstrated. The only criticism is that more effort should be made to engage with the PV community, specifically commercial companies, and see if there is interest even at this stage in adoption of this approach.

**Reviewer 3:** Project will allow for rapid evaluation of PSC materials growth for stability. University has taken advantage of facility resources to do growth and evaluation. Future work will focus on rapid evaluation using machine learning algorithms will allow quick turnaround for new device growth compounds. Budget is rich, but reward will be significant if successful.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 4 |
| Collaborates with sufficient stakeholders | 2 | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Given the critical importance of assessing the most relevant perovskite materials and devices, it is very important that samples come from throughout the community. The project organization and responsibilities "All aspects of the project are located the University of Washington main campus and led by faculty with expertise in photovoltaics, perovskites, and machine learning." is not a strength. The milestones are quantitative and are being met. One publication after a year of investigation is reasonable, since this is all new work.

**Reviewer 2:** Again, the work is excellent. There needs to be more engagement with the broader PV community, including the commercial sector.

**Reviewer 3:** Progress has been appropriate for first year of a two-year program. Project would benefit from collaboration with other outside labs and facilities. Publications such as recent ACS will help disseminate tools and results.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The development of tools to guide rapid assessment and prediction of stability of perovskite devices will be of great value. The approach is unique

**Reviewer 2:** Score: 5. Comments: Yes, the approach is well thought out, with appropriate tasks that build on each other.

**Reviewer 3:** Score: 5. Comments: Overall goals are critical, and process leading up to the success of those is appropriate. Logical approach of significant data collection to characterize materials then finding the algorithms that are predictive of lifetime is excellent.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** As mentioned, they need more input from outside partners.

**Reviewer 2:** Be careful of an ivory tower approach. The work you are doing is relevant and potentially very practical. Reach out and show what you are doing to a wider community.

**Reviewer 3:** PSC is rapidly evolving, and important for the project to be able to incorporate and test new device structures and materials.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** All the other SETO funded groups in perovskites.

**Reviewer 2:** I would like to see more interaction with the companies working to commercialize perovskite solar cells.

**Reviewer 3:** At this point the internal only team seems appropriate. This is considering that the team will continue with publications opening up their work to comment and evaluation. When further developed it would be good to add other device fabrication teams to broaden the data sets evaluated.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is a solid team with needed capabilities, tapping technologies already developed at others great expense. Perhaps the "all-in-one-place" organization of the project is needed in the initial phase. Now that they have shown their first success, they need outside collaborators to guide and benefit from the next stages of the research.

**Reviewer 2:** The SETO PM needs to help them reach out to the broader PV community, especially commercial companies. The work has the potential to be too insular. Their approach is excellent and should be evaluated further and the results put to use.

**Reviewer 3:** Approach is excellent for advancing PSC reliability predictions. Tools need to be versatile enough to successfully evaluate present and future material combinations. Encourage broader collaboration as results continue to be demonstrated.

## Quantum-Cutting Luminescent Coatings for High-Efficiency, Low-Cost Solar Cells – $200,000

*University of Washington | Seattle, WA | Principal Investigator: Daniel Gamelin*

This project is investigating the use of quantum-cutting down-conversion layers to be placed at the front surfaces of photovoltaic cells in order to remedy a major source of energy loss. The down-converting layer converts high-energy photons, which are normally reflected or inefficiently collected, into multiple lower energy photons. This enables the more efficient conversion of energy by the underlying photovoltaic material, which can double the current generated by the solar cell. This project is developing and optimizing quantum-cutting precursor ink formulations and large-area solution-deposition techniques. Together, these techniques will enable the integration of these high-efficiency, quantum-cutting, down-conversion layers onto the surfaces of commercially available silicon cells to realize low-cost, high-efficiency photovoltaic technologies.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 3 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 5 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** "Our material was recently demonstrated to have quantum yields exceeding 100%" is a great way to start the Project overview. Unfortunately, for this and many other PV veterans, it also triggers recall of the numerous time this claim has been read before. The report makes a good case that they do have this exciting result. The project goals and approach are predominantly sound and suitably aggressive. Focus on reproducibly making the needed films of Yb3+:CsPbCl1-xBrx, and standardizing the testing are both of high priority. Integrating these films onto silicon solar cells should not be left to this team alone. Several groups are working to develop conformal perovskite coatings for silicon cells as used in hybrid tandem devices. That expertise must be leveraged to help this project advance. Similarly, professors Gamelin, Kroupa and Crane should not recreate cost models, optical coupling models or other common tools of the PV community. Find them help for these.

**Reviewer 2:** The program has been well thought out and is well balanced. The inclusion of theory, modeling, experiment, and outreach are particularly appreciated. If the program is successful, the results will be a significant improvement in Si PV technology. Experimental results are encouraging. Kudos to the PI and team. There are two concerns. First, while the UV photons are better utilized, what of the lower energy photons? Are there unintended losses due to the down conversion layer? Apparently, the modeling indicates that is not the case, but this needs to be carefully considered. Secondly, how easily can this down conversion layer be integrated into Si cells without creating other issues? It seems that this will be considered, but good to make sure that it is. It is unfortunate that there is not a more robust US Si PV industry that could benefit from this!

**Reviewer 3:** Project addresses one of the long-sought solutions of capturing wasted wavelengths. It appears to build well on previous work done at the awardee's facility, taking advantage of existing capabilities. Initial work and results fit well into a logical approach moving forward.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 3 |
| Measures impact appropriately (e.g. quantitative) | 3 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 2 | 6 | 5 |
| Collaborates with sufficient stakeholders | 1 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** They have met the milestones of the project except for delivering 10 films with PLQE >150%. 17 films >136% is indeed very close and extraordinary. One of these films should be sent to another lab with the experience and capability to confirm this measurement. The report does not indicate where they will obtain silicon solar cells or if this will be by purchase or collaboration. The implication is that everything will be done with UW. This is a terrible plan. They must engage teams currently working with silicon PV -- Holman at ASU would be an excellent choice. They should be working with teams experience in perovskite films, particularly for monolithic silicon tandem cells - McGehee perhaps.

**Reviewer 2:** The team is doing an excellent job. The PI has pulled together a number of co-PIs and is also making a concerted effort to reach out to others. They have realistic, quantifiable goals and are meeting (or nearly meeting) them.

**Reviewer 3:** While the technical results are very encouraging, I'm surprised at the budget expenditures to date. Are the overhead numbers frontloaded, and does the group plan on staying on budget? Technical results are presented excellently and have been appropriately disseminated. Cost analysis in future tasks will be critical.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: Several tasks have been identified which should not be done as planned.

**Reviewer 2:** Score: 5. Comments: The program is well thought out and coordinated. The tasks build on each other.

**Reviewer 3:** Score: 5. Comments: Project development and measurement of progress is very strong. Tasks are well developed and lead nicely from one to the next, with results of each helping to define direction of next task.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** They do not demonstrate good knowledge of PV fundamentals. It is not clear that they know how much efficiency would be lost due to absorption up to 500 nm as shown in Figure B of their poster. The optical modeling image in the poster suggests that they may apply the film to textured glass (between glass and EVA both with n~1.5). Assuming n of about 1.8 for their material, it may get dual use as an AR coating if applied directly to Si.

**Reviewer 2:** The only real concern, which I believe has been addressed, is if there are any unintended consequences on longer wavelength photons from the incorporation of the down conversion layer.

**Reviewer 3:** Impact of process temperatures and methods on the base cell performance. Importance of enlisting guidance from cell manufacturing groups. Team assembled at university is diverse and seems well suited to assigned tasks - make sure all inputs are cross shared.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Experienced PV scientists, particularly ones with good silicon cells.

**Reviewer 2:** None. The PI has done an excellent job of reaching out, or planning to reach out, to others, particularly in the commercial world.

**Reviewer 3:** Internal team is strong, and important to add stakeholders to review process as results become clear. Technoeconomic phase needs to be very broad in reach.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This may be a very important new materials for 2 photon conversion to boost silicon cell performance. Early results should be confirmed by an outside source. Collaboration with the PV community should start as soon as possible.

**Reviewer 2:** This is a very well thought out and coordinated program. There is a lot of work getting done for the budget. I would strongly consider the PI for additional funding or programs in the future.

**Reviewer 3:** Concern with budget balance. Appears that materials and equipment should be a dominant expense to date, and not the overhead numbers presented. Important to look at cost of deposition when the technoeconomic phase is started. Encourage wide collaboration with industry players, at least what few remain in the US silicon cell manufacturing universe.

# Reliability and Standards Development

## Defect Kinetics and Control for Module Reliability – $862,000

*Arizona State University | Tempe, AZ | Principal Investigator: Mariana Bertoni*

Metal impurities, particularly sodium and potassium originating from the glass used in the solar cell module, have been correlated with the degradation of efficiency over time. This project investigates the thermodynamics and kinetics of impurity atoms within module device layers, including encapsulants, dielectrics, and within the silicon crystal itself and at its interfaces. This includes building physical models to explain the macroscale observations of solar cell degradation by parameterizing the evolution of impurity distribution in the module under operating conditions and the electronic impact of these impurities. With this understanding in hand, the team will develop a platform to predict degradation issues before they arise in emerging materials and architectures and offer design guidelines for new processes to prevent the incorporation of such impurities and/or mitigate their impact in existing wafer to module processes. By advancing the fundamental understanding of degradation mechanisms in low-cost silicon solar cell materials, this project has the potential to help drive down the levelized cost of solar energy.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 4 | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths include the fact that by looking at Na movement through the package they can evaluate what materials or methods could impede its progress and therefore minimize or eliminate the PID effect. The weakness is that most manufacturers have already solved this problem so most new products are already PID resistant. What would be useful is if in the time remaining the project were to look at other materials and try to predict which could be issues and how to go about solving those issues before they happen.

**Reviewer 2:** Successful completion would allow for more confidence in quantifying certain module defect pathways that are caused by mobile ions (e.g. Na and H). A focus on quantifying Na concentration in "real devices" through SIMS and CV measurements on test structures. Na concentration is hard to measure and hard to accelerate at PV-relevant conditions. Strengths: able to measure Na dynamics in real solar modules. Overcame challenges with the technique in order to improve accuracy. Used PV-relevant temperatures and voltages? Adds to the industry's understanding of PID Weaknesses: Unclear if the results are broadly applicable – would need to know what data would be needed for a module to be evaluated to the final model.

**Reviewer 3:** The primary strength is they have viable results that have resulted in a number of papers, the weaknesses are the bankruptcy of their industrial partner, and the dissemination to industry and measurement of impact is unclear.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 2 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The group has prepared a publication in each of the areas of the project so are working toward dissemination of the results. Teaching others how to make the measurements and calculations will be helpful since there are a lot of different module constructions and potential impurities that could need evaluating.

**Reviewer 2:** Several publications have resulted and will result from this work. Unclear who in industry was approached o contribute cells and modules. Were industry-relevant modules used? This kind of study would be interesting to repeat on a standard module and one that is deemed "PID-free" based on testing from a 3rd party test lab.

Reviewer 3: This project seems to have performed well with good results and papers, but the lack of an industry partner is problematic and thus there is no clear dissemination to industry partners. Also, the impact of the research seems unclear.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: This is a very detailed technical project trying to measure the diffusion of Na in a number of different materials and determining whether outside conditions (like application of an electric field) influence these results. Then all of the different materials have to be stacked together to model how the impurity will flow through the various layers in the stack. This then had to all agree with the experimental measurements of PID. Once the parameters for diffusion are determined the results can then be assessed to determine what changes can be made to the different layers to minimize Na flow. Once again, this all may be a little late as most manufacturers have already solved PID. The question for the remainder of the project should be where else can this be deployed to help stop the next PID before it causes field failures? The project may have been more useful if their industrial partner had not gone bankrupt.

**Reviewer 2:** Score: 4. Comments: It is important to understand the underlying material impacts of Na migration through the module as well as the net impacts to the module performance in order to build a comprehensive model.

**Reviewer 3:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Detailed scientific studies like this one are usually useful but often too late to really solve the problem that they were originally set up to solve. So they end up explaining the why but industry has already found a solution and gone on to the next squeaky wheel. This project can jump the cycle however, if it can identify future issues that are now solvable using the methodologies developed for the project.

**Reviewer 2:** The biggest blind spot in this study is to determine if the results are broadly applicable. The Trac-BTS approach is very intriguing, but relies on synthetic MIS device structures. It needs to be performed on textured cells that have gone through the typical cell processing steps (some care would need to be given to contact the emitter directly) as the thermal processing impacts the SiN properties.

**Reviewer 3:** Collaboration with industry, e.g. cell or glass manufacturer, measurement of impact.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** This project may have been more successful if it had included a module manufacturer who had struggled with PID in the past. In that case both the PID sensitive and PID resistant designs could have been evaluated side by side. They may have also been able to lead the team to future designs where other impurities could be the issue.

**Reviewer 2:** The project would benefit from measurements on modules and cells currently in mass production. This would show how modern Cz ingots and processing techniques compare to mc Al-BSF cells of a few years ago. Would also be interesting to see if these dynamics are different for HJT and TOPCon.

**Reviewer 3:** Glass and module manufacturers, Duramat for sharing results and software tools publicly.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Understanding the science of the PID effect has added value but the industry has already oved on.
2) Learning how to apply the methodology developed to new material systems can help alleviate potential problems.
3) Having an industrial partner who can guide what works and doesn't in the real world can add significant value to the university research.

**Reviewer 2:** 1) This project aims to quantify the movement of Na, which is recognized to be the main cause of PID.
2) The team has done a good job of measuring and modeling Na movement in the module through SIMS and C-V measurements. 3) The analysis should be expanded to industry-relevant cells and modules ASAP.

**Reviewer 3:** The PI should find a new industry partner, measure impact of results and reach out to glass and module manufacturers. They should also publish data and software tools to Duramat if they're not already doing that.

## Reliability Evaluation of Bifacial and Monofacial Glass/Glass Modules with Ethylene Vinyl Acetate and non-Ethylene Vinyl Acetate Encapsulants – $1,300,000

*Arizona State University | Tempe, AZ | Principal Investigator: Govindasamy Tamizhmani*

Photovoltaic modules with glass/glass encapsulation are expected to be more resistant to breakage and degradation than glass/backsheet modules. However, many glass/glass-module architectures continue to use ethylene vinyl acetate as an internal encapsulant, and it has been linked to significant life-limiting reliability issues, including glass cracking, encapsulant delamination, and encapsulant browning. This project assesses the merits and shortcomings of glass/glass modules with and without ethylene vinyl acetate encapsulants by evaluating new and field-aged modules. The team will then evaluate the expected reliability of these modules using indoor and outdoor accelerated tests.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** As the PV industry switches more to glass/glass modules it is extremely important to understand their reliability. This project should help the industry answer: Are G/G more reliable than G/B? Do they suffer from different failure modes than glass/backsheet modules? What encapsulants are most compatible with reliable G/G modules?

**Reviewer 2:** I believe there are a large number of glass on glass modules with EVA out there. As such, the results of this study are disturbing. The strength of the project is the results, but the potential weakness may be the sample size, which seems small. It would be good to confirm the results with a larger study.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The task plan is appropriate and they have been meeting the milestones and objectives.

**Reviewer 2:** It would be good if the team was working with a module manufacturer and not only DuPont who may be motivated to sell their non-EVA encapsulant material.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: This is an important project because it addresses a technology (G/G modules) that has become a significant share of the market. The project looks at old modules from the field, deploys new modules and mini-modules in the field and performs accelerated stress tests on matched modules and mini-modules. Having all 3 provides a more complete picture than many other such projects where they only have 1 or 2 of these. Because the modules and mini-modules are well characterized and brothers have been subjected to accelerated stress testing, there would be great value in continuing the exposure and monitoring of the outdoor samples for an extended time period.

**Reviewer 2:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** To some extent the project has assumed that glass/glass modules will fail and or degrade via the same mechanisms that G/B modules do. However they are using combined accelerated stress tests and are accelerating the stresses observed outdoors so they may identify different failure modes in G/G modules.

**Reviewer 2:** The lack of collaboration with a module manufacturer.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** This is a University/National Lab project. They do not have an industrial partner. For this work to have maximum impact it must be picked up by a module manufacturer and probably by a number of system owners.

**Reviewer 2:** Module manufacturers, Duramat to share data publicly.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** This was an important project because it addressed the reliability assessment of a technology that is becoming a larger fraction of the commercial industry. This project addressed old modules in the field, new modules and mini-modules deployed in the field and new modules and mini-modules subjected to accelerated stress testing. This makes a complete package that provides a lot more information than can be obtained by only addressing 1 or 2 of these methods. A continuation of this project at a low funding level to continue assessment of the fielded modules could be of great value. Since these modules and mini-modules are well characterized and identical to those put through the accelerated stress testing, there would be great value in continuing to monitor their reliability.

**Reviewer 2:** The results suggest we could have a big problem with EVA in glass on glass modules, which are coming to dominate the industry. However, the samples size seems small. I'm also concerned the results may be perceived as biased since DuPont is a partner and is motivated to sell non-EVA encapsulant. It would be good if they partnered with a module manufacturer. They should also publish data and software tools to Duramat if they're not already doing that.

## Ultrasonic Characterization of EVA Crosslinking for Quality Assurance and Lamination Process Control – $200,000

*Arizona State University | Tempe, AZ | Principal Investigator: Rico Meier*

Solar modules that are not properly laminated can produce less power over time because of cell breakage, corrosion, and other issues that may occur. This project is developing a method using very high-frequency sound waves to characterize the module lamination process, paying particular attention to specific bonding structures in the ethylene-vinyl acetate encapsulation layer, and quantify the achievable resolution and measurement uncertainties. This work will deliver new insights into how defects and lamination are related and how to optimize the lamination process, ultimately at the industrial scale.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Improving lamination (and the post-lamination rest) time would help to lower module costs through better line utilization. Moreover, deviations in lamination process or encapsulant formulation can negatively impact module reliability. A simple nondestructive method that could help characterize the degree of cross-linking of the encapsulant could help with design of experiment and for an in-line or batch testing technique to help improve quality. This an established technique that needs to be calibrated to see if it works for the purpose proposed by the grant If this project is successful, it could lead to a new in-line or end of line tool for quality control. Even if module cross-linking is not responsible for a lot of fielded failures, having more control of process will help module quality in general. This is a proof of concept demonstration and matches the timeframe and budget. It compliments existing research outside of the DOE.

**Reviewer 2:** No comment.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a relatively small grant, but could benefit from feedback from the community on the degree of issues from under or over laminated modules. Also to understand what formulations of EVA are of most value This project is just beginning, but the goals, timeframe and budget seem appropriate for the scope. As expected, there are no publications yet.

**Reviewer 2:** No comment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The parallel tracks to create and characterize modules using traditional techniques while also developing the modeling on the Lamb wave characteristics will help make this project achievable within the year.

**Reviewer 2:** Score: 5. Comments: No comment.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Changes in encapsulant formulations and other BOM changes that could potentially mask the signal that they are trying to detect with the ultrasonic technique. Unclear if this technique would be broadly applicable or would have different efficacies with different module manufacturers.

**Reviewer 2:** Need industrial partners if the project is to be adopted by industry.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See above description under "blind spots."

**Reviewer 2:** There are no collaborators, but this may be because it is early. Maybe Springborn labs or the successor of this company?

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) This project is a proof-of-concept grant that aims to utilize ultrasonic characterization to measure encapsulant properties post lamination in a non-destructive way. 2) More in-line testing is needed to ensure module quality at larger and larger volumes.

**Reviewer 2:** Very important work for long term reliability confirmation. Need collaborators. Good project to fund.

## Improving Solar Panel Durability through Novel Panel Designs, Advanced Manufacturing Equipment – $600,000

*BrightSpot Automation | Westford, MA | Principal Investigator: Andrew Gabor*

This project is conducting a fundamental study on the nature of cracked cells in crystalline silicon solar panels with the goal of improving module materials and designs to make them more resilient against crack initiation, propagation, and degradation over time due to the electrical isolation of cell segments. Key areas of investigation include determining the effects of accelerated lifetime testing on modules in inducing power loss due to cell cracking, and how these effects can be mitigated.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Cell cracks are a well-known issue in the PV industry that can cause accelerated degradation of fielded modules. The biggest challenge is that the cell cracks are not visibly and can impact plant production for years without being remedied. Reducing the occurrence of cracks will improve investor confidence and lead to lower O&M costs in the industry The goal to not only model what caused cell cracking, but also to devise a way to ameliorate the issue was lofty. The 3-year project with a potential commercial solution at the end for $750k is a good match. There was a lot of risk in understanding the mechanics of cell crack formation. If the RailPad can be commercialized at a reasonable price, there could be large impacts to the industry. Expect that the product will also need to lead to reduced BOS costs in order to implemented in large volumes vs just after an event (e.g. hurricane).

**Reviewer 2:** This project highlights some of the inherent potential issues with laminate in modules as concerns stress from real-life pressures. The suggested method to mitigation using the brace is an intriguing one. I wonder if that solution is more considerably effective as an integral design change to the module, to the racking system or as intended as a standalone product. In any case, there is certainly meaningful insight gathered using the study direction. It's not clear however if the duration of the funding will be sufficient to introduce and incorporate the expected test method into the international standard for PV modules or as a stand-alone standard considering the longer process for doing so with the IECEE and if applicable, within the U.S. as well. Some more information regarding the initial draft test method, including any initial ideas regarding test set-ups or assumptions would have been interesting to review and hopefully will be covered in the program this coming week.

**Reviewer 3:** The solar industry is experiencing a "hard market" for catastrophic damage insurance starting with a significant reduction of hail protection. This technology could help make modules more resilient to storms, possibly hail, although that's not mentioned in the material. As such, it could compensate for the downturn in insurance and support development of projects that may not otherwise be built in large swaths of the US where storm risk is high.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 3 |
| Collaborates with sufficient stakeholders | 5 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The MS table shows that the project has successfully completed the majority of their milestones, which is great. The team has also done a good job of publishing their results and demonstrating their RailPad solution. The technology and approach has been demonstrated at the FSEC test site. The second demonstration with a partner will be very valuable.

**Reviewer 2:** It appears that there has been sufficient collaboration with necessary stakeholders. It would be interesting to know if further outreach has been made with PV module manufacturers with facilities in the U.S. Similar to my comment above, it's not apparent if the duration of funding will be sufficient to secure consensus or publication for the test method.

**Reviewer 3:** The results of the project are clear and useful, however, the impact to performance, economics or support for new construction is unclear. Also, the project would benefit from collaboration with an industry partner such as a tracker company or module manufacturer and insurance company.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The ability to detect cracks more efficiently and to model them more accurately were required in order to develop the product that could be used to prevent/mitigate. Each task on their own also has value to the broader PV industry.

**Reviewer 2:** Score: 6. Comments: The overall concept of addressing the issue of cracking is very unique and has multiple potential applications. There seems to have been significant opportunities to share the approaches and sharing of the received feedback would also be of interest to gauge the overall project's potential for use by industry.

**Reviewer 3:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The total cost of ownership needs further evaluation.

**Reviewer 2:** It appears that there is a presumption that all crystalline modules have been treated as generic in its application under the project. Presuming there is homogeneous form and fit, the results could potentially not be considered applicable to all types of modules if there is actually varying size, thickness, shaping, laminate material, cell type, etc. among crystalline modules. It would have been insightful to ascertain if this is an assumption or if there could have been added one or two additional scenarios to address.

**Reviewer 3:** Lack of collaboration with industry partner, e.g. tracker or module manufacturer, insurance company.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** More input and collaboration from plant owners would be a great addition to this project.

**Reviewer 2:** It appears that module testing laboratories have been involved. It's not clear if those with significant and credible experience in both PV modules, mounting systems AND trackers have been involved such that any integrated or 'system' perspectives have been included.

**Reviewer 3:** Industry partner, e.g. tracker or module manufacturer, insurance company. Duramat to share data.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Despite being a known issue, there are still a lot of open questions around what induces cell cracking (e.g. why some modules in a field experience the problem more than their neighbors despite having similar BOMs). This work added improved understanding using FEA and showed a way to mitigate ex-situ to the module. This solution to mitigating their deleterious impact could lead to system cost reductions in unknown ways

**Reviewer 2:** First, verifying applicability to all crystalline modules or is there are variations that need to be further details (maybe with identifying assumptions that were made for the project specific to those crystalline modules). Second, given the specific location / constructional positioning of the brace in what appears to be trackers, it would be interesting to understand if there are potentially different results for rooftop mounting systems (or if this brace is intended for both). Lastly, additional consideration for what is required in order to develop, gain consensus and publish the test method with the IEC and/or UL would likely exceed the current project duration and require additional funding.

**Reviewer 3:** The RailPad technology could make a huge impact by strengthening the durability of PV modules as a reaction to the hard market we are entering for catastrophic insurance. Already insurers are no longer providing sufficient hail insurance. This will probably curb construction in large areas of the US where storm risk is high (TX, Midwest, Southeast). The challenge is getting this technology in the hands of manufacturers -- of trackers or modules, for instance. It would also be useful to reach out insurance companies with the solution to see if they would insure projects with the RailPad. They should also publish data to Duramat if they're not already doing that.

## Reliability and Power Degradation Rates of Passivated Emitter Rear Contact Modules Using Differentiated Packaging Strategies and Characterization Tools – $1,465,291

*Case Western Reserve University | Cleveland, OH | Principal Investigator: Roger French*

This project is conducting a systematic study of module degradation pathways in passivated emitter rear contact photovoltaic modules, benchmarking them relative to known degradation mechanisms and pathways of older module designs, such as full-area aluminum back surface field, which have been exposed to real-world and accelerated exposure conditions. Statistical models incorporating outdoor performance and accelerated testing data are being used to understand the dominant physical degradation mechanisms that occur in the field for a variety of encapsulant and backsheet combinations. These models allow for new and previously unmapped material interactions that are present in newly developed module architectures to be modeled, characterized, and ultimately accounted for in future design efforts.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 3 |
| Set critical challenges to overcome | 4 | 4 | 4 |
| Implement a high-risk, high-impact approach | 3 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 3 | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 3 | 3 |
| Advance the U.S. solar industry substantially | 3 | 2 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goals and objectives of this project are very important. However, the approach is not likely to achieve those goals. There are a number of problems with the approach. First, while it is always good to deploy and monitor modules outdoors, selecting a site like Cleveland with its cool cloudy weather is not likely to provide good answers to degradation processes driven by heat, light and humidity. At least a second outdoor site should have been chosen. The literature indicates that the biggest difference in outdoor performance between PERC and BSF is LeTid, which the project mentions but doesn't appear to do anything to evaluate. Instead they use long term damp heat testing, which many experts have repeatedly pointed out does not duplicate what is seen in the field. Yet most of their testing and modeling appears to be based on this.

**Reviewer 2:** The shift to PERC has had a major impact on reducing the LCOE of solar energy, but there are some open questions around how the stability will compare to the more established Al-BSF technology. When switching technology, a detailed analysis of the reliability of the new vs the old is critical to maintain investor confidence. One way to de-risk technology shifts is to compare to the incumbent. This team aimed to do just that by running outdoor and indoor tests. The impact could have been high. The biggest risk would be that there were not statistically significant differences between the technologies or if the samples had unintended differences in manufacturing that obscured the real differences. Unclear how the results will be used to improve module design or materials. The results shown are most likely specific to the samples used in the test and are not generally applicable to non-CSI cells. If the study continues, I suggest bringing in many suppliers and cell lines to do a statistical analysis.

**Reviewer 3:** The project aligns with SETO goals by seeking to improve reliability of PERC PV modules. Determining the power loss of PERC cells in a range of module packaging materials is a useful goal if it can be confidently extrapolated to long-term energy yields. The main project risk is that its results may not impact existing PERC product development activities. If successful, the project would accelerate the gain in market share for BOM materials with better cost/performance properties. The scope and duration is a good match for SETO, and the project has non-DOE members in Dupont and Canadian Solar. The proposal could advance the PV industry by accelerating the transition to next generation BOM components.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 2 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 3 | 3 |
| Disseminates results frequently and actively engages partners | 3 | 3 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The program plan is well laid out and has been implemented accordingly. Coordination of the number of partners has been done well. Their program plan has some issues. As pointed out above the choice of long term damp heat testing is one of them. Today combinations of damp heat, light and applied voltage would likely be a better choice. Also the use of just a few small samples of multiple technologies does not provide much in the way of statistics nor tell you whether your selection of a component (say using a less robust EVA) drives the results.

**Reviewer 2:** The project is 2.5 out of 3 years in. The results don't reflect the time frame or budget. Several publications are submitted. The team did a good job working with Dupont, Canadian Solar, and Cybrid technologies. I think the project could have benefited from more input from the downstream developers and reliability test labs who have lots of data.

**Reviewer 3:** The project has reported power loss metrics for mini-modules, but the work on degradation pathway network models seems to be delayed. The failure analysis work seems to use a novel nano-Voc technique but has yet to identify PERC specific degradation modes. The metrics for impact seem to be limited and not related to demonstrations of improve product lifetime or reliability. The project has a good publication history. The engagement with collaborators at Dupont and Canadian solar is not adequately discussed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The goal of the project was right on. The approaches they used had some serious issues. In hindsight the project could have been a lot more valuable although some good technical data has resulted. Many of the so-called conclusions like PERC being more stable than BSF is based on testing that is suspect in the PV community. Similarly the discussion about half cell versus whole cell modules misses the point that at lower current levels series resistance changes will not affect power as much.

**Reviewer 2:** Score: 5. Comments: The combination of outdoor IV scans, minimodules, indoor testing, and forensics are necessary to fully understand the results. The project could benefit from more samples and perhaps some iteration based on findings

**Reviewer 3:** Score: 4. Comments: The first task around data acquisition is important for gaining insights into real world module behavior, but only when coupled with dedicated performance analytics. Energy yield differences by BOM component may be impossible to discern from the minimodule production data. The second task focuses on fabrication and stress testing of minimodules and could reveal some differences between BOM components under accelerated stress testing conditions. The third task involves full module as well as microscale cross-sectional characterization. This kind of work may be unique but needs a more thoughtful discussion of how it could advance the PV industry. The fourth task around large-scale data analytics does not yet seem unique or important and the only reported outcome is that corrosion or series resistance increases are visible in EL images (this is well known already).

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project team has picked one accelerated stress test (long term damp heat) and based all of the results on that. Where is the data that justifies this? Field data would point toward evaluating the known difference between PERC and BSF – namely LeTid. How could this behavior be tested? Are there any long term consequences? What about combinations of stresses (damp heat and light, damp heat and voltage, etc.)

**Reviewer 2:** My biggest worry is whether the samples were correctly controlled in order to only pull out the differences between PERC and Al-BSF. Module processing can have a lot of variability even with the same bill of materials. It is imperative that the sample-to-sample variations are controlled for by statistics and tight controls.

**Reviewer 3:** The project report does not adequately show how the Canadian Solar outdoor data will be used to advance the study and improve modeling of failure modes. The project report does not demonstrate how <S|M|R> models will be used to predict accelerated test results and long-term energy yield.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** At this point it is probably too late to make any major changes to the project. The technical data will be made available but because of the choices made it will be of limited value.

**Reviewer 2:** See above description under "blind spots."

**Reviewer 3:** The project would benefit from increased engagement with its partners Canadian Solar and Dupont. If the project could be tied to qualifying a new material type or class of materials that would help. If the project could be tied to helping Canadian Solar decide how much extra to pay for higher quality materials that would also help.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

Reviewer 1: While the goals of a project may be very good, it is equally important to evaluate how the project team proposes to meet those goals. Use of just one type of accelerated stress test is never going to fully differentiate the reliability of different technologies. Detailed measurement of a small number of specially made samples can provide initial results but will not tell you the overall picture because the results can easily be due to the choices made. Just because one EVA causes something to happen doesn't mean all types of EVA will. You have to verify that via further experimentation.

**Reviewer 2:** 1) This kind of project would be a good fit for DuraMAT rather than a stand-alone project. 2) This project needs more stakeholders and data.

**Reviewer 3:** 1) Narrow the scope of the project and focus around distinguish a few well-defined degradation mechanisms for moisture corrosion in c-Si cells. 2) Focus on linking your accelerated test results to long-term energy yields. The scope of the study is too short to see much performance degradation in the field so you will need to determine acceleration factors and apply stress models to TMY field conditions. 3) Formulate a plan for making all data and models open source.

## Toward 50 Year Lifetime Photovoltaic Modules: Double Glass vs. Glass/Backsheet – $1,134,000

*Case Western Reserve University | Cleveland, OH | Principal Investigator: Roger French*

In order to enable photovoltaic modules to have a 50-year lifetime, researchers are exploring modules with double glass or glass/backsheet designs. To reduce degradation rates and extend the service lifetime of these high efficiency modules, researchers must better understand the operational conditions of solar cells within these modules. This project uses data from stepwise accelerated exposures and real-world photovoltaic systems to quantify the impact of module architecture and packaging materials on the degradation rates of double glass and glass/backsheet modules. Identifying and mitigating the degradation modes related to packaging materials and architectures for double glass and glass/backsheet modules could help to lower degradation rates toward 0.2 percent per year and lower the levelized cost of energy.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 |
| Implement a high-risk, high-impact approach | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 4 |
| Advance the U.S. solar industry substantially | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goals and objectives of this project are important as glass/glass is taking over a larger share of the PV industry. However, there are some questions about the approach being taken in this project. Once again selection of Cleveland as the one site for outdoor exposure means the results will not be consistent with testing in the more stressful high temperature and or high humidity environments. At least a second site should have been chosen. How much change are you going to measure from a short-term exposure of mini-modules? Any degradation in a year or two would indicate substandard quality materials not a test of glass-glass versus glass backsheet. There should be no question in anyone's mind that glass/glass will survive better in long term damp heat testing than glass backsheet. This has been proven multiple times. What hasn't been shown is whether there is a correlation between that and long-term outdoor performance.

**Reviewer 2:** Overall, the use of mini-modules to understand if the design approach is a unique element of this project. The sharing of information and results at the milestone stages should gather some valuable feedback on the plan. It appears that the initial challenges were overcome and continued progress is underway. It would be more helpful to a wider number of stakeholders if the milestone progress and results were more widely available to others so that the findings could potentially help more manufacturers in assessing potential product improvements.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The program plan is well defined and has been implemented well. Coordination of partners appears to be adequate. The major issues relate to some of the decisions made in the program plan. Accelerated stress testing using combinations of damp heat, light and voltage are of more interest than just longer-term damp heat, which has not been well correlated to field results. Testing of parallel samples outdoors and through accelerated stress testing is important, but in this case the outdoor testing must be at the appropriate locations and of extended duration or little will be learned.

**Reviewer 2:** As mentioned above, it's clear that there are good interactions between the project team, and sharing the milestone results more widely might enable additional feedback or interest in the project such that the overall project deliverable could be more helpful to more manufacturers in industry.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The goal of this project was right on. The approach leaves much to be desired. Why would we expect glass-glass to fail in the same ways that glass-backsheet modules do? For such a project to be effective it should really look at a number of possible failure modes and to evaluate the potential for GG to fail in each at a different rate than GB.

**Reviewer 2:** Score: 5. Comments: Planning, objectives and milestones are clearly well planned and appear on track. Overall task organization and execution is well planned and prepared.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The team seems to have fixated on one type of failure mode for GG and planned the whole project around that. The results are a foregone conclusion – GG will perform better in long term damp heat than GB. This has been determined in numerous studies, but never correlated to field results. What about cell breakage? What about delamination due to mechanical stress and damp heat? What about PID? These are all potential failure modes for GG that need to be investigated.

**Reviewer 2:** The only comment here is the use of other methods and channels to disseminate information and results. While some of the more traditionally technical PV events are certainly appropriate, additional outreach and communication to a wider stakeholder group would be beneficial.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Because of the focus on one accelerated stress test, the results are not likely to be very useful to anyone.

**Reviewer 2:** Collaboration with the other PV reliability and degradation project teams and understanding what dependencies or inter-related scientific impacts would be useful. I presume that SETO staff would provide those opportunity, insight or analysis.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** While the goals of a project may be very good, it is equally important to evaluate how the project team proposes to meet those goals. Use of just one type of accelerated stress test is never going to fully differentiate the reliability of different technologies. Outdoor testing needs to include the more stressful environments and needs to be continued for more than the length of a 2 or 3 year project.

**Reviewer 2:** SETO should continue to support target approaches like this as they can provide real insights into practical study methods. Similarly, the use and development can be directly useful in product innovation vs. more modeled approaches or indirect design guidance.

## Understanding the Mechanism of Light and Elevated Temperature Induced Degradation of p-type Silicon Solar Cells – $200,000

*Colorado School of Mines | Golden, CO | Principal Investigator: Sumit Agarwal*

The Colorado School of Mines and the National Renewable Energy Laboratory will develop strategies to mitigate degradation in p-type passivated emitter rear contact silicon solar cells, which are built to capture more light on the back surface of the cell, resulting from the interaction of hydrogen with light and high temperatures. This project aims to improve the long-term reliability of passivated emitter rear contact silicon solar cells.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 3 |
| Set critical challenges to overcome | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 |
| Advance the U.S. solar industry substantially | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** The project aligns with SETO goals by helping to develop strategies for mitigating light-induced degradation losses in p-type silicon solar cells. The goal to publish on the state of hydrogen in silicon as a function of stress conditions is an important part of building consensus on the LeTID mechanism. The low concentration and unknown spin states of the most electronically active defects increases the risk that this study does not reveal new information about LeTID defects. The project size and duration are well-matched to SETO, and most of the work will add value within the DOE. If an atomistic-level understanding of the LeTID defect leads to reduced power loss or improved long-term energy forecasting, this project would advance the PV industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 3 |
| Collaborates with sufficient stakeholders | 4 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Not yet started.

**Reviewer 2:** The project team has demonstrated some tantalizing differences in electron spin resonance (ESR) spectra as a function of wafer processing history. The metric for impact seems to be related to successful demonstration of new characterization procedures. The project team has a detailed publication record but not much on Si:H defect characterization for PV applications. The project team will engage its NREL collaborators through the co-advised lead researcher.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: It seeks to understand a thermal and light induced decay phenomena that appears in Perc cells.

**Reviewer 2:** Score: 3. Comments: The tasks as shown in the project report would benefit from additional metrics and specificity. The project would benefit from a brief literature review of existing ESR and FTIR characterization of H-saturated Si and the application to photovoltaics.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Needs industrial collaboration at some point.

**Reviewer 2:** The project team would benefit from working to forecast the impact of LeTID on long-term energy yields. Degradation and regeneration processes proceed in competition under field conditions and the net impact as modules age is not clear.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Needs industrial collaboration at some point.

**Reviewer 2:** The project would benefit from additional interaction with PERC cell process development teams. A lot of development has gone into 'stabilized' p-type silicon solar cells, using a complex annealing history to move cells to a regenerated state before the module build.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Should be funded. These basic materials mechanisms need to be understood. Looks like a capable and well-equipped team.

**Reviewer 2:** 1) Study hydrogen effusion carefully and attempt to forecast the long-term hydrogen concentration in fielded modules. It's a big unknown in forecasting the long-term impacts of LeTID. 2) Investigate the long-term stability of the regenerated state and the prospects for defect passivation for the operating life of a PV module. 3) If you end up needing to use wafers with huge excesses of hydrogen, make sure to conduct standard IV studies as a function of light and heat stress. Researchers will want to know how your cells change over time as compared to cells with more typical processing.

## Capturing the Full Benefits of Bifacial Modules to Approach a Levelized Cost of Energy of $0.03 per Kilowatt-Hour through a Regional Optimization of the Electrical Architecture – $1,500,000

*Cypress Creek Renewables | Santa Monica, CA | Principal Investigator: Jenya Meydbray*

Bifacial photovoltaic modules can yield efficiency gains, but the solar industry has been unable to accurately quantify the benefits of these modules at the system level, leading to uncertain cost estimates and lower adoption rates for solar energy systems that need financing. This project seeks to validate existing performance models for bifacial modules and quantify the impacts of system location, tracker height, module technology, and system architecture on bifacial efficiency gains and the projected levelized cost of energy. This project aims to improve investor confidence by providing new data on bifacial system performance gains across the United States and will validate a holistic system architecture that allows system integrators to meet or exceed the levelized cost of energy target of $0.03 per kilowatt-hour by 2030.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 5 |
| Set critical challenges to overcome | 5 |
| Implement a high-risk, high-impact approach | 4 |
| Match well with the level of DOE funding and planned project duration | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 |
| Advance the U.S. solar industry substantially | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: The subject matter for this study is focused on one of the most influential, impactful innovations and rapid trends that is happening in the industry currently. Bifacial modules are destined to become a significant value enhancer, and the adoption rates will be significant in the US market. With new module technologies such as this, understanding the energy benefits and how to appropriately model them is crucial to the success, and the industry does not yet have a comprehensive set of studies or tools that can ensure accuracy. There remains many investors and finance entities that either have not underwritten a bifacial project, or have done it in a way where the true value was discounted for risk. Strengthening the data and field performance to increase modeling accuracy is a meaningful effort. Weaknesses: The project appears to be limited in the types of applications and conditions and it is uncertain as to how the findings of this study will be applicable to a broader set of use cases and design choices. The project report does not detail quantitative impacts for the industry, rather makes broad statements. The data will need to be evaluated by an IE and the manner in which the operator maintained the system, calibrated equipment, and measured data will be important as a baseline.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 |
| Disseminates results frequently and actively engage partners | 5 |
| Collaborates with sufficient stakeholders | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team appears to be advanced in nature, has already achieved key milestones, and is comprised of experienced professional with a track record of success. Although the project is delayed, it appears as if the project is on budget, and has achieved key milestones to date.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: A detailed task list was not provided as part of the report, rather a summary of milestones status.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** These are the questions submitted to the PI and are indicative of potential blind spots: 1) How can the results from this study transpose to a broader set of geographical regions, or any varying site conditions (albedo, topo, etc.) that might influence performance? 2) How can the results of the study be applied to varying design configurations, racking structures, etc.? 3) How can the results of the study be applied to varying module technologies that are paired with bifacial (poly PERC vs. mono vs. half-cut, etc.)? 4) The report cites that the financing models were conservative and under-predicted the bifacial gain. How would the field data compare to the "as-built" energy model? 5) How will the analysis delineate between performance behavior that is attributable to the module, versus the design? For example, the backside PTC rating may be overstated in some instances. 6) What are the intended tools and work products that will be delivered to industry stakeholders to improve modeling practices and strengthen finance underwriting?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Independent Engineering will need to review the data and qualify the conclusions.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The project team is considered a strength of the project, they are highly qualified for this type of work, and the execution certainty is high. 2) The focus area of this project is aimed at one of the most impactful, relevant areas of the industry currently and this can be immediately impactful upon completion. 3) With or without DOE funding, this project can likely succeed and achieve the same outcomes. Also, there exists multiple similarly focused studies and projects running concurrent to this one.

## Direct Current Arc-Flash Safety for 1,500 Volts: Methodology, Verification, and Codifying – $1,010,726

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Michael Bolen*

The rapid release of thermal energy, pressure waves, and electromagnetic interference from an arc-flash all pose risks to people and equipment in a photovoltaic plant. However, there is a lack of understanding regarding how to calculate incident energy from direct current arc-flashes. This project is increasing the fundamental understanding of arc-flash mechanics in photovoltaic systems and providing the quantitative foundation and recommendations for adoption by the industry. This is being done by physically testing arc-flashes in a laboratory; developing a detailed physics-based model to confirm underlying methodology and key input variables; and documenting and disseminating results through guidelines submitted to code bodies, journal and conference publications, and an easy-to-use incident energy calculator.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 3 | 5 | 4 |
| Implement a high-risk, high-impact approach | 2 | 6 | 2 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 2 | 5 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Improving arc flash knowledge and safety is a laudable area of research for the fastest growing segment of the power industry. While this project is unlikely to have a high impact to the industry as a whole, it's important to ensure that the operational safety of the solar industry matches the environmental stewardship. As a result, the modest budget of this project appears appropriate.

**Reviewer 2:** The overall premise of the study is clearly important to solar worker's safety, not only for the scope of commercial PV plants, but in general, to bring consistency to modeling of the electric shock risk and therefore, to the necessary PPE required. By combining research, modeling and field tests a practical perspective can be implemented and the appropriate causes and effects on the impact of the modeling approach verified and supported. Considering one of the models currently is use if overly conservative, there is a direct cost impact in setting expectations on how to outfit crews who work in and around solar on a regular basis. While overall, industry has a duty to its workers to ensure they are properly outfitted, having more reliable knowledge about the basis for the appropriate gear is extremely important.

**Reviewer 3:** The goals and objectives of this project are deemed important and valuable and clearly aligns well with the SETO mission. Most anyone who has been involved in system design has experienced the challenges cited by the author and they are factually true, and has not substantially improved overtime. The end goal of a qualified, unified, and adopted method of determining arc flash risk and the subsequent impact of calibrating the PPE measures employed in the field directly supports increased reliability and safety objectives of SETO. I would not characterize this effort as being high-risk, high-impact, as the perceived feasibility of solving this challenge is high given previous and similar challenges solved by the industry in the past. I do believe that in addition to work performed outside of this effort would benefit, as EPRI is an organization that has meaningful credibility and is one of the likely organizations that could lead this effort per the project description. The schedule appears to be advanced and a Q1-2021 goal to achieve the milestones laid out. However, the report does not cite expected dates for which they expect to achieve the goals or objectives described in Section 7 & 8, which is ultimately the progress that then provides tangible positive impacts for the industry. It is unknown as to when modeling software, PPE determination tools, or wide adoption and acceptance by the industry will be achieved.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 3 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project appears to be well aligned with IEEE and associated stakeholders.

**Reviewer 2:** Given the project is close to completion, the report does not detail the latest progress. However, by the task chart, it appears that much of the substantive work has been completed as planned. I look forward to hearing more about the project completion and findings.

**Reviewer 3:** The project appears to have advanced in a meaningful way thus far and appears to be on budget, and this does not seem to be the type of project with incredible cost risk. The described impacts in Section 13 of the report are highly qualitative in nature and do not sufficiently provide one an opportunity to measure quantitively. While this is understandable given the nature of the project, and the objectives, as it is difficult to measure safety, and difficult to know the negative impact experienced by the industry to date, there seems to be some impact goals that can be measured and this should be explored further.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 0. Comments: The tasks appear to comprehensively correlate product, theory, and standards considerations.

**Reviewer 2:** Score: 6. Comments: Task consideration was well explained and included not only research and modeling, but also testing for validation. I would have liked to see more specific information regarding Task C.2; in particular the test setups, equipment utilized, the process itself and the intended test method. I presume that will be presented during the review itself. Similarly, more detail on tasks A.3 and in particular, A.3.2 would have been appreciate to ascertain whether specific goals have been diligently worked on and completed.

**Reviewer 3:** Score: 4. Comments: The task list sufficiently mimics the research and analysis objectives of the project, and clearly shows the steps that lead to verification of the modeling efforts. The task list does not however continue thereafter, to demonstrate the tasks and milestones that lead to the high-level objectives such as submission to IEEE, development of a PPE tool, or development of an arc-flash calculator as noted in the report.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** No comments here as there is limited detail on the remaining actions to complete the project; I also don't see any interim reports that were prepared during prior review.

**Reviewer 3:** The PI focuses on 1500Vdc systems, but may not be aware that this same challenge exists for 1000Vdc systems, perhaps not with the same gravity, but arc-flash determination was equally difficult for lower voltage systems for the same reasons noted by the PI. The PI may look to previous efforts related to arc-flash measures that were employed for 1000V systems as a proxy for how to go about solving 1500V. Additionally, the PI may be underestimating the gravity of effort and time that will be needed to ultimately socialize the findings, the tools, and the methods to the industry at large, and the effort to achieve buy-in and adoption by key stakeholders.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No comment.

**Reviewer 2:** It's not clear if any industry or specific feedback was gathered or shared with participants in the testing of the model since those specific details are not included here. However, that specific feedback would have been of interest to review to understand what implications or design changes might have been considered as a result of the field testing.

**Reviewer 3:** Stakeholders such as engineering firms who have significant experience in this field could be valuable, as a way to understand current methods and measures employed by the industry. Additionally, stakeholders such as asset operators, O&M service providers, and safety focused persons who can speak to field experiences, PPE methods and how they can be improved could be valuable for this project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** The first is the practical application of the model as useful and socialized with industry. The second would be the progress and hopeful completion of the standard as identified to be published. Lastly, a recommendation as to any necessity in the future to review the model and address its continued effectiveness compared to any incidents that may have occurred.

**Reviewer 3:** 1) There exists currently, meaningful efforts within the industry that are similar in nature to the project goals and objectives and this issue is likely be solved or improved with our without DOE funding. It may not however result in the same level of adoption or achieve the same timing as targeted by EPRI. 2) This issue cited by the PI is deemed valid and described accurately and is focused on an area of the industry where there is a leadership gap. The safe operation of systems is monumental to the industries growth, credence, and ability to continue to attract competitive capital. 3) The comparative impact of this project is deemed low, while not to be confused with not being important in nature. The success of the industry will not be substantially inhibited without this solution, nor will it experience significant advancement with it.

## Automatic Reference for Empirical Soiling – $1,149,848,000

*Fracsun | San Luis Obispo, CA | Principal Investigator: Catlin Mattheis*

The accumulation of dirt on solar panels can negatively impact the overall performance of solar arrays. To address this issue, this project is developing and test prototypes of a device that can measure dirt accumulation and calculate the best schedule for cleaning the solar array. This project aims to enable system owners to balance the cost of module cleaning against the loss of solar generation due to soiling and determine the best time to clean the modules, minimizing financial losses, and optimize the frequency of cleaning. As a result, this can lower a photovoltaic system's levelized cost of electricity and improve the system's profitability.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 6 | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 6 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is the sort of high impact research needed for the industry to continue to exceed expectations. Awesome work to develop the device and basic algorithm to already optimizing cleaning for lifetime value.

**Reviewer 2:** Soiling is probably the large source of energy production losses and estimate uncertainty. Soiling is a problem it seems the industry can easily solve, but hasn't. I know of two soiling measurement stations the from reliable sources, Atonometrics and Kipp & Zonen, so I was surprised to see DOE funding another, but I think the fact the project includes a method to track data and optimize washing schedules would be a huge benefit to the industry if it were shared for free and adopted widely. It's not clear from the material provided if the algorithm will be made available publicly, though.

**Reviewer 3:** By developing a commercial soiling monitor and providing feedback to array operators on when best to clean the array provides a useful function to the PV industry. By getting more kilowatts from already deployed systems, makes those systems more valuable and certainly reduces LCOE. This project does not provide a high value to outside funded DOE research but can provide increased value to already deployed PV systems

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The team seems to be deploying significant numbers of the test unit, getting real time feedback and rolling through their milestones.

**Reviewer 2:** The report mentions collaboration with customers, but none are mentioned. The dissemination of project results, specifically the algorithm to optimize washing schedules, was unclear.

**Reviewer 3:** The project appears to have met its milestones. The major dissemination has been to provide prototype sensors to a large number of potential customers to demonstrate to them the value of knowing when to clean their array.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Despite longstanding desire for cleaning to be taken seriously by the industry I do not know of similarly thoughtful approaches to this significant O&M expense. I think it is a unique technical approach, an ingenious combination of hardware/ software and a very significant contribution to the long term success of the industry by lowering ongoing costs by as much as 10%.

**Reviewer 2:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 3:** Score: 6. Comments: Development of a commercially available soiling sensor with software to provide cleaning guidance to the array operator is an important accomplishment. For a small company to develop and field test such a unit is a significant advancement. Their plan for providing prototypes for field testing to array operators is a good approach for creating demand for their services.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Combination with productized arrays such as those being developed by Nextracker, Terrabase and rooftop kits. Integration of the algorithm with design software suites to ensure that at the PoS there is sufficient commitment to the necessary O&M schedules.

**Reviewer 2:** Possibly public availability of soiling analysis and washing schedule optimizing algorithm or open source software tools.

**Reviewer 3:** Project is very focused on a particular solution – that is a particular type sensor to measure soiling and call for cleaning when it reaches a certain threshold. This may not be the best solution for all PV arrays. In some cases no cleaning at all may result in the lowest LCOE. There are also some types of soiling that cannot be satisfactorily removed with a simple automated cleaning system.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Combine this with some design stage solutions to really ensure widespread adoption of the insights and technology developed.

**Reviewer 2:** There was mention of customers, but it wasn't clear if they were O&M providers who would use the solutions developed by the project team. If soiling data will be made available, it would be good to collaborate with independent engineers so they can improve location-specific soiling loss assumptions in their energy production estimates. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 3:** The project team appears to have targeted large array owners and is working with a significant number of them already.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Keep moving forward. Combine with upfront design solutions and facilitate integration to ensure widespread adoption of this solution. Work with insurers, analytics companies and financiers to require this sort of approach - foster competition for cleaning tech as the next level in solar success.

**Reviewer 2:** Ideally, the algorithm developed to optimize washing would be made publicly available, e.g. Excel, GitHub, etc., so operators could use it with other soiling measurement stations available or already installed. It would also be good if the soiling data were made available publicly so the industry, specifically independent engineers, had a better way to estimate soiling losses based on location. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 3:** Sometimes fairly simple concepts can have some of the highest paybacks. Projects that can enhance the output of already installed arrays should be very cost effective.

## Durable Module Materials Consortium (DuraMat) – $30,000,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Teresa Barnes*

The Durable Module Materials (DuraMat) National Laboratory Consortium is designed to accelerate the development and deployment of durable, high-performance materials for photovoltaic modules to lower the cost of electricity generated by solar power, while increasing field lifetime. DuraMat is one of several consortia under the Energy Materials Network, which aims to solve industry's toughest clean energy materials challenges. DuraMat supports projects that improve module materials in partnership with industry and academia to further optimize reliability and energy harvest of low-cost photovoltaic modules. Sandia National Laboratories, Lawrence Berkeley National Laboratory, and SLAC National Accelerator Laboratory are collaborating in the consortium.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 6 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Many of the DuraMAT projects have the ability to reduce uncertainty of module reliability, which will lead to lower costs of capital and hence, lower LCOEs. Moreover, higher confidence in testing and models will allow for new cheaper materials to be introduced. DuraMAT is a highly collaborative consortia trying to overcome the major drawbacks of the current solar reliability paradigms that were setup at JPL. This is no easy task as many in the industry are apprehensive to share data and correlating accelerated testing data to real-world performance has been difficult. Highest risk has been getting the industry to share real-world plant operation data. DuraMAT has successfully been able to do this. The funding has been used both to create a platform for sharing data and results as well as to fund individual projects with high impact on their own right.

**Reviewer 2:** DuraMAT supports SETO goals by publishing reliability data and models for PV hardware and developing improved testing standards. The public data resource is available to PV community as a resource for product qualification and product development work. DuraMAT is not a high-risk program but rather an investment in building consensus around PV reliability topics. The impact is modest for now but expected to grow over time as the data becomes more comprehensive and the modeling more accessible to non-experts. DuraMAT is a large program that does not match the scope of most SETO programs. DuraMAT should highlight some of the applications and use cases of non-DOE users to date. It might take more tutorials and one-on-one collaborations to expand DuraMAT's impact on the PV industry and help it realize its potential.

**Reviewer 3:** Addressing the question of degradation uncertainty is arguably a topic that stands to make the largest impact on system cost and lifetime for near-term and existing PV projects. Combining beginning of life, standardized measurement techniques with fielded performance to identify failure modes ahead of deployment stands to bring significant value to the industry. This project takes a comprehensive approach, looking at materials individually, advanced models, and product level and fielded product performance.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** DuraMAT has done a good job of disseminating information with monthly calls and frequent reports. The DuraMAT consortia involves key national labs, module manufacturers, and the downstream community.

**Reviewer 2:** DuraMAT is organized well and meets its milestones even though the scope is broad and varied. The Data Hub metrics around user activity are useful metrics, but the data would be more useful with some interviews from some of the biggest users. The project has a good track record of publications and manuscripts. DuraMAT collaborates efficiently with public research institutions. The collaboration on metal matrix composites (Metzilla) with Osazda shows good initiative.

**Reviewer 3:** This project generates a lot of high-quality research and science. As a former researcher, I understand the importance and power of laying strong technical foundations, and a clear bridge between the highly technical research and development of new test standards exists. As a member of industry, I sometimes have trouble seeing the bridge from the impressive science to how system models can be positively impacted in the near-term.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The core areas are required in order to meet the goal of improving the durability of PV materials. The different activities feed into each other and improve their efficacy in identifying and solving problems in the PV industry.

**Reviewer 2:** Score: 6. Comments: The Data Hub task is unique and its importance will grow with the quality and quantity of its data. The multiphysics modeling is important for accurately forecasting reliability issues, but needs more work (and some imagination) to make it actionable for non-experts working in the PV industry. The improvements to accelerated stress tests is a necessary part of standards evolution. Standards move slowly and it's important that they move in the direction of better screening for early-life field issues and better targeting of known failure modes. The forensics work addresses gap in the PV industry but needs to add "pre-stress" (usually spares for the site) and "nominally OK" modules to the analysis. The material solutions tasks in DuraMAT start to directly impact the BOM solutions available on the market. This task is high-risk but with the chance of significant impact.

**Reviewer 3:** Score: 5. Comments: After reading the teams response to follow up questions it was clear to me how the projects contribute to the goals. There are a lot of organizations and a lot of projects under this important banner. It has not always been clear to me how the research will impact commercial/utility fielded system reliability near term.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Would need to dive in further, but a few potential blind spots could come from having the failure modes that are identified and modeled be irrelevant for modules being deployed in the near future. By continuing to engage stakeholders, DuraMAT management can avoid this blind spot.

**Reviewer 2:** The DuraMAT team would benefit from building a connection between degradation phenomena, site climate and long-term energy yield. Many module development teams struggle to estimate the LCOE impact of degradation modes with small power impact (5-10% of nameplate).

**Reviewer 3:** Much of the research focuses on identifying failure modes, but the industry would really value research into non-catastrophic power loss degradation mechanisms, particularly if they could be identified at deployment (i.e. differentiate a module expected to have 0.5%/year degradation from one with 1%/year degradation).

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None. This project is highly collaborative.

**Reviewer 2:** DuraMAT would benefit from some targeted engagement with module product engineering teams in the PV industry. These teams may not be using DuraMAT resources effectively and may need new tools or training to benefit from DuraMAT's work.

**Reviewer 3:** More industry engagement at a practical level would help the organizers understand and bridge gaps. Interactive formats that allow more questions and demonstrate how results can be applied would help industry understand how they can make immediate use of the great work the team makes publicly available.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) A comprehensive approach to module reliability has been missing from the industry for years. DuraMAT created the necessary platform to enable this approach. 2) Despite efforts to increase the dissemination of knowledge gained from this consortia, the more engagement the better. 3) This consortium should continue.

**Reviewer 2:** 1) Detailed energy loss modeling of fielded module versus their original state is a key gap in the PV industry. DuraMAT is positioned to expand the Fielded Module Forensics work to include more 'nominally good' modules experiencing routine power degradation in addition to including modules that have failed. 2) The project would benefit from increased focus on relating standard reliability tests to real-world stress conditions and making long-term energy forecasting more accessible to non-experts. 3) The "Material Solutions" part of the program is very different from the rest of the R&D focus. It seems like DuraMAT might magnify its influence on the PV industry by championing select BOM technologies.

**Reviewer 3:** Having a method to apply beginning of life testing that would result in quantified degradation curve values and shape would be a game changer for PV development and manufacturers This consortium is contributing to that topic in high quality measurements, simulations, tool development, method development, etc. I believe there are challenges in community understanding how to apply research to systems in practice.

## Multimode Characterization Approach for Understanding Cell-Level Photovoltaic Performance and Degradation – $3,630,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Glenn Teeter*

This project enables the combined use of several complementary measurement techniques to better understand the performance and cell-level reliability of solar photovoltaic technologies. The characterization techniques, which include X-ray and ultraviolet photoelectron spectroscopy, will be augmented to consider how factors like high temperatures and exposure to humid air affect solar modules during operation. The research team will also develop new and advanced characterization techniques, such as near-field transport image in 3-D, making it easier to study different parts of the solar cell. The team will create models to establish clear connections between cell performance and solar cell damage under various operating conditions. The new methodology and device models will speed the improvement of efficiency and durability of thin-film and perovskite photovoltaics.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 3 |
| Set critical challenges to overcome | 5 | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 3 |
| Advance the U.S. solar industry substantially | 4 | 5 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The primary strength is they have viable results that have resulted in viable results, the weaknesses are problems with equipment, degradation recovery among thin-film modules, lack of an industry partner, e.g. a PV module or cell manufacturer, the dissemination to industry and measurement of impact is unclear. Another weakness may be that the team may not be uploading data to the Duramat data repository or making software tools available to the public to the Duramat GitHub. I don't believe that was mentioned in their paper.

**Reviewer 2:** This project aims to establish new characterization techniques and models to facilitate the characterization of defects within PV interfaces and devices. The techniques are being developed with applicability to multiple device classes (including CdTe and perovskite) defect characterization. The work will support efforts toward improved initial device performance and lower degradation. Characterization techniques that can be applied to emerging devices across material sets are critical to establishing a level playing field for identifying the barriers to product maturation so that solutions can be found.

**Reviewer 3:** The project aligns with SETO goals indirectly through improving understanding of thin film device dynamics and enabling thin film process development team to improve the LCOE of their products. The goal of linking degradation modes to microscopic mechanisms could improve solar cell technology, but only if the information leads to new process developments. It is low risk for the study to generate a lot of characterization data which might be useful to the research community, but it is high risk that the study will be accessible and applicable to process development teams in the industry.

The scope and duration of the project is well-matched to SETO. The project organization seems to be focused around collaborators at NREL and would benefit from involvement by First Solar or early-stage perovskite companies. The transparent buffer layer MZO as applied to CdTe devices could have a path to impacting the industry, but only if First Solar's buffer layer technology is a semi-transparent layer such as CdS. The potential benefits of the project to perovskite development have yet to be specified.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 2 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 3 |
| Collaborates with sufficient stakeholders | 3 | 5 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project seems to have performed only moderately well because of equipment issues and degradation recovery of thin-film modules, but still seems to have good results. The lack of an industry partner is problematic and dissemination to industry is unclear. It may benefit from sharing data and software tools publicly through Duramat.

**Reviewer 2:** The project appears to have made significant progress in new models and measurement techniques within its first year of activity. Once further along, publication and model release are expected.

**Reviewer 3:** The project achievements since Oct 2018 seem to be trending off track. The development of new XPS/EBIC/KPFM techniques is a nice start, but the report does not contain enough information to evaluate the novelty or success of the new capabilities. The development of COMSOL models of thin film solar is also a useful piece but not necessarily novel or useful by itself. The main metric of success impact seems to be publications by the PI or other members of the project team but there are no publications to report. It seems that the progress to date involves contributions from across the project team.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 2:** Score: 6. Comments: This project has an impressive combination of innovation characterization techniques and models.

**Reviewer 3:** Score: 3. Comments: The first task for technique development does not adequately specify what development challenges were overcome and how the validation process was conducted. The project report does not contain sufficient details to evaluate the value of the new techniques. The second and third tasks around COMSOL modeling do not adequately highlight the context or importance of the models or how they relate to the techniques developed in the first task.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Collaboration with industry, specifically a PV module or cell manufacture, measurement of impact, and sharing data and software tools publicly through Duramat.

**Reviewer 2:** None are apparent at this time.

**Reviewer 3:** The project team does not adequately demonstrate the goal of the new technique development in the context of existing techniques. The report does not show how limitations in existing techniques block thin film development.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Module or cell manufacturers, e.g. First Solar, Hanergy, Solar Frontier, Kaneka considering much of the work is on thin film.

**Reviewer 2:** None at this time. There appears to be industry and academia engagement and the PI is correct that this level of research into materials fundamentals is unlikely to be undertaken by industry. This is the type of project that must occur at labs and academia.

**Reviewer 3:** The project team would benefit from increased involvement and steering from the device fabrication groups (Sampath, Berry, and perhaps new additions). The project would benefit from involvement with First Solar or another thin film fabrication company.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The PI should find an industry partner, measure impact of results and upload data and tools to Duramat.

**Reviewer 2:** This project stands to lay important foundations for characterization of emerging technology performance and degradation. The approach is a comprehensive application of experimental technique and modeling. Given the expense involved in developing new microscopy techniques, the potential value is high for a relatively modest cost.

**Reviewer 3:** 1) Focus on previously published work on thin film band alignment and try to find a controversy in the literature. Use one of your characterization techniques to provide evidence in support of one of the competing interpretations. 2) Find a device partner in thin film fabrication and offer your characterization services. Perhaps you can help them determine the root cause for the difference between "good" and "bad" samples (either due to experimental conditions or process drift). 3) Scale back the broad array of technique development and publish on the one that is the most novel and useful, even if the applications extend beyond SETO's scope.

## Operation and Maintenance of Photovoltaic Systems: Data Science, Analysis, and Standards – $800,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andy Walker*

This project is a collaboration between two national labs and private-industry practitioners to advance photovoltaic systems operations and maintenance. Using data from different climates and weather conditions, the team focuses on understanding operational risks, drivers, and cause-and-effect relationships that lead to low performance ratios and high operations and maintenance costs. By conducting foundational analysis, the team aims to create best practices and international standards for the reliability and availability of residential, commercial, and utility-scale photovoltaics.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Great opportunity to build on prior work and assess additional areas to address to improve O&M, which has more ambiguity and consistency in practice compared to other services areas for larger PV projects. Typically subject to more budget constraints due to this ambiguity, the insight gained can help asset managers understand better the implications of those budget constraints in relation to performance for can help O&M providers communicate the necessity for consistency and the appropriate budget for necessary and emergency approaches.

**Reviewer 2:** This project focuses on improving O&M practices which is a key aspect of LCOE for solar electricity. O&M impacts LCOE both through its impact on long-term energy yield and the direct costs needed to maintain a PV system. The focus on PV system availability also supports SETO's resiliency goals by improving uptime monitoring. The project goals of improving reporting standards, building an O&M knowledge base, and studying log data are important pieces of strengthening O&M practices. The scope and duration generally matches SETO, but this project may benefit from longer duration to build a critical mass of knowledge and training experience. By its focus on PV system operators, the project is largely focused on adding value outside of the DOE. The project advances a key piece in solar LCOE by focusing on the people in charge of running a PV system for 30 years, long after the design and product teams have moved on.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Overall, there appears to be the proper stakeholders involved in the project activity and data collection (once the insurance angle was addressed). This has produced some delay in the project meeting original milestones, but things should progress smoothly.

**Reviewer 2:** The project team has made good progress working with IEC and NERC rule making process. Knowledge base documents have yet to be generated but are set for this year. I would have preferred to spread out the knowledge base documents through the duration to start building awareness in the industry. The failure mode analysis based on log data has begun but is still in early phase. The project has set metrics around community engagement in the standards development and knowledge base tasks, but has not reported PV asset volume or assert owner counts yet. The project team has highlighted a large number of publications and is an active member in several industry working groups or collaborations.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The major outcome of the standard, while appropriate to establish consistency, will need additional effort for industry and O&M providers to implement. The presence of a standard alone may not be enough so outreach and encourage from industry associations and other important influencers should be considered.

**Reviewer 2:** Score: 4. Comments: The first task around availability reporting standards is an important part of O&M and may help providers minimize downtime and attribute root causes more efficiently. However, if the goal is to improve downtime management of inverters, the team does not adequately show how the standards work with NERC and IEC is the best way to accomplish that. Bridging O&M knowledge gaps is an important task and I don't know of a public source for such guidance. Analysis of work logs is likely to be important for certain tasks, assuming adequate data quality. I'm not familiar with other published analysis of work logs so this may be a novel task.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** As mentioned prior, the engagement with industry associations, project owners and service providers will be critical to ensure that the practices are taken into daily action and actual improvements in cost realized. There should be interest on behalf of industry to assist with those efforts.

**Reviewer 2:** The principle blind spot of the project team is around the discussion of performance ratio and energy yield. The goal of "improve Performance Ratio from <85% to >95%" is both too optimistic and not specific enough. The project team may need to review a significant amount of time series production data as compared to original energy models and with weather-correction exercises.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Stakeholders seem well represented in the key areas, see my prior comments about industry associations and other affiliates.

**Reviewer 2:** The project team is targeting the right stakeholders in "PV power asset and O&M managers with at least 20 GW of global PV installations (≥ 2 MW)" and "250 unsophisticated asset owners of small commercial, state, local, and federal PV systems". I'm sure some would object to being called "unsophisticated" and others would heartily agree. The project doesn't show much about how the outreach is going, but they must reach these stakeholders to expand the project's impact.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** It's important that the work products and reports are disseminated widely and in forums that would enable more service providers to access them. This would mean not only focusing on the rigor and science behind what has been discovered but also translating that into specific actions that can enable the cost savings imagined. Secondly, the expansion of the database and the opportunity to continue to contribute data so that this is an on-going practice would be further supported by encouraging another project or study using that database and focusing on any progress from prior study or extensions of these knowledge areas.

**Reviewer 2:** 1) Collect monthly energy yield data, the original designed monthly forecast, and weather-corrected monthly energy yields for at least a handful of sites. Compare the energy yield data with the work log data and highlight the most significant relationships. 2) Try to target a few market segments and system types with your cost model and make it easy for users to carve out part of the costs to assign to subcontractors when they work through the steps. 3) Find a DOE/NREL collaborator to support and host the O&M knowledge base to make sure it can continue to grow outside the scope of this project.

## Photovoltaic Cell and Module Performance Testing – $7,800,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Nikos Kopidakis*

This core photovoltaic support project maintains the National Renewable Energy Laboratory's Photovoltaic Cell and Module Performance Laboratory and provides access to photovoltaic performance measurements and best practices to universities, national laboratories, and the Solar Energy Technologies Office. Through its primary reference cell calibrations, this laboratory maintains the photovoltaic peak watt rating for the United States. This work assures that consumers, installers, and project developers can have confidence in the power ratings of the modules they purchase, enabling a more robust U.S. photovoltaic industry. This project also provides a world record of photovoltaic performance measurements, which is essential for tracking the progress of photovoltaic research and development.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project aligns with SETO goals by facilitating R&D and manufacturing efforts across the United States. Every cell or module laboratory I've worked in used solar simulators calibrated with NREL reference cells. The goal to support any size or technology for any user is critical for having a common efficiency baseline in the industry. We take for granted that reports of module power or efficiency are accurate even when collected using secondary standards in 3rd party labs. The biggest project risk would be for the measurement service to discontinue or be interrupted. The project has a long duration so I was surprised it was part of this SETO peer review. The project adds value to all of its non-DOE users. By helping the PV industry stay aligned on how to calibrate its solr simulators, this project keeps us moving steadily forward.

**Reviewer 2:** This project supports the calibration and third-party testing capabilities at NREL. Having a trusted third party measuring and tracking efficiency records for all technologies is extremely important.

**Reviewer 3:** This effort is clearly the world's benchmark for PV cell and module testing and calibration. Their work continues to be essential to the continued innovation and R&D progress for manufacturers and researchers world-wide.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has performed well against its operational metrics and has kept up with new device types and form factors. The metrics of turnaround time and total measurements seem appropriate. The publication record is strong and includes the Progress in PV Efficiency Tables. The collaboration effort for round-robin calibration testing with other labs is an important exercise that must continue.

**Reviewer 2:** The project is on schedule and budget. The lab boasts the lowest uncertainty measurement capability in a method developed in house. The lab also maintains appropriate ISO accreditation.

**Reviewer 3:** All the stakeholders who rely on the accuracy of the measurements from this laboratory service are aware of its importance and continued need to stay current or ahead of potential paths of innovation in cell technology.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project has done a good job supporting new and emerging PV technologies as well as numerous c-Si cell and module variants. The project would benefit from a task to continue reducing measurement uncertainty for power ratings on full-size modules.

**Reviewer 2:** Score: 5. Comments: Supporting audits to maintain accreditation is complete. Developing methods to probe innovative devices is underway. The efforts underway to perform lab comparisons of spectral response measurement is valuable to industry.

**Reviewer 3:** Score: 6. Comments: The opportunity for the staff to be regularly informed or engaged in new ideas isn't that apparent in the report. I can only presume that there is some method by which the team can assess future technology improvements in order to assess any impact to their methods or equipment and that this is achieved through networking, attendance at key events and the like.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project team is very strong with flash testing and solar simulators, but what techniques can be taken from indoor testing and applied to outdoor testing? Once a module has left the factory, flash testing becomes a rare and expensive type of data. Generally a module will only have string IV or module IV under outdoor irradiance and temperature conditions which is usually lower than 1000 W/m2 and higher than 25 deg C. How can we close the accuracy gap between field characterization and lab characterization?

**Reviewer 2:** None at this time.

**Reviewer 3:** In addition to the continued services, it would be important to consider including a report on advances that have been made in the last decade or so and how that has moved manufacturers forward in innovating their products and advancing solar. There is unique insight that the team would have from a very particular perspective in helping portray the advancement of technology over time. No one else world-wide would have this insight.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project would benefit from engagement with stakeholders in charge of calibrating test equipment at PV module manufacturing facilities. What work needs to be done on test equipment and calibration procedures for companies involved with cell and module manufacturing?

**Reviewer 2:** None at this time.

**Reviewer 3:** It appears that all the relevant stakeholders are aware of and engage with the lab as needed and as expected.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Develop a roadmap to push module peak power uncertainty to even lower values than might seem achievable. Your lab needs to push beyond what manufacturing facilities practice today. 2) Offer guidance on methodology for peak power testing on PV systems under outdoor conditions. Peak power testing is important and frequently occurs as part of PV system commissioning, but the uncertainty is significantly greater than of indoor testing of modules. 3) What processes do you have in place to make sure the program continues its success as members on the team retire or leave?

**Reviewer 2:** The function served by this group is crucial to the industry and emerging technology. Maintaining the ability to measure all devices on a level playing field is very important. The comparison of spectral testing is long overdue and will be welcomed by investors and manufacturers.

**Reviewer 3:** I would suggest referring to the above comment regarding the inclusion of some type of historical perspective on technological advancements that can be included in future funding work. Continued support and funding for this project is essential to industry and its future advancements.

## Photovoltaic Proving Grounds – $1,200,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Chris Deline*

This project conducts short to long-term field research to understand the functionality of photovoltaic systems under real world environmental operating conditions. Short term research focuses on validating technology improvements designed to increase solar energy harvest while long-term research is conducted to assess photovoltaic system reliability and validate computer models for predicting power generation. Researchers design and install photovoltaic systems to meet these goals, often in direct partnership with module manufacturers or equipment providers. U.S. companies benefit from this direct interaction with the National Labs, allowing them access to unique capabilities and expertise in module and system performance assessment. The photovoltaic industry as a whole benefits from the publicly available output performance data. Beyond module manufacturers, beneficiaries of the photovoltaic performance measurement and research include system designers, installers, investment bankers, public utilities and independent third-party test labs.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project provides an important opportunity for manufacturers to verify their product's performance and effectiveness overtime through the process that includes consistency in installation, data collection and analysis. The feedback provided would also provide insight into performance in different climates and environments. The project objectives are well-formed and the approached is well articulated and executed.

**Reviewer 2:** This is one of the few projects performing outdoor testing at multiple locations for multiple years. Also one of the few with PV+storage field studies. Lowering uncertainty in long term performance is critical to the industry. It also supports two of SETO's missions - reducting LCOE and increasing system lifetime. With PV product evolution so fast-paced, this work has exposed new degradation modes on early-lifetime fielded products (PERC).

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 6 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** It would not be possible to carry out the project without the engagement of manufacturers and other stakeholders. There is also a rational division of tasks in installing, collecting and analyzing the data.

**Reviewer 2:** The work funded here is some of the most prolific in the PV industry. As a resource, the PI is invaluable to the industry.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Considering the multiple sites and potential for variability, the project plan has been well formed and identifies the necessary steps to achieve milestones, data collection and review of the data. It's not articulated how much and what is shared, quantitatively and qualitatively, with the manufacturers, so it would be great to see some examples of that information

**Reviewer 2:** Score: 5. Comments: Research into fielded module performance and identification of new degradation effects for new and mature products is useful. Researching PV+storage is sorely needed.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It's not clear from the report if there are any specific O&M practices that are consistently applied to each module at each location and if there is similarity or tracking associated with those practices. I would be interested in hearing about that if there are.

**Reviewer 2:** None at this time.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It appears that the appropriate stakeholders are involved. I'm not sure about O&M services or providers or if that is conducted by NREL or other project team staff.

**Reviewer 2:** None at this time. The project PI is actively involved in conferences, publications, and engagement with the industry.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** It appears that there is good climate variation between the sites to assess the performance of products. It would be of interest to see the reporting templates that are provided back to the manufacturers on their product performance and if there is an opportunity to standardize those into practice with O&M providers or project owners so that industry could have good examples of how to best collect data, track it and understand its impact on the durability and lifetime of the systems.

**Reviewer 2:** Having "real-world" systems available to the national labs for research is one of the most important subjects to fund. The labs are highly respected and the trend toward larger system research in the last decade has increased their value. More balance of system project research is critical to achieving the DOE goal of extending useful life. More research is needed at NREL into PV+storage systems. They need to be researched as a whole, not in components in separate groups.

## Reducing Uncertainty of Fielded Photovoltaic Performance – $5,400,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Chris Deline*

This project aims to improve the analysis and reporting of photovoltaic system field performance to increase confidence in system performance among owners and financiers. The team compares the outdoor performance and degradation rates of conventional module technologies with those of new, high-efficiency silicon technologies. To do this, they are studying how exposure to light, water, and other potential sources of degradation affect photovoltaic system components, and then use the results to develop new models and automated analysis techniques to measure system performance and production shortfalls. The team works with industry partners and the Durable Module Materials Consortium's data hub to enable private investors to upload and evaluate photovoltaic production data anonymously.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** We're seeing systematic underperformance among recent utility scale projects. The results of this work will help the industry solve that problem. Probability distributions of performance data and losses within specific categories, e.g. soiling, downtime, will be very useful to independent engineers in estimating probability of exudence cases (p-cases).

**Reviewer 2:** This particular project has immense value to industry because of its considerable data collection and resulting value to industry. This data is incredibly useful to developers and other stakeholders in assessing and modeling performance given many factors, including module type, installation configuration and climate. Having a reference data set like this available enables more reliable modelling for many purposes including proposals, equipment procurement needs, expected financial return and other necessary parts of an overall project proposal.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 6 |
| Collaborates with sufficient stakeholders | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has performed very well and there appears to be good information dissemination through the PV reliability workshop and papers. There's also a software component. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** Continual updating of the data has provided near current state information that is useful and valuable to industry. This is exactly the type of value that industry finds in NREL's work as it helps provide user, actionable information.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 2:** Score: 6. Comments: The three resulting tools from this project provide significant insight that is useful to industry, which speaks to the uniqueness and importance of this value. Similarly, the ability to include data that gives information on newly installed technologies helps with modernization of the projects over time. The project also seems to have its challenges since not all the implementation data or other important factors may not be available to known to provide additional insight or conclusions about the data collected or other observations.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Collaboration with independent engineers and upload of data and software tools to Duramat.

**Reviewer 2:** As noted in the report, the lack of information with regard to O&M or installation configuration can make the data incomplete in comparison to when that data is available and provided. In spite of that, however, the overall data is incomparable to any other data set publicly available so far.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Independent engineers, Duramat

**Reviewer 2:** If there was an opportunity to combine data from other similar projects from private organizations who are monitoring similar data for fleet or other project purposes, that would provide more robust data analysis valuable to industry.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Keep this going. Encourage more collaboration with independent engineers. Ask that all data be put into a format that can be easily used to create probability distributions to support energy production estimates and probability of exceedance estimates (p-cases). They should publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** This particular project has built in its own importance in the modeling and analysis now in practice by industry. I would ask SETO consider if there has ever been a wider spread survey to industry to ask about other potential uses for the data or additional expansion that might be fruitful for additional purposes. Similarly, the opportunity for specific conclusions about the data to be implemented into O&M practices or other uses could also be helpful.

## Reliability Core: Research and Development to Ensure a Scientific Basis for Qualification Tests and Standards – $15,115,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Ingrid Repins*

This core capability project performs research and development that leads to science-based tests and standards that can better ensure photovoltaic system reliability and quality. The team designs and performs accelerated stress tests on photovoltaic products and then correlates the results with successes and failures of products in the field. Testing focuses on the module package—including the glass and frame, interconnection devices, and solar cells—and the micro-characterization of both failed and healthy modules to help improve test accuracy and predictive ability. The new tests will help photovoltaic system owners better predict long-term safety and energy generation of different products while lowering the cost of photovoltaic electricity by extending the lifetime of photovoltaic modules.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is tying physics-based models to accelerated lifetime tests, so we understand why modules degrade, have defects, etc. This is an important step in solving these problems and leading to more reliable and durable modules. A weakness may be that the quantification of impact is unclear in the material presented, but that is difficult to assess across so many subtopics, so it may be present in the papers. Another weakness may be that the team may not be uploading data to the Duramat data repository or making software tools available to the public to the Duramat GitHub. I don't believe that was mentioned in their paper.

**Reviewer 2:** This project comprises a multitude of important research angles that help contribute to industry's better understanding of its products' performance and impacts to on-going degradation comprehension. The overall approach to ensure the program's work provides the necessary background and research to improve or establish new tests for products that will continually improve over time based upon the results of such tests.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a very strong program that is leading to many papers and wide information dissemination using typical channels. It may benefit from sharing data and software tools publicly through Duramat.

**Reviewer 2:** Utilizing the NREL PV reliability workshop provides a good opportunity to share the program results widely with other in the scientific community. Ensuring that the work is effective in aiding in the revisions and improvement of international standards also provide an opportunity for the work to have a wider scale of utilization that directly impacts the design and materials researched and incorporated into the products. It is suggested that there be additional outreach on a wider industry basis to share the overall impacts of the full project with nonscientific industry participants so that it can be more widely understood how the industry can 'give credit' for a longer expected lifetime of the product and resulting projects in how future projects are developed, insured, guaranteed and how financial treatment is appropriately considered.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 2:** Score: 6. Comments: The project identifies key areas of concern and research that can help industry better understand how to address the field of degradation. By identifying certain areas, the project tasks provide directed insight so that industry and their researchers can develop and explore different approaches to material selection and design to the products. These tasks also enable inspiration and ideas for research that can be further developed. I would have like to see more detailed information about the different tasks, however I realize that the report template it quite limited.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Possibly quantification of benefits and the distribution of data and software tools publicly through Duramat.

**Reviewer 2:** The current audience for the work is others in the PV scientific and engineering community, it would also be beneficial for the results to be shared with a wider audience, such as investors, financiers and O&M providers so they can assess and determine the impact of these technical improvements into the overall financial and lifetime models.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Possibly some PV and modules manufacturers that don't regularly attend the PV reliability workshop. Duramat.

**Reviewer 2:** It's not clear from the summary how the results are shared with other industry stakeholders, such as financiers, investors, service providers, etc. While it appears that some of the events at which results are shared are open to many different stakeholders, there is little detail in the current report.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Keep this project going. It's filling the gap of understanding why we see degradation and defects in accelerated lifetime testing, which is an important step in solving those problems. It also helps calibrate tests to make them more efficient and effective. Encourage team to share data and software tools publicly through Duramat.

**Reviewer 2:** The expectation for solar to outlive even the current expected lifetime of 25+ years is important to compete with other energy producing sectors and the overall LCOE comparison. Understanding of the product-specific factors is important for the SETO to continue to determine how the project is a continued good investment for research. Additionally, the expectation and actuality that the research feeds into standards and tests is important to be realized.

## International Photovoltaics Research Collaborative – $100,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Laurie Burnham*

The solar industry is undeniably global, from both a manufacturing and deployment perspective, yet access to comparable high-fidelity climatic and photovoltaic data from around the world is lacking. This project addresses that void by creating an international research collaborative dedicated to the generation and sharing of quality data. Members of the collaborative have agreed to share meteorological and solar data, deploy a common set of technologies and technical approaches, and exchange best practices with respect to the monitoring and maintenance of emerging technologies. This international organization furthers the solar community's understanding of the climatic and other local factors that influence solar output and longevity, creates a platform for cross-climate research, and makes available to researchers, manufacturers, developers, investors, and others a global database that is unprecedented in scope.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Developing a worldwide network for meteorological measurements is important for PV. It is also important that this data be provided in a consistent way around the world. The last step is to make this data PV friendly rather than catering to solar thermal and human comfort reporting.

**Reviewer 2:** Overall, the opportunity for the international scientific community to share data and research is an endeavor that could result in significant time, cost and effort-savings if there are clear collaborative opportunities and the appropriate resources. Such insights that can be shared among research teams or even allow the opportunity to increase the research scope of projects without significant increase in cost can be mutually helpful for multiple reasons.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Getting 10 other research centers to join is in itself an accomplishment. The groups have been meeting until the Corona virus put a stop to travel. The key will be having an important enough program to keep the laboratories interested and over time to attach additional measurement laboratories.

**Reviewer 2:** The team has amassed a great network of international collaborators. It seems that the main challenges have been with the varying degrees of funding available to those outside the U.S. but an innovative approach was utilized to help mitigate the situation. It's not super clear yet, but maybe this will be presented in the review, what the progress is for the best practices completion and publication. I would also be interested in knowing what channels the group will utilize to share the gathered information with industry.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: This was a unique effort to establish a worldwide network of measurement laboratories so that they could work together on establishing standard practices for measuring solar irradiance. As PV is a worldwide business it is critical that the solar resource data around the world be measured and reported in the same way. Someone wanting to build a PV power plant anywhere in the world should have access to data measured and recorded in the same way to facilitate system performance modeling.

**Reviewer 2:** Score: 6. Comments: Certainly the effort to gather and form a new team is a significant challenge but with a shared purpose and opportunity to collaborate on common research issues provides good incentive. Having defined specific areas of research provides a good platform for participation of the team. I would be interested in hearing more about how tasks were shared among the participants and how resulting information has been used by the different members in their current projects.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI must continue to focus on making PV Camper a permanent organization. It is easy for such an organization to slowly drift away especially if resources become tight.

**Reviewer 2:** It's not clear if additional commercial/national testing laboratories such as NRTLs or other international certifiers have been engaged in the process. Certainly there could be more insight into the usefulness of the research objectives into other avenues and potential integration with other standards issues. Similarly, feedback of installed systems to validate or compare data or research the collaborative has undertaken could provide additional insight or indicate of any change in direction or scope of the current research.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This effort is really going to need at least some continued funding beyond the present contract if the project is going to have a long-term impact. Gong beyond the establishment, the organization should begin the discussion about what exactly are the correct solar resource parameters that should be measured? The historic values like horizontal irradiance are based on proving data for other purposes and are not ideally suited for PV. PV Camper may provide the appropriate group to begin the transition to PV optimized solar resource measurements.

**Reviewer 2:** Repeating my earlier comment - It's not clear if additional commercial/national testing laboratories such as NRTLs or other international certifiers have been engaged in the process. Certainly there could be more insight into the usefulness of the research objectives into other avenues and potential integration with other standards issues.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project will require continued funding. Need to continue to grow the number of laboratories involved. Try to use this forum to optimize the way solar resource data is measured and reported for PV.

**Reviewer 2:** The voluntary participation by other international teams may have been difficult to amass at the project start. It's possible that more organizations may have been interested if funding was available from similar organizations to the U.S. DOE SETO in the other countries were invited to the effort and to provide funding. It's not clear if this was done or support from SETO could have helped with this effort but it is something to consider for similar opportunities in the future. Next, it appears that there was limited opportunity to share the progress of the group and its work on a wide-spread basis. I'm not sure if this was based on timing of projects or events, but additional collaboration with industry to share this information could help here. Lastly, SETO should consider developing a channel to publish research that is gathered in this way, maybe that could be an international effort similar to how IEA does it so that there is more opportunity for these projects to inform product development and other research.

## Photovoltaic Performance Modeling – $1,725,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Stein*

This core capability includes development, implementation, and validation of new performance sub-models in the areas of module thermal behavior, dynamic soiling, and degradation and stakeholder engagement, which is accomplished through the Photovoltaic Performance Modeling Collaborative and International Energy Agency Photovoltaic Power Systems Program Task 13. The project objectives works to reduce uncertainty in photovoltaic performance models by developing and validating new and improved models, creating and managing an open source repository of modeling functions and data, and building and growing the collaborative group. The results of this project will be communicated by workshops, the Photovoltaic Performance Modeling Collaborative's website, open-source software, and reports and conference papers and presentations.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The strengths of these project are they are producing useful data for the industry to improve energy production estimates and they are proven team. They are also publishing the data publicly. The weakness is they could improve with collaboration with independent engineers and quantify impact a bit better.They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** The project aligns with SETO goals by making PV production modeling tools open source, universal and constantly improving. The goals to continuously improving performance model accuracy and filtering new results into pvlib play an important role. The project is not high risk at this point, because there are so few groups focused on improving models of outdoor performance and because pvlib is now the dominant modeling standard. The main impact will be when project developers or project owners start modeling significant GW of capacity using tools based on pvlib. One risk would be for pvlib to lose the support of full-time engineers and start losing its central role in the PV research community. The scope of the project matches SETO, but the duration seems to be longer than typical. The PVPMC conference and pvlib add a lot of value outside of DOE as judged by the participation and engagement.

**Reviewer 3:** The work supported by this funding brings together the community (manufacturers, investors, developers, IEs, labs, utilities, academia) to collaboratively discuss challenges and improvements to modeling. Increasing modeling accuracy has a direct impact on PV project financing. Having this effort led by the national labs brings together teams that traditionally have trouble "playing nicely" together.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 6 |
| Collaborates with sufficient stakeholders | 4 | 3 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has performed very well and there appears to be good information dissemination through the PV reliability workshop, papers and public data repositories. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** The project has made significant progress on each of the PVPMC, pvlib and model development milestones. User and view counts are good metrics for project impact, which should be supplemented by examples of modeling changes made in the group and rolled out to standard PV tools in the industry like PVsyst, SolarGIS, SolarAnywhere, Aurora, etc. The project has good publication output and effectively engages its collaborators through its ongoing work with pvlib and PVPMC.

**Reviewer 3:** The PVPMC workshops and consortium have grown substantially. Having been part of the workshops since inception, the quality of the discussions continues to improve and the contribution to the industry is extremely valuable and relevant especially as modeling challenges have grown with new technologies.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 2:** Score: 5. Comments: The project is one of many efforts to reduce uncertainty in PV performance models, but it is also well-positioned to widely publish and disseminate new modeling results. PVPMC's online archive of presented materials is a great resource for the PV modeling community.

**Reviewer 3:** Score: 5. Comments: Improving model accuracy is valuable. Bringing the modeling experts together in a neutral setting has pushed efforts forward significantly and is expected to continue to add significant value. Modeling software and new model development (temp and soiling) will generate buzz in the expert community.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Could benefit from more collaboration with independent engineers who are the end users of results, data, software, etc. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** The project team, as far as I know, has not tried to deliver all-in energy models for PV systems. It would be useful to partner with DOE members or 3rd parties to receive an as-built design and then run a full performance and loss model to estimate the performance index. In the industry we are used to weather-adjusted models having standard deviations in monthly performance index of >5%. We need a dedicated team providing open source tools and resources to tighten the spread.

**Reviewer 3:** Not a blind spot, per se, but prioritizing models and datasets with sub-hourly capability will be an increasingly important industry need. Some focus on performance of components other than modules (module and inverters) and their contributions to modeling uncertainty would also be of value.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Independent engineers, Duramat.

**Reviewer 2:** The project would benefit from more engagement from financiers of PV projects. Most financiers have preferences for how to model long-term energy yield of PV systems and this project can provide an independent perspective on where negotiations around performance modeling should start.

**Reviewer 3:** No changes here. The work brings together a larger cross section of stakeholders than any other project I know. I think it would be beneficial to do an "industry-wide" comparative study on models as was done about 10 years ago (different groups were given the same information to model system output using their preferred tools, and the organizers compiled and anonymized results). Perhaps it should be an annual or biannual effort.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Keep this going. Encourage more collaboration with independent engineers. Ask that all data be put into a format that can be easily used to create probability distributions to support energy production estimates and probability of exceedance estimates (p-cases). They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** 1) The project team should play a more active role publishing materials for the PV industry on thermal losses and soiling losses expected for PV systems. Most of the industry uses legacy models in Excel or outdated parameters in PVsyst and there is a serious lack of independent studies on these loss factors. 2) Even though thermal losses have a lot of uncertainty due to local air flow and system design, the status quo for how these losses are modeled in the PV industry is frequently primitive and anecdotal. Even though soiling losses are also a function of the module cleaning schedule and cleaning dates/quality vary in practice, this project can offer an open-source toolkit for estimating soiling losses in energy yield models. 3) Consider leading a round-robin modeling exercise where a standard system is modeled using the leading PV modeling tools and the differences/similarities are compared. Negotiations and debates about PV energy yield modeling would benefit greatly from independent, open-source analysis.

**Reviewer 3:** This work brings together the PV modeling community in an invaluable way. Having this work hosted by the labs provides oversight and credibility no other organization can bring. Contributions to open source software and data warehouses are extremely valuable. For example, the new soiling model is highly anticipated.

## Photovoltaic Proving Grounds – $5,640,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Bruce King*

This project conducts short to long-term field research to understand the functionality of photovoltaic systems under real world environmental operating conditions. Short term research focuses on validating technology improvements designed to increase solar energy harvest while long-term research is conducted to assess photovoltaic system reliability and validate computer models for predicting power generation. Researchers design and install photovoltaic systems to meet these goals, often in direct partnership with module manufacturers or equipment providers. U.S. companies benefit from this direct interaction with the National Labs, allowing them access to unique capabilities and expertise in module and system performance assessment. The photovoltaic industry as a whole benefits from the publicly available output performance data. Beyond module manufacturers, beneficiaries of the photovoltaic performance measurement and research include system designers, installers, investment bankers, public utilities and independent third-party test labs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** PV proving ground is an important project because it allows for large scale system testing in the highly respected national lab groups. Quantifying degradation of systems is one of the more important problems in the industry at this time. Improving accuracy of modeling losses (such as angle of incidence loss) also adds value. Current indoor measurement techniques outside of Sandia are not without controversy, so adding capability here is valuable, particularly to evaluate coating durability.

**Reviewer 2:** Coordination and merging between the two original projects has provided benefits; although it appears that integration was still challenging. The results that show the LeTID susceptibility show that the project has merit and uncovered issues that can be addressed in the product design and manufacturer R&D to address. Perhaps some additional estimation of the project challenges to integrate the efforts could have been afforded more time to effectuate so that the next steps may not now be potentially rushed.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has met or exceeded its milestones on time and budget. Three different validation systems in different climates are installed. Industry partnerships have been established and installed product exceeds targets for commercially available modules.

**Reviewer 2:** Project reasonably includes a substantial amount of stakeholder interaction to continue the necessary activities. The continued sharing of results at events also helps provide insight and gather feedback from others in industry on the overall project. It could be beneficial to share more widely about the project to gather additional interest and potential participants.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, establishing a wide variety of product to test and climates to test in are valuable. Furthering research into incidence angle loss, coating durability, and new benefits/challenges of half cut cells are also valuable.

**Reviewer 2:** Score: 5. Comments: This report doesn't list the discrete tasks but I am generally aware of them from project 34347 (NREL). They seem appropriate.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** More systems level research is needed. As the DOE targets 50 year useful life for projects, components other than the modules (inverters, trackers) need to be studied with similar attention. Studying PV+storage as a system (Loads, degradation, dc-coupled components, use cases, etc.) will be critical for the next decade to continue to grow PV market share in the US.

**Reviewer 2:** Same comments as project 34347 NREL, where it is not readily apparent about the impacts or engagement with O&M practices and how that might affect or influence the data collection or analysis.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** In general the group does a good job of engaging the technical community with conference attendance and publication. More contact with industry (involved in system design and deployment (developers, owners, independent engineers) earlier in the process (such as surveys of the questions industry would most like the labs to tackle) would help focus research to align with relevant challenges.

**Reviewer 2:** It appears that all the required stakeholders are involved; again, as mentioned above, it's not clear if there are O&M providers involved or if that is handled by Sandia or NREL and if there are impacts to the data.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** More focus is needed on balance of systems research, system-level research, and PV+ storage. Industry engagement to disseminate results is done well. Earlier engagement (during experiment selection and design) would help focus this invaluable team on questions that are important to the industry.

**Reviewer 2:** Same as project 34347 NREL, it would be interesting to understand how the findings are more anonymized and shared with industry and O&M service providers, asset manager, project owners, etc. to determine if there is a more influential opportunity to affect the on-site practices on other sites or if there is insight that could be more practically applied.

## Solar Performance Insight – $300,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Clifford Hansen*

Solar operations and maintenance providers often cannot effectively monitor photovoltaic systems because existing tools often don't meet their needs or are cost-prohibitive. This project is developing a lightweight, affordable, intuitive photovoltaic modeling and analytics platform to calculate performance from real data acquired by multiple data systems. This would improve efficiency among photovoltaic operations and maintenance service providers and solar contractors while lowering soft costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Project is a low-cost software project with good potential to reduce soft costs around solar O&M.

**Reviewer 2:** Performance predictions are critical to utility scale and making sure actual meets predictions is vital to success. This open-sourced software development system is well suited for meeting this success.

**Reviewer 3:** This project will have useful insight for industry and the proffered O&M services on an on-going basis. It's still very early stages, but certainly continued progress in a short-time frame will be great to see.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a new project -- first results to be available next Spring.

**Reviewer 2:** Team is exceptionally strong, and if coordinated as planned will provide significant input to the O&M industry. Budget seems appropriate and I note that program is just beginning (March 2020).

**Reviewer 3:** Still too early to assess at this stage; however, good set of stakeholders are identified.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task is a key part of the project and the project seems to be making a unique contribution to reducing solar PV O&M costs.

**Reviewer 2:** Score: 5. Comments: Direction is well thought out, and inputs from partners will be critical to make this a success.

**Reviewer 3:** Score: 4. Comments: The tasks identified appear relatives to the objectives although the timing seems to be very aggressive. Considering the current situation with the pandemic, there will likely be an impact on the opportunity to share information about the project at conferences and / or events. It's not clear if there is a user testing approach and process to identify any bugs and to address those in another programming phase.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** First task is use cases which are critical to the following success.

**Reviewer 2:** Make sure roll out is widely disseminated and inputs from parties are encouraged during the development of the tool.

**Reviewer 3:** The main event at which to share information, Solar Asset Management North America, has been delayed until later this Fall. It's expected that there will be an opportunity to still provide information when it is rescheduled. However, it's not clear if that opportunity was intended to gather feedback on the use cases. As such, the team might consider if another event or method should be used to gather that info.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Have strong set of stakeholders to initiate project.

**Reviewer 2:** PI has done an excellent job of coordinating users. Would addition of end-users like utilities (i.e. NextEra) operating large PV fleets or financial and insurance groups interested in performance and resilience be appropriate?

**Reviewer 3:** It appears that the relevant stakeholders are participating.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Identify high impact use cases.

**Reviewer 2:** This is a critical tool for a more universal approach to systems O&M Development on an open-source platform will encourage widespread, non-proprietary tools List of project team is impressive.

**Reviewer 3:** The overall timeframe may be overly aggressive and considering the COVID-19 impact, some consideration might be given to allowing a little more time. Other than Amicus' use of the open source deliverable, it's not clear what other dissemination or announcement of the code availability will be provided in case other organizations are interested in its use. Lastly, it's not clear if assessment of the deliverable will be as effective as intended compared to other privately-held platforms currently in use or innovated later.

## PVInsight: A Toolkit for Unsupervised Photovoltaic System Loss Factor Analysis – $625,000

*SLAC National Accelerator Laboratory | Menlo Park, CA | Principal Investigator: Sila Kiliccote*

Evaluating the performance of a photovoltaic system under varying, real-world environmental conditions informs the design of system components and highlights potential causes of degradation. However, detailed and accurate performance analysis is not available for smaller residential and commercial systems. Current performance-analysis tests also require that system data be manually collected or verified. In an effort to streamline these processes, this project is developing an open-source tool kit that uses machine learning to automate power-loss-factor estimations for small and medium-size photovoltaic systems, thereby drastically reducing the manual work typically needed to identify and quantify them.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 3 |
| Set critical challenges to overcome | 6 | 4 |
| Implement a high-risk, high-impact approach | 6 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 |
| Advance the U.S. solar industry substantially | 6 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project's clear sky model and software has already made a big impact in the scientific community and is starting to impact industry. It works well to use a much wider range of data to assess PV performance than was previously feasible. The weakness could be that industry, specifically independent engineers, may not be adopting it as quickly as they could. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** This project is tied to SETO goals by improving the tools for studying operational PV systems. The new tools could improve system monitoring and management if integrated into an O&M platform for a distributed generation fleet. The goal to extract quantitative results from PV systems with no metadata and variable data quality is useful to fleet managers. The project is high risk because the tools require integration work before they can deliver value to fleet managers. If adopted, the toolkit could have significant impact on fleet management efficiency. The project is largely focused on delivering value outside of the DOE, because most DOE members do manage fleets of distributed generation assets. The PVInsight toolkit could lead to advancements in the PV industry, particularly for residential systems, but even if the project completes all milestones a lot of work remains to be done.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 2 |
| Disseminates results frequently and actively engage partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The impact of the technology is hard to measure, but also unclear in the materials presented. It's probably very large. It would be good to get independent engineers to use this to hone the energy production and probably of exceedance (p-case) estimates using empirical data, a notable gap in their process.

**Reviewer 2:** The project is making good progress against to its milestones and is tackling the important challenge in "performance disaggregation." Performance disaggregation is a method by which all the loss factors, or deviations from the "ideal PV signal," can be quantified and compared. The project has highlighted the availability of new open source tools and would benefit from adding false positive, false negative and accuracy metrics for the new functions and software tools. The publication record is strong for the project. The project would benefit from stronger contributions from O&M fleet analysis teams.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**Reviewer 2:** Score: 5. Comments: The first task involves forming a technical advisory committee and holding a workshop which is important for gaining access to time series data. The second task involves developing signal processing techniques for PV production time series data which is a unique approach but may or may not delivery benefits over performance models based on system metadata. The third task estimates metadata from production time series, which is a unique approach and has applications in validating site metadata across a fleet. Task 4 and 5 involve developing and publishing performance disaggregation analysis, which would be helpful if the methods are proven to be accurate and robust.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Collaboration with industry, e.g. independent engineers and project operators, measurement of impact. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** The main blind spot is that O&M is expensive on residential systems and even with excellent insights, it's rare that any on-site hardware changes will be made. Also the PVInsight does not compare its results against simple rules-based alarm systems that are common in the industry today.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Independent engineers, Duramat.

**Reviewer 2:** The project team would benefit from more engagement with dedicated O&M providers to help assess how to use PVInsight to orchestrate site remediation activities.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Encourage industry to provide more data for analysis, make results of data analysis available in probability distributions for use by independent engineers in their energy production and probably of exceedance (p-case) estimates. Ensure independent engineers know about the data and tools produced by this great project. They should also publish data and software tools to Duramat if they're not already doing that.

**Reviewer 2:** 1) The signal processing approach is useful for sites with no metadata. Expand the scope to include sites with some known metadata information. 2) The signal processing approach may not be sensitive to problems such as "1 missing module" at a residential site, even though that could dramatically impact energy yield. What other common problems is PVInsight's performance disaggregation likely to miss and how can you mitigate that? 3) Focus on how your fleet managers might generate more kWh with your tool. Offer training docs and case studies for using PVInsight to lower O&M costs or improve site outcomes.

## Reducing Module Soiling with Scalable and Robust Photocatalytic Coatings – $999,500

*Swift Coat, Inc. | Peoria, AZ | Principal Investigator: Peter Firth*

The project is developing and scaling multilayer, anti-reflective and anti-soiling coatings for solar glass to be deposited by a technique that sprays dry nanoparticles. The coatings have the potential to increase annual energy yield by reducing the loss of energy output that results when light gets reflected or when dirt lands on the modules. They are also capable of reducing operation and maintenance costs because the modules won't require as much cleaning. The team plans to perform outdoor testing in collaboration with the National Renewable Energy Laboratory.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 6 | 6 |
| Set critical challenges to overcome | 4 | 6 | 6 | 6 |
| Implement a high-risk, high-impact approach | 6 | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 6 | 4 | 6 |
| Advance the U.S. solar industry substantially | 2 | 5 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project will use a photocatalyst to oxidize and volatilize organic contaminations on module glass coating. I am concerned because a large fraction of the soiling is particulate--which this coating will not address.

**Reviewer 2:** This project loos to develop an anti-soiling and anti-reflective coating to enhance solar yields by an estimated 3%. The focus is on an improved deposition process using aerosol impact driven assembly to improve porosity control and hence refractive index.

**Reviewer 3:** This is a very promising approach to the challenging problem of reducing module soiling in the field. Their deposition approach is inexpensive and appears to incorporate the $TiO_2$ in nanoscale particles so small they will not scatter light and the porosity needed to keep the index of refraction of the film low. Films of $TiO_2$ has been shown to help remove organic and inorganic particles held to the surface with organics and other soiling entities. Apparently, this accounts for about 3% annual energy yield loss. The PI understands both the optical and durability challenges his coatings will face and has set a rigorous testing regime that will provide the answers. The collaboration with Cardinal seems serious since they will host a 39-inch coater in their facility later in this 18-month project.

**Reviewer 4:** The claims made in the report are legitimate. Soiling is a major source of avoidable loss in the solar industry. Independent Engineers attempt to capture soiling loss in production estimates, but the complicated logistics of washing consistently undermine the accuracy of those estimates. As such, soiling is one of the highest sources of uncertainty. It would be good to obviate the need for washing with this technology that appears to be proven in the window industry. One weakness of this proposal appears to be a lack of collaboration with a module manufacturer. Another potential weakness is that this coating will probably not completely obviate the need for washing in high-soiling areas, e.g. California's Central Valley, where organic particulates from fields combined with fog make soiling layers very intense. Thus, it would be good to test the efficacy of the solution in different regions or in a lab with different soiling and ambient conditions.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score | Reviewer 4 Score |
|---|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 6 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has just begun, so a judgment of performance is premature. I would like to see an estimate of what fraction of the soiling is particulate and what is organic.

**Reviewer 2:** The project is just getting started. The researchers claim a 3% improvement in energy yield but do not indicate what the baseline for this measurement is nor do they explain how the benefit will be quantified.

**Reviewer 3:** They have not begun work yet, so the scoring is rather arbitrary here. However, the PI provide excellent and sophisticated answers to my email queries scientifically and the proposal lays out a reasonable plan for engagement with Cardinal. Outdoor field testing at NREL will be essential to market acceptance.

**Reviewer 4:** This project has not yet started, so there is no performance to assess. They need an industry partner, e.g. a module or PV glass manufacturer.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: It is adequate.

**Reviewer 2:** Score: 5. Comments: Creating a porous $TiO_2$ film to lower refractive index is a novel adaption of a well characterized material. The milestones step through proving the basic capability, creating a scalable deposition process, field testing proto-types and then pre-commercialization.

**Reviewer 3:** Score: 6. Comments: A good plan.

**Reviewer 4:** Score: 6. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** They are missing the role of particulate contamination in the soiling study.

**Reviewer 2:** Validating the actual impact could prove a very difficult task due to the many variables associated with measurement method. Additionally, the most significant benefits of such an improvement would be on large utility scale systems that currently incorporate 72-cell silicon or 2.4 meter thin film modules. Can the AIDA source be scaled to ~1.5 meter?

**Reviewer 3:** 1) Coating should be tested against development of desert varnish since so many solar panels are deployed in the desert. 2) Consider whether UV life testing of the coating and other additional testing should be applied. 3) Wondering if there's a first small market (like remove agricultural pumping) to use as a niche market for this product and obtain early experience before setting up a full line with Cardinal.

**Reviewer 4:** The lack of collaboration with a module manufacturer and regionally specific testing of different soiling chemistries and ambient conditions, e.g. fog (which causes dust to stick more than drier areas).

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I think all the stakeholders are there.

**Reviewer 2:** The collaboration between Swift, Cardinal and NREL is probably the right combination for this stage of the work. Proof of capability in the field, however, will require assistance from commercial manufacturers and operators.

**Reviewer 3:** I see no definition of a niche entry market to get a lot of field experience. The solar industry is likely to be gun-shy about incorporating a new kind of cover glass at large scale.

**Reviewer 4:** Module or glass manufacturer, Duramat for information sharing.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Consider the role of particulate in soiling. 2) Will the coating address particulate soiling? 3) Limiting soiling is an important consideration in PV.

**Reviewer 2:** 1) Module soiling can have a significant adverse impact on PV system performance. 2) The researchers believe that they can improve energy yield by 3% using a novel porous $TiO_2$ that maintains has superior anti-soiling and anti-reflective properties. 3) This work intends to validate the material and demonstrate a commercially capable deposition that produces the film at low cost.

**Reviewer 3:** 1) Find a great niche market with a soiling problem and get experience from it. 2) Take advantage of NREL's expertise in standardized testing of modules.

**Reviewer 4:** Not having to wash modules would be a game changer. Washing is logistically complicated and often not done according to expectations. Thus, it is a primary source of energy production loss and uncertainty in estimates. The technology proposed appears to be proven from the window industry. The cost/benefit analysis seems legitimate. I recommend finding a module manufacturer to collaborate with along with a major buyer and an operator with projects in dusty areas. First Solar would meet both those criteria, but there are also plenty of crystalline modules companies and solar developers operating west of the Rockies where the lack of summer rain causes more soiling loss. Also, I think it's important for the team to test the efficacy of the technology among different soiling chemistries and ambient conditions. This can be done in the field or lab. They should also publish data and software tools to Duramat if they're not already doing that.

## Mobile In-situ Imaging of Photovoltaic Modules – $1,148,024

Tau Science | Hillsboro, OR | Principal Investigator: Greg Horner

As photovoltaic solar modules are added to the electric grid in greater numbers, new inspection and qualification techniques are required to maintain reliable electricity generation. This project is developing a non-contact scanner that can operate in solar fields at night and detect various failure and degradation modes of solar modules.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Cell cracks are a well-known issue in the PV industry that can cause accelerated degradation of fielded modules. The biggest challenge is that the cell cracks are not visibly and can impact plant production for years without being remedied. The technique developed by Tau science potentially allows for rapid scanning of power plants without requiring that the modules be disconnected. This could potentially allow for scanning of whole systems at any point during the project lifecycle. The team explored both line scanners and area-based cameras. They developed methods and regions of accuracy for both options. The successful completion of this project could have a large impact by making field EL measurements economical.

**Reviewer 2:** Today a lot of time and money is spent on doing EL imaging in the field. Having equipment that can do it without requiring the modules to be disconnected and powered externally should be of great value to the PV industry.

**Reviewer 3:** Tau Science is developing more sophisticated characterization techniques for indoor and outdoor PV applications. The outdoor application has the potential to make O&M activities more efficient and somewhat improve energy yields. The goals focusing around compact prototypes are important for bringing electroluminescence into field operations. The project team is collaborating with module manufacturing labs, public labs (SERIS), and outdoor PV operators. The outdoor work could improve LCOE through better onsite failure analysis and screening. The indoor work could improve efficiency by leveraging more automated characterization in R&D and manufacturing teams.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has met most of the goals set forth in a timely manner and has remained under budget. The project is set to conclude in August 2020. A few demonstration setups have been shared with Sunpower and other stakeholders as well as several publications.

**Reviewer 2:** The tasks and milestones have been met even though there have been some challenges and requirements to make changes to the equipment.

**Reviewer 3:** The project team has done a great job being flexible and observant about what products can serve customers. The development of the imaging sensor, thermal management and mounting approaches show an agile and creative project team. The main metric of success seems to be shipping tools to customers and I fully support this metric. The project team has published detailed content on their website and at the PVSC conference. The project team collaborates with industry members and national labs.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Testing and developing the line scanner and area camera were both needed in order to understand what techniques work best with what modules. Now that the Tau science team has iterated a few times, the product is more effective.

**Reviewer 2:** Score: 5. Comments: This is a project with objectives that can have a significant impact on the PV industry. EL has become a routine method for screening PV modules both before installation and after exposure to evaluate damage. The present method is both time consuming and somewhat hazardous. The instrument being developed in this project doesn't require disconnect so could be done in place in an array. There is a great advantage to this. The second very useful result could be development of algorithms to identify and evaluate the EL signals from cracks and other failure modes like PID.

**Reviewer 3:** Score: 4. Comments: The focus on crack detection is useful for most types of physical cell damage but electroluminescence can deliver other important information about PV devices. The Phase 2 goal to ship systems to the ield for feedback and commercial sales is targeted and important. Building the next generation imaging systems based on customer feedback and specialized categories will help ensure that the team develops products with a use case.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Biggest blindspot is a detailed comparison of the EL images generated by this technique with associated crack detection as compared to lab-based or other field-based techniques.

**Reviewer 2:** The project team has been very focused on succeeding with a particular EL technology. There could be other sensor approaches that are as effective but are ignored in this project.

**Reviewer 3:** The main blind spot of the team is the focus on crack detection when EL also delivers information about metallization damage, corrosion damage, Voc degradation, potential-induced degradation, excess series resistance and other sources of power loss in aged PV modules. Although the field application is not conductive to injection-level studies (i.e. multiple images at varying current injection or incident irradiance), that is another approach for their existing imaging hardware to provide even more information. The image resolution requirements for performance evaluation are lower than for crack detection. Can you image a series of injection values with one sweeping light source?

5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** It would be nice to see more developers and module vendors involved in this report. It looks like other sites will be scanned before the end of the grant period and hopefully, that will satisfy this gap.

**Reviewer 2:** They are already working with UC Florida and NREL, have delivered a unit on a commercial basis (SERIS, Singapore) and have plans to deliver a prototype to a PV manufacturer/installer (SunPower). Their team is fairly complete for this stage of the project.

**Reviewer 3:** The collaboration with public labs is good but I’d like to see more feedback from the “powerplant owner-operators, banks and insurance company” stakeholders mentioned in the impact section.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Microcracks are an issue. Despite the industry’s knowledge that microcracks represent a “silent killer” to plant financials, there remain several important open questions about the scale of this problem. This technique could help the modeling community understand how pervasive this issue is. 2) Contactless EL imaging is a great way to quantify the presence of mircoracks in fielded-modules. 3) The Tau science setup represents a great system to rapidly scan a site without the need to disconnect or de-install panels.

**Reviewer 2:** Value of this project is that it is addressing a need for implementation. DOE should look for more technology areas where they can accelerate a good technical idea into a commercially available measurement instruments. Encouraging cooperation between the different entities involved in PV can lead to valuable results. In this case a national lab development is being commercialized by a small business with the help of a University and a large PV manufacturing company.

**Reviewer 3:** 1) Incorporate the principles of quantitative EL into your tools in addition to crack detection. 2) Spend more time in the field and train O&M technicians in the use of your product. Offer to do a free audit of a PV system for one of your partners and publish the results. 3) Keep up the great equipment design work.

## A Data-Driven Approach to Real-World Degradation of Backsheets – $1,500,000

*Underwriters Laboratories | Northbrook, IL | Principal Investigator: Ken Boyce*

The backsheet of a solar photovoltaic module is the backing of the module. In combination with the front glass sheet, the backsheet helps to seal the module from the outside world. The backsheet is typically made of multiple layers of various types of polymers, a type of plastic, and can degrade over time from climate conditions, making its design an important predictor for how long a solar module can last in the field. However, current accelerated tests for backsheet degradation and the lifetime performance of the module have limitations. This team is working to employ a data-driven approach to analyze backsheet degradation for modules in the field in order to better understand the real-world environmental stresses of airborne pollution, solar irradiance, water, temperature, and abrasion on module performance. The team is using a large sample size to model and quantify the variance in degradation rates and link these to the backsheet materials being studied. This information will help inform a variety of stakeholders in the solar industry and could enable the development of more accurate standards for photovoltaic modules.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 5 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 3 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aims to improve our understanding of how time and location impacts backsheet health. Main challenge that this project tries to overcome in reliability community is getting field validation. This project will get data from a plethora of sites. This body of data and prediction model will be very useful to plant operators This project has risks in that the data may not be representative, the BOM composition may not be known, and that the methods of characterization and binning (spatio- temporally) miss a hidden variable. However, if the team gets this right, this could do a lot to improve our empirical understanding of how backsheets degrade.

**Reviewer 2:** This project is going to use in field inspections and data on site weather to try to determine what causes back sheet failures. Serious backsheet field failures have been reported for several specific materials. This project may give us more data on where and how these materials failed. However, the industry is most likely well past the stage where any of he suspect materials will be used in PV going forward. Therefore this study is interesting but not critical to the future of PV.

**Reviewer 3:** I very much like the combination of scientific and practical, modeling and in-field approaches employed, including the sharing with multiple stakeholders and perspectives. Similarly, the intention to develop standardized tools and share those with industry and other stakeholders could provide future opportunities to further investigate and follow-up on the practices and re-look at the data.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 6 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is just beginning. However, the timeframe and budget seem appropriate The project team represents a trusted partnership and has good relationship with developers and plant owners who will gain a lot by collaborating.

**Reviewer 2:** The project has been going for 8 months. One main task, establishing a standardized protocol for field assessments, has been completed. Efforts are underway to identify the appropriate arrays to inspect but it doesn't appear that the team has selected their sites yet. With the Corona virus situation this project is likely to get behind schedule.

**Reviewer 3:** The project is still early stages and the current progress to establish the approach and methodology is good progress. The schedule to conduct the in-field surveys will need to be very timely to meet future timelines.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes. Field surveys of backsheet health coupled with some lab testing fed into DataHUB is required to develop the tool to predict backsheet health

**Reviewer 2:** Score: 4. Comments: Inspections of arrays is not really a unique activity. Nor is establishing a standardized protocol for filed assessments as there are already several such approaches documented. This project is a routine application of standard PV activities. The most unique aspect may be the large number of diverse entities involved in the project.

**Reviewer 3:** Score: 6. Comments: The surveys and collection of data are very important to the entire project. It is a considerable task to gain agreement and access to a significant, if not just several, sites that are willing to cooperate and provide access. This alone is a significant achievement!

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I believe the team is aware of these risks, but I see the following potential blind spots: unrepresentative BOM, lack of details on module BOM, processing defects on site(s) that skew results, incorrect feature set used in training data, etc.

**Reviewer 2:** Backsheets have value particularly in high voltage systems. However, there are modules that have survived in the field for many years after their backsheet fell off. There are ways to design a module without an actual backsheet. So while it is important to identify poorly performing backsheets and remove them from the market, it may not be necessary to know everything possible about how, why and where these backsheets failed.

**Reviewer 3:** Considering the current COVID-19 situation, which could not have been foreseen, there will be a likely impact to the schedule and access in order to conduct the survey in compliance with social distancing and other health requirements. Similarly, some additional thought should be given to how the project results will be shared more widely with industry.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The team has engaged the relevant stakeholders. The team could possibly cast a wider net if budget and time allow.

**Reviewer 2:** This is a very diverse and knowledgeable team. However, the results of this project need to be communicated to backsheet manufacturers, module manufacturers and module purchasers. They should all be aware of what is failing in the field. But they really don't have to know many of the details of these failures. That information is only needed by those who hope to design and develop the next generation of PV module backsheets.

**Reviewer 3:** It appears that all the right stakeholders are involved or plan to be engaged throughout the project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Backsheets are the cause of a lot of field defects. 2) Improving our understanding of the link between environmental and chemical makeup with backsheet health will help the industry be more proactive in catching field issues before they arise.

**Reviewer 2:** We don't always need to know everything about why something has failed, especially if the industry has moved on and no longer uses the materials that failed. What we do need is the development of accelerated stress tests that will quickly identify those materials that fail in the field.

**Reviewer 3:** The impact on COVID-19 on the overall schedule is important as well as more detail on widespread dissemination of the project progress and results. I think it would also be important to ensure that the efforts to share the survey tool are carried through.

## Understanding and Overcoming Water-Induced Interfacial Degradation in Silicon Modules – $588,505

*University of California, San Diego | San Diego, CA | Principal Investigator: David Fenning*

This project is developing a spatially-resolved characterization methodology to detect the location and amount of water present in photovoltaic modules and to model any predicted acceleration in performance degradation. The project team is examining the physical underpinnings of these effects by combining first-principles atomistic modeling of the segregation, diffusion, and chemical effects of interfacial water with continuum finite element method modeling of water distribution and its effects. Based on the resulting physical model of a module's water exposure over time and predicted changes in material properties and power output, the project team plans to develop statistical response surface models to predict a module's hazard function.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Being able to measure the humidity level within a module could be a good research and QA tool. Comparing the moisture ingress modeling with the results of the instrument being developed could provide validation of the models and help to predict future behavior and improve module designs.

**Reviewer 2:** New characterization techniques to improve our understanding of module degradation will aid the industry improve module reliability and lead to lower LCOE It has been a challenge to measure water content in the field. In the lab, people have used FTIR, but it appears that the technique described here-in can be used to assess whether or not water is present at unacceptable levels in fielded modules. However, this use appears out of scope for the current grant Most researchers in the PV don't consider water to be a major issue for fielded glass-backsheet modules. The breathability of the backsheet is considered the "vent" that allows for water beyond the solubility limit to be exhausted from the module. If this tool discovers that fielded modules do suffer from too much water, that could have a huge impact. Concern on why all results are for modules during DH testing. The real value would be to see this on modules in the field.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has made good progress in laboratory development. As the prototype equipment is perfected it needs to be demonstrated to determine where it can have the biggest impact.

**Reviewer 2:** This project is nearing its end and has met the majority of its milestones. They have made several publications and presentations. Would benefit from more collaboration from plant owners who have many modules available for scanning that cover a broad range of conditions and BOMS.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The equipment being developed could be useful for research – to assess moisture ingress models and develop improved moisture barriers where necessary. Since moisture ingress impacts almost all PV technologies, this work could ultimately have an impact across the PV industry. If a low cost, portable unit is eventually developed it could also be used for in-field monitoring especially for at risk arrays- those in high humidity areas or those using new technologies

**Reviewer 2:** Score: 5. Comments: The tasks around developing the technique and tuning the results to other methods are appropriate. It is unclear why minimodules needed to be built when there is a wealth of fielded modules to use.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:**

**Reviewer 2:**

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Condensed water is much worse than moisture in the encapsulant. The proposed technique only detects the moisture in the encapsulant so it would not see what has condensed. However, it is likely that by looking for saturated levels, this instrument would point to the likelihood of condensation. Then you could use other means to look for condensed water.

**Reviewer 2:** The presence of water may not actually be a big cause of well-made modules in real conditions. The presence of water in DH testing is expected to be reduced after the test but before flash testing to remove it.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project will need to connect with those who need this tool. The first adopters are likely to be for research in PV. That can be at Universities, National Labs or commercial companies looking at moisture ingress models and designs for modules. Once the equipment has been validated at this level and advanced to be more portable, system owners or system engineers may be interested in using it to assess problem arrays.

**Reviewer 2:** This project could benefit from interaction with the DuraMAT community and plant owners.

## Characterization of Contact Degradation in Crystalline Silicon Photovoltaic Modules – $1,581,926

*University of Central Florida | Orlando, FL | Principal Investigator: Kristopher Davis*

This project is developing a highly-automated metrology solution that can non-destructively extract the series resistance and recombination of individual cells encapsulated within a photovoltaic module with minimal uncertainty for both parameters using calibrated electroluminescence imaging. This metrology can be used in reliability and durability evaluations to accelerate cycles of learning and to help develop new technologies that reduce cell- and module-level power losses and integrate them into high-volume manufacturing. Each of these applications has the ability to reduce the solar costs by minimizing variance in production, reducing the number of failures due to contact and interconnect failure, reducing degradation rates due to contact and interconnect degradation, and accelerating the adoption of new technologies.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a highly technical measurement effort to develop techniques for extracting cell parameters from EL –PL. In itself this project is not going to reduce LCOE or even provide a path to that. However, this project can provide methodologies for other researchers to use in their development and evaluation of device performance.

**Reviewer 2:** This project is focused on using EL and PL to understand the components of J0 and Rs in a commercial module. If successful, this could potentially be used to optimize module processing (e.g. firing temperature) or reduce costs (find the limit for solder content in ribbon design) or potentially capture cold solder and other defects before the modules get to the field De-convolving these complex components while dealing with signal to noise ratios represent a big challenge Seems like a lot of money for an analysis technique based on commercially available tools. This could have a big impact if and only if it leads to reduced module costs or prevents solder-joint degradation in the field.

**Reviewer 3:** The project aligns with SETO because improved electroluminescence techniques could benefit the PV industry in cell R&D, cell manufacturing process control, and module troubleshooting. The goals include calibration of Rs/J0 values, developing the EL-PL imaging tool, and applying the technique to fielded modules. The size and duration of the project matches SETO's typical project. The collaboration with BrightSpot Automation and Tau Science will facilitate the release of new EL-PL algorithms into research and manufacturing sites. Many players in the PV industry predominantly use EL as a qualitative technique, and more work like this project can help the industry detailed quantitative information on the device under test.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 5 |
| Collaborates with sufficient stakeholders | 4 | 4 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is a fairly complex project that has successfully worked its way through a number of technical milestones. A significant number of publications have already been prepared.

**Reviewer 2:** This project is 2.5 years in. Have made progress in comparing J0 and Rs within a module using EL and PL. The work has resulted in 3 papers published, 8 in preparation. They have several module types. Would want to see more input from developers and plant owners who have experienced issues with solder-joint degradation.

**Reviewer 3:** The project report includes demonstrations of the Rs/J0 validation and calibration exercises for a range of commercially-relevant PV cell technologies. The metrics for success include accurate detection of Rs/H0 changes across a range of module types and stress history. The project team has a good publication track record and has shown a commitment to making data publicly available. The collaboration with ASU was a key part of the calibration study but more information should be provided on the prospects for deploying new characterization procedures to BrightSpot Automation and Tau Science.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: There is a lot of good science coming from this project but it gets a lower score in terms of having a substantial impact on the PV industry. Projects like this need to be done to provide background for future research.

**Reviewer 2:** Score: 5. Comments: Yes. The method development for extracting J0 and Rs is as important as being able to de-convolve the components

**Reviewer 3:** Score: 5. Comments: The technical background for Rs/J0 fitting and the use of circuit network models are not novel, but they have yet to be applied widely in the PV industry. I've worked at 4 module manufacturing companies where in-house engineers were tasked with analyzing EL images, and usually the analysis was qualitative at best. The tasks around minimizing error in Rs/J0 estimates and detecting small changes are appropriate for applications in studying fielded modules and control cell process.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI and project team have selected EL/PL as their tools in this effort. Those are good tools used by many in PV, but they might not be the best tools for collecting the type of data they want.

**Reviewer 2:** With so many free parameters and other unknowns there is a risk to over-fitting that make the results less broadly applicable.

**Reviewer 3:** The project report omitted discussion about how optical changes in the module can impact EL-PL intensity. For instance, anti-reflective coating degradation or encapsulant yellowing may cause significant artifacts in the data analysis pipeline.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** For real success the project will have to lead to development of commercial equipment that can be sold at reasonable cost to labs and manufacturers.

**Reviewer 2:** The project could benefit from having more collaboration with downstream plant operators.

**Reviewer 3:** The project team would benefit from increased engagement with cell process development teams. The application of the analysis technique may only apply to fielded modules after they have been removed from the rack. If the project team sees applications in fielded modules as a key application they should engage with O&M providers or project owners.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Scientific developments like this project should have clear focus with a vision as to how the technology will be implemented if/when the project is successful. Scientific studies like this one should address multiple technologies so their results aren't limited to only one or two companies. Often instruments used for one type of measurement (EL to see cracks) can also be used to extract significantly more information.

**Reviewer 2:** 1) This project could be interesting if they can use their technique to uncover issues before deployment. 2) Unclear if this technique is being designed for a low-cost quality control tool or is specific to R&D. 3) Want to see this technique demonstrated.

**Reviewer 3:** 1) Publish your software to help engineers get the benefit of your analysis work without having to purchase new hardware. Open source tools for analyzing EL-PL images can enable engineers today to get more value from their existing imaging capability. 2) Obtain c-Si modules with damp heat corrosion damage causing nonuniform EL intensity changes (e.g. at cell edges or at busbars). Explore how best to use your software to analysis these modules. 3) How long do your measurements take and what are the prospects for developing a minimal analysis set to yield similar information (e.g. using 3 injection levels instead of 10 but only after product-specific calibration)?

## Levelized Cost of Energy Reduction through Proactive Operations of Photovoltaic Systems – $1,189,101

*University of Central Florida | Orlando, FL | Principal Investigator: Joseph Walters*

This project is developing new methods for characterizing fielded modules in order to provide greater certainty in fielded energy output and degradation rates over their lifetimes. New methods for data analysis and interpretation algorithms are under development in order to maximize fleet performance through a monitoring system that has a higher resolution than state-of-the-art methods currently allow. Additionally, models are being developed to examine the effects that different resolution photovoltaic monitoring systems have on energy yield simulations based on a power plant's design, size, location, environmental considerations, and expected system lifetime.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The metrics for the project focus on comparing past availability and production numbers to future ones after additional monitoring algorithms have been implemented. The project intends to monitor inverter, combiner, string and module level performance. String performance is monitored with high accuracy tracers. Due to equipment failures and lack of additional budget, the project has abandoned module-level monitoring. For inverter and combiner level monitoring, it does not seem additional sensors were installed to measure with high accuracy.

**Reviewer 2:** The overall premise of the research would provide important insight into the current monitoring practices, equipment and value and how they can be properly value as essential to an overall solar project's value. It is unfortunate that there were issues with the equipment that limited the number of data streams for the project. However, this does provide insight into additional constraints that could be taken into account for future endeavors and if additional equipment might be needed to preserve the intended scope and goals of the project. While this could potentially increase the overall research project cost, the ability to ensure that the proper number of data points to inform the project and the outcome would be worth the additional cost. SETO should potentially allow a contingency in the project budget within a certain allowance. In general the project's goal to quantify the value of monitoring as a portion of LCOE is important to understand as it is certainly foreseeable that the necessity for more data and not less, will be required in the future to better value the project, its energy production and how incentives or other financial considerations are better formulated.

**Reviewer 3:** The data signals the project is creating are useful in identifying in-field failures, but they seem like a small quantity compared to the probable number of failures out there. Also, the equipment and data issues the team is encountering makes me wonder if industry would adopt the same techniques. If they don't, the results of this project may not be that useful I'm sorry to say.

## 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 3 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project faced challenges with tracer equipment failures (without spares or additional equipment budget) leading to monitoring only 1/3 of the originally planned measurement points. Tracers currently only measure string level IV curves, not module level. Failures contributed to time delay in the installation. I believe the project would have benefited in the planning stages with more engagement with advisers from industry who are experienced with operating systems. They could have recommended planning for tracer failure, provided feedback on where to add high accuracy sensors to monitor points in the system, and could have provided some existing publication references to focus efforts on high value goals by incorporating prior industry knowledge.

**Reviewer 2:** Despite the challenges with equipment, it appears that the project has been able to retrieve significant insight to continue to move ahead with next tasks. The collaboration with other laboratories and researchers provided insight and advancement to the objectives, the techniques and the scientific method. It's not clear if there could have been additional opportunities to share the on-going findings of the study more widely with industry or if that is preferred to be done following completion. Additional insight may have been fruitful if other monitoring systems were utilized and results compared; however, it appears that using NREL SAM was intended to provide a general, common basis so that results could be more consistently analyzed and compared. However, given the quality concerns of the equipment, there is likely an issue that these results may not have as much impact as expected.

**Reviewer 3:** The fact the team include NextEra is valuable. NextEra is a major developer and operator of solar power plants in the US. The team has been productive, but equipment and data issues have stymied their progress it seems. As mentioned, I'm concerned the IV monitoring technique may be too burdensome for operators to adopt and thus the work of this project may go unused.

## 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: I think this project could benefit from industry operator input if allowed. O&M groups, asset managers and independent engineers could have contributed to improving the experiment design and made the results more impactful if consulted in the early stages.

**Reviewer 2:** Score: 4. Comments: Project steps are well organized and considering the focus on equipment and software, necessarily sequential in order to provide the basis for data collection and analysis. The project members have developed a well thought-out plan and have proceeded against it well.

**Reviewer 3:** Score: 5. Comments: Each task appears to be appropriate, but I am not a deep expert like members of the project team.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI does not seem to know prior work on statistical analysis of string current (Thevenard, SPI poster 2015), the notorious inaccuracy of inverter level power measurements when trying to use them to determine performance (Thevenard, PVPMC talk 2018), and the industry learnings on best practices (such as the move toward aerial thermal imaging instead of IV curve statistical analysis during system operation).

**Reviewer 2:** Based upon the report provided, I didn't see any other blind spots that the project team hadn't already uncovered. However, the issues with the equipment may have limited value with the results.

**Reviewer 3:** Complexity of monitoring infrastructure for wide-spread adoption.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Operators, technical asset managers, IEs, performance engineers with focus on operational data tasks could all help support this work in advisory roles.

**Reviewer 2:** It's not clear if O&M providers or similar service organizations were consulted or interviewed to uncover any other variations or issues could be considered. Similarly, asset managers could have been surveyed to understand if there are any other constraints in play that might affect on-going data capture and/or maintenance.

**Reviewer 3:** Possibly commercial lab partners (RETC, PVEL, VDE, TUV, etc.) who may use the technology to diagnose faults in a lab setting. Duramat.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** I think the project stands out because it involves a utility and a large (real world) project scale. The experiment would contribute significantly more value if high accuracy metering was installed at module, string, CB and inverter level. The project has faced significant challenges, including equipment failures, schedule delays. Algorithms are currently only applied to one system and expanding applicability could be challenging.

**Reviewer 2:** Overall, this was a good project to invest in and will provide important insight to industry on the part that monitoring plays in the overall progress towards solidifying the LCOE of solar, particularly as compared to other energy sources. However, I think that there is an additional step to consider in socializing the findings and their importance with asset managers and O&M providers so that there is consideration of impacts to on-going practices for procurement, implementation of the expected best practices and what additional actions could provide more insight, including further necessary research.

**Reviewer 3:** I recommend you work to confirm NextEra and other operator would actually use IV monitoring on an industrial scale to take advantage of the signals the team is producing to identify faults. If not, perhaps the signals could be used in a lab environment when diagnosing issues. They should also publish data and software tools to Duramat if they're not already doing that.

# System Design and Energy Yield

## Racking System for Commercial Solar Arrays – $1,205,000

Acme Express | Cleveland, OH | Principal Investigator: Don Scipione

Current solar panel racking systems have several components and require pre-ordering, transporting, inventorying, and labor-intensive deployment. This team is developing an automated racking system that produces the rack from raw material on-demand and on-site during an automated installation process. It is expected to reduce the cost of commercial, flat-roof solar installations by approximately nine percent.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 3 |
| Set critical challenges to overcome | 1 | 1 |
| Implement a high-risk, high-impact approach | 1 | 4 |
| Match well with the level of DOE funding and planned project duration | 2 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 1 | 2 |
| Advance the U.S. solar industry substantially | 1 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project, if successful, will enable modest benefits to the racking costs of the smallest PV market in the US (flat commercial roofs). This type of DOE funded product development hasn't been very successful in the past because it's very easy for companies to ignore key concerns or requirements of commercial customers.

**Reviewer 2:** Strengths: The focus of this project is considered unique and novel, and would certainly introduce a new method of racking production and installation that is not available currently. The team appears to reasonably aware of the conditions and restrictions applicable to racking product development and is targeting cost reduction as the primary objective. The level of ambition is deemed high-risk and if the goals can be achieved and the product is able to achieve commercial adoption, it could provide significant value. Weaknesses: The project report and scope of study appears to overlook critical considerations and does not sufficiently contemplate the challenges that lie ahead. Rooftop racking in the US is already ~$0.10/w, so the goal of achieve $0.11/w would not be meaningful. The project does not adequately consider or address key items such as testing and certification, site variability, code requirements, bankability, and other key areas of qualification that will be needed prior to industry adoption.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 5 |
| Measures impact appropriately (e.g. quantitative) | 2 | 4 |
| Disseminates results frequently and actively engages partners | 3 | 4 |
| Collaborates with sufficient stakeholders | 1 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** It's unclear what voice of customer work this team is employing during the early stages of this project.

**Reviewer 2:** The project team appears to be well organized, focused, and able to reasonably meet performance objectives to date. The report sufficiently details the progress made to date and it is considered significant and positive in nature. They have a clearly defined set of schedule milestones and tasks, and appears to have engaged partners.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The tasks appear reasonable but early voice of customer efforts should be included.

**Reviewer 2:** Score: 4. Comments: The task list is clearly defined, provides clear goals and success metrics and the cadence appears logical and valuable. The report does not discuss the measures or resources that will enable the project's future tasks.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No further comments.

**Reviewer 2:** These are the questions submitted to the PI and indicative of the blind spots: 1) Please confirm that the target market is focused on rooftop installations. The labor comparison table cites rooftop racking manufacturers. 2) How will the product allow for varying tilt angles, corresponding GCR designs, and sloped roofs? 3) Please discuss the roofing materials (EPDM, TPO, etc) that will be suitable for this racking product and any efforts to collaborate with roofing manufacturers to maintain roofing warranties. 4) To what extent will the racking product allow for a range of wind speeds, snow loads, air moisture, seismic categories, or other design constraints? 5) Will the product undergo ASCE 7-05 or similar wind studies? 6) Will the product be certified to UL 2703 for grounding/bonding, mechanical loading, and fire listing? 7) What are the provisions that will be included in a product warranty and what will be the financial backstop to give the warranty credence? 8) Is it envisioned that ACME will provide on-site services for installers during the racking installation? If so, what is the method in which this service will be resourced? 9) What is the approximate labor savings expressed in $/w expected?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No further comments.

**Reviewer 2:** Other valuable stakeholders would include large solar focused engineering firms, inclusive of the IE community, designers and engineers, testing agencies, EPC companies.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** No further comment.

**Reviewer 2:** 1) The goal of achieving $0.11/w for a rooftop racking product is insignificant as the current pricing is already below that in some cases and will only be lower going forward. 2) The project scope does not sufficiently contemplate the challenges, key considerations for commercial acceptance, and has a low likelihood of success 3) This project is not solving a critical challenge for the industry.

## Non-Contact Simultaneous String-Modules I-V Tracer – $709,999

*Arizona State University | Tempe, AZ | Principal Investigator: Govindasamy Tamizhmani*

This project is developing a non-contact module-level I-V tracer for the rapid and accurate characterization of photovoltaic modules under operating conditions. This tracer aims to enable accurate degradation science and fielded performance monitoring to be conducted on modules under operation.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 |
| Set critical challenges to overcome | 2 | 1 |
| Implement a high-risk, high-impact approach | 1 | 1 |
| Match well with the level of DOE funding and planned project duration | 2 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 1 | 1 |
| Advance the U.S. solar industry substantially | 2 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** There are many commercial efforts underway to enhance DC health analysis for operating projects. These include aerial inspection, MLPE, and advanced tracker solutions. There are even competing DC string solutions on the market. It's also unclear why the non-contact nature of this solution is significantly enabling.

**Reviewer 2:** Strengths: The goals of this project are deemed valuable and would result in safer methods for field testing, and reduce O&M labor hours. I am unaware of an existing IV curve tracer that has the capabilities cited in this report – this would be a positive enhancement to currently available tools. The project team appears to be detail oriented, technically proficient, and aware of the application to solar PV. Weaknesses: The project objectives, the advancement that it would result in is not considered to be substantially beneficial for the industry, or solving a high priority problem. There are clear benefits, but they may be financially insignificant.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 5 |
| Measures impact appropriately (e.g. quantitative) | 2 | 5 |
| Disseminates results frequently and actively engages partners | 2 | 4 |
| Collaborates with sufficient stakeholders | 2 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** From the report "It is expected that once the field testing has successfully been completed, the commercialization of the technology will be investigated." I think the commercial potential of the solution should have been evaluated prior to undergoing the lengthy and expensive technical analysis.

**Reviewer 2:** The project team appears to be well organized, focused, and able to reasonably meet performance objectives to date. They have a clearly defined set of schedule milestones and tasks, and appears to have robust engagement partners.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: See prior comments.

**Reviewer 2:** Score: 5. Comments: The task list is clearly defined, provides clear goals and success metrics and the cadence appears logical and valuable.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** See prior comments.

**Reviewer 2:** The PI may not be aware of competitors in the market that may be developing similar products. Additionally, there are important steps beyond this project inclusive of product testing, certification, and commercialization that is equally as important

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See prior comments.

**Reviewer 2:** Other valuable stakeholders would include O&M service providers, asset operators, and EPC commissioning persons.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This type of university-led product development should be avoided where private companies are developing similar solutions.

**Reviewer 2:** 1) The overall impact of this project to the industry is considered low, to very low, and does not appear to solve critical challenges that would advance the industry substantially. 2) It is not unreasonable to believe that a technology like this could be developed and commercialized without DOE funding. 3) The project team appears focused, well informed, technically proficient and capable of achieving the goals of this project.

## Automating Detection and Diagnosis of Faults, Failures, and Underperformance in Photovoltaic Plants – $2,000,000

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Michael Bolen*

Using machine learning and developing algorithms, this project team is working to identify reasons for unplanned maintenance events at utility-scale solar photovoltaic plants and differentiate them from power fluctuations due to causes that do not require on-site maintenance, like weather or module degradation. By analyzing the continuous energy-production data stream coming from utility-scale photovoltaic arrays, this technology can eliminate false alarms that are sent to photovoltaic system owners and operations and maintenance firms. This would decrease the labor required to review underperformance, lower the levelized cost of photovoltaic electricity, and increase energy output.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Prior work by EPRI laid a foundation for the proposed project. The team is experienced to work with plant operators for operation optimization.

**Reviewer 2:** This project starts 4/1/2020. The report was written before the start date.Therefore, the scores are place holders and represent the reviewer assessment of the worthiness of the project, the approach, the details of the prosed tasks and assisted milestones. The project ultimate goal is to enable owners/operators of PV plants make smart and efficient decisions with the information derived from data flowing from PV plants. This is accomplished by smart and improved automation of "detection and diagnosis of faults, failures, and underperformance" in PV Plants. Just as high performance and cost of PV is a major goal of the DOE program, addressing issue related underperformance of the PV module in the field, and failure and faults of the total system, is also important and can have impact on the LCOE to the consumer. The project is well described with goals and objectives that are assessed to be worthy of support. The tasks are clear and well defined in terms of responsibilities of the team members. The team consists mostly of industry who has a stake in the progression of the tasks and successful outcome.

**Reviewer 3:** Strengths: The subject matter for this study is focused on a meaningful challenge for the industry. The challenges cited by the PI are valid and the ability of the industry to efficiently and accurately monitor and detect faults and underperformance events is deemed inadequate currently. Current industry methods and resources to monitor and detect faults is not considered robust, can be cost prohibitive or inhibited by qualified technique or instrument. Fleet operators are incumbered with enormous amounts of data that is often unhelpful and does not allow for efficient decision making. The ability to actively monitor and identify defects and underperforming modules without rigorous testing would provide significant value for the industry. Weaknesses: The project report does not sufficiently prescribe or detail the quantitative benefits or impacts that might be realized by this project, whether focused on performance or maintenance benefits. It is not entirely clear how the method or outcome of this study would be significantly different or beneficial in addition to many existing or current efforts of similar nature. Lastly, the project does not clearly detail the tangible means in which the results of the study can lead to actionable and correctable efforts by the industry, how it can be socialized in a manner such that key stakeholders can realize impact.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has not started officially so it is hard to give a fair score on milestones achieved. From the GNG's set, it showed the team planned for measurable performance for the project. The project plan would require their close collaboration with plant operators and other industry partners.

**Reviewer 2:** The milestones reflect progress along the timeline in terms of performance metrics, success value, and the method and tool of measuring success. The project consists of the PI institution and five other stakeholders from industry. I anticipate that this project will perform on the tasks in a timely manner, as it will be guided by the stakeholders.

**Reviewer 3:** The project has just commenced and thus, not major milestones or schedule progress has been made from which to evaluate the performance to date. The provided project plan and associated partners is deemed qualified and a strength of the project.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes. The sub-tasks are reasonably organized to provide critical steps for the success of the project.

**Reviewer 2:** Score: 6. Comments: The nature of the project as described is such that the value/impact of the goals are very significant, since it contributes to making a PV plant smart, efficient, and low-cost operation/maintenance.

**Reviewer 3:** Score: 5. Comments: The project plan inclusive of the detailed tasks, key milestones, and methods of measurement are deemed comprehensive and professional.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project plan covers all important aspects of the project.

**Reviewer 2:** At this time, I cannot specify "blind spots."

**Reviewer 3:** 1) The means in which the results of the study can be adopted broadly by fleet operators who operate with varying instrumentation, technologies, and quality of data may impede accelerated adoption. 2) Many fleet operators have on their own developed proprietary means to achieve similar outcomes. 3)Cost may inhibit the ability of some fleet operators or some project types, as instrumentation and data collection varies by project type (residential, small commercial).

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The team has worked years in this field and has enough collaborators.

**Reviewer 2:** A major strength of the project is the number of industrial stakeholders.

**Reviewer 3:** Independent Engineering will need to review the data and qualify the conclusions. O&M service providers, SCADA companies, and asset management companies can be critical to help shape implementable means.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The success of the project heavily relies on data analysis with machine learning. Hope the report would show the EPRI has the capability or have the access to the capability.

**Reviewer 2:** Because the project is just starting and no results to assess, the reviewer cannot suggest issues as feedback for SETO consideration.

**Reviewer 3:** 1) The project team is considered a strength of the project, they are highly qualified for this type of work, and the execution certainty is high. The fleet operators that are involved are deemed high quality and a strength of the project. 2) There exists multiple similarly focused studies and projects running concurrent to this one, or previous studies that touch on similar topics. It is unclear how this project would be uniquely different in nature. 3) Operational performance and the value of monitoring underperformance events efficiently is considered a critical challenge for the industry.

## Technoeconomic Analysis of Novel Photovoltaic Plant Designs for Extreme Cost Reductions – $199,968

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Joe Stekli*

This project team is performing a techno-economic evaluation of photovoltaic plant design innovations to reduce costs and enable more dispatchable solar energy. Using machine-learning techniques, they are working gather data about both the plant components and the plants to optimize performance and significantly lower the levelized cost of energy. This will provide the photovoltaic community with a new opportunity to focus resources on technologies and designs that will have the greatest impact on cost reduction.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 3 | 5 |
| Implement a high-risk, high-impact approach | 5 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 2 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 3 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project team is performing a techno-economic evaluation of photovoltaic plant design innovations to reduce costs and enable more dispatchable solar energy. Using machine-learning techniques, they are working gather data about both the plant components and the plants to optimize performance and significantly lower the levelized cost of energy. This will provide the photovoltaic community with a new opportunity to focus resources on technologies and designs that will have the greatest impact on cost reduction.

**Reviewer 2:** Strengths: The focus area and goals of the project are deemed unique in nature, and is exploring both ambitious and interesting system features that may provide performance value for project. The scope includes ambitious advancements such as tandem modules and +1500V system operation, both considered high risk and potentially high impact. The industry has already realized significant cost savings and efficiency of performance from prior voltage increases to 1000V and now 1500V. A clear focus on LCOE reduction is aligned with the SETO mission. Weaknesses: The project does not include an explicit assessment of feasibility, related to commercial development and availability for items such as tandem modules, or +1500V design. Both have incredible barriers to overcome, and both appear to require multiple years of development before they could ever reach the industry. If any of the potential design features included in the scope are not realistically achievable, then the study itself loses value. Additionally, the project does not sufficiently describe how cost impact, either specific to the product, or as an integrated item, and this itself is key to understanding LCOE impact. The inclusion of bifacial modules is not particularly valuable, as the technology has already been adopted and will realize significant gains for the industry, and does not require deep analysis to substantiate it.

**Reviewer 3:** On it's face, this work should be covered by available LCOE tools and sophistication of the utility solar development community. However, in practice, developers and EPCs are scrambling to simple slightly improve the design of the system they most recently financed/built. Exploration of the full suite of benefits of a technology like MLPE including: 1) Pmax mismatch, 2) extended string length, 3) reduced inverter clipping, 4) reduced degradation, 5) enhanced bifacial performance etc. will be enabling for enterprising developers to take a chance on an emerging technology. Challenges will include assuming the correct price and reliability assumptions, so I encourage the team to consider aggressive, mid, and conservative cases for these parameters with significant uncertainty.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 1 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 1 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 1 | 3 |
| Collaborates with sufficient stakeholders | 4 | 1 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** No comment.

**Reviewer 2:** The project report indicates that the project has not commenced, does not mention the level of commitment by participants, and does not provide a task list or descriptive milestone schedule.

**Reviewer 3:** It will be easy for this work to be lost as just another paper. I encourage the PI to focus aggressively on working with a development or EPC partner.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: An initial challenge of this work will be defining baseline model characteristics to accurately capture existing plant-level performance. Many factors can influence actual plant performance, and these may be difficult to parameterize. To properly capture these conditions, detailed plant design schematics and construction documents, as well as any plant faults and site weather event data, will be reviewed. The larger anticipated issue for this project is proper capturing new technology performance within NREL's SAM. SAM is currently limited in its ability to accurately capture the performance of technologies such as bifacial modules and tandem modules. As a result, NREL SAM's source code may need to be edited to fully accomplish the integration of these components. Concurrently, little to no utility-scale PV plant data is available for the future PV plant components to be analyzed (bifacial modules, tandem modules, increased plant voltage (+1500V), and module-level power electronics for large-scale plants) due to their limited commercial availability. Leading researchers and technology providers will be consulted in an attempt to properly capture the anticipated performance behavior of these components within the model. Creation of a machine learning algorithm capable of interacting with NREL's SAM may also become challenging as processing time between SAM and the optimization model, which may have to be in an external programming language such as Python, may be excessive. For this reason, each future plant component is to be optimized on an individual basis initially, to mitigate early optimization obstacles. Lastly, it is unclear whether a >20% LCOE reduction is possible through integration and optimization of these components. This may be a potential project scalability and impact issue as a LCOE reduction of greater than 20% is likely necessary to interest the Department of Energy (DOE) and commercial entities to invest further resources in the identified approach and/or identified new technologies to reduce PV LCO.

**Reviewer 2:** Score: 1. Comments: The project report indicates that the project has not commenced and does not provide a task list or descriptive milestone schedule

**Reviewer 3:** Score: 4. Comments: No comment.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None noted.

**Reviewer 2:** These are the questions submitted to the PI and are indicative of potential blind spots: 1) In the exploration of benefits related "tandem" modules, what cell material, in addition to silicon based technologies, is the assumed tandem portion? 2) How will the study go about determining baseline product and system integrated costs for each potential feature? For example, how will the study incorporate material and installation costs for +1500V design? 3) How will the study go about determining baseline product timing, the expected commercial availability, for each new performance feature? 4) To what extent has the PI already investigated the product development challenges and risks leading up to commercial deployment? 5) Will the project include an assessment of system reliability impact (better or worse) for new products such as +1500V, optimizers, or tandem modules?

**Reviewer 3:** See prior comments on how conservative developers and EPCs are on adopting new technologies.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Plan is to disseminate much like SAM, so collaboration is the end point.

**Reviewer 2:** Other critical stakeholders could include large asset operators, solar development engineers or IE's. Additionally, testing agencies and code bodies may be helpful for high voltage design assessments.

**Reviewer 3:** See prior comments.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Fund this project. Will benefit PV power plants. Industry as a whole if successful will benefit.

**Reviewer 2:** 1) Multiple features included in the scope of study, such as +1500V design or tandem modules, do not have a reasonable probability of achieving commercial availability, and if either happen to do so, it would be years from now that it could even begin to reach implementation. 2) The inclusion of bifacial modules is unnecessary as the product has already gained wide adoption, and the benefits are reasonably understood and accepted. 3) It is unclear how the study itself, if it were to achieve it's goals, how it would lead to tangible action and benefits immediately for the industry.

**Reviewer 3:** See prior comments.

## Deciphering Degradation: Machine Learning on Real-World Performance Data – $1,249,978

*kWh Analytics | San Francisco, CA | Principal Investigator: Adam Shinn*

The study of solar degradation has historically been limited by the unavailability of predictive and accurate analyses based on real-world, time-series photovoltaic plant performance data. This project is working to build a machine learning model on an industry-wide data repository by collecting energy generation data and system metadata on approximately 20 percent of America's operating photovoltaic plants. This will enable the team to statistically quantify degradation rates on an ongoing basis, quantify the impact that various materials and components have on degradation rates, and deliver systemic impact by enabling the world's largest reinsurers to accurately insure and therefore reward reliable solar products.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 3 | 5 |
| Set critical challenges to overcome | 5 | 2 | 4 |
| Implement a high-risk, high-impact approach | 3 | 2 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 6 |
| Advance the U.S. solar industry substantially | 4 | 2 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** While several papers have been published in the last 5 years on degradation, it remains one of the largest drivers of project valuation that has very little consensus. Having consistent analysis on a dataset that represents 20% of US install base, including a range of system sizes, duration, equipment, etc. will be extremely valuable. One of the biggest challenges to publishing more fielded results historically has been owner refusal to share data, a challenge the PI references in explaining why DOE funding was critical to success. The challenges I expect to meeting the project goals are the chance that other factors that can look like degradation may increase uncertainty of the results. Unfortunately, the industry is currently placing multi-million dollar impact on levels of precision that cannot be measured in reasonable time frames (less than 5 years) with field data measurement uncertainty. When enough time series of data is available, applicability of results from older products needs to be addressed. The results of this project could show that rates currently being used in financing are too optimistic, which will be valuable to the industry but may not contribute to the reduction of LCOE.

**Reviewer 2:** The project addresses SETO goals by helping to identify PV technologies with higher long-term performance. If higher performing technologies were to capture a larger market share that would help advance SETO's goals. The project sets forth tasks to aggregate a large amount of production data and then publish any relationships between long-term performance and PV system metadata. The main risk to the project was gaining access to production data plus metadata and these steps seems to have completed successfully. The large amount of data processing by a small team matches DOE funding and planned project duration. The project has yet to contribute significant value outside of DOE. This work could impact the PV industry by highlighting BOMs or climates with lower energy yields, but must somehow be applied to particular financing arrangements before it can have an impact.

**Reviewer 3:** The key strength of this project is its unique approach and focus on degradation which may enable improved value of PV systems in both physical design as well as financial modeling. The key challenges are 1) the data is backward looking and may be deemed non-representative of today's system designs, 2) it's my understanding that the bulk of the data is from rooftop systems and therefore less transferable to utility system modeling which undergo the greatest scrutiny from financiers. Obviously prediction of 30+ year degradation rates is extremely difficult so this work is valuable as a differentiated approach. Contributions to open sourced software is good but greater impact might be achieved by applying these ML results to the kWh data from systems that D Jordan has studied at the module level. If the ML model correctly reproduces the measured degradation rates, then perhaps, some additional analysis could be done on glass/glass modules which closely represent today's utility bifacial systems.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 2 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 3 | 6 |
| Collaborates with sufficient stakeholders | 3 | 2 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** So far, the main goal has been around processing large data sets, with the machine learning algorithm development on-going. Though the milestones discuss early stakeholder involvement and later letters of support, it is unclear how stakeholders are currently engaged and how results are disseminated. More frequent engagement with stakeholders, such as IEs, labs, etc. could help broader acceptance by incorporating concerns and ideas to differentiate effects that may mask or mimic degradation.

**Reviewer 2:** The project seems to be on track for meeting milestones, but has not yet shown any splits by BOM or climate in the degradation data. The project does not suggest a quantitative metric for measuring its impact on PV financing decisions, in part because most financing decisions are not public. The team plans to publish with scientists at NREL and seems to work well with its partners. The project team has a good relationship with its data providers, but does not adequately engage other independent engineering firms or financiers.

**Reviewer 3:** The project team appears well aware of how their work fits into the larger degradation research. They appear to have the right points of engagement and present cogently on the scope and results of their efforts.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Separating tasks into analysis groups by system size is logical as many of the predictor variables and data available will not overlap. Project is divided into data mining, algorithm development and publication of results. Sub-steps such as algorithm iteration and improvement, and meta data collection (for predictor variables), for example are implied but not specifically addressed.

**Reviewer 2:** Score: 4. Comments: The measurement of degradation on a database of 10K PV systems would be unique claim in the published literature as far as I know. Depending on the results the study could be important, but the project does not share much about its conclusions regarding the impact of PV metadata on long-term performance. The application of machine learning models to noisy, high-correlated data before utilizing basic statistical techniques is premature. The goal of disseminating the results is a good step but not likely to factor into negotiations around new products that were not part of this project.

**Reviewer 3:** Score: 0. Comments: The tasks and sequencing appear reasonable.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PI does not seem to contemplate how a published degradation of 1% could actually have the opposite effect on cost of solar from their goals. They reference that added certainty to degradation values can lower the cost of capital, but somewhat ignore that many findings are based on values of 0.4%/year or less. I am unsure the added certainty will offset the differential in annual % value and result in lower cost of capital.

**Reviewer 2:** One of the biggest blind spots on the team is the impact of operating and maintenance procedures on apparent long-term degradation. PV systems with good cleaning and frequent repair/replacement of faulty strings/modules should be expected to show higher energy yield than poorly-maintained counterparts. The project does not adequately discuss how to decouple “intrinsic” hardware performance from operational history.

**Reviewer 3:** I’m not sure this is a blind spot but I encourage the PI to explore how kWhA’s ML results can be used to extend other empirical and accelerated degradation studies as these are better understood by manufacturing and financing communities.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I think collaboration with IEs and national labs are important. It is unclear whether those organizations are currently involved. Discussions with financiers and developers of residential, commercial and utility scale projects about the potential impact of a result showing system degradation of 1%/year are also recommended.

**Reviewer 2:** The project would benefit from including other independent engineering firms. Many firms have been asked to issue guidance on PV system degradation rates or approve models of long-term energy yield in the normal course of business. This existing body of work is not public and rarely shared outside the context of a particular financing negotiation. For a project like this to have an impact it must reach the engineers and finance experts tasked with creating long-term energy yield models.

**Reviewer 3:** It appears that this team is well connected with the National Labs which should be their primary collaborator.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The result has a decent chance of showing higher degradation rates that what are currently being used in market (by developers and by IEs). Comprehensive degradation study of different equipment, system characteristics, climates, etc. is extremely valuable regardless of the value shown. A 0.1% change in assumption can swing project values by millions of dollars and more as the goal of achieving longer year useful life is met.

**Reviewer 2:** 1) The team should publish an overview of their data analysis pipeline and show simple splits by BOM category/climate/etc, even if the results are not statistically significant. 2) The team must account for site-to-site and regional O&M differences and its impact on long-term energy production. 3) The team must engage with project finance teams to learn more about how long-term energy models are created, validated and used in contracts.

**Reviewer 3:** 1) Try and extend this work to rapidly inform new cell and module designs (e.g. glass/glass, multi-wire, shingled cells, etc.). 2) The greatest success will be for this technology to apply to utility projects. How can the ML results be extended to other aspects of utility project development and operations? 3) Any correlation with HALT results, perhaps even on a climate basis, could be very impactful to our industry.

## Highly Efficient Steel Cable Solar Photovoltaic Mounting System – $1,000,000

*P4P Energy | Carbondale, CO | Principal Investigator: Kendra Joseph*

This project is developing a unique photovoltaic panel suspension system utilizing tensioned cable design to reduce cost of solar parking structures. The team's strategy is to minimize weight and materials cost, while increasing assembly and construction efficiency to produce a markedly less expensive solar canopy that produces valuable shade as well as electric power. P4P Energy is researching a high volume, high efficiency product that will be both aggressively competitive and aesthetically pleasing.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 2 | 5 |
| Set critical challenges to overcome | 2 | 3 |
| Implement a high-risk, high-impact approach | 1 | 6 |
| Match well with the level of DOE funding and planned project duration | 2 | 2 |
| Add significant value to existing research outside DOE-funded efforts | 1 | 4 |
| Advance the U.S. solar industry substantially | 1 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Carports are a small segment in the US and this is a high risk approach. If the idea has merit, piloting of this technology will happen without SETO funds.

**Reviewer 2:** Strengths: The focus of the project is aimed an area within solar that is deemed worthy of investing in. Carport structures for parking lot applications are faced with significant cost impediments, the racking structure currently costs approximately $0.40/w and installation price including foundations adds another $0.50/w. When compared to rooftop racking or 1-Axis trackers, the price for carport projects is approximately $0.50/w higher or more, without the benefits of added performance. It is clear that carport structure pricing reductions represent a meaningful are of focus, and is considered low-hanging fruit. The P4P product is novel, and has a reasonably informed hypothesis for the value of their product. There is a clearer path towards applications such as agriculture or aqueducts than there is for parking lot locations. Weaknesses: The project does not adequately define or quantify its key objectives, specifically those aimed at cost reduction or labor efficiency. The project does not reasonably acknowledge the challenges related to testing, code requirements, design constraints, and other regulatory or safety considerations that will significantly influence the development process. Without identifying how the product can achieve the broadest available market, inclusive of high snow load or seismic locations, the impact may be limited. The project team does not seem to have the breadth of application experience from which factors such as fire code, vehicle damage, lighting requirements, and other factors that are common to most projects.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 2 |
| Measures impact appropriately (e.g. quantitative) | 2 | 2 |
| Disseminates results frequently and actively engages partners | 2 | 2 |
| Collaborates with sufficient stakeholders | 2 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** See prior comments.

**Reviewer 2:** It is also apparent from the project report, that the team resources have been unstable, tasks are delayed, accomplishments to date are limited, and execution certainty is a risk. The milestone status description lacked detail and does not demonstrate quantitatively what has been achieved.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: This project is unique but product development is very high risk.

**Reviewer 2:** Score: 1. Comments: A task list was not provided in the report, however, a brief summary of the milestones was included. Overall, there is no demonstration of the tasks, it's importance and why milestones are deemed critical.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** See prior comments.

**Reviewer 2:** These are the questions submitted to the PI and are indicative of potential blind spots: 1) For the goal of achieving the lowest cost canopy, is this measured by product cost or installed cost? 2) What are the cost benchmarks that P4P is targeting for the product, and the installed cost of the product expressed in $/W-dc? 3) To what extent will P4P assess energy performance for a typical parking lot installation and how might this be different than existing products? 4) What is included in the design criteria with respect to site specific conditions such as seismic, corrosion, wind speed, and snow load? 5) To what extent are considerations included for vehicle access and traffic for parking lot applications? 6) To what extent are Fire Code requirements being considered for the canopy design (for parking lot applications)? 7) Please explain the means in which the P4P canopy will be able to achieve a higher power density or higher kWh/land as compared to competitors? 8) How will the P4P canopy integrate module grounding/bonding and certification to UL 2703? 9) For parking lot applications, will the P4P canopy enable lighting fixtures to be included beneath the canopy itself? 10) What measures are included to enable system inspections, troubleshooting, and general maintenance? 11) How will the P4P protect against potential vehicle damage?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See prior comments.

**Reviewer 2:** The team could benefit from entities such as IE's, solar engineering companies, EPC's, permitting and code consultants.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** See prior comments.

**Reviewer 2**: 1) The focus and aim of what the PI is seeking to achieve is a valid area of investment for the industry, as carport structures have significant cost impediments currently. 2) The project team does not appear to be sufficiently resourced, managed, or have access to key considerations and experiences that would shape this study appropriately. 3) There is no clear quantitative objective or goal cited by the PI, nor anticipated impact, nor addressable market.

## Enhanced Convection for Higher Module and System Efficiency – $1,040,000

*Portland State University | Portland, OR | Principal Investigator: Raul Cal*

This project is developing new solar photovoltaic modules and solar system-scale designs that promote an increase of the convective heat transfer coefficient of at least 40 percent. This reduces the operating temperature of the solar photovoltaic panels and leads to a boost on the annual energy yield and a potentially significant increase in the reliability of modules over time. Extensive modeling and early stage experimentation is being conducted to determine the dynamics of air flow needed to produce vortex generation and flow channeling effects that would lead to lower temperature of the array.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 3 | 4 |
| Implement a high-risk, high-impact approach | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The PI's clearly identify convection cooling as a significant driver of system performance however it's unclear if the alterations to system design necessary to achieve 5% greater energy yield will entail trade-offs which cause project capex to rise by 5% or more. That said, many of design adjustments may be synergistic with bifacial system optimizations (higher torque tube, lower GCR) so if this work leads to an improved understanding of why bifacial systems yield higher energy then the work will be impactful.

**Reviewer 2:** Strengths: The project focus is a valid and meaningful area of the industry. PV systems do experience significant energy losses and annual degradation and it is one of the most significant levers within a project and has a high impact on value. The goals of the project are impressive and if achieved, would be considered substantial for the industry. Weaknesses: The project does not sufficiently consider offsets, such as cost impact, design constraints, or impact on conventional value levers such as system capacity, CapEx, land use, or other key determinants. Additionally, the cited LCOE improvement is not specific to a type of project, nor does it mathematically make sense. The report does not sufficiently explain how 5% energy yield gains can be achieved, and how that relates to current energy yield values.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 2 |
| Measures impact appropriately (e.g. quantitative) | 4 | 2 |
| Disseminates results frequently and actively engages partners | 3 | 3 |
| Collaborates with sufficient stakeholders | 3 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** It's unclear to me based on the poster and report summary if the promise of Task 3 "a set of new vortex generators and macro-scale flow deflectors will have been designed and their performance tested with wind tunnel experiments and numerical simulations." has been started. Further, it's unclear if the results from Task 2 suggest that the use of vortex generators and flow deflectors can be used to significantly impact cell temperatures for commercial modules and layouts.

**Reviewer 2:** The project report does not sufficiently explain progress made to date as compared against the original schedule, nor does the report provide sufficient task lists and schedules from which one can determine likelihood of success. The report does not adequately discuss partner engagement practices or substantiate the role of each stakeholder.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 0. Comments: Convection current cooling has certainly been treated as a dependent variable in PV system design so this project's focus is a unique approach. If the findings inform actionable system design changes to enhance cooling then the project will be extremely impactful.

**Reviewer 2:** Score: 2. Comments: The task list does not sufficiently detail the task list, key milestones, nor a measure of success at each milestone. The report only mentions completion of initial milestones that are not defined or characterized as successful or not.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Typically any change to component or system design entails added costs and the PI hasn't explained their full understanding of how significant these trade-offs might be.

**Reviewer 2:** 1) What type of PV system applications is this project aimed at? Utility scale trackers, rooftop projects, other? 2) The overview summary mentions an effort to develop a "new PV module", in addition to assessment of design practices. Please describe what it means to develop a new PV module, whether it is cell technology focused, or aimed at the assembly of the finished product. 3) For efforts to increase energy yield by at least 5%, is this specific to a type of system, geographical region, or design practice? How could this energy yield gain vary based on system type or location? 4) What is the approximate annual energy yield loss percentage attributed to module level temperature losses currently and what would be the resulting loss percentage as an outcome of this project? 5) For module degradation reduction targets of 0.3%/year (loss reduction), how much of the annual module degradation is attributed to temperature loss currently? 6) For LCOE reduction targets of $30 - $45 per MWH, is this specific to a type of system, size of system, or geographic region? What would be the approximate resulting LCOE expressed as $/MWH that could be realized by 2022/2023? 7) Does the project team have confirmed access and consent, both physical and data, to operating PV projects that will be utilized for field testing purposes? 8) How is the project team taking into consideration cost impacts of either the new PV module, or the design methods that may enable target objectives for LCOE? 9) Will the new PV module or the design methods have an impact on operational expenses or performance risks? 10) How will the project team consider design constraints based on site attributes, code requirements, and constructability?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It's unclear what interaction beyond a single EPC engagement (Mortenson) the PI has with industry. The use of vortex generators and macro-scale flow deflectors will have implications to module manufacturers and perhaps tracker companies.

**Reviewer 2:** Key stakeholders that would enhance value and success would include design engineers, EPC's, technology suppliers, and Independent Engineering companies.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Consider this work in the context of the transitions that are already happening in ground mount PV. Specifically; bifacial PV with higher torque tubes, 2P SAT designs, and glass/glass with 30mm frame depths as well as relaxed GCIs and larger panels.

**Reviewer 2:** 1) The ambition of the cited goals and objectives appear both misplaced and overly ambitious. The likelihood of success is very low, near improbable. 2) The PI does not take into account many key considerations that would influence, restrict, or limit methods that could be discovered by this project. The project team does not appear suited to accomplish the objectives and would need additional resources and consultants to shape this effort correctly.

## Single Model Characterization – $541,504

*Power Factors | Larkspur, CA | Principal Investigator: Steve Voss*

This project is developing a methodology capable of quantifying and categorizing all losses from nominal energy to energy delivered by photovoltaic systems. This represents a significant streamlining of how photovoltaic experts compare large modeled and measured datasets, and would improve agreement between energy yield models and energy production datasets, which are vital to improving the reliability and bankability of photovoltaic systems. This project enhances the quality and handling of performance data and future modeling efforts.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** It's difficult to understand the full impact and potential of the SMC project based on the poster and report but it appears to be a powerful analysis technique for operating systems which goes well beyond current efforts common among operators.

**Reviewer 2:** Strengths: The focus area and goals of the project are deemed highly valuable and aimed at improving an industry weakness that is well known and has existed throughout the industries lifetime. Accuracy and predictability of operational performance will be increasingly more important and valuable for the industry, as a key lever to reduce risk, which has financial benefits. Additionally, as solar is more frequently paired with batteries, the accuracy of predicated models will be more important. With improved data and known discrepancies, project developers and owners will be able to improve design, determine O&M and OpEx tactics with increased confidence, and investments can be more successful. The project team has the breadth of experience and proficiencies necessary for success. They have clear goals and a well understood process. Weaknesses: The project report does not sufficiently prescribe or detail the quantitative benefits or impacts that might be realized by this project. While the report mentions that the industry will benefit, there is no detail provided. Additionally, there is insufficient detail as to how the industry will have access to the data or tools from this project and for this to benefit parts of the industry that are not affiliated with Power Factors.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The team appears to have done a good job collaborating with Recurrent and in doing so came to an understanding of the limited data that's typically available on commercial systems. As a result, they appear to have developed techniques to overcome these limitations.

**Reviewer 2:** The project team appears to be well organized, focused, and able to reasonably meet performance objectives to date. The report sufficiently details the progress made to date and it is considered significant and positive in nature. They have a clearly defined set of schedule milestones and tasks, and appears to have engaged partners.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: No comment.

**Reviewer 2:** Score: 6. Comments: The task list is clearly defined, provides clear goals and success metrics and the cadence appears logical and valuable. The project appears to be in advanced stage and key objectives have been achieved thus far.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Perhaps the PI is aware but the majority of operators in the US PV industry still primarily focus on inverter uptime. In time this should improve (particularly as inverters become more reliable) but this type work will be critical to help re-frame the way operators think about DC health and rationalized operating plans.

**Reviewer 2:** These are the questions submitted to the PI and indicative of the blind spots: 1) How does the SMC consider and incorporate various inputs to the predicted model, such as .PAN and .OND source files, weather data source, or other key inputs that are commonly sourced from 3rd parties and have varying quality? 2) For the example above, how does the SMC look to normalize performance behavior within a diverse portfolio if the underlying energy model varies in quality? 3) For older systems, the energy models that serve as the predicted case, is likely of lower quality and comprehensiveness as compared to newer projects. How does the SMC consider shifting predicted baselines as modeling methods improved over time? 4) Has the project considered or incorporated bifacial module technology assessments? 5) How does the SMC consider or account for technology advancements throughout a large operating portfolio, specifically module technology, and its impact on the performance data? Could this result in something like "thermal derate" or "dc current" to behave differently depending on the vintage of the project? 6) Where does the operating data provide sufficient coverage and diversity for certain types of systems (i.e. utility trackers in SW region), and where does the operating data lack in its ability to characterize geographical trends or project types (rooftop, etc)? 7) Who are the key stakeholders within the industry that stand to benefit the most and how? 8) How will the findings and capabilities of the SMC influence project development, financing, or operations? 9) What are the ways in which projects may benefit financially, or reduce other key barriers for increased solar deployment? 10) What are the means in which the results and capabilities of the SMC can be accessible to the industry at large?

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** See prior comments.

**Reviewer 2:** None that I considered critical.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** See prior comments.

**Reviewer 2:** 1) The focus and purpose of this project is aimed at a well-known issue for the industry and the importance of performance predictability only increases over time. 2) The project report does not sufficiently detail quantitative benefits and impacts for the industry, nor how key stakeholders will be able to achieve it. 3) The outcome of the project should clearly demonstrate how the industry at large can access and utilize the tools or studies from this project.

## Bifacial Photovoltaic Module Energy Modeling Validation Study – $200,000

*PVEL, LLC | Berkeley, CA | Principal Investigator: Tara Doyle*

Bifacial photovoltaic module suppliers are conducting their own efficiency tests in an effort to demonstrate energy gains to customers, but these tests often lack third-party review. To enable more accurate and bankable solar production forecasts for bifacial modules, this team is working to establish an outdoor test that compares modeled energy from bifacial models to measured energy generation in common types of ground or roof coverings. These tests will account for multiple scenarios for bifacial modules, including placement on painted flat roofs, placement in fields with low-lying vegetation, and soiling from dirt or sand. The team plans to publish the results of this analysis to improve modeling efforts, energy-yield estimates, and bankability for bifacial modules on the market.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 5 |
| Set critical challenges to overcome | 5 |
| Implement a high-risk, high-impact approach | 4 |
| Match well with the level of DOE funding and planned project duration | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 |
| Advance the U.S. solar industry substantially | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: The subject matter for this study is focused on one of the most influential, impactful innovations and rapid trends that is happening in the industry currently. Bifacial modules are destined to become a significant value enhancer, and the adoption rates will be significant in the US market. With new module technologies such as this, understanding the energy benefits and how to appropriately model them is crucial to the success, and the industry does not yet have a comprehensive set of studies or tools that can ensure accuracy. There remains many investors and finance entities that either have not underwritten a bifacial project, or have done it in a way where the true value was discounted for risk. Strengthening the data and field performance to increase modeling accuracy is a meaningful effort. Weaknesses: The project appears to be limited in the types of applications and conditions (1 region, 1 project type) and it is uncertain as to how the findings of this study will be applicable to a broader set of use cases and design choices. There are many design variants and technologies that will incorporate bifacial modules and broad applicability is important in order for the industry to benefit.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 |
| Disseminates results frequently and actively engages partners | 6 |
| Collaborates with sufficient stakeholders | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team appears to be advanced in nature, has already achieved key milestones, and is ahead of schedule. The project team is well qualified for this type of project and has deep industry credibility and will have a receptive industry audience.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The task list is detailed, professional in nature, details clear objectives and milestones and is appropriately structured

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** These are the questions submitted to the PI and are indicative of potential blind spots: 1) How can the results from this study transpose to a broader set of geographical regions, or any varying site specific condition that might influence performance? 2) How can the results of the study be applied to varying design types such as 2P trackers, or half-cut bifacial, or other technologies would be significantly different in behavior? 3) As part of this study, was their an underlying "predicted" energy model from which to compare the field performance and understand the behavior? 4) Are soiling effects, rear-side of module, a condition that is being considered? 5) What are the tools or methods that will be shared with the industry to improve modeling practices and hence increase confidence? 6) What type of discoveries and findings will be disseminated to the industry to understand the key influencers and conditions that drive bifacial gain, and how to model for them?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None are missing that are deemed critical.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The project team is considered a strength of the project, they are highly qualified for this type of work, and the execution certainty is high. 2) The focus area of this project is aimed at one of the most impactful, relevant areas of the industry currently and this can be immediately impactful upon completion. 3) With or without DOE funding, this project can likely succeed and achieve the same outcomes. Also, there exists multiple similarly focused studies and projects running concurrent to this one.

## Optimized Bifacial Modules and Systems – $1,590,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Stein*

Bifacial photovoltaic technologies are developing rapidly and are predicted to play a key role in the future of solar energy. This project aims to develop and validate advanced bifacial performance models capable of simulating a wide range of system designs and perform design optimization studies of a range of bifacial system types utilizing high performance computing resources and tools available at Sandia and the National Renewable Energy Laboratory. Additionally, the team is working to deploy and monitor typical bifacial systems for model validation and work with industry to improve standards and best practices in the areas of module and system rating, capacity testing, site prospecting and safety.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 0 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Bifacial PV has provided the greatest single reduction to PV LCOE since SAT. This work has already been critical in accelerating the adoption of bifacial in the US and ongoing tasks will enable bifacial PV to more quickly reach its full performance entitlement.

**Reviewer 2:** Strengths: The subject matter for this study is focused on one of the most influential, impactful innovations and rapid trends that is happening in the industry currently. Bifacial modules are destined to become a significant value enhancer, and the adoption rates will be significant in the US market. With new module technologies such as this, understanding the energy benefits and how to appropriately model them is crucial to the success, and the industry does not yet have a comprehensive set of studies or tools that can ensure accuracy. Sandia's progress to date matches well with the planned schedule and funding. Weaknesses: There are few weaknesses associated with the project and none that are considered significant in nature. It is true that with or without this project, industry adoption will be vast and accelerated, so the actual impact of this project will not deter the trend, but will certainly enhance it.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has engaged successfully with both the development and finance community to enable a dramatic transition to bifacial PV for ground mount applications. The team has been receptive to ideas from the commercial PV community and understands the ongoing challenges that need to be addressed to further improve the commercial competitiveness of bifacial PV.

**Reviewer 2:** The project team appears to be well organized, focused, and able to reasonably meet performance objectives to date. The report sufficiently details the progress made to date and it is considered significant and positive in nature. They have a clearly defined set of schedule milestones and tasks, and appears to have robust engagement partners.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The publication list is extensive and the milestones have been achieved.

**Reviewer 2:** Score: 5. Comments: The task list is clearly defined, provides clear goals and success metrics and the cadence appears logical and valuable. The report does not discuss future milestones however, so the tasks that lie ahead should be detailed as part of any advancement going forward.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** The PI and project team is a trusted team with high credibility and experience in the industry, so blind spots are likely limited. It is possible that as bifacial module technology advances with new module construction techniques, new cell technologies, that some of the current studies may require updating.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No comment.

**Reviewer 2:** Other valuable stakeholders would include large solar focused engineering firms, inclusive of the IE community, designers and engineers, and asset operators.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Bifacial isn't a static technology. It will continue to evolve with optical optimization as well as electrical optimizations. DOE should continue to invest in system optimization studies to push developers to adopt these incremental improvements.

**Reviewer 2:** 1) Bifacial technology is currently experiencing wide adoption and acceptance, and it ranks as one of the most significant trends that will advance the industry. 2) Energy modeling for bifacial designs is considered limited at the moment, while not a thing that is grossly mismanaged, the common practices and techniques utilized in the industry need to be standardized and accepted by key stakeholders. 3)With or without DOE funding, bifacial adoption will proceed and be significant, and the modeling practices will ultimately be well understood and adopted uniformly, it may just be delayed without the leadership of Sandia.

## Snow Characteristics as a Factor in Photovoltaic Performance and Reliability – $2,100,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Laurie Burnham*

As solar markets expand into northern regions of the United States, the impact of snow on the energy productivity of solar installations is of growing interest. The buildup of snow and ice on solar panels can stifle electrical output, erode reliability, and decrease lifetime performance. To better understand and combat these deleterious effects, this project is working to identify and quantify the factors that contribute to snow-induced energy losses and gains, as well as to validate the efficacy of technological improvements (e.g., advanced coatings) and design configurations that increase annual energy yields. Additionally, the team aims to refine existing predictive models, bringing greater accuracy to levelized-cost-of-energy calculations. This work transcends previous research by being both field- and lab-based, with outdoor experimentation and demonstration supported by high-precision laboratory analysis of snow-module interactions. The knowledge gained will inform product development, improve system designs, and lead to more accurate performance models, thus giving investors, asset owners, insurers, and other stakeholders greater confidence in levelized-cost-of-energy calculations and helping expand solar in northern latitudes.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Trackers and bifacial are now going into snow climates. This work provide some of the first quantitative analysis on the benefit of using these technologies in snowy climates and goes further to look at other system design considerations which may help further. It's unclear how easily the findings from this work can be adopted into current commercial energy modeling because many companies use DNVGL's snow model which is based on a different weather structure. Finally, tracker companies have recently introduced snow shedding algorithms which should be incorporated into this work.

**Reviewer 2:** Strengths: The focus area and goals of the project are deemed highly valuable and aimed at improving a critical industry issue. Significant increases in overall solar installations are occurring in the Northeast and the Midwest and are expected to continue going forward. Markets like Maine, New York, and Massachusetts are going to see meaningful capacity growth, and most will be ground mount applications. Snow modeling is known to be one of the most difficult, yet impactful areas of predictive energy modeling efforts. The objectives of this project can have a substantial impact on the industry. Weaknesses: The project report does not sufficiently prescribe or detail the quantitative benefits or impacts that might be realized by this project, whether it is performance metric based or reliability focused.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team is starting something new and had a difficult speed bump with the closure of the RTC. Still it appears they are engaged with a broad set of collaborators and have quickly developed the tools and methodology necessary to get defensible results.

**Reviewer 2:** The project team appears to be well organized, focused, and able to reasonably meet performance objectives to date. The report sufficiently details the progress made to date and it is considered significant and positive in nature. They have a clearly defined set of schedule milestones and tasks, and appears to have engaged partners.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The future tasks appear appropriate but it might also help to compare the results of this revised snow model with existing models used by IEs for commercial transactions.

**Reviewer 2:** Score: 6. Comments: A detailed task list was not provided, however, the report indicated that the project is advanced and has produced many key deliverables thus far. Based on the demonstration of multiple studies and publications completed to date, the project appears to have achieved unique and important value.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Snow losses are modeled based on IE's proprietary models and assumptions. It will be critical for this group to reach out to these IEs to ensure that these learnings are incorporated into these IE's models.

**Reviewer 2:** These are the questions submitted to the PI and are indicative of potential blind spots: 1) For a topological type feature such as a coating, has the PI explored the potential implications of voided warranty risk? 2) Does the study of design features to either inhibit snow attributed energy loss, or to enhance performance, will the project include assessment of cost impacts or other constraints? 3) Does the project scope include rooftop or other non-ground mount-based project applications? 4) In the event that "2P" (two module wide) 1-Axis tracker systems gain increased adoption, how might that influence models and reliability positions? 5) As PV modules increase in physical size due to form factor or cell size, how might that influence models? 6) There is a reasonable probability that Alaska remains a low solar capacity market. 7) How does the PI propose socializing and leading implementation efforts for industry adoption? 8) What key stakeholders is the PI planning on engaging with to accelerate and standardize adoption? 9) Will the bifacial component of the project include assessment of albedo driven gains and how that varies with snow scenarios?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See prior comments.

**Reviewer 2:** Other critical stakeholders could include large asset operators, solar development engineers or IE's. There exists at the moment, a few accepted snow modeling methods utilized by the industry, so it is important at some point, to interface with the industry points of entry.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** See prior comments.

**Reviewer 2:** 1) This is a critical challenge and a topic focus that is deemed substantially valuable for the industry. The Midwest and Northeast regions of the US are highly certain to see some of the highest solar capacity growth in the country going forward. 2) Snow attributed energy losses are one of the most misunderstood, immature areas of predictive energy modeling for solar development. Snow losses and characterization is very distant from achieving standardization and accuracy and Sandia is well positioned to help improve upon that. 3) Any potential design features identified as performance enhancing, or energy loss mitigation needs to be paired with a feasibility and cost assessment.

## Spread Spectrum Time Domain Reflectivity for String Monitoring in Photovoltaic Power Plants – $800,000

*University of Utah | Salt Lake City, UT | Principal Investigator: Michael Scarpulla*

This project is investigating the application of spread spectrum time domain reflectivity to detect faults and their locations in a photovoltaic string in real time without disconnecting the string during the test. For example, the technique can decipher which panel or section of wiring has experienced a physical or operational change. By detecting the fault location in the connected string, this project will enable more efficient repair and maintenance of photovoltaic power plants, maximizing future energy output, and reducing the levelized cost of energy.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 5 |
| Set critical challenges to overcome | 5 |
| Implement a high-risk, high-impact approach | 6 |
| Match well with the level of DOE funding and planned project duration | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 |
| Advance the U.S. solar industry substantially | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: The focus area and goals of the project are deemed valuable and the project scope is considered unique and novel. I am unaware of an existing tool that can replicate the same capabilities. Current industry methods and resources to monitor and detect faults is not considered robust, or it is cost prohibitive in nature and that inhibits active monitoring. The ability to actively monitor and identify defects and underperforming modules without rigorous testing would provide significant value for the industry. Weaknesses: The project report does not sufficiently prescribe or detail the quantitative benefits or impacts that might be realized by this project, whether focused on performance or maintenance benefits. The project does not appear to consider cost impact, or provide a clear path towards commercial deployment.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 |
| Disseminates results frequently and actively engages partners | 5 |
| Collaborates with sufficient stakeholders | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team appears to be well organized, focused, and able to reasonably meet performance objectives to date. The report sufficiently details the progress made to date and it is considered significant and positive in nature. They have a clearly defined set of schedule milestones and tasks, and appears to have engaged partners.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project report outlines a very detailed task list and clearly demonstrates the milestones and key achievements.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** These are the questions submitted to the PI and are indicative of potential blind spots: 1) Are there plans to develop similar technology for 1500V systems? 2) What considerations are provided for potential 3rd party testing, necessary certifications as applicable (or re-certification by OEMs)? 3) How would the SSTDR work in conjunction with existing inverter-based technologies that are also include fault detection features? 4) Does the project scope investigate potential cost impacts for projects? 5) What is the anticipated frequency and granularity of active performance monitoring for each source circuit? Does this occur daily or hourly? How will the SSTDR measure for accelerated degradation on an annual basis – is it a tolerance band type assessment?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Other critical stakeholders could include asset operators, string inverter manufacturers, and testing agencies.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Current industry methods for fault detection, module quality monitoring, and troubleshooting are not considered to be advanced, easily performed, or cost efficient. This product has significant potential and would provide valuable impact. 2) 1500V solutions should also be pursued and is arguably going to be more impactful for the industry going forward. 3) A robust product development, testing, certification and commercialization plan will be critical to the project's success. Partnership with inverter manufacturers is key for industry adoption.

# Concentrating Solar-Thermal Power

# List of Reviewers

**Diego Arias**, Amazon

**Amit Bagchi**, Naval Research Lab

**Ted Bergman**, University of Kansas

**Frank Burkholder**, Galvanize Inc.

**Chuan-Hua Chen**, Duke University

**Minking Chyu**, University of Pittsburgh

**Gilbert Cohen**, Eliasol Energy

**Saied Delagah**, U.S. Bureau of Reclamation

**Gani Ganapathi**, NASA Jet Propulsion Laboratory

**Zhixiong Guo**, Rutgers University

**Holly Johnson-Churman**, GHD

**Alan Kruizenga**, Kairos Power

**Charles Lewinsohn**, Ion Storage Systems

**Noam Lior**, University of Pennsylvania

**Adrienne Little**, Malta Inc.

**Gary Pickrell**, Virginia Tech

**Veera Rajendran**, EXEL Industries

**Frederick Redell**, BlüNebü

**Drake Tilley**, CoorsTek

**Milton Venetos**, Wyatt Enterprises

**Brent Webb**, Brigham Young University

**Justin Zachary**, Samsung

# Analysis Methodology

Reviewers had evaluation criteria for each project and scored them on a 1–6 scale:

**1** – Strongly Disagree

**2** – Disagree

**3** – Slightly Disagree

**4** – Slightly Agree

**5** – Agree

**6** – Strongly Agree

In addition to numeric scores, reviewers were asked to provide qualitative comments and feedback to justify the scores awarded to projects. Other criteria only required qualitative feedback.

# Project Evaluation Form

**1. The project's goals, approach, and expected impact:**

a. Align well with this topic's goals and support SETO's mission (1-6)

b. Set critical challenges to overcome (1-6)

c. Implement a high-risk, high-impact approach (1-6)

d. Match well with the level of DOE funding and planned project duration (1-6)

e. Add significant value to existing research outside DOE-funded efforts (1-6)

f. Advance the US solar industry substantially (1-6)

*Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.*

**2. Based on performance to date, the project team:**

a. Meets important milestones within reasonable timeframes and budgets (1-6)

b. Measures impact appropriately (e.g. quantitative) (1-6)

c. Disseminates results frequently and actively engages partners (1-6)

d. Collaborates with sufficient stakeholders (1-6)

*Using the above criteria, please summarize the performance of this project in 100-200 words.*

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

*Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.*

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

# Project Reviews

Independent review is an important part of SETO's overall portfolio management process, as it provides alternative viewpoints from leaders in industry and academia on current project activities and strategies. Reviewers who participated in the virtual peer review evaluated projects by assessing project reports and posters written by each project's principal investigator. Any questions about the project were addressed via email exchange between the principal investigator and the reviewer. Each project was assigned two or three reviewers.

Below, you will find a list of the projects reviewed organized by track and topic. Projects are alphabetized by the awardee name and represented in the following format:

**Project Title – Funding Program, Amount Awarded**

*Awardee Name | Awardee Location | Principal Investigator*

Project Description

Project evaluations completed by reviewers are found after the descriptions.

## Robust Solar Receivers Using MAX Phase Materials – $360,000

*Argonne National Laboratory | Lemont, IL | Principal Investigator: Dileep Singh*

As operating temperatures for concentrating solar-thermal power plants continue to increase, current metal-based receivers have structural stability issues that need to be addressed to accommodate higher temperatures. This project is developing receivers using ceramic materials that can operate at temperatures higher than 800 degrees Celsius. The team aims to demonstrate the viability of these new class of materials.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 6 | 5 |
| Advance the U.S. solar industry substantially | 3 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project addresses a need, and handles it well. The goals are well expressed ant eh deliverables are clearly stated. The MAX phased receivers design, fabrication using binder jet processing technology, and characterization of thermo-mechanical performances are appropriate. Comparison with conventional processes, if any, will allow improvement of materials and processes for CSP applications.

**Reviewer 2:** The idea and exploratory work on developing >800C solar receivers that use MAX phase ceramics, which have excellent properties for such applications, including excellent oxidation resistance, low density, high strength, high thermal conductivity, corrosion resistance, and are easily machinable, align well the proposed project's goals with this topic's goals, and supports the SETO mission. At the same time, much more needs to be known about the long-term mechanical and thermal/radiative properties of receivers/tubes made from these materials, about their forming, and cost. Expected challenges include long-term stability of the radiative and mechanical properties under extreme operating conditions, and their cost, which is currently very high. Contingency plans are not shown. It is a high-risk high-impact approach, conditioned by the cost and stable long-term operation. The project's goals, approach, and expected impact match very well with the level of DOE funding and planned project duration. They add significant value to existing research outside DOE-funded efforts. If the goals are met, they would advance the US solar industry significantly. Strengths: an innovative material approach for developing and applying rather modern ceramics to the construction of solar receivers that operate well at CSP temperatures >800C. Weaknesses: Very high material costs, the long-term mechanical and thermal/radiative properties of receivers/tubes made from these materials, uncertainties in practical forming ability.

**Reviewer 3:** The overall project goal is to develop MAX phase material-based receivers fabricated using low-cost additive manufacturing process and demonstrate their performance. The key challenges are: (a) Based on the available material properties of MAX phase materials, to demonstrate the feasibility for the receiver application. (b) Ability to form tubular shapes using the precursor powders such as TiC. (c) The remaining challenge is densifying the green binder jetting fabricated parts so that the resulting material has a high MAX phase purity. The high-temperature high-performance receiver is a key component for operation of next generation CSP plants. The current lab-scale binder jetting printer system is limited in size. However, there are commercial systems available that can scale the printing to a tube with dimensions of 1 m. The project duration is one year. ANL is responsible for all activities. One of the key components for the deployment of next generation CSP system is the receivers to collect thermal energy from sun into a heat transfer fluid (HTF). Because of extreme operating conditions of temperature, temperature gradients, and thermal cycling, advanced materials for receivers are needed. Conventional metallic materials operating in these conditions require adequate creep and creep-fatigue strengths. Ceramic materials will additionally require adequate ductility to avoid brittle failure caused by thermal shock during heating. These MAX phase ceramics have unique properties, including excellent oxidation resistance, low density, high strength, high thermal conductivity, corrosion resistance, and are easily machinable, which makes them excellent candidates for high temperature receiver materials. With recent developments of additive manufacturing techniques, it is possible to develop high performance low cost robust receivers with excellent long-term reliability using advanced high-temperature MAX phase materials. These MAX phase ceramics have unique properties, including excellent oxidation resistance, low density, high strength, high thermal conductivity, corrosion resistance, and are easily machinable, which makes them excellent candidates for high temperature receiver materials. With recent developments of additive manufacturing (AM) techniques, it is possible to develop high performance low cost robust receivers with excellent long-term reliability using advanced high-temperature MAX phase materials. Strengths: The new material of high temperature and high performance in connection with AM will make the receiver very desired. Weakness: It is not sure if it is scalable to the desired receiver size in commercial CSP plants.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 3 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 2 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The performance of the year-long project is somewhat difficult to assess, especially in view of the fact that they have two basic tasks, and they do not have any go/no-go gates. However, the project seems to be progressing well, and if the fabrication of the design is successful, they should accomplish their objectives. The key will be if they will meet the desired material properties for this application.

**Reviewer 2:** The project just started so it is impossible to form a solid opinion yet. The PI-s and their past work and performance are good, but their current selection of stakeholders, and dissemination, if any, are absent in the report we received.

**Reviewer 3:** The project just started and only first quarter work done yet, focusing on analysis and simple demonstration of binder jet printing. The materials and process technology being developed is not limited to receiver applications but could be utilized for other high-temperature components for CSP, such as pump components, etc. Further, this technology will be of interest to other energy generation systems, such as nuclear and fossil fuel, where the focus is also for higher power block efficiencies. Results from the work will be disseminated in journal publications, conference presentations, etc. Only ANL is involved for a one-year project. Extensive thermal and stress analyses were performed to optimize the receiver tubes using MAX phase material. Using commercial TiC powders with average particle size of 100 µm, binder jet printing was conducted. The process parameters were optimized to produce tubes and plates with green densities of 49%. These printed structures are being densified using melt infiltration with silicon to produce Ti3SiC2 MAX phase.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are well laid out and well structured. The scientific challenges are fair and appropriate. I wished that there were a few metrics to meet. The key will be to achieve the desired properties in the materials and components fabricated. It is too early to comment on the success of that step. Significant amount of the initial design work is already completed, thus mitigating some of the risks.

**Reviewer 2:** Score: 5. Comments: Yes, with the reservations about lack in some areas.

**Reviewer 3:** Score: 5. Comments: This is a single year innovative project which started on October 1, 2019. During the first quarter, Milestone 1 related to receiver tube design was completed. In addition, a detailed literature review of the MAX phase materials was carried out and the key highlights were compiled. During this period, work was initiated for Milestone 2 where the binder jet process was demonstrated to fabricate tubular structures using MAX phase precursor powders. This activity will continue into the next quarter.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Did not identify any go/no-go gates. The technical metrics could be more quantifiable.

**Reviewer 2:** Much more needs to be known about the long-term mechanical and thermal/radiative properties of receivers/tubes made from these materials, about their forming, and cost.

**Reviewer 3:** Whether it is scalable to real receiver size using AM technique and where it is cost-effective.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The stakeholders and teaming of this project are appropriate. The cost is reasonable.

**Reviewer 2:** The report does not show PI-s collaboration with others, and it would be advisable to include experienced ceramics manufacturers and users, as well as CSP systems experts.

**Reviewer 3:** It is a small demonstration project.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** a) go/no-go gates; b) quantifiable metrics.

**Reviewer 2:** 1) Significantly address long-term (many years) stability of the radiative and mechanical properties under extreme operating conditions, formability, as well as economics. 2) Contingency plans are needed but not shown. 3) It would be very advisable to include experienced ceramics manufacturers and users, as well as CSP systems experts.

**Reviewer 3:** 1) Is it really cost effective? It is a high-risk, high impact project. 2) Is this a low-cost robust receiver?

## Economic Weekly and Seasonal Thermochemical and Chemical Energy Storage for Advanced Power Cycles – $3,300,000

*Arizona State University | Tempe, AZ | Principal Investigator: Ellen Stechel*

This project seeks to integrate multiple thermochemical energy storage components into a concentrating solar-thermal power design so that a plant can have multiple storage durations, including daily and long-term. These components will be designed for integration with supercritical carbon dioxide power cycles. The team is conducting techno-economic analyses to improve concentrating solar-thermal power system design and operation for guaranteed year-round energy dispatchability.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 5 | 6 |
| Set critical challenges to overcome | 2 | 4 | 2 |
| Implement a high-risk, high-impact approach | 3 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 4 | 6 |
| Advance the U.S. solar industry substantially | 3 | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project addresses future opportunities to possibly reduce the effective cost of CSP by increasing revenues through production of useful byproducts. There were few scientific or technical details in the materials provided, the focus was more on the economics of the situation. It is not clear how the various tasks are related to each other, if at all, and it is not clear whether the failure of one task would jeopardize the other tasks. The report describes a potentially high-impact outcome, but probably not in the near term. The level of scientific and technical risk involved is not clear to this reviewer so it is unclear whether the work is high-risk. The proposed work appears to be based on a supposition that the many scientific and technical challenges of CSP for power production will be resolved, without directly addressing how this team will help resolve those challenges. In that sense, the effort appears to be somewhat peripheral. It is not clear how the research will add significant value to specific entities outside of DOE. Strengths: A potentially creative approach (or approaches) to reduce the cost of solar electric power generation in the future, or utilize CSP in new ways. Weaknesses: A large team is formed and it is unknown how the team members will coordinate their activities. The level of the scientific and technical discussion in the report precludes a meaningful assessment of exactly what is being done in all of these tasks.

**Reviewer 2:** The team attempts to explore 4 potential energy storage systems specifically designed for high temperature and pressure. The main concern is the extend of the work needed to cover all the proposed systems.

**Reviewer 3:** Strengths: It aligns well with this topic's goals and supports the SETO mission.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 3 |
| Disseminates results frequently and actively engage partners | 3 | 2 | 4 |
| Collaborates with sufficient stakeholders | 2 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** A large menu of activities that seem to be only peripherally related to each other is to be pursued. It is not clear how the milestones presented for the various tasks in the table are related to each other, if at all. It is not clear how the activities of the various individuals listed in the other table are to be integrated and coordinated. Therefore, it is difficult to assess the importance of milestones. The report describes a broad research activity that would perhaps form the basis of a federally funded university center, but even then, the proposed work seems fragmented.

**Reviewer 2:** The project is just in its incipient phase. As mentioned above, the challenges set by the team are very significant. It will be very difficult without a very close oversight, to determine the success of each task. A full blown progress evaluation matrix must be developed.

**Reviewer 3:** This project, as I understand, did not start yet so performance cannot be assessed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The overall goal of the project is not clear, and it is not clear how the individual tasks are related on a meaningful level, if at all. This effort has the appearance of several individual projects running in parallel without strong linkage to each other.

**Reviewer 2:** Score: 3. Comments: This project has 4 technologies set up for evaluation and demonstration. For practical reasons, they should be treated not as tasks, but stand-alone projects. In my opinion rather than running them in parallel, select the most critical ones and perform them one by one. Setting performance gates will facilitate the process.

**Reviewer 3:** Score: 5. Comments: As I wrote above, the goals and general plan are very good, but sufficient details are absent.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The technological and scientific aspects of the project are not described in enough detail to answer the question.

**Reviewer 2:** Collaboration with industrial partners, and review of the current status of each technology from literature and discussions with other research institutes (not only in US but other countries)

**Reviewer 3:** Mostly described in my previous comments.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It is not clear who the stakeholders are for the various tasks in this project. The degree of industry involvement is not clear. On a project of this size, breadth, and managerial and technical complexity, an industrial advisory board might serve an important role to help set priorities.

**Reviewer 2:** As mentioned above, explore the possibility to enlarge the number of industrial participants in addition to Siemens. A literature review will indicate, which other universities or research institutes are interested in similar activities. While they might not be needed to fully participate, it could be very useful to have them as reviewers.

**Reviewer 3:** Missing are the industry, especially of power generation, solar energy, and chemical.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project appears to consist of many separate tasks whose relationships to each other is unclear. 2) There is a paucity of science and engineering discussed in the Report, making technical assessment difficult.

**Reviewer 2:** 1) Set priorities among the technologies selected and concentrate on only one at each stage. 2) Integration of more than one technology requires coordination and detailed modeling of their interaction. 3) Involve other shareholders, to accelerate the final outcome.

**Reviewer 3:** The entire report focuses on goals and positive expectations, without adequate details about the ways to achieve them, and no contingency plans to be used when the progress happens to fail to match the plan. Through rewriting and additions are needed. Some details are included in my previous comments.

## Integrated Solar Receiver with Thermal Storage for a Supercritical Carbon Dioxide Power Cycle – $2,599,959

*Brayton Energy | Hampton, NH | Principal Investigator: Shaun Sullivan*

This project integrates a novel solar absorber architecture and metal hydride thermal energy storage in a single close-coupled system. The high energy density of the thermal energy storage allows it to be mounted up-tower alongside the receiver, which further enables up-tower mounting of the entire supercritical carbon dioxide Brayton power block. Mounting the thermal energy storage and power block up-tower eliminates the need for costly piping and fluidic connections between the receiver and a large centralized element, making the system ideal for modular implementation and growth.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This is relatively mature project, having been launched in October 2015. The objective is to design and build a CSP system that integrates a thermomechanical storage concept. The target is 6 cents/kWh. The project has achieved its milestones to date, with demonstration testing of the integrated system remaining.

**Reviewer 2:** This project leverages the ultra-high energy density achievable via thermochemical reactions of Metal Hydrides (MH) to store solar thermal energy for electrical dispatch after the sun goes down. Holding high temperature and high pressure as well as the reaction of MH with hydrogen. There is significant risk in developing the HTMH for energy storage as they have not been used. Successful completion of the program will help the DOE achieve their SunShot cost goals for CSP by the 2030 deadline. 5-yr close to $3M project. The system itself is a high-efficiency design that has the potential to achieve cost-competitiveness with fossil-fuel-based power systems. By incorporating thermal energy storage, it furthermore overcomes the traditional shortcomings of renewable energy in being dispatchable during periods of peak demand. High temperature metal hydrides could be extended to work with other CSP technologies such as molten salt or direct steam. This could allow for a reduction in cost of thermal energy storage for these other technologies making them more financially viable. This application is envisioned as a factory-assembled, truck-transported, high-volume manufactured CSP solution that is similar to the commercial wind turbine business model that eliminates uniquely engineered solutions in favor of a standard product offering. Strengths: A high efficiency $sCO_2$ receiver capable of surviving the required 30-year life of a CSP system. An integrated system for the exergetically-efficient delivery of concentrated solar energy into an isothermal energy storage system.

**Reviewer 3:** The main weakness of the project report is the lack of information about the work being done by SRNL and Greenway energy on the development of metal hidrades. The report and additional responses from the PI, Shaun Sullivan, indicates that all the receiver, heat exchanger and system level activities have been conducted very thoroughly. I asked the PI regarding considerations that were not clear in the report, in particular how the system would behave as a whole. The responses indicate a lot of effort in modeling with tools of different levels of complexity (from equation based to FEA and CFD analyses). The PI has considered how the system would operate during startup (may need to add gas to start up, or using storage), solar transients, parasitic power consumption, and power block efficiencies when running under sun and from storage.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 2 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 6 |
| Disseminates results frequently and actively engage partners | 4 | 6 | 1 |
| Collaborates with sufficient stakeholders | 6 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** There is no documentation of dissemination of project results. Further, because of the small physical scale of the demonstrate unit the project was unable to procure materials capable of withstanding the 760C target temperature. In the system fabricated as part of this work the temperature is limited to 730C.

**Reviewer 2:** The milestones outlined are met. This project leverages the ultra-high energy density achievable via thermochemical reactions of Metal Hydrides (MH) to store solar thermal energy for electrical dispatch after the sun goes down. High quality papers are published. The most important milestone achieved to date is the LCOE calculations which vary between 8.8 to 9.6 ?/kWh depending on the HTMH precursor material cost. This cost fits well with the DOE goals for a peaker system. The cost metric of less than $15/kWhth is difficult to achieve because of the high cost of heat exchangers required. However, cost savings elsewhere in the program have allowed us to achieve the low LCOE even with higher storage costs. The high temperature metal hydride reaction with hydrogen is reversable and with an adequately sized regenerator located between the low temperature and high temperature beds to recover the sensible heat in the hydrogen, losses can be kept low. Heat loss calculations show the round trip efficiency of the thermal energy storage system as 99% for the 10MWe system. Similarly, the round-trip exergy efficiency of the cycle is also high at 97.7%. Major Recent Accomplishments: 1) A novel heat exchanger architecture that effectively transfers heat into a static TES media is being developed; this design is agnostic to the media itself, so it is suitable for use with sensible heat material, thermochemical media, or phase change materials. 2) A high efficiency sCO2 receiver capable of surviving the required 30-year life of a CSP system. 3) An integrated system for the exergetically-efficient delivery of concentrated solar energy into an isothermal energy storage system (e.g. thermochemical or phase change)

**Reviewer 3:** The report did not include the current expenditures, it only showed the budget, which is why it is not possible to estimate if milestones have been met within timeframe and budget. The report listed only one conference presentation since the beginning of the project. The report listed 3 additional publications before the project started. This is the basis for the low score on disseminating results. The project participating organizations are a good mix of national laboratories and industry. However, it lacks the involvement of a solar project developer.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The milestones have been reasonably laid out, and the achievement of the milestones has been successful through Phase 2.

**Reviewer 2:** Score: 5. Comments: The team has had to make some corrections to their phase 3 test facility design to accommodate realities in material availability, budget, and time. The 760°C fluid temperature specified in the commercial design is impossible to achieve in the budget and scope of phase 3. They have had to reduce the maximum operating temperature to 730°C and the maximum operating pressure to 20 MPa.

Reviewer 3: Score: 6. Comments: The project report listed the tasks during each phase of the project, and how the milestones have been met. The tasks were reasonable and important for achieving the project goals.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** None serious. The 730C limitation in temperature is unfortunate.

**Reviewer 2:** May explore other energy storage material.

**Reviewer 3:** The proposed system is quite complex and has several subsystems with significant challenges. The PI responded to questions regarding challenging components that are not the main goal of the project: 1) A thermocline energy storage: while this is not fundamental to the operation of the system, if not designed and operated correctly, this could reduce singnificantly the overall efficiency of the system. 2) Startup operation: if not carefully designed, this could result in significant natural gas usage and or time lost every day.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Interaction with suppliers of needed components capable of withstanding the 760C target is needed.

**Reviewer 2:** May have some universities got involved in for fundamental research as well.

**Reviewer 3:** Solar developers: this concept contains many new components and systems, and it will take developers and independent engineers to understand the risks and operation in order to make this a commercial product.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) The work is ready to begin demonstration testing after designing and fabricating the integrated system. 2) The achievable LCOE for this system is about 9 cents/kWh. I understood the DOE target was 5 cents/kWh. In a response to my question the PI indicated the 5 cents/kWh target is for baseload units, and they indicate this system is for use in "off-sun shoulders of the day" during peak demand, where the target is 10 cents/kWh.

**Reviewer 2:** 1) Develop an optimized integrated CSP system that employs thermochemical energy storage to achieve an overall LCOE of 6Â¢/kWhe 2) Design of TES Heat Exchangers. 3) Metal Hydride Material Property Testing under high temperature/high pressure.

**Reviewer 3:** 1) Good balance of risk and reward. The development of the metal hidrides, heat exchanger and overall system could extend beyond power generation. 2) Need to get to hardware demonstration very soon. 3) Need to involve developers to scale up and demonstrate feasibility of commercial systems.

## Integrated Thermal Energy Storage Heat Exchanger for Concentrating Solar Power Applications – $1,178,556

*Brayton Energy | Hampton, NH | Principal Investigator: Jim Nash*

This project is developing a heat exchanger that uses a composite phase-changing material to store and release heat from a concentrating solar-thermal power receiver to a supercritical carbon dioxide power-conversion cycle. The team is designing a new heat exchanger and testing the durability of its components by exposing them to high pressures and temperatures, helping to optimize the heat exchanger and create a scalable design for supercritical carbon dioxide concentrating solar-thermal power plants. This project performs component-level research and development for a concentrating solar-thermal power system.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 4 | 4 | 3 |
| Implement a high-risk, high-impact approach | 4 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Effective and economical heat exchanges integrated with pcm for solar heating of the CO2 working fluid indeed align well with this topic's goals and supports the SETO mission, and the proposed approach to their design remains promising. The complexities of sold/liquid moving interface and the differences in properties of the two phases. Cost of the was found to be too high. Flammability of the graphite. Reassuring contingency plans are not shown. If the cost can be reduced to acceptable levels, I would say that this is a medium-risk high-impact project. If not, the risk is high too. They do if the proposed goals are met, which, based on my comments, is still hard to predict despite the earlier accomplishments. They do, if the proposed goals are attained. If the goals are met, they would advance the US solar industry significantly. Effective economical heat storage and transfer is one of the most significant contributors to commercializing CSP. Strengths: A relatively conventional but promising approach for developing a high temperature integrated solar heat exchanger with PCM heat storage. Weaknesses: Strong uncertainties in the chances to meet the goals, high costs, some flammability risk.

**Reviewer 2:** The research aligns well with the goals and clearly supports the SETO mission.The challenges are nicely elaborated upon in the report. The graphite HX currently suffers from high cost and potential commercial non-availability. The copper HX might suffer from material compatibility with the PCM. In my opinion, this is a high-risk and potentially high-impact approach to develop the HX for high-temperature CSP. The project began in 2018 and is scheduled to end in one year. It appears that significant challenges remain and a focused effort will be needed to ultimately develop a good HX design. The budget appears to be reasonable. The general topic of HX-PCM designs is of considerable interest outside of DOE. The investigators mention a technical paper in Item 13 and are encouraged to disseminate the results obtained so far. The high-temperature HX-PCM concept is an important key to advancing high efficiency and economically competitive CSP.

Strengths: The research addresses a key question and bottleneck in advancing high-temperature CSP. The investigators are pursuing a presumably low-cost but higher technological risk option of the copper-based HX concept. Attention is being paid to many aspects of the HX design, in other words, little of any practical concerns and considerations are left unaddressed. Weaknesses: Few technical details are included in the report or poster.

**Reviewer 3:** This work was launched in October 2018, and has as its objective the design of a integrated latent-heat thermal energy storage heat exchanger for use in the next-generation CSP system. At this point in the project the equipment cost for the integrated system has been found to be more than twice that of the DOE target, and the storage costs are approximately 6 times the DOE target. These cost hurdles are significant challenges in the project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 3 | 4 | 3 |
| Collaborates with sufficient stakeholders | 5 | 4 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project is progressing but met some challenges and was delayed and took measures to overcome them and seems to be back on track. Meeting the device cost goals remains to be a problem.

**Reviewer 2:** Detailed milestones and timelines were missing so assessing them is difficult. The budget seems to be reasonable. Energetic efficiency, exergetic efficiency, economic viability, were all addressed in the report. This is good. As noted earlier in this review, it would be good to share some of the key results obtained so far. It is not clear to this reviewer which industrial partner might ultimately manufacture the HX. It is not clear, due to the nature of the project, that more stakeholders need to be involved at this point. Therefore, yes, there is sufficient collaboration. The project has had some challenges (technical and personnel) that are discussed in the report. It is not clear whether the graphite HX option will ultimately prove to be viable, given the time remaining on this project funding. To this end the investigators are also considering an alternative copper design.

**Reviewer 3:** There is no evidence of dissemination of results yet. Perhaps the PIs need to engage more broadly those who are involved in the graphite-based thermal energy storage industry to explore ways to bring the costs down to approach the DOE targets.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, with the reservations expressed above. Clear contingency plans are not shown.

**Reviewer 2:** Score: 5. Comments: The approach taken includes a variety of scientific and technological components, and takes into consideration the challenging economic hurdles posed by the graphite HX concept especially.

**Reviewer 3:** Score: 5. Comments: Again, the significant costs identifies thus far for both equipment and storage are limiting progress against the project goals.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The challenges of the phase change heat transfer and HE design and ways to overcome them, especially at low cost, were not elaborated.

**Reviewer 2:** The PI has, in my opinion, done a good job in developing a plan forward at this time. However, it is not clear how much graphite will be needed for full scale deployment, and whether this amount of graphite can be made available and at a reasonable cost.

**Reviewer 3:** Perhaps the PIs should have done a bit more research related to the cost of high-temperature latent heat thermal energy storage materials before proposing this work.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project seems to be well staffed, but should benefit from cooperation with designers, manufacturers and users of high temperature phase change heat exchangers, especially large ones, as well as of CSP systems.

**Reviewer 2:** None to my knowledge.

**Reviewer 3:** High-temperature latent heat PCM manufacturers.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Significantly improve the explanation and solutions planning of the device's encountered technical problems and the proposed way to overcome them. 2) Significantly improve the explanation and solutions planning for achieving the cost goals. 3) Develop contingency plans, including, if possible (and with my full respect to the team's experience and competence), more cooperation with designers, manufacturers and users of high temperature phase change heat exchangers, especially large ones, as well as of CSP systems.

**Reviewer 2:** 1) The project is focused and has specific goals. 2) It seems that a successful full scale HX design will be difficult to attain in the short time remaining on the funding. 3) On the other hand, with so much time invested so far, it would be wise to push forward with the project.

**Reviewer 3:** The storage and equipment costs are significantly (multiples) higher than the DOE targets.

## Creep and Fatigue Characterization of High Strength Nickel Alloys Thin Sections in Advanced Carbon Dioxide Heat Exchangers – $700,000

*Brayton Energy | Hampton, NH | Principal Investigator: Jake Boxleitner*

Brayton Energy and Oak Ridge National Laboratory are examining creep behavior—the tendency to deform under mechanical stress—in thin-sheet nickel alloys 740H and 282, to see whether they can improve the lifetime of supercritical carbon dioxide heat exchangers in high-temperature concentrating solar-thermal power plants. This will provide information about structural characteristics in metals used to build heat exchangers and determine how thick their components should be.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project is planned to start on 4/1/2020 and end on 9/30/2021. The project work scope includes developing a dataset and predictive models necessary for the design of heat exchangers using the gamma prime strengthened nickel superalloys. Material will be fabricated and the properties of the as manufactured test articles will be measured. A creep behavior investigation of thin sheet and foil forms will be accomplished. The primary objective is to quantify manufacturability and performance of these materials. The goals of the project are in line with the overall goals of the program and the mission of SETO. The planned work and timeline are in line with the funding level planned.

**Reviewer 2:** The development of an inexpensive yet high performance material for high-temperature CSP heat exchangers aligns well with the SETO mission. The project has not yet started. The approach seems to be to address difficulties in manufacturing as they arise. Strategies to address the difficulties are somewhat unclear. It is not clear whether a durable, thin-walled folded-fin HX can be developed (high-risk). One would expect the cost of such a HX will be relatively low (high-impact). The funding level and project duration seem appropriate. If successful, the proposed HX design would have applications in a broad set of technologies. Reducing the cost of the HX could help advance the solar industry. Strengths: The technology that is proposed is important to CSP and a wide variety of other industries. The HX could be of relatively low cost and offer satisfactory thermal performance. Weaknesses: It is not clear whether the pressure drops within the HX will be acceptably low and it is unclear what the thermal performance targets are. The Report and poster lacked detail relative to other reports and posters.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 |
| Disseminates results frequently and actively engage partners | 5 | 2 |
| Collaborates with sufficient stakeholders | 5 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project will begin on 4/1/2020. As such the project is on schedule and on budget. I cannot make any judgements as to the ability to meet milestones, collaborate with stakeholders etc. The scores given in this section are reflective of the lack of data available for the project but this needs to be addressed with the panel as to how to handle what the score should be given in the absence of any information to make the decision on.

**Reviewer 2:** The project has not yet started. There appears to be no heat transfer performance testing involved. It is not clear, then, what is meant by "benchmarking against existing solar receiver and energy storage heat exchangers." No dissemination plans were discussed. There appears to be little collaboration with entities other than ORNL. The project has not yet started but, as provided in the Report and poster, the project focuses on HX manufacturing issues associated with thin sheets or foils of gamma strengthened nickel superalloys. It is confusing when statements are also included such as "In addition, HX manufacture and modeling will yield recommendation for optimal heat exchanger design…" which suggests actual HXs will be manufactured, heat transfer and fluid flow will be modeled, and optimization studies will be performed. However, these activities do not appear to be in the scope of work, and it is not evident that the team is prepared to perform these tasks.

#### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: I believe that the work planned does meet the overall objectives as outlined in the report and adds important value to achieving the overall goals of the project.

**Reviewer 2:** Score: 3. Comments: The separation of the work into fundamental (ORNL) and practical (Brayton) tasks is reasonable. These tasks are materials related. It is not clear who will do the thermal modeling.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I did not identify any blind spots in this project.

**Reviewer 2:** There appears to be a lack of thermal expertise on the team.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** I did not identify any additional collaborators, organizations or stakeholders that should be included in this project to accomplish the work scope and meet the goals of the project.

**Reviewer 2:** As evident in my other remarks, the team might benefit from adding thermal expertise, especially since it is stated that they will manufacture a heat exchanger and perform modeling to identify optimal heat exchanger designs.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** The project is planned to begin 4/1/2020. This project if completed successfully as stated in the project description could add significant value to the understanding and development of improved heat exchanger systems. The overall project goals are in line with the goals of the program and the mission of SETO.

**Reviewer 2:** 1) An indication of exactly what tasks will be performed and who will perform them would have been helpful. For example, there are locations in the Report that mention modeling and performance of heat exchangers, which suggests that heat transfer and fluid flow expertise is needed. It is not clear whether this expertise is represented on the team. It is not clear whether these tasks are actually included in the work statement, or were just mentioned in passing. 2) The focus seems to be on addressing materials and manufacturing issues and the stated objective of the practical investigation is to "quantify manufacturability." I am unsure what is meant by this. 3) The focus of the project could be sharpened a bit for subsequent reviews and discussions.

## High Temperature Silicon Carbide Composite Receiver Assembly for Liquid Pathway Concentrating Solar Power Operating Above 700 Degrees Celsius – FY19 TBD

*Ceramic Tubular Products | Lynchburg, VA | Principal Investigator: Kristen Frey*

This project team is developing silicon carbide composite receiver tubes for molten chloride salt and liquid sodium receivers in concentrating solar-thermal power plants. The tubes have thermomechanical properties and corrosion resistance that are superior to metal alloys at high temperatures. As a result, the lifetimes of these tubes could increase, enhancing concentrating solar-thermal power system performance.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project meets the goal and supports the mission set by Gen 3 CSP program for solar receiver at temperatures above 700°C. The overall goal for this project is to manufacture a 200 kWth prototype receiver assembly. This will prove the viability of a full SiC receiver assembly. 11 tasks are identified and two challenges are listed. Ceramic Tubular Products' (CTP) multilayer tube products have already shown superior properties in Gen 3 operating conditions, including low corrosion in 750°C molten chloride salt, and excellent thermal and mechanical shock resistance and solar absorptance. Total budget is about $M2.3 with 20% cost share in two years. Impact beyond DOE project is limited. Receiver is an important component in CSP technology. Strengths: 1) Fabrication, assembly and experimental tests of thermo-mechanical performance. 2) Corrosion testing will be performed on CTP fabricated SiC corrosion specimens in molten chloride salt at 800°C for 500 hours. 3) Strong collaborative effort. Weaknesses: 1) Not clear how to achieve emittance <0.75. In the poster, the current emittance is above 0.86. 2) Not clear how to remain cost effectiveness.

**Reviewer 2:** The project "High Temperature Silicon Carbide Composite Receiver Assembly for Liquid Pathway Concentrating Solar Power" addresses a critical need for thermal concentrated solar power: high temperature, high efficiency solar receivers, Ceramic Tubular Products has developed unique, silicon carbide composite materials for nuclear applications, but these materials are very well suited to CSP applications. Although ceramics, especially silicon carbide offer excellent optical and thermal properties for the intended application, un-reinforced ceramics are brittle and can fracture easily. Fiber-reinforced ceramic composites, on the other hand, offer flaw tolerance and damage resistance to prevent catastrophic failure. Therefore, the approach offered by Ceramic Tubular Products is rational but must address manufacturability and integration with other system components, handling and installation procedures, and cost. This project addresses many of the relevant issues, but has an extremely ambitious timeline.

**Reviewer 3:** The project's strength exists in the depth of the fabrication processes and evaluation planning of the multiple layer ceramic coated tubular sections for the high temperature CSP receiver. The processes are clearly laid out and the evaluation steps are clearly identified. The teaming is good for the objectives, and a good combination of Federal, academic and industry strengths. The key question/concern of this reviewer is about the go/no-go gates, which appear to be prior to start of project.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Project not started yet. Planned to start on March 15, 2020. Schedule looks reasonable. From manufacturing a 200 kWth prototype receiver assembly to developing a conceptual design for a 2 MWth SiC-based receiver for molten chloride salt. Engage collaborators well. A commercialization roadmap will be developed. Collaborations are sufficient. Expected performance should be fine.

**Reviewer 2:** The team is highly skilled in component development and will likely design components relevant to the CSP system designers' needs. The planned Advisory Board should include members from CSP system designers, whether from National Labs or industry. The timeline seems too short to accomplish all the required tasks and the project would benefit from additional time to address integration and handling issues.

**Reviewer 3:** The team has provided enough details to quantify the steps and details in the project. The target performances are clearly listed, and the manufacturing technologies at the component, assembly and systems level are discussed. The testing again emphasizes a basic science and a systems level evaluation that takes into account the performance of the resulting receiver under the elevated operating temperatures.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Successful fabrication and assembly of the proposed receiver is the key. Thermo-mechanical and corrosion testing should have done before the assembly of the 200kWth SiC-based receiver. Solar spectrum testing should have demonstrated before the project.

**Reviewer 2:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project. Many methods have been proposed for joining silicon carbide composites to themselves or to metals. Hopefully, the team will select and evaluate existing methods before trying to invent a new one. Resources could be spent more beneficially on developing handling and installation methods for the materials and components. Although events such as dropping a wrench are inevitable, the outcome is not a result of the material being brittle, but that the wrong tool and method was used. GE has introduced silicon-carbide ceramic matrix composites into commercial jet engines which have been flying for almost 3 years. The material is clearly acceptable for life-critical applications. Photovoltaic panels incorporate brittle materials, silicon and glass, that would fail catastrophically if a wrench was dropped on them but packaging and tooling has been designed to allow them to be used in high volume.

**Reviewer 3:** Score: 5. Comments: The tasks are clearly laid out, and explained. The key concern, as expressed earlier, is how do these tasks relate to the go/no-go gates? The go/no-go gates are either before the start of the project or at the end of year 2.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** The solar spectrum test results for CTP's multilayer SiCtubes previously tested at Sandia National Labs showed emittance is above 0.86, not as designed < 0.75.

**Reviewer 2:** The fibers used to make the composites developed by Ceramic Tubular Products cost between $5,000-$10,000/kg. Although the temperature capability of the ceramic composites may be significantly higher than superalloys, the cost of materials and fabrication needs to be evaluated on a normalized basis, such as levelized cost of electricity.

**Reviewer 3**: The only blind spot for the PI to consider is how does she explain the placement of the go/no-go points at the end and prior to start of the project?

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** It would be better to include a solar radiation spectrum expert and material scientist to help achieve high solar absorptance with reduced emittance. Currently such a task is just to be tested in Sandia National Laboratory, lack of a real solution.

**Reviewer 2:** It is not clear whether CTP manufacturers the entire tubes in-house, purchases tubular mandrels, or contracts out some aspects of fabrication. Therefore, CTP and DOE should consider whether to include key suppliers or materials processors on the Advisory Board.

**Reviewer 3:** The PI and her industry team will be the lead implementer and technology transition partner, the federal lab will help with solar spectrum and other testing (and I presume as an adviser to the testing), the academic partner will conduct the corrosion testing. This is a good partnership, and I wished that there was a bit more on the transition pathway -- I am assuming it will be the PI and her organization.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) The receiver will be expandable for use in commercial 50-100 MWth CSP plants. 2) The prototype fabrication is the key of success. 3) How to meet optical, thermal, and mechanical requirements with cost effectiveness.

**Reviewer 2:** 1) Ceramic Tubular Products has developed ceramic composite tubes that offer significant benefit to CSP systems if key challenges are addressed: manufacturability and integration with other system components, handling and installation procedures, and cost. 2) Emphasis should be placed on developing cost-effective handling and installation procedures instead of demanding that practices suitable for other materials be used. GE has shown that the materials can be used commercially and installed and maintained by skilled labor using appropriate procedures. 3) Although CTP has a well-ordered plan to address critical issues, it appears to be compressed into too short of a time frame.

**Reviewer 3:** 1) good engineering project; 2) go/no-go points; 3) good partnership between the teaming members.

## Narrow-Channel, Fluidized Beds for Effective Particle Thermal Energy Transport and Storage – $1,177,701

*Colorado School of Mines | Golden, CO | Principal Investigator: Gregory Jackson*

Using particles to replace the heat transfer fluid in a concentrating solar-thermal power system may be the simplest way to increase the operation temperature and therefore increase the power cycle efficiency of a concentrating solar-thermal power plant. Colorado School of Mines is working with Sandia National Laboratories and Carbo Ceramics to develop and test a narrow-channel, counterflow fluidized bed receiver and heat exchanger designs. These are used to analyze flow conditions and improve heat transfer rates in the receiver and heat exchanger. The team uses these insights to test a modular panel for an indirect particle receiver and/or particle to supercritical carbon dioxide power cycle heat exchanger. The program will deliver detailed multiphase flow modeling tools to assess how receiver and heat exchanger designs can meet receiver cost targets of $150 per kilowatt hours of heat and thermal-energy system targets of $15 per kilowatt hours of heat.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 3 |
| Set critical challenges to overcome | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 |
| Advance the U.S. solar industry substantially | 4 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The proposed work covers the development of an extremely novel heat exchanger concept with very challenging performance metrics. If successful, this work could allow for the use of direct-contact heat exchange in thermal systems, obviating the need for traditional fluid-to-fluid HXs and potentially reducing system cost and complexity. Findings are likely only relevant to a HX with the specific geometry indicated in this work unless a specific effort is made to correctly structure heat transfer coefficient correlations such that they can predict performance over a wider range of geometries.

**Reviewer 2:** The project will develop and implement geometries and operating strategies for narrow-channel, counterflow fluidized beds as an innovative approach primarily, to extract thermal energy from oxide particles in particle-sCO2 heat exchangers and secondarily, to deposit thermal energy into the oxides in an indirect solar particle receiver at particle inlet temperatures Tp,in > 600°C, about 100°C below GEN3 goal. Development of 40-kWth heat exchanger with narrow-channel, counterflow fluidized beds presents uncertainties due to the novelty of this concept. The heat exchanger design and testing with high-temperature alloys present a cost challenge for development. The challenges make it high risk. The 40-kWth heat exchanger developed in Phase II is largely sized based upon available sCO2 test facilities at Sandia, but this size is adequate to prove the viability for this heat exchanger for potential scale-up to a 10 MWelec CSP plant demonstration. Strength: Collaboration. The team has identified how operation of the counterflow fluidized bed can be tailored to optimize heat transfer under both continuous particle flow and batch mode conditions. Model results predict reasonably well fluidized bed experiments. Weakness: Operation T is not above 700 °C.

## 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Project team is reaching out to a range of partners to help with correct manufacturing of both particles and heat exchanger test section. Target metrics allow for a highly quantitative approach.

**Reviewer 2:** Milestones have not been fully met. The narrow-channel counterflow fluidized bed heat exchanger with its very high hT,w can reduce particle heat exchanger costs below DOE targets of $150/kWth. A journal publication is listed. Mines and Sandia and Carbo Ceramics will employ ceramic particles developed by CARBO in narrow-channel counterflow fluidized beds as a means for achieving high density heat transfer for oxide-particle TES subsystems. The team will use oxide coating engineering, lab-scale testing, and multiphase-flow modeling to identify preferred oxide particle properties, optimal bed operating regimes, and geometric configurations for efficient particle-to-sCO2 heat exchangers and indirect particle solar receivers in a particle TES subsystem for CSP applications. Mines had developed quasi-1-D models to simulate steady-state operation of particle-sCO2 primary heat exchangers. Mines has focused work on optical/thermal barriers for receiver leading edges with scalable dip-coating of porous oxides.

## 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Tasks cover the full range of technical challenges related to the development of this type of heat exchanger including manufacturing challenges of particles, particle integrity, HX manufacture and operation, thermal cycling of proposed HX design, and targets for HX performance.

**Reviewer 2:** Score: 5. Comments: Milestones are clearly stated toward meeting all the counterflow fluidized bed operability and heat transfer performance.

## 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Heat transfer coefficients are usually reported as empirical correlations fit to experimental data. The core physical phenomena driving a given heat transfer performance are often lost in the development of these correlations. A push should be made to understand the underlying physics of experimental heat transfer performance, and provide correlations in the form of physics-based analytical models.

**Reviewer 2:** Scalability from the 40-kWth particle-sCO2 heat exchanger to MW scales for future CSP plants of high-temperature and high pressure. Contribution of particle radiation.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Even low-levels of particulate in the working fluid could cause considerable damage to downstream equipment in power block. Turbomachinery manufacturers should validate whether or not the target level of particulate are acceptable in terms of turbomachinery reliability and longevity.

**Reviewer 2:** This technology approach is being considered by Brayton Energy and Sandia as an alternative particle-sCO2 heat exchanger design for their respective SETO Gen-3 TES subsystem development efforts. Involvement of Brayton Energy is suggested.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Work should focus on developing physics-based correlations instead of empirical correlations. Correlations should allow for applicability across a range of geometries besides the one tested in the proposed work. 2) Input is needed from turbomachinery manufacturer on if target particulate levels are acceptable. 3) Target performance metrics are challenging and will lead to a compelling HX design if successful.

**Reviewer 2:** 1) Narrow-channel counterflow fluidized bed heat exchanger with its very high hT,w can reduce particle heat exchanger costs. 2) The data will support heat exchanger model development to optimize particle-sCO2 heat fluxes and thereby minimizing heat exchanger volume and costs. 3) The team will demonstrate thermal cycling stability of novel barrier coatings at Sandia's ASHES facility at radiative fluxes > 1200 suns to assess their viability for indirect particle receivers.

## Thermodynamically Stable, Plasmonic Transition Metal Oxide Nanoparticle Solar Selective Absorbers towards 95 Percent Optical-to-Thermal Conversion Efficiency at 750 Degrees Celsius – $400,000

*Dartmouth College | Hanover, NH | Principal Investigator: Jifeng Liu*

This project aims to achieve an optical-to-thermal conversion efficiency of 95 percent for concentrating solar-thermal power receivers using a spray-coated solar selective coating. Specifically, plasmonic metal oxide nanoparticles are thermodynamically stable at 750 degrees Celsius and improve the coupling of incident light with the metal's electrons, thereby improving receiver efficiency. The team is testing whether optimizing the plasmonics response of transition metal components increases the optical-to-thermal conversion efficiency to 95 percent. The project will break through the current efficiency limit of about 89 percent and resolve deterioration issues in high-temperature solar absorbers without increasing the costs.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project investigates spray-coated plasmonic transition metal oxide nanoparticle (NP) solar selective absorbers that are thermodynamically stable at 750 °C in air to achieve an optical-to-thermal conversion efficiency (?therm) of 95% for Gen3 CSP receivers. A few challenges are identified. Impact is high. Match well with the level of funding and duration. Impact general coating industry. Due to the robust design that enables spray coating fabrication, the technology developed in this project has a great potential for large-scale applications. Strength: Milestones are met.

**Reviewer 2:** This project has a rather simple objective: Increase the solar optical-to-thermal conversion efficiency of a receiver surface at 750C by tailoring a spray-coating with selective high-temperature absorptivity and low-temperature emissivity. The work has been successful in achieving an efficiency of 94.8%, and thermodynamic stability has been demonstrated over 40 day-night cycles. The reduction in LCOE is modest--estimated to be 0.38 cents/kWh.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engage partners | 6 | 6 |
| Collaborates with sufficient stakeholders | 6 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Milestones and budget are well thought. Expect to reduce the levelized cost of energy (LCOE) by ~0.38 ¢/kWh from this innovation in high-efficiency solar selective coatings alone, compared to DOE's goal of 1 ¢/kWh reduction in LCOE from TES, receiver, and O&M combined by 2030. For a typical 110 MWe CSP power plant, this innovation in solar selective absorbers transfers to ~$2 M increase in annual revenue. Results are disseminated well. Small project with one industry partner. 5. Excellent accomplishments have been carried out.

**Reviewer 2:** Progress has been made against the project milestones. It appears that longer-time stability testing is needed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Tasks and milestones are well outlined to achieve the project goal.

**Reviewer 2:** Score: 4. Comments: The results are positive, but modest in reducing the LCOE.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Erosion and long-term durability test.

**Reviewer 2:** No blind spots noted.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** For a small project, the current team seems function well.

**Reviewer 2:** It appears needed collaborators have been involved.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) All tasks and milestones are met. 2) The desired efficiency is almost realized. 3) Whether further cost reduction is possible.

**Reviewer 2:** 1) The projected increase in optical-to-thermal conversion efficiency has been demonstrated, and the coating's stability over 40 day-night cycles has been shown. 2) The coating's reduction in LCOE is rather modest--0.38 cents/kWhr, and thus, any deviations from ideal operation would negate the advantages of the coating.

## Power Cycle with Integrated Thermochemical Energy Storage – $1,000,000

*Echogen Power Systems | Akron, OH | Principal Investigator: Timothy Held*

Echogen and the Southern Research Institute are designing, modeling, and testing a novel integrated supercritical carbon dioxide power cycle and thermochemical energy storage system for concentrating solar power. The system uses supercritical carbon dioxide both as a power cycle working fluid and as a reactant in the thermochemical energy storage reactor. The team is designing, building, and testing a prototype-scale supercritical carbon dioxide power cycle and reactor to validate the design and performance of the system.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 |
| Set critical challenges to overcome | 3 | 4 |
| Implement a high-risk, high-impact approach | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 3 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** High energy density thermochemical storage aligns well and supports the SETO mission. The scientific and technological challenges are not clear from the report. Similarly, scientific and technological bottlenecks to progress are not clear. Development of thermochemical storage poses high risk. However, it is stated that the energy density of the MgO sorbent is comparable to molten salt systems and, so far, the initial testing has demonstrated an energy density approximately half of the target value. This is before parasitic losses are accounted for. Taken together, this suggests that the impact, even if successful, might be modest. The success to date has been limited, and the actual thermochemical performance of the sorbent has not been as good as expected. This is before the many parasitic losses in the storage system are taken into account. The technological hurdles appear to be significant. Thermochemical energy storage is of broad interest to the scientific community. Based on the limited success to date, it is unclear how this particular thermochemical energy storage concept will be successful. Strengths: The research addresses a key question and bottleneck in advancing high-temperature CSP. Weaknesses: The progress to date appears to be modest, with actual energy densities of the promoted material being modest compared to expectation.

**Reviewer 2:** In the context of CSP and other advanced energy applications, study, design, construction and operation of an efficient and economical CSP and energy storage system integrated with an sCO2 power cycle, that is aimed at delivering highly-efficient, low-cost energy storage on a utility scale, with the cited quantitative goals, is aligned well with this topic's goals and supports the SETO mission. Critical challenges to overcome: MgO sorbent optimization, fabrication, testing, and optimization of the lab-scale TCES reactor and long-term cyclic test program. Heat and phase change and transport magnitudes and dynamics, especially at interfaces. More information is needed for effective planning for choosing an optimal design path to high efficiency and long-term operation robustness, and appropriate cut-and try design+testing. Contingency plans are not shown. This is a medium-risk, high-impact project in the context of CSP and energy storage. The plans would match well the funding and duration if the proposed goals are met, but it seems that the delays in acquiring materials and components will extend the expense and duration. The plans would add significant value to existing research outside DOE-funded efforts, if the proposed goals are attained. If the goals are met, the project would advance the US solar industry significantly, since there are very few such systems in existence that could attain the planned goals, and they all are in the experimental stage (as far as I know). A successful system also has significant export potential. Strengths: A promising approach for developing an efficient and economical CSP and energy storage system integrated with an sCO2 power cycle, that is aimed at delivering highly-efficient, low-cost energy storage on a utility scale, with the cited quantitative goals, Weaknesses: Some procurement delays and associated insufficient testing so far creates uncertainties in the chances to meet the goals, inadequate information about the partially cut-and-try methodology for effectively reaching the goals, no clear contingency plans.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 6 |
| Collaborates with sufficient stakeholders | 3 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Unfortunately, the progress has been somewhat limited. The key partner, Southern Research, has had personnel turnover including the sole author of the single publication that has come out of this effort, a facilities relocation, and they discovered after the fact that they could not produce the sorbent materials as originally planned. I understand this is one reason for an increased budget request for BP2. Key impacts and targets are quantified. Dissemination to the broader community has included a patent application and a conference paper, which is good. Industry partners who might ultimately manufacture the TCES units were not identified. It is of some concern that some of the activities proposed for BP1 could not be achieved, and that outsourcing was necessary. The project has had some challenges, both technological and with personnel, as discussed in the report. Some of the proposed activities for BP1 could not be achieved, necessitating outsourcing and an increased budget request for BP2. The proposed energy densities compare to those associated with molten salts. Targeted energy densities for the sorbent materials have not been achieved. Unfortunately, progress has been somewhat limited.

**Reviewer 2:** The project made important progress but also encountered several challenges that delayed it. It was reported that some ways to overcome the challenges were employed with some success. Impacts are measured appropriately but delivery delays create a problem. Results are disseminated in appropriate meetings and conferences. The interactions between the PI-s, as well as between their companies were not described in any detail. It was not reported that they collaborate with sufficient stakeholders, such as power systems, chemical reactor manufacturers, and CSP experts.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: There appear to be no extraneous tasks in the project. Each task appears to be important and contributes to the overall goals.

**Reviewer 2:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project, with the reservations expressed above. Clear contingency plans are not shown.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Based on the need to request more funding because of tasks that could not be completed as proposed in BP1, this reviewer wonders whether more budgetary blind spots will surface in BP2.

**Reviewer 2:** It is important to pay more attention to detailed systematic planning of the partially cut-and-try methodology for effectively reaching the goals, especially in the heat storage reactor, in view of the experienced and potential challenges, and create clear contingency plans. Note that properties of $sCO_2$ vary abruptly and strongly around the critical point.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It is not clear which team members are responsible to quantify the parasitic losses, which could potentially be severe, in the TCES storage units. It is not clear who that expert is and whether such expertise needs to be identified.

**Reviewer 2:** The project seems to be staffed with experts in thermal power systems development, and to some extent in chemical reactors design, but should benefit from cooperation with designers, manufacturers and users of high temperature power generation and energy storage systems, as well as in CSP.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The budgetary planning for BP2 should be approached very carefully, considering the shortcomins in budgetary planning for BP1. 2) Even if successful, it is not clear how the TCES approach described here might be better than alternative PCM approaches, for example. The energy densities of the sorbent itself seem to be low. 3) It is not clear who the expert is that will quantify the parasitic losses in this TCES approach.

**Reviewer 2:** 1) Significantly increase attention to heat and phase change and transport magnitudes and dynamics in the reactor, especially at interfaces. Note that properties of sCO2 vary abruptly and strongly around the critical point. 2) Significantly improve the explanation and optimal solutions planning and execution for achieving the goals. 3) Develop contingency plans, as well as, if possible, more cooperation with developers of the rest of this power system components, and designers, manufacturers and users of high temperature power generation systems, especially using sCO2.

## Improving Economics of Third Generation Concentrating Solar-Thermal Power System Components through Fabrication and Application of High-Temperature Nickel-Based Alloys – $1,499,901

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: John Shingledecker*

In order to reduce high-temperature concentrating solar-thermal power plant costs, this team is investigating manufacturing methods for alloys that had previously been designed for high-temperature power service in advanced ultra-supercritical steam. They are examining the cost and performance advantages of manufacturing pipes and tubes from flat sheets after further processing, which can lower capital costs. If these alternate manufacturing routes of alloys can produce pipes that are able to maintain operating lifetimes similar to piping produced from other nickel-based alloys, they have the potential to reduce the cost of these components by about 30 percent.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The overall project goals are aligned well with the goals of the CSP program. The project plans to reduce system cost by developing manufacturing techniques for welded pipe from alloy 740H. Plans to achieve cost reduction will be achieved through reduced wall thickness of the pipe made possible by the increased hot stress capability of the 740H alloy. While it is very well aligned with the CSP program goals, it is not immediately clear to this reviewer where the technology will find widespread application outside of DOE funded efforts. The project goals and timeline match well with the level of funding.

**Reviewer 2:** This project is focused on developing lower cost methods of producing superalloy components for CSP applications. By considering specific designs and code requirements, the project addresses the critical needs for development of full-scale components, which could accelerate implementation of Gen 3 CSP technology. The Principal Investigator, Dr. Shingledecker, is not only extremely knowledgeable about the metallurgy and relationships between processing and properties of the specific alloy, he is also acutely aware of the unique mechanical and environmental issues associated with Gen 3 CSP applications and pro-active about solving them. This will improve chances of success in obtaining the projects goals and providing value to other relevant applications, despite the significant challenge in obtaining adequate creep strength of thin-walled, welded tubes.

**Reviewer 3:** The goal of this project is to develop methodologies and validate those methodologies for tubes and other piping products. The main approach appears to be welded tubes made of superalloy materials. The application will definitely be in solar energy sector, but also in other sectors for pressure vessels and piping in general. The method is used for making large diameter pipes and so fundamentally the method is not new. The applicability to smaller diameter pipes and for more difficult to weld materials will be new. The techniques suggested are standard, but the application is different. So, the question really is if it is new research or is it advancing current research as good engineering development. My opinion is that it is a necessary development, but not necessarily high risk research into new forays.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 6 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project began on 10/1/2018 and ends on 9/30/2022. The project appears to be substantially on schedule with delays in a few of the tasks. The reduction in welded hot strength of the welded tube measured. Attempts are being made to determine if reprocessing the welded tubes can recover a significant portion of the strength loss. Even without the strength loss recovery, the report states that the results to date indicate a 30% cost reduction can still be realized. The reprocessing task addition will not delay the start of other major task items as it appears to be conducted in a parallel development path.

**Reviewer 2:** The Principal Investigator is keenly aware of the activity required to qualify an alloy and processing method for an industrial application, such as the Gen 3 CSP. To this extent, he has not only designed and implemented a well thought out technical plan, addressing issues on the critical path to application of using welding to reduce the cost of components made of Ni-based alloys, but he has engaged necessary stakeholders and established frequent communication and dissemination of results throughout the formal and informal team. For example, he engaged directly with other investigators investigating erosion, who were less familiar with metallurgy and design issues, to improve the relevance of their testing. Furthermore, the team from EPRI demonstrates that they are very thorough in comparing their results with others, to verify their findings and conclusions.

**Reviewer 3:** The project performance is satisfactory up to now. However, it is a four-year effort. I have no reservation that the team will not continue the same rate of progress and disseminate the data in due course of time. Perhaps the suggestion will be to ensure that the project team include observers from other industry sectors, e.g., piping manufacturing and steam power systems, to ensure that the transition to those industry sectors can also take place without delay or without going through intermediaries.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: All of the tasks proposed and completed appear to be well aligned with determining the feasibility of development of welded pipe from the 740H alloy. In addition, other necessary fabrication techniques will be demonstrated including pipe to header welding and induction pipe bending. In addition study of the creep behavior of the thin sheets will be accomplished for use in the heat exchanger. These tasks important to determining the overall cost reduction potential for using the 740H alloy.

**Reviewer 2:** Score: 5. Comments: Each task in the project adds unique and important value to the overall goals of the project.

**Reviewer 3:** Score: 5. Comments: The tasks are well laid out and the metrics are clear. The planning of the tasks as well as the teaming is good.

**4. What ‘blind spots’ the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Since the 740H alloy is undergoing additional heat treatments and possibly reprocessing in some fashion, are other critical properties also being measured in addition to mechanical strength, creep and fatigue testing? Will properties such as change in corrosion resistance, erosion resistance, etc be important in this application and if so should they be included in the testing matrix for the proposed solution?

**Reviewer 2:** As planned, there doesn’t seem to be any molten salt exposure, static or flowing, and subsequent testing of welded components.

**Reviewer 3:** I think the PI has not shown any blind spots in the project writeup. He has demonstrated that the impact of the work is in solar energy as well as other industries.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I did not identify any stakeholders, organizations or collaborators that are missing from the project.

**Reviewer 2:** Teams developing other solutions. The EPRI team has a vast depth of knowledge and is highly skilled. They could contribute significantly to other teams developing other processing approaches.

**Reviewer 3:** I would suggest bringing in other industry sectors, as mentioned above, to ensure that any manufacturing, quality control, throughput and/or life-cycle cost/reliability aspects are addressed early enough, without having to go through intermediaries.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** I think that the project goals and tasks are well defined and align well with the overall CSP program goals. The project has demonstrated success in meeting the project objectives and has added some task elements in order to further improve the demonstrated strength values obtained so far.

**Reviewer 2:** 1) The EPRI team has developed a rigorous plan to address critical issues in developing a lower-cost method for fabricating Ni-based alloy components for Gen 3 CSP. They are executing this plan professionally and have engaged with component designers, coding bodies, alloy fabricators, other investigators and the materials community to improve the likelihood that their project will have a successful outcome. 2) Additional collaboration between EPRI and other investigators, or expanding the scope of the project to include other materials and processes, would likely be beneficial to achieving DOE’s Gen 3 CSP goals. 3) The project is lacking activity to address the effects of molten salt on the mechanical behavior of the alloys under investigation.

**Reviewer 3:** 1) innovation; 2) fatigue and creep performance of the joints; 3) broaden the target implementation/transition industry sectors.

## Near-Net-Shape Hot Isostatic Press Manufacturing Modality for Supercritical Carbon Dioxide Concentrating Solar-Thermal Power Capital Cost Reduction – $2,500,000

*GE Global Research | Niskayuna, NY | Principal Investigator: Jason Mortzheim*

This project is working to fabricate advanced super critical carbon dioxide power cycle structures for concentrating solar-thermal power plants from metal powders by pressing these powders at high temperatures. This process is estimated to reduce the manufacturing cost of these components by at least half and lower equipment costs. This will enable a U.S.-based supply chain and strengthens the nation's role in advanced manufacturing and high-efficiency power generation.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This new project is to demonstrate the efficacy of powder metallurgy (PM) based near-net-shape (NNS) hot isostatic pressed (HIP) process for fabricating turbine components of CSP power block. The primary material selected for this project is Haynes 282 which is a gamma-prime-strengthened, Ni-based superalloy. The proposed process offers design flexibility for producing parts of complex shape. It is a relatively fast process and capable of reducing production time when compared to conventional manufacturing methods, such as machining, welding and casting. Moreover, the NNS HIP process can be more cost saving by generating less waste material. Weakness: PM-based HIP process inherits certain limitation and risk, such as shrinkage and inferior properties against creep and low cycle fatigue, compared to a cast product of the same component material. While the project team has proposed a plan for mitigating perceived risk, it is difficult to assess the plan effectiveness at this very stage of the project.

**Reviewer 2:** The project aims to utilize Near-Net shape (NNS) hot isostatic press (HIP) process to make turbine components for sCO2 cycle using HA282 powder metallurgy material. If this innovative process works then a $100/KWe or more cost reduction is possible which aligns well with the SETO cost goals. The weakness could be to achieve same as or better material properties such as strength, toughness, brittleness/ductility, creep resistance etc. using the NNS HIP process.

**Reviewer 3:** Well defined team with capabilities to perform the tasks. The methodology could be further applied to other sCO2 turbine parts. On the negative side, GE is funded for a parallel effort from other sources

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 4 | 3 |
| Collaborates with sufficient stakeholders | 5 | 4 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project started on April 1, 2020 and there is no tangible result and sufficient data to facilitate a performance review. The project is led by GE Research with Synertech as a collaborating partner. Synertech will be responsible for developing a HIP canister and producing parts based primarily on HA282. GE Research will perform material characterization and establish necessary database for Synertech's HIP model. Haynes International will be the provider for HA282 powders.

**Reviewer 2:** This project is just starting so many of the questions are not applicable. The reviewer assumes that the project team has been set up well, project plans, tasks and milestones have been well-defined. The reviewer also assumes communications with partners as well as stakeholders are happening without any issues.

**Reviewer 3:** For other components of the turbine, the NNSH Hot Isostatic press is been used. Therefore the risk of failure are low. In house experience can be applied.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks and milestones have been well defined and each serves an important role in achieving the overall project goals. In summary, the project consists of 3 phases. In Phase I, a smaller part of nozzle ring is to verify the capability of NNS HIP and to confirm the manufacturing tolerance. Phase II of the project will produce a turbine casing as a single piece with intricate features. Phase III is to develop NNS HIP capability with multiple materials demonstrated by making a dual-alloy pipe. Most of the tasks are directed to verify if the material properties, e.g. allowable tensile stress, low-cycle-fatigue and creep, of HIP-produced parts are comparable to those of corresponding cast parts. Effort will be made by performing a techno-econo analysis to demonstrate the proposed NNS HIP process can render a 50% cost reduction over traditional manufacturing approaches.

**Reviewer 2:** Score: 5. Comments: The project tasks have been laid out well and align with the milestones and overall project goals.

**Reviewer 3:** Score: 4. Comments: Tasks for this project need to be completed in order to validate the methodology. After calibration and validation of the HIP model, a design review will be useful to go to next step of optimization.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Compared to superalloy components made by casting, e.g. directional solidification, HIP produced parts in general inherit lower stress limit and weaker creep-resistance properties. This will imply shorter component's service life and increased costs for repair and part replacement. In a long run, this would offset the cost saving advantage for production as claimed in this project.

**Reviewer 2:** Material property testing needs to be focused to go hand in hand with process development and making the prototype components.

**Reviewer 3:** Too early to evaluate - frequent design reviews will indicate the path forward.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** As the project directs its primary applications for fabricating sCO2 turbine components, partnering with a turbine OEM could be beneficial. Within GE, both GE Power and GE Aviation have superb technical expertise and could offer potential collaborations.

**Reviewer 2:** This question is not applicable for this project as the project is just getting started. From the project summary all critical aspects are included in the project for it to succeed.

**Reviewer 3:** Involvement of other GE teams specialized in manufacturing as well as suppliers of HA282 materials for processing and advise on the proper application of material properties.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** The underlying objective of this project is to demonstrate the potential of NNS HIP process as a viable alternative to casting or other complex fabrication processes for producing parts of hot section. This is evidenced that the primary material that the project team selects is a Ni-based superalloy, HA282. One of the main advantages of NNS process is to minimize material waste, hence it is economically beneficial. HIP is a relatively well-developed powder metallurgy (PM) process. The process is inexpensive and scalable by varying the size of HIP canister. If the material properties are well characterized and the resulting properties are comparable to those of cast parts, then HIP could render significant economic benefits to SETO program. Overall, a viable techno-economic analysis, as one of the project tasks, will be useful. The HIP PM process might have certain limitation on producing parts with complex internal structures. For parts of hot-section, they often require internal features, such as coolant or sealant passages. This may compromise the value of the project.

**Reviewer 2:** 1) Using NNS HIP process to make sCO2 turbine components such as turbine nozzle ring and turbine casing that can withstand the high pressures and temperatures is innovative and has the potential to reduce costs dramatically. 2) Material characterization and modeling will be key in this feasibility study. It might be worthwhile to ask: What is the desired material property and trying to work backward to set HIP process parameters to achieve the desired material properties. 3) Good project plan with milestones and appropriate team members with the right expertise are in place.

**Reviewer 3:** 1) Evaluation of cost and savings from application of this methodology. 2) Detailed analysis of risks associated with proposed fabrication as well demonstration the improved properties (tensile, creep and low-cycle fatigue). 3) Comparison with other method or materials.

## Advanced Characterization of Particulate Flows for Concentrating Solar Power Applications – $1,352,194

*Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Peter Loutzenhiser*

This project addresses a knowledge gap within the field of particulate flows for concentrating solar-thermal power applications. The team is working to characterize the flow and heat transfer of particulate media over a range of operating conditions, including temperature, particle size, and construction material. Through experimentation and modeling, the team will determine the properties needed for inputs at these high temperatures. These results will provide guidance to the concentrating solar-thermal power industry for ongoing work related to the design and modeling of solar particle heat receivers and reactors.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 4 |
| Set critical challenges to overcome | 6 | 4 |
| Implement a high-risk, high-impact approach | 6 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 3 |
| Advance the U.S. solar industry substantially | 6 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project seeks to characterize fundamentally the properties of granular flow and radiative properties for particulate matter proposed for use in falling particle CSP systems. The intent is to gather critical information that can be used to more accurately model the mechanical and thermal behavior in particle flows.

**Reviewer 2:** This is again an ongoing basic properties project from 2018. The presented results indicate a sound approach and reasonable success. The research is limited of one type of granular media and it is very limited in scope.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 |
| Disseminates results frequently and actively engage partners | 6 | 3 |
| Collaborates with sufficient stakeholders | 6 | 2 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** A strong interdisciplinary team has been assembled to characterize the particle mechanical and radiative properties. Good progress is being made in the work, and results have been published.

**Reviewer 2:** This is basic heat transfer and mechanical properties. Since the team is in the middle of phase 2, it should continue.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The milestones are reasonable, and they are being achieved on schedule.

**Reviewer 2:** Score: 4. Comments: Yes the methodology is well selected.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** I see no blind spots in the project.

**Reviewer 2:** Expend the search to other type of granulated media.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** All needed stakeholders, collaborators are being involved.

**Reviewer 2:** It is (as mentioned above) a basic research project. I consider that involvement of some industrial partners, could provide a different perspective on the methodology.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The particulate property data being collected are needed for accurate modeling of falling particle CSP systems. 2) Good progress is being made in the work.

**Reviewer 2:** Pertinence of the use of granular particles as working media in CSP. There are many other options.

## Thermophysical Property Measurements of Heat Transfer Media and Containment Materials – $1,966,441

*Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Shannon Yee*

This project researches and analyzes the thermophysical properties supporting third generation integrated thermal systems. This team is investigating thermal conductivity, thermal diffusivity, and specific heat across the range of temperatures and materials of interest to third generation concentrating solar-thermal power systems. The team will perform measurements on molten salt chemistries and containment materials, including alloy, ceramic, and cermet materials. This research will be shared to address the knowledge gap in third generation thermophysical properties.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This captures a key need. I think many more challenges are before them in measuring the liquid properties. While they found creeping was an issue on the DSC there are likely additional challenges on thermal diffusivity of liquids. Thermal conductivity is the most difficult property to measure (with viscosity coming in a close second) and if they are able to get good, representative measurements then it would mean that the temperature profile in the receiver and heat exchangers will be better predicted and can be sized appropriately. The budget seems good, but the duration of the measurement is very long. It is unclear if this will cause other issues with DOE's concurrent projects. This is definitely needed and different than other projects. It is enabling, with the engineering properties this cannot make progress.

**Reviewer 2:** The project involves the measurement of thermophysical properties of various fluids and solids relevant to high-temperature CSP. The project is focused on property measurement, requiring new devices to probe the materials and infer the properties. The probe and instrumentation development does not appear to be as high-risk as other projects, but the development of a reliable property base is crucial to accurate modeling and design of high temperature CSP systems. This is a five-year project and it is stated that the "engineering models" which describe the thermophysical properties will come near the end of five years. It would be good to have at least some of these quantitative descriptions of properties available before that time. Perhaps measurement and "engineering model" development should occur in parallel, not sequentially. The successful development of the measurement techniques will impact technologies in addition to the DOE-funded efforts. Again, property measurements including measurements of properties of non-pristine materials will help advance the US solar industry. Strengths: This is a relatively unique project that serves investigators across a broad spectrum of CSP technologies. The research is targeted at thermophysical properties to be measured at high temperatures. The communication with other CSP investigators as to which property data are most important is commendable. Weaknesses: The immersion measurement technique is a bit behind schedule. Radiation heat transfer is not mentioned and may be important in these materials at these high temperatures.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engage partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Were not included in the report, but in general process seemed to be going in a logical direction. Project Results had some discussion of the current photothermal technique with accuracy and precision called out. No other participating organizations, but report shows frequent interactions with NREL. Stakeholders are clearly captured in their work progress.

**Reviewer 2:** The immersion technique was to have been completed at this stage. It is not clear why the budget is at the level it is, and what the "other" charges are for. Knowledge of relevant thermophysical properties of the various materials at the high temperatures of interest is important. The investigators appear to be qualified to make these measurements. The reported levels of accuracy (< 10% for example) are in obvious error and have been clarified by the PI. The development of the property web site is a good approach to disseminate property information to a broad audience. There appears to be an effective collaboration mechanism in place with CSP researchers to identify the most important properties of interest. The measurement techniques being developed are two-fold, an immersion technique for liquids and a photothermal technique for solids. The development of the web site of thermophysical property information is good, but the accuracy of the measurements is not clear based on information in the Report and poster.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: They are making really solid progress and just executing on the thermal property measurement of the solid materials is a good start.

**Reviewer 2:** Score: 4. Comments: The tasks are all interrelated and important to providing CSP researchers with properties that are needed. I am, however, that volumetric radiation is important in these materials at these temperatures and have not been addressed in the materials provided.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Having a NIST collaborator, even informally, to help get this put into NIST achival data would be helpful. Historical information (such as can be found here: https://www.nist.gov/srd/national-standard-reference-data-series, see NSRDS 15 as an example), but is very useful for getting funding and investment as the properties have a quality pedigree associated with them. Having this more formally included with NIST standards would help substantially in reducing future risk.

**Reviewer 2:** Are the measurements repeatable if a second probe were manufactured and used? That is, are the results independent of the probe that is used? Based on the literature, radiation heat transfer may be important in the semi-transparent materials at these temperatures. Radiation has not been mentioned in the Report or the poster and, if important, will call the thermophysical property measurements into question.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Having a NIST collaborator, even informally, to help get this put into NIST achival data would be helpful. Historical information (such as can be found here: https://www.nist.gov/srd/national-standard-reference-data-series, see NSRDS 15 as an example), but is very useful for getting funding and investment as the properties have a quality pedigree associated with them.

**Reviewer 2:** The investigators are encouraged to engage a researcher who is familiar with thermal transport in high temperature semitransparent media to check if radiation heat transfer is important. Although three respected experts in measuring thermophysical properties of materials were consulted, to my knowledge none of these three experts focuses on measuring radiative properties of semitransparent media.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project is good and greatly needed. 2) Properties are very difficult to measure and having pedigree and a referenced standard is very helpful for the community to buy into the work. 3) Critical review of the data, especially key data with good error analysis and bounds on the data, is needed for designers.

**Reviewer 2:** 1) This is a project whose goals affect a broad range of CSP researchers. Property data are important. 2) Radiation heat transfer may be important at these temperatures and for these semitransparent materials. If so, the measured thermal responses will have to be analyzed carefully to account for radiation effects. This extra step will add a level of significant complexity to determination of the measured property values and may also show that radiation properties need to be measured for these materials at these temperatures. If volumetric radiation is important, if it is not measured, and if it is not accounted for in the design of CSP, there is a big problem. 3) The timeline might be juggled a bit to reflect are more parallel measurement/dissemination scheme as opposed to the more sequential scheme described here.

## Additive Manufacturing of Corrosion Resistant Ultra High Transmission Coating Materials for Chloride Salt to Supercritical Carbon Dioxide Brayton Cycle Heat Exchangers – $250,000

*Lawrence Livermore National Laboratory | Livermore, CA | Principal Investigator: James Kelly*

This project is developing an ultra-high-temperature ceramic heat exchanger based on Triply Periodic Minimal Surface geometries, which can only be fabricated by additive manufacturing methods. The goal is to develop a heat exchanger that provide up to ten times higher heat transfer coefficients per unit reactor volume, while retaining smooth features and moderate pressure drop, which enables compact design with high efficiency. It is being constructed from materials known to retain their strength at temperatures between 1200 and 2100 degrees Celsius and is expected to be compatible with molten chloride salts and supercritical carbon dioxide.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Additive manufacturing of heat exchangers has potentially high impact for smaller HXs for niche applications where performance and/or compactness is at a premium. CSP plants may be one of these applications, but given the large physical sizes of power cycle HXs, AM HXs are fairly early stage for next generation CSP plants. There is currently no evidence that AM methods are sufficient for making reliable HX units, especially considering that AM processes inherently include voids and discontinuities in the HX material structure that are sensitized sites for corrosion and fracture under thermal or pressure cycling conditions.

**Reviewer 2:** The project is well organized and well-structured with clear milestones. There is no apparent weakness in the project. There are lots of uncertainties/risks in the project, especially if the 8 UHTC will lead to three solutions that are worthwhile for pursuing for future heat exchanger designs. A key positive of this effort is the cost of the project is quite low, and it is important that the data from this project is properly disseminated as it can be very useful basic materials data.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 3 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1**: More information is needed on the specific quantitative targets of the proposed work. What are expected corrosion targets, and how will they be met with the inherent porous structure of AM parts? What are the material strength targets, and how sensitive are they to parts with material discontinuities? Need to define how corrosion is occurring. What are the mechanisms? Are corrosion failures related to average corrosion rate, or is corrosion attacking pores and discontinuities introduced from AM process? Project should include initiative to include SEM imaging of exposed samples in order to determine the corrosion mechanism.

**Reviewer 2:** The stakeholders in this research are the materials scientists and engineers who can apply this set of suggested materials in heat exchanger designs. To that effect, the project should perform well. The key is if the sorting of the materials based on the criteria listed will indeed identify three well qualified materials as the PI and his team suggest.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Tasks are missing regarding the determination of corrosion mechanisms. Also need tasks indicating the range of manufacturing methods used to make samples since the AM manufacturing parameters are likely to significantly affect as-made coupon properties.

**Reviewer 2**: Score: 5. Comments: The tasks are clear and the milestones are being met as part of executing the tasks. The uncertainty is what if the three materials are not found to meet or exceed the criteria/metrics set up.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Structural integrity of a given sample will rely both on raw material properties as well as manufacturing method. Need to understand how both of these factors will be screened when running sample material property tests.

**Reviewer 2:** This reviewer appreciates the frank discussion in Section 11 of the report, especially on the material availability and possible technical problems with binder jet additive manufacturing process. In a one year project, even with the experience and expertise of LLHL and ORNL in the area, identifying, acquiring and using such materials in binder-jet process and then to do the testing and analyze the results appears a bit risky.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Commercial acceptance of AM HXs will be very challenging. Team needs to interface with ASME or other regulatory bodies to determine what needs to be qualified before such components will be accepted by local pressure vessel and boiler codes.

**Reviewer 2:** The team needs to expand the stakeholders and bring in potential users of such materials and their comfort level to integrate the material with binder jet as well as other manufacturing processes. Quality of the parts, consistency between the parts and between lots, for example may be issues. However, if successful, this project should be able to suggest new materials which can augment the selection of materials for additive manufacturing of high temperature ceramics, which is a new area for additive manufacturing.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) SEM imaging of corrosion samples necessary to determine exact mechanisms of corrosion in AM parts. 2) Team would benefit from more engagement from regulatory bodies and commercial offtakers to determine if AM manufactured HXs will ever realistically be accepted for power plant applications. 3) work has high potential to be effective in other industries where more compact and extreme high efficiency HXs are needed, i.e. aerospace and vehicles.

**Reviewer 2:** 1) identifying the consistency and quality of the additively manufactured test coupons from the three selected materials; 2) success with binder jet processes and subsequent post processing; 3) creep and fatigue characteristics at high temperatures.

## Novel Corrosion and Erosion Protective Amorphous Alloys Coatings – $1,146,108 ♦

*LM Group Holdings | Lake Forest, CA | Principal Investigator: Evelina Vogli*

This project evaluates and applies amorphous alloy coatings to molten salt system components, such as impellers, sealants, pipes, and tanks, to enable operation at temperatures above 700 degrees Celsius. Amorphous metals combine ultra-high strength, high hardness, and ductility—the ability to stretch—into a single material. In addition, they are more resistant to corrosion compared to conventional metals. The amorphous alloy coatings will be applied to molten salt system components using a high-velocity oxygen fuel coating technique. This novel approach will improve the overall properties of the manufactured components, helping to increase throughput in concentrating solar-thermal power systems.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Effective corrosion and erosion resistant novel amorphous metal-based coatings for high temperature (above 700C) to pcm (molten salt) heat storage tanks, impellers, sealants and conduits, in the context of CSP, indeed align well with this topic's goals and support thee SETO mission, and the proposed approach to their selection and application is promising. It seems that the proposal is not addressing the critical need for low cost. Selection of coating materials, their application, and long-term testing for corrosion and erosion. More information is needed for effective planning for choosing various materials and for their application. Cost reductions should be considered. Contingency plans are not shown. This is a medium-risk medium-impact project in the context of CSP. They would match well the funding and duration if the proposed goals are met, but perhaps underestimated the needed effort and duration. They would add significant value to existing research outside DOE-funded efforts, if the proposed goals are attained. If the goals are met, they would advance the US solar industry. Effective corrosion and erosion resistant coatings for high temperature (above 700C) to pcm (molten salt) heat storage tanks, impellers, sealants and conduits, etc., in the context of CSP, indeed align well with this topic's goals and support thee SETO mission to commercialize CSP, and the proposed approach to their selection and application is promising. It seems, however, that the proposal is not addressing the critical need for low cost. Strengths: A promising approach for developing effective corrosion and erosion resistant novel amorphous metal-based coatings for high temperature (above 700C) to pcm (molten salt) heat storage tanks, impellers, sealants and conduits, in the context of CSP. Weaknesses: Strong uncertainties in the chances to meet the goals, the methodology for effectively reaching the goals inadequately described, no contingency plans, seemingly lack of cost considerations.

**Reviewer 2:** The goal of this project is to study the preparation and corrosion performance for amorphous metal-based coatings in molten salt at high temperatures. Application of the amorphous metal coatings was by thermal spraying technique and the project includes understanding how to spray ID and other complex coating applications areas. Corrosion and mechanical testing were planned to evaluate the performance of the coating and compare it to the base metal performance under identical conditions. The project planned to achieve a bond strength of greater than 10,000 Ksi. The project began 8/26/2018 and ends 8/25/2020. The goals of the project are generally well aligned with the overall goals of the CSP program.

**Reviewer 3:** The project Novel Corrosion and Erosion Protective Amorphous Alloys Coatings led by Dr. Vogli at LM Group Holdings has developed amorphous metallic coatings offering significant corrosion resistance to either ferrous or nickel-based alloys. In addition to materials development, LM Group Holdings has demonstrated application of the coatings via commercially viable processes. Key issues, such as corrosion rate, the ability to coat the ID of piping, porosity, microstructure uniformity, cohesion, adhesion and hardness, and thermal cycling have been investigated thoroughly. Application of the coatings to more complex shapes may prove challenging, but the technology could significantly reduce the cost of CSP systems by enhancing the lifetime of alloys with suitable thermomechanical properties or allowing lower cost alloys to be used. The coatings may have value in other technological applications were the lack of dislocation or grain boundary displacement or transport mechanisms could be extremely beneficial.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project just started so it is impossible to form a solid opinion, but it is run by a competent team. It is progressing but met some challenges in applying the coating, and took measures to overcome them.

**Reviewer 2:** The goals and milestones of the project are generally aligned with the overall goals of the CSP program. The report lists the milestones and indicated all but two milestones (including final report submission) have been completed. The project appears to be on or ahead of schedule and it appears that significant progress in demonstrating that the amorphous metal coatings significantly reduce the corrosion rates when compared to the underlying base alloys under similar conditions. The project has produced 2 conference, one journal and one patent application which is good for the length of time and the nature of the experimentation. While the report does not list the milestone due date nor the actual completion date, it is assumed that all the completed milestones were met on-time as no description of any delays in meeting any of the milestones is included. The milestones do not list quantitative measures for the corrosion rate, bond strength or other material performance criterion, but are written in a qualitative fashion. Since the hot corrosion rates measured were reportedly zero in the molten KCl-MgCl2 mixtures at 750C nor in the carnallite salt exposures, it is suspected that the coatings would have performed well against quantitative targets if these have been defined. Coatings produced were described as dense and with good bonding but no quantitative data is provided. Overall the project appears to be on-time and on-budget.

**Reviewer 3:** LM Group Holdings coordinated an outstanding collaboration with Oak Ridge National Laboratory and Savannah River National Laboratory. Results from the work have been communicated at Technical meetings. The project could benefit from collaboration with CSP component designers so that the specific dimensions of components requiring coating could be included in the study.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, with the reservations expressed above. Clear contingency plans are not shown.

**Reviewer 2:** Score: 6. Comments: Overall the project appears to be structured well with tasks that are necessary to determine the potential for the amorphous metal coatings studied to substantially reduce the corrosion which might be experienced by the base metal alloy in the molten salt exposure environment.

**Reviewer 3:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** The challenges of selecting, preparing and applying the optimal coating materials and processes that results in coatings that have the necessary long-term corrosion and erosion protection may require many difficult analyses, tests, and decisions, and I wonder whether this was taken adequately into account in the proposal duration and budget. Cost of the coating was not considered/shown in the proposal, but is obviously important.

**Reviewer 2:** I think that given the scope and goals of the project, I did not identify any blind spots for the completion of the project as planned. Some additional future questions might be: Is the structure of the coatings being evaluated before and after exposure - i.e. do they remain amorphous or do they crystallize, and if they crystallize do the grains grow with time under the high temperature molten salt exposure) in order to contribute to the understanding of the mechanism of improvement in the corrosion resistance and be able to factor into the models for lifetime predictions. For the corrosion testing related to coatings, is there a model or measures that are currently being evaluated to translate coating performance into projected lifetime of the components given the fact that the coating thickness is relatively small (and therefore the corrosion rate may be low for a period of time and then increase rapidly at a later time as the coating is degraded) and non-uniformities in the coating quality over the entire component surface may exist?

**Reviewer 3:** Although the PI has tested adhesion and thermal cycling behavior, it is not clear if this testing covered rates experienced during start-up, shutdown, and unplanned transients. Unplanned events are typically those that lead to failure since they may exceed design criteria.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The project seems to be well staffed, but should benefit from cooperation with designers, manufacturers and users of high temperature phase change heat exchangers, especially large ones, as well as of CSP systems.

**Reviewer 2:** I did not identify any missing stakeholders, organizations or collaborators to successfully meet the stated project goals.

**Reviewer 3:** CSP component designers.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Significantly improve the explanation and solutions planning of the encountered technical problems and the proposed way to overcome them. 2) Significantly improve the explanation and optimal solutions planning and execution for achieving the goals. 3) Develop contingency plans, including, if possible (and with my full respect to the team's experience and competence), more cooperation with designers, manufacturers and users of high temperature phase change heat exchangers, especially large ones, as well as of CSP systems.

**Reviewer 2:** The project is structured appropriately with goals that are well in line with the overall program goals of the CSP. The project is on time and on budget. The project has achieved the stated milestones and the results to date show significant reduction in the corrosion rate of the amorphous metal coated samples compared to the base metal alloys in the high temperature molted salt exposure experiments.

**Reviewer 3:** 1) This project has developed coatings that appear extremely effective against corrosion. 2) Since they involve novel, amorphous metals they may have significant benefits, or weaknesses, over state-of-the-art solutions. 3) Additional long-term testing in flowing molten salt environments and thermal shock testing are recommended.

## Ceramic Castable Cement Tanks and Piping for Molten Salt – $1,768,424

*Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Asegun Henry*

This team is developing ceramic castable cements to be used for thermal storage tanks and piping, which carry and store high-temperature molten salts at 750 degrees Celsius. This project is also investigating engineered high-temperature cements that can be used to form a self-insulating thermal storage tank. These ceramic castable cements are being chemically engineered to resist corrosion and penetration by the high-temperature salts of interest for the liquid pathway.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 3 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The goal of this project is to demonstrate that castable ceramic compositions developed can resist corrosion and penetration by molten MgCl2-KCl salt by fabricating and operating a lab scale ceramic tank at 750C in a pumped closed loop configuration. In addition, the project will demonstrate that liquid-tight seals between pipe sections are maintained under pressurized conditions. Techno-economic analysis will be accomplished to demonstrate that the projected total costs for the cast ceramic tanks and piping will be much less expensive than the nickel alloys which would otherwise be required. The goals of this project are well aligned with the goals of the program and the mission of SETO. The goal of the project, approach and expected impact match well with the funding level and timeline.

**Reviewer 2:** Cost reduction with advanced materials. Repairing issues/defects along with qualification of materials for use are both challenges. From section 14: ...and materials cost of $2.5/kg; the cost of each pipe is estimated to be $1258/m, which is lower than that of correspondingly sized Ni alloy piping. There is a discussion about the cost reduction in using these materials, would be helpful to include an apples to apples comparison to see how large the payoff could be. In section 12 there was an indication that it would 25% lower, which is still relatively expensive in view of all additional hurdles that would be need to be addressed. Seems relatively expensive, but timing is good. This seems to be an obligatory advanced materials project, but it seems unlikely that this would be used for a pressure containing structure without significant testing and qualification of the fabrication process. I don't think that, on the time scales we are discussing, that this project will advance the industry.

**Reviewer 3:** This project addresses a critical need for molten salt based thermal energy storage, hence CSP systems: economical storage of corrosive, molten salts. The Principal Investigator, Dr. Asegun Henry, has teamed with Purdue and Westmoreland Advanced Materials, who both contribute key technological capability to the project. MIT's role, in fact, appears to be mostly testing and component design. Due to the unique chemistry of the molten salts, unique cement chemistries are required for corrosion resistance. Therefore, the materials developed in this project may only be relevant to molten salt storage and the particular molten salt chemistry investigated at that. Nevertheless, proof-of-concept that castable cement is a viable option for thermal storage would have a significant impact on thermal CSP technology economic viability. The primary challenge related to this work is likely the joining and sealing of components, however Westmoreland Advanced Materials appears to have made an interesting discovery that shows promise in overcoming this challenge.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project began on 10/1/2018 and ends on 10/1/2020. An intermediate go/no go decision point was scheduled for 7/15/2019. Progress is being made on measurement of the corrosion rates and penetration extent for the compositions developed. The molten salt circulation loop has been designed, constructed and commissioned with a 17 hr 750C molten salt test conducted. Results have been presented at a conference. Thermo-mechanical modeling has been performed but the results are not listed. Addition of carbonaceous materials has been found to inhibit salt penetration. The milestone section does not list the milestone log with planned date, actual date completed and description of milestone status, so it is not clear if all the milestones have been met on time and what remaining milestones and dates are yet to be completed. The cumulative budget percentages for the actual spending does not appear to be showing up properly, however, the project does appear to be on budget at this point in time.

**Reviewer 2:** No red flags. Cost of previous projects are given, but goals are not given. Appears as though they are trying to get to 25% lower cost than Nickel alloys. Looks like work is distributed. Could use a component developer, like a tank builder or pipe fitting company, to weigh in and provide feedback.

**Reviewer 3:** The project, led by MIT, combines designers (MIT), materials specialists (Purdue), and industrial manufactures (Westmoreland Advanced Materials). Given the composition of the molten salts in question, it is likely that Westmoreland could develop a compatible material; therefore, the non-testing budget appears a little plump. Nevertheless, fabrication of relevant parts and testing them with flowing molten salts at the appropriate temperature is critical to demonstrating proof of concept, similarly with methods of joining and bonding. The project team addresses these issues with logically planned, quantitative milestones.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in the project does add important value to determining the feasibility of using castable ceramic tank and piping and therefore supports achieving the overall goals of system cost reduction.

**Reviewer 2:** Score: 5. Comments: These all seem good, but are missing tasks/milestones around qualifying casting process or having some procedure for doing so. This seems a bit like 3D printing where the material and process are intimately linked together and should be explicit about that.

**Reviewer 3:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I did not identify any blind spots for the project to achieve the goals and planned work as stated. Some additional things that may be considered in this or a future project may include measurement of the oxidation rate of the carbonaceous materials being used in the composition for salt penetration mitigation. In addition, it may be valuable to measure strength and strength reduction as a function of thermal cycling. An analysis of the effect of salt being cooled in the tank below the solidification point on the mechanical integrity of the system may be beneficial.

**Reviewer 2:** This project seems similar to 3D printing in that the material and process are intimately linked together. The casting process and parameters will need to well documented and, if they are to be proprietary, there should be some type of 'proof' or quality assessments developed to build confidence in the material.

**Reviewer 3:** Although Westmoreland has discovered fortuitously that molten salts don't wet certain carbonaceous materials, joining and bonding development doesn't appear to be well-planned. Methods of repairing tanks would also be a valuable addition.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** I did not identify any missing stakeholders, organizations or collaborators for the project to achieve the stated tasks and goals.

**Reviewer 2:** Tank Designers/fabricators to provide honest feedback.

**Reviewer 3:** A CSP system designer might be able to make sure that component designs are compatible with system requirements.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** The project is making progress toward the stated goals. The testing system has been commissioned and castable ceramic compositions have been determined and the salt corrosion/penetration rates have been determined. Testing of the cast ceramic piping in the molten salt flow loop is anticipated in the near future.

**Reviewer 2:** 1) Will this need to be in a code or qualified? If it's going to be anything more than a liner then it's a non-starter for CSPs needs. 2) Supply Chain assessment - how specialized of equipment is needed to make this work? Will the current supply chain allow for this new material and processing or will significant changes need to be made? 3) Field repairs - suggest making a side project where they have to damage and repair a pipe or, at the very least, replace a section. It this cannot be done the technology won't work as it stands.

**Reviewer 3:** 1) The project is designed well, and being executed well, for lab/bench-scale proof-of-principle of using castable ceramic cement as molten salt tanks. 2) MIT's contribution is design and testing, but it is only 1/3rd of the project budget. 3) More, scientific and logical effort on joining and sealing may be beneficial to the final outcome.

## High Temperature Pumps and Valves for Molten Salt – $1,892,185

*Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Asegun Henry*

This project develops high-temperature liquid-phase pumps and valves that use novel ceramic-metal composite materials that are stable at high temperatures, instead of steel or nickel-based alloys, to create components that can reliably operate with molten salts at 750 degrees Celsius. Low-cost novel refractory materials and processes are used to form these materials into the complex shapes needed to form pump and valve components. The team is testing the integration of these components in both liquid pumps and valves and investigate whether any new corrosion mechanisms arise due to salts flowing through the pumps in comparison to stagnant salt. This will enable the scale-up of a liquid pump that can be implemented in a multi-megawatt flowing molten salt loop with high reliability and used in third generation concentrating solar-thermal power plants.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 4 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project launched in October 2018. It has as its objective the design of pump components whose temperature ceiling is extended to over 700C. The relevance of such work to CSP systems is clear, since all components in a CSP system need to withstand higher temperatures in order to reach the DOE-stated goals for thermal efficiency. With the length limitations of the report it was no possible for the PI to describe the distribution of effort. There are three graduate students (one at MIT and two at Purdue, 100% of time for all), one research scientist (at MIT, 33% of time), and two post-doctoral fellows (at Purdue, 100% of time for both) involved in this effort, which, without explanation, may seem excessive. The project progress description is necessarily limited in length and the involvement of all personnel is not included.

**Reviewer 2:** This aligns well. Repairing damaged refractory components was not listed and if not able to be readily overcome is potentially show stopping. This is high risk in using refractory materials for this purpose. One problem is the use of a inert system at the small scale vs. having to make the small scale system work to enable a reasonable design at scale. Air will be present and will begin to degrade carbon structures. The funding seems relatively high, but hardware development should be more representative given the cost. Hardware development is a worthy pursuit and done by a lesser number of the currently funded projects. Work being done by MIT and Purdue should be used by Flowserve as the partnership has the higher risk activities taking place at the universities at smaller scale.

**Reviewer 3:** The project started 2018 it is advanced development stage. The team has demonstrated ability to overcome technical difficulties. If successful, the project will demonstrate capability to provide critical components (f high temperature pumps and valves) or sCO2 molten salt full size plants. The concern at this stage would be (in case of failure) what might be alternative materials

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 4 |
| Disseminates results frequently and actively engage partners | 3 | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 6 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The molten salt circulation look for use in testing the new pump design has been built and tested. Some of the pump components designed using new high-temperature materials have been fabricated. The work is progressing and seems promising.

**Reviewer 2:** Budget seemed a little high, but it's a minor point. No particularly quantitative and difficult to assess, should include journal publications and not only conference publication/presentation.

**Reviewer 3:** The project is in advance stages and at this junction the only alternative is to complete the program. As always, a more detailed plan with go/no go milestones could be help to avoid delays.

The team should (as mentioned above) have a very detailed plan for alternative and managing potential set-backs or delays.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project uses a reasonable approach and associated timelines for achievement of each of the tasks. Each task is necessary in the accomplishment of the work.

**Reviewer 2:** Score: 6. Comments: These tasks seemed to be clear and in good order.

**Reviewer 3:** Score: 4. Comments: This is a chain program, with all steps are important - The team should explore in more details the “what if” type of potential failures. For a reviewer such plan provides reassurance of successful recover.

**4. What ‘blind spots’ the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** I see no obvious blind spots.

**Reviewer 2:** Refractory materials need to have a way to be repaired in the field. If this is not possible to perform a field repair to fix small issues, then this will not be scalable - no technology developer would take it on as the risk is too high.

**Reviewer 3:** What assurance is provided for alternative material if the selected refractory material selected will not achieve expected results.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It appears the PI has engaged the appropriate expertise at Purdue for design and fabrication of the new, higher-temperature pump components.

**Reviewer 2:** Team would benefit from a systems integrator to help provide direction/guidance to ensure that the project is moving in a direction for scale up and deployment.

**Reviewer 3:** Some industrial partners with experience in manufacturing and future “scale-up” for the product. The challenge is especially complex for valve and full scale VTP operating with ternary chloride salt at 750C.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** The project seems to be making progress in meeting the objective of designing and fabricating a molten salt pump with elevated temperature ceiling.

**Reviewer 2:** 1) Practical considerations in working with these materials. Can they be repaired? If air rushed into the system at 750C would the material used have issues with auto-ignition or generally fail? Simple furnace tests should be performed if not already on representative geometries/sizes to ensure there isn’t a showstopper. 2) Processing Conditions / Codes & Standards -- many of these materials are relatively new for the application. Does there look to be a issue with bankability (i.e. doesn’t fall under a given code) in moving forward? Also, along the same lines, are the processing conditions (or inspection criteria) rigorous enough at the small scale that this work doesn’t need to be re-done after scale up? 3) Supply Chain - does getting these materials require any unique or new additions to current supply chains?

**Reviewer 3:** 1) How to meet the stated design goals for the use refractory materials in in a pilot demonstration. 2) What are the alternatives in case that the material chosen is not compatible with molten salt operating conditions. 3) What if the goal of design of a pump form conventional Ni-based materials is proven to work OK for a 2MW pilot plant?

## Solid State Solar Thermochemical Fuel for Long Duration Storage – $2,000,000

*Michigan State University | East Lansing, MI | Principal Investigator: James Klausner*

This project is developing a low-cost, zero-emission, solid-state fuel that enables energy storage for short or long periods. This environmentally sound fuel can be stored in a bin until it is used to provide low-cost solar energy storage. Since it can be readily scaled up to 100 megawatts, this novel fuel will aim to be economically competitive at long durations and large capacities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 6 | 4 | 4 |
| Implement a high-risk, high-impact approach | 6 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 2 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 1 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** It is not clear how long-term energy storage will advance the solar energy industry. High temperature central receiver plants will need to have a high utilization in order to amortize its cost over long operation times. But generating fuel for long term usage would not help its high utilization; at best, solar power systems should have up to 24 hours of storage, and be placed in good-solar resource location. If the goal is to demonstrate a high temperature production, there are other materials that need high temperature sources and that can use a renewable energy source to reduce their carbon footprint. This project creates solar energy source for a new fuel, which does not have a supply and demand chain. This project has very little chance of succeeding: it has a very early description of a completely novel technology, but because little is known, it deceptively appears as a simple system. The budget level is too high for investigating a novel concept, tasks that should be done through modeling. And the budget is too low to have any chance of getting to a meaningful demonstration.

**Reviewer 2:** The basic idea and exploratory work on developing a solar heated reactor for producing fuel that could be stored and then oxidized as needed to produce heat is well known and attractive. The fuel is produced by using concentrated solar radiation in a falling-particle, reactor to reduce Mg-Mn-O at >1350°C, then its oxidation supplies heat of up to 1500C for electricity generation or industrial processes, and then returned to the reactor for regeneration. The process aligns well the proposed project's goals with this topic's goals and supports the SETO mission. At the same time, much more needs to be known about the reactor details, and cost Expected challenges include long-term durability and efficiency of the reactor and overall system, as well as about the operations' (including reactions') transport rates, kinetics and reversibility, and cost. Contingency plans are not shown. It is a high-risk high-impact approach, conditioned by the cost and stable long-term operation. The project's goals, approach, and expected impact match very well with the level of DOE funding and planned project duration. They add significant value to existing research outside DOE-funded efforts. If the goals are met, they would advance the US solar industry significantly. Strengths: A reasonably innovative approach for developing a system for storing solar energy at about 1300C by conversion to fuel that can release heat at ~1500C. Weaknesses: Many uncertainties in the design and steady long-term operation.

**Reviewer 3:** The proposal directly addresses the development of a novel thermochemical energy storage concept. Some discussion was available that addressed the materials issues, and the material handling issues. The Report would have been more helpful if additional challenges would have been briefly identified. The approach appears to be novel, involves very high temperatures, and appears to have the potential to be an attractive energy storage option capable of delivery thermal energy at very high temperatures (1500 C). The three-year project duration seems appropriate. Without more details, it is difficult to comment on the amount of funding. However, the project does involve significant experimentation. The proposed approach is novel, and the research will likely spin off results of interest to a broad scientific and technical audience. The proposal directly addresses the challenge of high temperature thermochemical energy storage for CSP. Strengths: This is a novel approach to energy storage. If successful, the project will have an important impact on CSP and perhaps other intermittent energy production technologies. Weaknesses: The overall conversion efficiency is not that impressive.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 3 | 5 | 3 |
| Collaborates with sufficient stakeholders | 3 | 5 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** I awarded low scores to the questions above because the project has not started. The investigators should include industry partners (technology providers and commercial project developers) in order to understand the challenges that novel technologies like the one proposed here will face in order to achieve a pilot commercial demonstration project.

**Reviewer 2:** The project just started so it is impossible to form a solid opinion yet. The PI-s and their past work and performance are good, but their current selection of stakeholders, and dissemination, if any, are absent in the report we received.

**Reviewer 3:** Milestones were not listed in the Report. This is a new project. Some quantitative technical (e.g. standard deviation on the actual particle mass flux, 10 percent loss in chemical energy over 30 days) and economic (e.g. cost per kg of the storage medium, levelized storage cost) metrics were included in the report such as a standard deviation of the particle mass flux. It was not clear how the technical and economic metrics are linked. The parasitic losses involved in the conversion of (1) solar energy into the CSP tower to (2) heat delivered by the oxidation reactor (about 50%) seem high.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project summary did not include a breakdown of tasks. The overall project tasks and responsibilities are reasonable for the proposed scope and timeline.

**Reviewer 2:** Score: 5. Comments: Yes, with the reservations expressed in previous responses about lack in some areas.

**Reviewer 3:** Score: 4. Comments: The tasks are briefly described in the materials provided for review. There is little material to base comments on.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The concept, as presented in the report and poster, is deceptively simple. So many issues will appear in order to make this work, that the PI nor industry partners (not included in the project) can identify at this moment.

**Reviewer 2:** Much more needs to be known about the reactor details, and cost. Contingency plans are needed. Appropriate stakeholders and expert collaborators from the power generation and solar power generation would be useful.

**Reviewer 3:** The investigators might also focus on how to reduce the parasitic losses, which appear to be relatively large.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The investigators should include industry partners (technology providers and commercial project developers) in order to understand the challenges that novel technologies like the one proposed here will face in order to achieve a pilot commercial demonstration project.

**Reviewer 2:** The report does not show the named PI-s collaboration with others, and it would be advisable to include experienced expert collaborators from the power generation and CSP generation industries.

**Reviewer 3:** The team appears to be appropriate to meet the project objectives.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project will not significantly advance the solar energy industry, as it proposes to create a new fuel with no demand not supply chain. 2) This concept should be demonstrated through modeling and simulation, for which the budget is too high. In order to demonstrate this system, the budget and timeline would need to be much larger than what is allocated to the project. 3) The investigators should include industry partners (technology providers and commercial project developers) in order to understand the challenges that novel technologies like the one proposed here will face in order to achieve a pilot commercial demonstration project.

**Reviewer 2:** 1) Much more information needs to be described and known about the reactor details, and cost. 2) Contingency plans are needed. 3) Appropriate stakeholders and expert collaborators from the power generation and solar power generation industries would be useful.

**Reviewer 3:** 1) This is an interesting, high-risk potentially high-reward project that directly addresses a key bottleneck (high temperature thermochemical storage) in reducing the cost of solar power. 2) The approach appears to be novel. 3) The project is just starting, and the team appears to be well positioned to address the scientific and technological challenges.

## Oil-Free, High-Temperature Heat Transfer Fluid Circulator – $1,678,243

*Mohawk Innovative Technology | Albany, NY | Principal Investigator: Hooshang Heshmat*

This project is working to develop a maintenance- and oil-free high-temperature heat transfer fluid circulator for gas-based third generation concentrating solar-thermal power systems through research, design, and testing. The heat transfer fluid circulator is designed for system simplicity, maintenance-free operation, high reliability, and reduced capital and operating costs by isolating the drive from the heat transfer fluid and designing foil gas bearings and seals that are able to use the heat transfer fluid as lubricant.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 6 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** In the context of CSP and other advanced energy applications, a >50% efficient oil-free low-cost SCO2 (or other gases) compressor that operates reliably for long periods at temperatures of 700C+ and pressures up to 25 MPa, indeed aligns well with this topic's goals and support the SETO mission, and the proposed recognition of the key associated issues and the approach to its design and construction is promising. More information is needed for effective planning for choosing an optimal design path to high efficiency and long-term operation robustness, and appropriate cut-and try testing. Contingency plans are not shown. This is a medium-risk high-impact project in the context of CSP. They would match well the funding and duration if the proposed goals are met, but it seems that the long delays in acquiring designed components will extend the expense and duration. They would add significant value to existing research outside DOE-funded efforts, if the proposed goals are attained. If the goals are met, they would advance the US solar industry significantly, since there are very few compressors and systems in existence that could attain the planned goals, and they all are in the experimental stage (as far as I know). A successful system also has significant export potential.

**Reviewer 2:** Develop of this new design of a new heat transfer fluid circulator is commendable. The project is a good design engineering effort. The nickel-based superalloy additive manufacturing fabrication is (can be) a challenge; but not enough details provided to comment on the issues the team may face.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 4 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project is progressing but met some challenges in acquiring some key components and took measures to try to overcome them. Impacts are measured appropriately, but delivery delays create a significant problem Results are disseminated in appropriate meetings and conferences. It seems that the PI should be actively engaged with Brayton Energy, but it was not described in the report. It was not reported that they collaborate with sufficient stakeholders, such as power systems, compressor manufacturers, and CSP experts.

**Reviewer 2:** The performance of the team is good. The goals are appropriate and relevant. The timeline is appropriate. There may be applications of the technology beyond the immediate solar energy area to a broader industry base.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project, with the reservations expressed above. Clear contingency plans are not shown.

**Reviewer 2:** Score: 6. Comments: The tasks are clear and represent the evolution of the successive tasks. Thus, I find them relevant and appropriate. The manufacturing aspects may be a bigger challenge, but they also likely will have a broader impact.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** It is important to pay more attention to detailed planning of the partially cut-and-try methodology for effectively reaching the goals in view of the experienced and potential challenges, and create clear contingency plans.

**Reviewer 2:** I did not see any blind spots on the part of the PI or the team. However, I was surprised by the large budget being sought by the team, and I did not see a whole lot of details justifying that (not a requirement for the team).

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The project seems to be staffed with experts in turbomachinery development, but should benefit from cooperation with designers, manufacturers and users of high temperature power generation systems, including CSP.

**Reviewer 2:** I do not see any missing stakeholders in this project.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Significantly improve the explanation and solutions planning of the encountered technical problems and the proposed way to overcome them. 2) Significantly improve the explanation and optimal solutions planning and execution for achieving the goals. 3) Develop contingency plans, including, if possible, more cooperation with developers of the rest of this power system components, and designers, manufacturers and users of high temperature power generation systems, especially those using SCO2.

**Reviewer 2:** 1) cost; 2) manufacturing risk; 3) fabrication using additive manufacturing of this class of alloys will have a wider impact beyond solar energy.

## Electrochemical Control for Corrosion in Molten Chlorides during Concentrating Solar-Thermal Power Plant Operation – $498,851

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Judith Vidal*

Due to their high thermal stability and low cost, molten chloride salts are a promising heat-transfer fluids for concentrating solar-thermal power plants. However, associated corrosion concerns must be addressed. This project focuses on designing electrochemical methods and reactors for controlling and mitigating identified corrosion mechanisms expected during plant operation. Through redox control mechanisms, the team uses electrochemical elimination of corrosive impurities formed by salt hydrolysis in the presence of oxygen or water. If galvanic coupling occurs, the team plans to use cathodic protection of dissimilar alloys. These approaches aim to keep corrosion to less than 20 microns per year.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 6 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This aligns very well and clearly with the program goals. The critical goals are missing, in my opinion, a few items. Missing details around cost, if the cleanup system is too expensive then it would be a show stopper. Also, there needs to be better aim at simplicity of operation. There is so much that is being called out that it is hard to believe that such a system would be attainable within 5-10 years of development. Simplicity is key to ensuring functionality. This might not work and that would likely mean the technology, as a whole, would fail to be economically viable. Given the very recent start to the project this seems fine. This project effectively focuses on different techniques to modify and adjust the chloride redox potential. This is different than that other items considered as part of this review. Success on this project is considered enabling. This project is definitely exciting and going in the right direction. It's just started so it is very difficult to know if it is on track or possible.

**Reviewer 2:** Corrosion in molten salt CSP systems is a perceived problem. The project proposes electrochemical control of the corrosion inducing species by utilization of magnesium and/or zirconium anode/cathode systems. The project is very well aligned with the goals of the overall program. Electrochemical corrosion control is a well-established technique in other industries and therefore provides significant background information to draw upon, but at the same time, the particular high temperature molten salt environment posed by the current program goals is new and requires study and validation of the concept. The project just began on January 1, 2020, but it seems good progress is already being made. One suggested additional area of study might include evaluation of the particle size distribution of the solid particles which are formed. The project report states one of the strategies is to "Localize the production and precipitation of purification byproducts, especially particles in the CSP loop to only the electrochemical subsystem; thus, easily implement the physical separation of these, thus avoiding damage to components if it flows with the salt in the CSP system." It is not clear what size particles will be formed and if they are very small, how they will be removed from the flowing molten salt system. Addressing the question of what particle size distribution of solid particles will be formed and based on this what removal strategy will be employed may be beneficial to realizing such a system in the actual operating environment. Overall, the project is well defined, the objectives are clear and meaningful in the context of the overall program goals, and it appears the investigators are well on their way to accomplishing the stated goals of the project.

**Reviewer 3:** Electrochemical corrosion is a major concern with high temperature chlorides in Gen 3 CSP. This project seeks to mitigate that by utilizing sacrificial anodes. The project is very useful for the higher temperature CSP systems, and thus is very relevant to the SETO. The authors state the goals, methods and scientific challenges very clearly. I wished that they also included a timeline for the activities. However, considering that this is only a year-long (or less) effort that primarily explores the feasibility of a concept, one can ignore the absence of the timeline. The approach is well written and the end points are clearly identified.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 6 |
| Disseminates results frequently and actively engage partners | 6 | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The time between milestones seems very short and I question if it will be possible to accomplish the ambitious scope within the time period provided. In looking at section 13, the impact is difficult to quantify. I tend to agree with the statements made, but there is not any real quantification associated with it. Lacks a technology developer or component developer to help guide direction of work. Dr. Vidal is widely well known and involved, so this is likely mitigated by her involvement.

**Reviewer 2:** The project started on 1/1/2020 and because the milestones are dated toward the end of the project, it is somewhat difficult to answer the questions related to meeting the milestones. I have erred on the side of assuming the positive outcome if no data was available to the contrary.

**Reviewer 3:** I am in an interesting place as a reviewer -- the project has not started (or perhaps has barely started), and so it is not fair to comment on the performance of this project. So, I will comment on its potentials. The project has a good teaming arrangement by bringing in federal and academic resources, and a good research plan to explore a new idea to control high temperature chlorides effect on corrosion. The approach will lead to a simple determination of success or lack of by the end of the year. The partnering could be a bit stronger if an industry were included as a pathway to implement it in a commercial setting. I presume that responsibility will rest with the federal laboratory.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: All the tasks address major considerations except for sizing/cost of the conceptual engineering design.

**Reviewer 2:** Score: 6. Comments: Each of the tasks identified will provide unique and important information to achieving the overall goal of demonstrating the viability of the electrochemical corrosion control in the flowing molten salt systems.

**Reviewer 3:** Score: 5. Comments: The tasks are well laid out and explained. The details are adequate, and for a one year project the go/no-go gates at the end of the year are acceptable. The team should be well equipped to achieve the end products/objectives.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Lacks a technology developer or component developer to help guide direction of work. Are amounts of air/moisture leakages into the system realistic? Are the materials being considered consistent with what will be used?

**Reviewer 2:** As mentioned also above, one suggested additional area of study might include evaluation of the particle size distribution of the solid particles which are formed. The project report states one of the strategies is to "Localize the production and precipitation of purification byproducts, especially particles in the CSP loop to only the electrochemical subsystem; thus, easily implement the physical separation of these, thus avoiding damage to components if it flows with the salt in the CSP system." It is not clear what size particles will be formed and if they are very small, how they will be removed from the flowing molten salt system. Addressing the question of what particle size distribution of solid particles will be formed and based on this what removal strategy will be employed may be beneficial to realizing such a system in the actual operating environment. The other potential area that could be investigated is will the magnesium ions or species such as magnesium chloride be transported out of the localization of precipitation zone and react to form particles elsewhere in the system. It may be that this will be an insignificant amount, but addressing this potential issue would enhance the concept of localized formation and precipitation/separation of the particles.

**Reviewer 3:** From a programmatic point, the project seems reasonably adequately described. The concern is with the timeline for the tasks, and the lack of a clear explanation of the budget, especially since it does not address the total budget sought based on the breakdown items.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Lacks a technology developer or component developer to help guide direction of work.

**Reviewer 2:** For the success of the project as measured by achieving the stated project goals, I did not identify any additional organizations or collaborators that are missing.

**Reviewer 3:** An industry focused project of this kind, even one that is fairly basic science oriented as this one is, I would have felt better with an industry partner to look over the two participating research teams and make the technology transition smoother.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Integration of this subsystem into the overall plant - this will need to be tied intimately into the overall plant and cannot be thought of afterwards. If this proves viable it should be fast tracked into a larger system. 2) Cost of this system - coming out of this work some approximate cost values should be provided. While the chloride salts are inexpensive the CAPEX and OPEX might be high enough that the chloride salts do not prove worth it. 3) Complexity of processes being performed - if the design of the system is not sufficiently simple from an operability view point, then that would make me question the viability of the system in practice.

**Reviewer 2:** 1) The project is well defined with clear and impactful goals, well aligned with the overall program goals. 2) The project is early on but is currently on track and posed to make substantial contributions in demonstrating the potential for electrochemical corrosion control. 3) Understanding the particle size distribution formed in the electrochemical corrosion control section as well as the potential for particle formation elsewhere in the system due to magnesium ion or other species migration and reaction elsewhere may be beneficial in selection of the particle separation technologies to be employed within the system.

**Reviewer 3:** 1) budget explanation; 2) timeline for the tasks; 3) technology transition.

## Environmental Design of Cost-Effective High-Temperature Sensible Thermal Energy Storage Using Industrial Byproducts – $1,700,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Youyang Zhao*

This project is designing a cost-effective structure for thermal energy storage tanks using composite concrete instead of metals to help achieve the thermal energy storage cost target of $15 per kilowatt-hour thermal. The team is also working to improve the mechanical strength and thermal stability of the tanks' internal insulation materials by creating a new composite ceramic material with cenospheres—small, lightweight, hollow balls of silica or alumina that are filled with gas—added to prevent salt from seeping in.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 4 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Internal tank insulation can inform a wide range of applications within existing plants with 565 C solar salts, as well as external applications for any system that uses thermal energy storage. Proposed idea to differentiate the materials that provide insulation vs. those to provide mechanical strength of the vessel is likely the most effective way to approach the problem of containing very high temperature liquids. Team includes designers from industry with deep expertise in real tank designs. More detail on how exactly the expect to accomplish a ceramic insulation layer design whose insulation properties will not change significantly even when cracking occurs. No budget indicated.

**Reviewer 2:** Low score was given to the budget and planned duration, as the budget was not included in the report.

**Reviewer 3:** Economical containers that can withstand well the high temperature and the often corrosive storage materials align well indeed with this topic's goals and support SETO mission. The critical challenges include the long-term properties behavior of the materials, including their interactions, especially at their interfaces. Contingency plans are not shown. I would say that this is a medium-risk medium-impact project. They do if the proposed goals are met, which, based on my comments, is probably impossible to predict a-priory. They generally do but much helpful information is available about composite containers for very cold and hot media. If the goals are met, they would advance the US solar industry reasonably well. Strengths: A thoughtful and somewhat innovative approach for developing containers for low-cost high-temperature corrosion-resistant for CSP high temperature thermal storage. Weaknesses: Strong uncertainties in the chances to meet these goals.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 3 | 5 |
| Collaborates with sufficient stakeholders | 4 | 6 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Project has not yet started. No performance to comment on yet.

**Reviewer 2:** Low scores were given as the project has not started. The project includes a balanced group of researchers and industry, which can accelerate the implementation of the findings for the commercialization of this technology.

**Reviewer 3:** The project just started so it is impossible to form a solid opinion, but the team is excellent and experienced.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Proposed concept to develop ceramic material that is resistant to through-cracks is compelling, but needs more detail on why this would be possible for the given application. Leverages existing know-how from NREL on salt properties. Unclear what the importance is of using industrial byproducts as filler materials. There seem to be enough technical challenges with tank design and ceramic development, and it is unclear why (or what the cost differentiation is) between standard filler materials and those that are industrial byproducts.

**Reviewer 2:** Score: 6. Comments: The project report did not include the tasks that will be undertaken in this project. The succinct project description is reasonable for the level of proposed level effort and budget.

**Reviewer 3:** Score: 5. Comments: Yes, with the reservations expressed previously, about ways to deal with the critical challenges that include the long-term properties behavior of the materials, including their interactions, especially at their interfaces. Contingency plans are not shown.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Why were internal insulation designs not used for standard solar salt tanks at 565 C? The same factors that made internal insulation tanks unattractive for those applications will also apply to tanks for higher temperature salts. This needs to be considered before an assessment can be made as to if the proposed internal tank insulation design is feasible in commercial plants from a performance and reliability perspective.

**Reviewer 2:** It is not clear if the PI has a clear view of the cost benefits that can be achieved on the total system by replacing the materials of the storage tanks alone

**Reviewer 3:** I wonder about the behavior of Portland cement under the long-term operating conditions. A reminder (not necessarily blind spot) of the need to address carefully the short and especially long-term interactions among the materials used in this composite structure. Contingency plans should have been developed.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Team is strong because it includes Worley. Considerable experience in commercial tank designs and knowledge of common tank failure mechanisms.

**Reviewer 2:** It would be advantageous to include CSP developers to verify the benefits of replacing the materials of the tank walls, and understand the needs for bringing this technology to a commercial pilot plant.

**Reviewer 3:** The project seems to be well staffed, but should benefit from cooperation with designers, manufacturers and users of high temperature containers, especially large ones, as well as of CSP systems.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Consider removing part of the project that look at industrial byproduct filler material and focus on ceramic development. 2) ask for justification on why this type of tank design is likely to be successful for commercial plants, especially considering the fact that they were not used in commercial plants for lower-temperature salts. 3) high potential to inform next gen CSP, existing CSP, and wide range of applications outside of CSP industry. Many opportunities for tech transfer.

**Reviewer 2:** 1) Interesting project that brings knowledge in materials and methods used in other industries into the CSP industry. 2) Not clear of the overall benefit of replacing the materials of the tank walls on the economics of the entire solar power plant.

**Reviewer 3:** 1) Significantly improve the explanation and planning of the research, to base the seemingly cut-and try process on a minimal carefully selected sequence of science and technology assumptions. 2) Address carefully the short and especially long-term interactions among the materials used in this composite structure. 3) Develop contingency plans 4) Plan carefully the needed measurements and other experimental analyses. 5) Add cooperation with designers, manufacturers and users of high temperature containers, especially large ones, as well as of CSP systems.

## Molten Chloride Thermophysical Properties, Chemical Optimization, and Purification – $1,000,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Youyang Zhao*

This project addresses the thermophysical properties and handling of molten chloride salts that can be used as both the heat-transfer fluid and thermal energy storage material. The team is investigating the purification of commercial salts, optimization of chemical composition, and handling of procedures for concentrating solar-thermal power applications. They also plan to create and publish guidelines and protocols needed for obtaining accurate and reliable thermophysical properties of molten chloride salts.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Gaining consistent handling procedures is very important and needed for success. Getting a consistent handling and starting material for the system is extremely high impact and enabling. Georgia is also doing property measurements and should likely be included into this project.

**Reviewer 2:** Having accurate thermophysical properties for high temperature salts is a requirement in order to develop Gen3 central receiver systems. This project is methodically developing guidelines for salt handling and preparation, and measuring thermophysical properties of chloride salts.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engage partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Metrics should be identified for clarity, but success in a given area seems more or less clear. Seems as though there is good interaction given the size of the group and dispersed responsibilities. Georgia and ORNL not being included here is why I provided a 5 instead of a 6. I am aware of some purification work being done at ORNL (recent TMS presentation) where they are working on methods to purify the chloride w/o CCl4.

**Reviewer 2:** The project has been meeting milestones as planned.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: These are all very reasonable. Priority should be placed on getting the guide released as soon as possible.

**Reviewer 2:** Score: 6. Comments: The project report included a list of tasks that are reasonable for meeting the project goals.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Has the PI considered working to get the titration technique added into a formal standard to an archival format? Is there a general specification on the salt, composition that is required or part of the handbook, similar to Solar Two along with the techniques/analysis methods to determine the composition? This would be helpful to ensure the entire community is working within the best allowed specification at present.

**Reviewer 2:** None. The narrow scope of the project allows for delivering very actionable data for designing high temperature chloride salt power systems.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Other organizations doing similar work - i.e. Georgia for sure and likely NIST. Having a pedigree, standard materials, and error bars on the property measurements are needed to provide confidence for technology developers.

**Reviewer 2:** This project has the right balance of partners involved.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Handbook/Handling Guide. Being released as a NREL report, instead of a journal publication is preferred. A journal publication could be a great outcome, but the handling guide, with lessons learned as an appendix, would help to buy down risk of different companies/institutions using this salt in the future. 2) Getting this released soon is very important, as there seems to be inconsistent practices among the various projects. 3) 5 kg is a small heat of material. It there are struggles at that size it's going to be very difficult.

**Reviewer 2:** 1) The results of this project are very actionable data that will allow the development on high temperature central receiver systems. 2) The project involves the right balance of partners, from researchers to salt manufacturers and commercial developers. 3) This effort needs to continue as supporting tasks for a commercial pilot plant.

## Re-Designing the Concentrating Solar-Thermal Power Thermal Energy Storage System to Enable Higher-Temperature Performance at Reduced Cost – $1,103,467

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Youyang Zhao*

Current commercial concentrating solar-thermal power plants store energy via a heat transfer fluid in large metallic storage tanks that are made of stainless steel. As the operating temperature of heat transfer fluids continues to rise to increase plant efficiency, more expensive alloys will be needed for the storage tanks to handle these higher temperatures. The goal of this project is to develop designs that will eliminate the need for expensive alloys: first, in today's hot tanks operating at 565-580 degrees Celsius, and second, to point the way for similar design approaches to reduce the thermal energy storage costs for tomorrow's much higher operating temperatures.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 3 | 4 |
| Set critical challenges to overcome | 4 | 4 |
| Implement a high-risk, high-impact approach | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 3 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 |
| Advance the U.S. solar industry substantially | 3 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The concept is applicable to molten nitrate salt, which is a limited type of application. The approach is correct and the selection of candidates' materials is relevant.

**Reviewer 2:** In the context of CSP and other advanced energy applications, study, design, and possibly construction and testing of an efficient yet economical energy storage system for a Gen2 sensible heat molten nitrate system operating at 565-580Â°C is aligned well with this topic's goals and supports the SETO mission. The cost reduction is proposed to be attained primarily by internally insulating the TES tank to enable safe separation of a relatively inexpensive external structural shell from the internal high temperature corrosive nitrate, searching for a relatively inexpensive porous insulation. This task is a difficult and not very innovative one. I note that I was asked to review a similar SETO proposal by the same PI. Corrosivity and very high temperature, long-term integrity and continuity of the insulation and its cost are the main challenges. More information is needed for effective planning for choosing an optimal design path to long-term operation robustness, and appropriate cut-and try design plus testing. Contingency plans are not shown. This is a medium-risk, medium-impact project in the context of CSP and energy storage. The plans would match reasonably well the funding and duration if the proposed goals are met with minimal effort, but the cut-and-try approach is likely to extend the expense and duration. The plans would add significant value to existing research outside DOE-funded efforts, if the proposed goals are attained. If the goals are met, they would advance the US solar industry significantly, since there are very few such systems in existence that could attain the planned goals, and they all are in the experimental stage (as far as I know). A successful system may have export potential. Strengths: A thoughtful and somewhat innovative approach for developing containers for low-cost high-temperature corrosion-resistant containers for CSP high temperature thermal storage. Weaknesses: Strong uncertainties in the chances to meet these goals.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 |
| Disseminates results frequently and actively engage partners | 4 | 4 |
| Collaborates with sufficient stakeholders | 3 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The phase 1 results will be very useful for the phase 2. As mentioned above the direction of the selected candidate's material is appropriate.

**Reviewer 2:** The project is progressing but met some challenges in selecting materials. Impacts are measured, but the performance criteria weren't shown. Dissemination of results is not mentioned in their report. It was not reported to which extent they collaborate with sufficient stakeholders, including Worley.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The researcher has set up a reasonable set of tasks and ways of achieving them.

**Reviewer 2:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project, with the reservations expressed above. Clear contingency plans are not shown.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Include more indusial partners. Prepare for better testing of the products. The key is experimental work.

**Reviewer 2:** It is important to pay more attention to detailed systematic planning of the partially cut-and-try methodology for effectively reaching the goals, in view of the experienced and potential challenges, and create clear contingency plans.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Industrial partners and power plant operators to provide raw materials

**Reviewer 2:** The project seems to be well staffed, but should benefit from cooperation with designers, manufacturers and users of high temperature containers, especially large ones, as well as of CSP systems, and I am not sure to which extent Worley is available for that (in expertise and budget).

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Viability of selected materials for large scale applications. 2) Future need for this type of materials. 3) Possibility to extrapolate the results of other type of molten salts beyond nitrate.

**Reviewer 2:** 1) Significantly improve the explanation and planning of the research, to base the seemingly cut-and try process on a minimal carefully selected sequence of science and technology assumptions. Explain the relation between this proposal and their similar one being reviewed by SETO. 2) Address carefully the short- and especially long-term interactions among the materials used in this composite structure. 3) Develop contingency plans.

## Thermomechanical Behavior of Advanced Manufactured Parts, Subcomponents, and Their Weldments for Third Generation Concentrating Solar-Thermal Power – $2,000,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Judith Vidal*

This project is developing strategies to prevent corrosion on piping and other metal surfaces that would be in contact with molten chlorides in Generation 3 concentrating solar-thermal power systems. The team is exploring advanced manufacturing techniques for components like heat exchangers as well as cladding for piping materials. This will extend the lifetime of concentrating solar-thermal power components and plants.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project team has set high goals in a verity of related topics. It is imperative to provide before any further award a very "detailed" plan of implementation for each of the three major goals of the project. The variety of the team expertise, assembled for the project, indicates a relatively good success chance for the development of practical and meaningful solutions to the project challenges. In my opinion, one should separate budgets of each of the tasks.

**Reviewer 2:** This project seeks to explore novel metallurgical approaches to reducing the cost of high-temperature, corrosion-resistant components in next-generation CSP systems. The project is early in its progress.

**Reviewer 3:** This project will characterize materials and manufacturing methods for high temperature components, needed for enabling Gen3 systems.

## 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 6 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 3 |
| Disseminates results frequently and actively engage partners | 1 | 6 | 3 |
| Collaborates with sufficient stakeholders | 3 | 6 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project is its initial stages of development starting on 02/01/2020 - therefore it premature to evaluate at this stage any practical results.

**Reviewer 2:** The project is too young to evaluate the performance. The program was launched only in February 2020.

**Reviewer 3:** Low scores were given as the project has not started. The project includes a balanced group of researchers and industry, which can help reduce the time to commercialize the findings from this project.

## 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: As mentioned above, there are three distinct goals. To proper answer this question, the project team must develop and suggest evaluation criteria for each goal individually, in order to make a meaningful evaluation. There is a substantial amount of interaction between the outcome of each goal. The team should evaluate how the success of one goal will impact the overall cost of Gen3CSP projects

**Reviewer 2:** Score: 6. Comments: Seems reasonable.

**Reviewer 3:** Score: 5. Comments: The project description included succinct descriptions of the general activities of the project. The tasks are reasonable for achieving the project goals.

## 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Provide more quantitative details about meaning of cost-effective for each of the project goals. Explain the suggested methodologies and need for setting numerous go-no go decision points, particularly at the initial development stages.

**Reviewer 2:** No blind spots noted yet in the project.

**Reviewer 3:** None. The project report included challenges and mitigation strategies that address concerns for integration and involving industry.

## 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Add some outside large industrial partners, with experience in manufacturing piping, heat exchangers and other critical components, for the sole purpose of reviewing, provide critical comments and suggest alternatives.

**Reviewer 2:** None that were obvious.

**Reviewer 3:** Technology providers and CSP developers, to get them familiarized with the methods characterized here and to understand requirements for commercial demonstration.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Set up very detailed plans for each goal definition of perceived success and level of practical implementation in the future full scale Gen3 CSP projects. 2) Request the project team to quantify the tasks in terms of effort and expenses for immediate and longer-term stages. 3) Review in details the current technology levels in each of the goals and how the project team expects to exceed them.

**Reviewer 2:** 1) Project is in its early stages. 2) It is hoped that the economic benefits of the new approaches can be evaluated.

**Reviewer 3:** 1) Novel techniques for manufacturing high temperature and high-pressure components will be characterized in this project. These techniques are needed, as receiver components are having issues while exposed to high solar concentrations. 2) This project has a balance group of partners, from researchers to industry.

## Cast Components for High Temperature Concentrating Solar-Thermal Power Thermal Systems – $1,000,000

*Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Govindarajan Muralidharan*

High-temperature concentrating solar-thermal power systems operate at temperatures greater than 700 degrees Celsius, which can be a challenge for components made from conventional metal alloys. While these components are typically hammered into the appropriate shape and then welded, this project explores the feasibility of casting, a simpler and lower-cost manufacturing process in which liquid metal is poured into a mold to create precisely shaped components. Casting is best suited for intricately designed concentrating solar-thermal power components like heat exchangers, tubes, and vessels and could significantly reduce fabrication costs, helping to reduce overall concentrating solar-thermal power capital costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1**: This project focuses on reducing the manufacturing costs of components such as tubing by using a centrifugal casting process. Since the alloys which have the potential to meet the target high temperature mechanical properties are not available in cast form and the properties are very sensitive to the composition and heat-treatment, it was important to fabricate these alloys in the cast form with compositions very close to their design compositions. This challenge was overcome by procuring commercially available material and making laboratory scale castings by melting and casting these alloys. Very little information was available on the effect of heat-treatment properties on high temperature tensile and creep properties of commercial alloys. This challenge was overcome by selecting heat-treatment conditions using computational thermodynamic and kinetic modeling and using the heat-treatment for wrought products as a guideline. Impact is high. The project has been able to achieve all the targeted milestones in Budget Period 1. This project evaluates the feasibility of fabricating object such as pipes using a centrifugal casting process. This works has for the first time shown the feasibility of fabricating good quality investment casting of plates of Haynes®282®. Further work is required to evaluate the feasibility of fabricating more complex shapes using investment casting. Strengths: Identified challenges are tackled. Reduction of fabrication cost. Weakness: unknown yet.

**Reviewer 2:** The goal of this project is to evaluate the feasibility of using centrifugal casting to lower manufacturing costs of pipe and other components and to measure the properties of the alloys manufactured using this process. The overall driver is cost reduction. Computational thermodynamics and kinetic modeling were used to select heat treatment conditions as a guide for part casting parameters. The project goals are aligned with the overall program goals and supports the SETO mission. Since pipes have not been manufactured in this way before, there is significant risk but significant reduction in overall costs would have a high impact. The projects goals, approach and expected impact align well with the level of funding and the planned project duration.

**Reviewer 3:** The project aims to develop methods for casting superalloy tubes to reduce the cost of components for CSP systems. Reduction in cost of superalloy components would significantly reduce the cost of electricity or power derived from Thermal CSP. Cast superalloy components may have cost benefits in other industries also. The team has cast successfully laboratory scale heats and evaluated their mechanical properties. One of the alloys has been cast on a commercial scale. The mechanical properties of these cast materials are close to those of the wrought alloys, demonstrating that the approach is likely technically feasible. Further work, however, is required to test the creep properties of the material and properties relevant to specific application conditions. Most of these activities are planned.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project met all milestones so far with a reasonable timeframe and budget. This project evaluates the feasibility of fabricating object such as pipes using a centrifugal casting process. Since pipes are anticipated to be used to transport hot gases, and molten salts, this technology could be widely used in the Gen 3 CSP systems. Cost analysis will be pursued in this project to evaluate the potential cost savings that would be achievable through the use of casting technologies.

Furthermore, this work will serve as the basis for the development of casting technologies for other components such as valve bodies, pump bodies, and pump impellers. Dissemination is planned. It seems the team is doing well, 5. The project performs well in period 1. Due to COVID-19, periods 2 and 3 could be delayed. It would be better to provide a quantitative analysis of cost reduction.

**Reviewer 2:** The project start date was 10/1/2018 and the end date is scheduled to be 9/30/2021. There are two go/nogo gates, one on 9/30/2019 and one on 9/30/2020. The milestones in budget period one were completed successfully. The milestone in budget period 2 is a little past due but deliverables are expected to be completed soon. Haynes 230, Haynes 282 and IN740H have been successfully produced by centrifugal casting. The latter two have achieved the high temperature yield strength requirements. An initial centrifugal casting of Haynes 282 in tube form has been completed and a second casting was targeted for February 2020. Plates and other test specimens have also been fabricated. No publications are reported so far. Generally, the project appears to be on schedule and on budget. It appears that the project is planning on measuring the appropriate parameters.

**Reviewer 3:** The team has performed successfully a technological challenge: casting a high-temperature superalloy and obtaining mechanical properties near that of the wrought material. This result will likely have commercial impact. The work, however, is somewhat narrowly focused on metallurgy and material properties without collaboration or coordination with end-users such as system and component designers. For example, the testing doesn't consider the actual stress states expected during service, whether this is under the conditions for sCO2 or molten salts. If the application requires thin-walled tubes, there is limited testing planned to address lifetime concerns. If the team were more familiar with the specific design requirements of solar applications, their skills and capabilities would likely allow them to increase the impact of their work.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: This project has proven that Haynes®282® and Haynes ®230® can be successfully cast in industrial scale heats in the form of plates and test specimens. It was also shown that by careful design of heat-treatment conditions, the targeted high temperature tensile properties (=80% of wrought Haynes®282® between 750°C and 800°C) and targeted short-term creep properties ( =85% of the lower limit in the scatter) when compared to Haynes®282® at equivalent stresses and temperatures can be achieved in cast Haynes®282®. This works has for the first time shown the feasibility of fabricating good quality investment casting of plates of Haynes®282®. Further work is required to evaluate the feasibility of fabricating more complex shapes using investment casting. In the next stage, targeted high temperature properties have to be demonstrated in centrifugal castings of alloys. Weldability and mechanical properties of welds must be evaluated. Cost-benefits analysis has to be performed to evaluate cost savings achievable using castings.

**Reviewer 2:** Score: 6. Comments: In general, demonstrating the feasibility of using centrifugal casting to produce pipe sections to reduce overall system cost entails developing the process to produce the pipe sections and measuring the appropriate properties to demonstrate the components are fit for use in the systems. The project utilized modeling and simulation to determine initial casting parameters to start with and then proceeded to fabricate parts for property measurement. Each of the work components listed does provide important value toward reaching the overall project goals.

**Reviewer 3:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the goals of the project.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Except for tensile, are there any other important mechanical properties that need to be evaluated after heat treatment?

**Reviewer 2:** I did not identify any blind spots in the project plan to achieve the goals of the project as specified. Additional things to consider in this or a continuation of the project might be determining the effect of centrifugal casting on the corrosion properties of the component in the expected operating conditions. In addition to the mechanical property testing planned, microstructural analysis, phase distribution and phase composition analysis may add additional insight into the properties observed and give direction for future improvements.

**Reviewer 3:** The investigator has a solid grasp on the metallurgy of the system and the need to investigate the relationships among properties, processing and (micro)structure. The blind spot appears to be application relevant considerations and testing, such as oxidation, corrosion, etc.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Characterization of a whole spectrum of properties.

**Reviewer 2:** For completing the planned work and achieving the project objectives, I did not identify any additional stakeholders, organizations, or collaborators critical for the project's success.

**Reviewer 3:** CSP system and component designers.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Cost reduction in manufacturing of working components for CSP plants. 2) Milestones are met. 3) Budget is reasonable.

**Reviewer 2:** The goals of the project are in line with the overall goals of the program and the SETO mission. The project generally appears to be on schedule and within budget. Developing a significantly lower cost processing method as in the goal of this project to produce components with acceptable properties for the application could have a sizeable impact on the overall program and the SETO mission.

**Reviewer 3:** 1) The investigators have performed useful and commercially relevant work leading to proof-of-principle of cast superalloy components. 2) Additional knowledge of CSP system design requirements would make development and testing more efficient. 3) Additional materials characterization, most of which is planned, is required to improve confidence that these cast materials could be used in industrial applications.

## Development of Cast Valve Bodies for High Temperature Service – $500,000

*Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Govindarajan Muralidharan*

This project aims to lower the costs of materials and components in concentrating solar-thermal power systems so capital costs can be minimized while still achieving high operating temperatures. To obtain the lowest cost in castings, there is a significant need to maximize yields in castings by decreasing rejects due to casting defects and to minimize waste in lost material in the gating systems. The scope of the work includes collection of data required for computational design of the casting, design of the rigging system for the casting using computational modeling, development of melting and casting process parameters, casting fabrication, casting integrity evaluation, comparison of experimental evaluation of casting quality with results from modeling, and evaluation of microstructure and tensile properties in a critical location.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 4 |
| Set critical challenges to overcome | 6 | 2 |
| Implement a high-risk, high-impact approach | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Goals are inclusive of manufacturer engagement which allows for appropriate design for manufacturing. Impact is more likely to be substantial because of this engagement. Goals also include experimental validation of solidification and other models that can potentially be applied to the casting of other components. Manufacturing techniques that can be used with Haynes 282 are not well-developed. The ability to cast usable components would have a notable impact on next generation CSP development, especially since valve operation in CSP plants is often cited as a problematic area for real plant operation.

**Reviewer 2:** The goals of the project are set clear. However, the scope of the investigation is quite limited. On the positive side, the team working on the subject have the knowhow and the resources to solve the challenges. The proposal should include details and scope of the cast fabrication and other goals for the third and final quarters of the project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 2 |
| Disseminates results frequently and actively engage partners | 6 | 4 |
| Collaborates with sufficient stakeholders | 6 | 2 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Team is still at earlier stages of the project, but given the amount of time on the grant so far, notable progress has been made.

**Reviewer 2:** The description of the project review is lacking important information about the final experimental goals. It would be important for the reviewing team to fully understand not only what but how the next project quarters objective will be performed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Valves in lower-temperature plants have been identified as critical for operation. Challenges in valve cost and usability will only increase with temperature. This work helps both increase reliability of valve operation (Casing only) and bring cost down.

**Reviewer 2:** Score: 2. Comments: See above. The next steps are not explained. In particular, (the most relevant step) the fabrication of the cast. There are many others working on Haynes 282. Need to fully understand the uniqueness of the team approach.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Often valve failure occurs because of bad valve heat trace, or leakage through valve packing. It is unclear if these issues have been considered first in valve development, or if the given design they are fabricating is amenable to design improvements in packing or the ability to be effectively heat traced.

**Reviewer 2:** How to apply the knowledge gained in this project to large scale component manufacturing.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None are missing. The team is complete.

**Reviewer 2:** The team involved GE and Flowserve. They involvement should be continued and expended, based on their capabilities to take the knowhow and convert to industrial products.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Should first focus on valve packing and valve heat trace issues. 2) Casting process and technology developed here could apply to many different types of components and have a multiplicative effect on CSP project success.

**Reviewer 2:** 1) The topic is important for future component development. 2) The team must set up quantitative goals for the next steps, allowing effective oversight. 3) Conduct frequent reviews and reporting of achieved results.

## Enabling High-Temperature Molten Salt Concentrating Solar-Thermal Power through the Facility to Alleviate Salt Technology Risks – $5,000,000

*Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Kevin Robb*

This project focuses on the design, construction, and operation of a lab-scale test facility to alleviate salt technology risks. This facility is a versatile, high-temperature molten chloride salt facility designed for temperatures greater than 700 degrees Celsius and for a variety of testing in support of the third generation concentrating solar-thermal power molten salt pathway. The facility and its accompanying research will provide the foundational capabilities necessary to support third generation concentrating solar-thermal power.

**1. The project’s goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic’s goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Development of a standardized system to demonstrate corrosion from the chloride salts for the various components of a high temperature CSP system can reduce the risks and allow easier scale up of the technology for future power plants. To that extent, this proposal takes on a systematic approach to provide a set up for all CSP technology providers/utilizers to avail of. The only weakness I can see is that other than throughput this approach does not significantly improve the higher temperature capabilities for such evaluations -- 700 to 725 C. I like the systems approach to addressing and, if possible, mitigating the risks.

**Reviewer 2:** This project is one of the core items related to the SETO’s mission of deploying a molten salt system for CSP. The challenges are all present in this system and seem fairly represented. There are a lot of things that could go wrong with doing this all in one system, which is high risk. The reward is a platform for many other salt components that can be tested at a smaller scale. The funding seems appropriate for the work level, duration, and scope. This project is enabling, because all other projects do not have an integrated system. Needed to move the industry forward.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** As a basic platform development for advancement of CSP systems, this is good project, and it has met or exceeded the performance to date. The publications are good, and the organizational teaming will help with dissemination of the technologies to other users. The availability of this facility will allow industry to utilize this facility for future system component evaluations.

**Reviewer 2:** Between demonstrate shake down testing on 7/31/2019, there needs to be a more time run on the system simply at isothermal. Addition in a heat exchanger without milestones indicating stable and predictable performance is missing. Stable operation for sustained times to vet the technology feasibility and latent operational challenges are not well characterized in the metric and should not be excluded. No issues observed. Only missing a commercial partner, but other partners seems very good.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks are well developed and well sequenced. The objectives show a well laid out plan, starting from 2018, and the milestones are easy to understand and well laid out. They all lead towards meeting the overall goals of the project in FY 2020.

**Reviewer 2:** Score: 5. Comments: There needs to be a baseline operational task. The MSTL system and Sandia never had a solid plan to operate a sustained amount of time and the costs were too high. Having a task that demonstrates unattended operation is needed to prove this system to be a DOE assess in the future, as staff cost and time is the largest expense on these projects typically.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I did not see any obvious blind spots for the PI to address in this project.

**Reviewer 2:** It is unclear how the major components are getting qualified as fit for service. If there are any options to shakedown equipment before putting on FASTR that would be ideal. The general concern is that the component fabrication time to project deliverable is line to line and there might not be margin for the inevitable issue that comes up during early commissioning.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The assumption is that the technology dissemination will be through public presentation and publication of the results and findings from this research, and through the three federal laboratories. I wished that they had included a workshop or something like it to address a broader dissemination of their capabilities and platform for evaluation of molten salt systems for CSP.

**Reviewer 2:** Technology Developers and component developers are primarily needed. It looks as though component developers are involved, so more systems level organizations are needed at this point.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) workshop for technology dissemination to the community; 2) consider adding a technology implementation industry partner in 2020.

**Reviewer 2:** 1) This is probably your most important project for molten salts, so this needs to work. I would put more resources at this project if needed to ensure that it is successful. No one will attempt to build a system without a reliable system running. 2) Time on the system and pushing operation to find latent flaws. This is a first of a kind, so if there are problems that arise they should be expected. The goal is to solve them practically and quickly, such that you are able to get more run time on the system. 3) Don't over complicate the mission of this system. There is a lot of possibilities and missions outlined by the PI on this system. If the PI can run the system in a stable way, for thousands of hours, with imposed, planned (and unplanned) transients then that is success. Being able to test some supporting components (flanges, valves, etc) should be considered ancillary until the system runs reliably.

## Interface Evolution with Molten Salts – $200,000

*Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Gabriel Veith*

This project aims to understand the surface evolution of high nickel alloy surfaces under molten salt conditions. The team is using a variety of scattering and in situ approaches to follow the interface evolution, with nanometer resolution, as a function of time and temperature. Understanding these interfaces enables the team to identify and evaluate passivation layers and coatings that mitigate materials migration. Understanding changes in the salt chemistry allows for the prediction of additives to stabilize the salt chemistry. Additionally, the atomic scale in situ studies allows for the direct measurement of reaction mechanisms and kinetics aiding in the simulation of lifetime and hardware stability.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** It aligned well with chemistry monitoring methods to help with corrosion control techniques. This seems to be well understood. The high risk is if the Electrochemical Impedance spectroscopy (EIS) is if the correct mathematical model is selected and the system behavior is well understood. In a laboratory setting this can be better understood, but in moving to a real system this may not work well and may be a poor choice for the future. Good fit with cost and timing. EIS is different, but might not provide any additional insights outside of what is currently funded. Personally, I do not think it is needed at this time. I don't think this will have a large impact to the overall for the solar industry, but the work will be interesting and potentially valuable for method development and perhaps some insight into the underlying science.

**Reviewer 2:** This project aims to develop non-destructive, electrochemical methods for detecting corrosion and component health in Gen 3 CSP systems. Since electrochemical methods are used for inspection in a variety of important applications, the probability of being able to develop a successful approach appears high. On the other hand, there are many unique challenges related to molten salt, for example, the application environment and unknown electrochemistry of the planned materials in question that this project must address in order to be successful. The use of Dynamic Impedance Spectroscopy addresses many of these challenges, however there are many complex interactions that could occur and verification of results via other methods will be critical in development of a method applicable to field use in Gen 3 CSP systems. The Principal Investigator, Dr. Veith, is keenly aware of these issues and has key milestones and metrics to demonstrate proof-of-principle.

**Reviewer 3:** The goal of this project is to demonstrate an electrochemical tool kit to identify, and in real-time, follow the corrosion of nickel super-alloys and eventually mitigate this corrosion through in operation repair processes. Challenges include demonstrating the ability to fabricate heterostructures of the nickel super-alloy and a potential passivation layer and integrate this within a high temperature impedance cell, and developing the ability to react to changes in the salt chemistry with time at a time scale not typically probed. The project is not ready for industry and requires prototyping and demonstration. Small budget for one year. Understanding corrosion processes are critical to developing mitigation strategies. This work can be extended to other system perturbations to rapidly prototype failure modes and passivation coatings. This tool could be used to monitor the health of a components and develop electrochemical processes to repair damaged components. Strengths: high-risk/high reward small project. Corrosion is a critical issue. Identification of corrosion in time is required. Weakness: no result yet.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engage partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 3 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Milestones (Test Cell Construction and glovebox installation) are sensible, but they are a bit incomplete. Quantification of impact is difficult and would require additional effort. Does not apply, there are no other participating orgs. Does not have any tasks/milestones that would enable collaboration with stakeholders (i.e. component designers).

**Reviewer 2:** Although this project follows a logical approach to method development, it seems like the scope is very ambitious for the given time frame and budget. The proposal to develop in operation repair in this time frame is quite a stretch. Since this is a 1 year-long project, interaction with component designers, fabricators and system operators would also be a lot to expect. Nevertheless, some further understanding of the issues that may be encountered during full scale application may be valuable during method development.

**Reviewer 3:** Budget is reasonable. Milestones are unknown. Impacts are identified properly. The results will be distributed through peer reviewed publications and presentations. A small project by Oak Ridge National Laboratory only. The project just started.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: Tasks were minimally included and made difficult to evaluate

**Reviewer 2:** Score: 4. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project, however the goal of in operation repair seems secondary to developing a method for monitoring component health which would have significant value to CSP, and other, systems.

**Reviewer 3:** Score: 6. Comments: The goal of this project is to demonstrate an electrochemical tool kit to identify, and in real-time, follow the corrosion of nickel super-alloys and eventually mitigate this corrosion through in operation repair processes. To achieve our goal, and prepare to address our ultimate goal, we will address the following objectives: (1) build and validate a high temperature impedance cell with sealed heterostructure electrodes using films of Haynes 230 with and without a carbide passivation layer, (2) demonstrate mechanistic understanding of corrosion of the heterostructures utilizing dynamic sub-second impedance spectroscopy, (3) measure changes in corrosion rate with the introduction of water impurities in the salt.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** How would the work done in the laboratory transfer to large engineered systems? Will there be any interfere due to many concurrent processes (heaters, dynamic flow conditions, etc.) to ensure this method will be robust?

**Reviewer 2:** A potential blind spot is all the noise and complexity of instrumentation that would occur in full-scale, field deployment of Gen 3 CSP. Nevertheless, the proof of principle and value of the method need to be demonstrated first.

**Reviewer 3:** Dimension of test cell needs some good justifications.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** NREL and other organizations performing salt chemistry work would benefit from the results of this work.

**Reviewer 2:** Component designers and plant operators.

**Reviewer 3:** Maybe a non-contact visualization or corrosion detection expert should participate in addition to the electrochemical knowledge of the PI.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) This is another sensing technique, but it is not as robust as the open circuit potential methods. EIS is typically for thin film behavior, as it can leverage different mathematical models to fit behavior. This is complicated and not particularly straightforward. Complexity in interpreting results typically lends itself to follow on studies. 2) The proposed method of adding chemicals to the salt to 'heal coatings in place' has been considered during CSP. Problems are frequently that the large TES systems do not allow for cost effective amounts of chemicals for this purpose. I do not see this method of surface repair being particularly feasible, perhaps additions to adjust the redox of the salt could happen, but not elements to heal coatings. 3) In real systems with complex solubility of oxygen, moisture, and other contaminants my concern if this project does not use industrially obtained, low grade salts that there will be much rework after optimizing for an high purity grade in the laboratory. This should be clarified.

**Reviewer 2:** 1) This project addresses a critical need for CSP systems that could significantly enhance safety and reduce operating costs (identify maintenance needs prior to failure). 2) The timeline is ambitious for all the tasks included. 3) It may be challenging to apply this method in the field.

**Reviewer 3:** 1) Early detection of corrosion is critical. 2) Mitigation of corrosion through in operation repair processes.

## High Flux Microchannel Receiver Development – $2,000,000

*Oregon State University | Corvallis, OR | Principal Investigator: Brian Fronk*

This project continues Oregon State University's development of a microchannel solar receiver using supercritical carbon dioxide as the heat transfer fluid. The research is working to resolve key issues associated with the commercial viability of the technology, which allows for a radical reduction in the size of a solar central receiver. The project will culminate in an on-sun test of a commercial scale receiver module with a surface area of approximately one square meter.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project, launched in October 2015, seeks to design and demonstrate a microscale heat exchanger for next-generation CSP systems. Significant progress has been made on smaller-scale systems. In this final phase it was determined that the demonstration approach would be re-scaled to a smaller system tested at UC Davis. The project description did not quantify pressure losses encountered in the experimental work, nor the heat transfer enhancement. Challenges associated with fabrication in scale-up to demonstration scale were not able to be overcome.

**Reviewer 2:** Very useful project developing microchannel receivers for $sCO_2$ systems. This is a high risk/high reward project that could benefit the development of $sCO_2$ solar power towers.

**Reviewer 3:** The project directly addresses the development of low-cost, high-temperature HX receivers for CSP. s the project comes to an end, the challenges appear to have been mostly met. As the project comes to an end, looking back, the project was high-risk at time it was proposed, and can have a high impact on CSP. The project has been successful for the 5-year timeline and project budget. The technology can have broad application in technologies other than CSP. As noted in the Report, these include nuclear, oil and gas, and other high temperature applications. The HX that was developed has the potential to advance the US solar industry to higher temperature receivers. Strengths: Successful development of a micro pin fin HX that operates at high temperatures and high pressures corresponding to $sCO_2$. The cost of the HX appears to be reasonably small. A good team of researchers and experts was assembled. Weaknesses: Development of the commercial size HX (1m2) for on sun testing might not be achieved as originally proposed.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 6 | 4 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The work has progressed well, but few quantitative heat transfer and pressure drop results were reported on the demonstration tests. Reference is made to experimentally validated thermal models that allow prediction of goals exceeding the DOE SunShot goals. Fabrication challenges will prevent achievement of the larger-scale testing proposed.

**Reviewer 2:** It is important to involve technology providers and commercial project developers in order to work on pilot plants for next generation solar power towers. The project investigators have published their results regularly, and have filed for a patent application.

**Reviewer 3:** The milestones have been, for the most part, met in this 5-year project that is coming to conclusion. The budget appears to have been adhered to. Perhaps the NTU of the HX is of practical interest for the various fluids and fluid conditions considered, and could have been reported. Cost and durability metrics are included in the Report. The dissemination of results has been modest, but the plans for future dissemination are good. The patent application is also good. Good collaboration with SNL and NETL is noted. The performance of the 5-year project that is reaching its conclusion has been impressive. Substantial work appears to have been done from the materials perspective, the heat transfer perspective, and the economics perspective. The actual performance and cost of the HX are good as well.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The PI has apparently achieved what was proposed, although the description of results is vague.

**Reviewer 2:** Score: 6. Comments: The project report summarized the tasks and milestones for all the project phases. Tasks were reasonable for achieving the goals of the project.

**Reviewer 3:** Score: 6. Comments: Good integration and involvement of appropriate expertise was described in the Report. The tasks were appropriate and, for the most part, achieved.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** No blind spots. It is not clear that the challenges encountered could be anticipated.

**Reviewer 2:** More than blind spots, the challenges that the project has found to meet the goals of the project are very significant.

**Reviewer 3:** Not applicable. The project is concluding.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No additional entities needed.

**Reviewer 2:** It is important to involve technology providers and commercial project developers in order to work on pilot plants for next generation solar power towers.

**Reviewer 3:** Not applicable. The project is concluding.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Insufficient quantitative information given relative to the performance of demonstration units. 2) DOE will need to decide whether the change in scope of the project warrants additional funding.

**Reviewer 2:** 1) Very valuable project, developing high temperature receivers for sCO2 solar power towers. 2) Need to engage with technology providers and commercial project developers.

**Reviewer 3:** 1) Good team from academia working with experts from the DOE laboratories to develop an impressive HX for CSP. 2) Good experience gained and lessons learned in terms of testing such HXs at high temperature conditions to failure. Good decision to pursue a failure analysis. 3) The HX might be a good benchmark against which new designs can be compared.

## Selective Thermal Emission with Radiation and Adsorption in Annuli: An Advanced Heat Exchanger Concept for Supercritical Carbon Dioxide Power Cycles – $395,000

*Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Peter McGrail*

One of the key limitations affecting ability to achieve the efficiency and cost saving advantages of a solar thermal supercritical carbon dioxide power cycle resides with the primary heat exchanger, where costs can exceed 50 percent of the plant capital budget depending on design. This project lays the foundational groundwork for a new type of heat exchanger optimized to take advantage of radiative heat transfer to supercritical carbon dioxide. Using principles from the new field of optical metamaterials, selective thermal emission coatings are being designed to radiate light tuned to the strong infrared absorption band of carbon dioxide. Heat transfer simulations show that an advanced heat exchanger implementing this selective thermal emitter is 25-40 percent smaller than conventional heat exchanger designs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The launch date of this project as noted in the project description (10/01/2020) is clearly incorrect, and makes it difficult to assess progress against projected milestones and timetable. It is clear that heat exchanger design issues with sCO2 are critical to the SETO vision. This work seeks to tailor surface emissivity, tuning it for optimized absorption in the 4.5 micron emission band of sCO2. he PIs suggest that this could reduce the size of a sCO2-heat transfer fluid heat exchanger by 25%. Early work identified significant roadblocks with the design of band gaps for the tailored surface. Other designs are being explored. There was insufficient information to assess whether a surface tailored to absorb preferentially in the 4.3 micron emission band of sCO2 will really have the impact proposed. Further, this reviewer has some question about the spectral absorption characteristics of sCO2.

**Reviewer 2:** The project is focused on micron-level structured coatings to enhance heat transfer efficiency. The project has just begun, but it has developed innovative approaches, based on sound physics, to enhance the optical properties of materials. Applying the approaches, photonic crystal structures and distributed Bragg reflector structures, to large scale, commercially relevant materials and structures may be a main challenge of the approach. Nevertheless, the project is likely to have benefit to others in the solar energy field and to other applications where adsorption and radiation are important.

**Reviewer 3:** This project will design and demonstrate operational performance of a selective thermal emitter coating for a supercritical CO2 heat exchanger optimized for radiative heat transfer. The improved radiant heat transfer could reduce heat exchanger size by 25% over conventional designs and thus can deliver one of the largest potential capital cost reductions in this system. The identified challenges include assessment of statistical metrics associated with optimization of designs for various selective emitter coatings and assessing sensitivity of these designs, the uncertainties with cavity-based photonic crystals, which show good emission properties in air but may perform poorly in actual operation when the cavities fill with scCO2. This is a high-risk project. But the high reward with 25% size reduction is in doubt. The budget in BP1 is about $400K. The timeline in the report is confusing. It impacts scCO2 heat exchanger technology. The claims are purely based on simulations which might be not very realistic. Strengths: some preliminary modeling works available. The selective thermal emitter is designed as a surface coating, it can be applied to virtually any of the advanced materials and heat exchanger design concepts being developed specifically for this power cycle. Weakness: Real fabrication of metamaterials is difficult based on principles of photonic metamaterial design and nanophotonic bandgap theory to design the selective thermal emitter.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 3 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The work is in its early stages. There have not yet been results worthy of disseminating. There is some question as to whether the PIs can achieve what they propose by end-of-year 2020.

**Reviewer 2:** The team, led by Principal Investigator Dr. Peter McGrail, has a well-defined plan with measurable milestones to accomplish. It is too early to comment significantly on the team's communication of results. Although the team includes a member who will perform heat exchanger modeling, Dr. Ognjen Ilic from the University of Minnesota, a more thorough, initial discussions with developers of proposed or planned CSP HX concepts (materials and component designs) may accelerate adoption of coatings developed in this, or follow-on, projects.

**Reviewer 3:** Only one milestone for first quarter is listed. 4 Tasks are listed. The improved radiant heat transfer could reduce heat exchanger size by 25% over conventional designs and thus can deliver one of the largest potential capital cost reductions in this system. Expect to partner with one or more of the organizations and companies that are developing and testing advanced designs for $scCO_2$ heat exchangers to implement the technology. Expected project outputs include publications in high impact scientific journals. Collaboration with Univ. of Minnesota. Provided results were preliminary modeling results published before. The project just kicked off and has no current work to justify its performance yet.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: One year to perform the design and demonstration of the tailored selective-emission surface seems too ambitious.

**Reviewer 2:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**Reviewer 3:** Score: 4. Comments: Project is organized into four Tasks: 1) Emitter Material Design and Selection, 2) Selective Emitter Fabrication, 3) High Temperature IR Spectroscopy Measurements, and 4) Heat Exchanger Simulations. Instead of simulation, experimental demonstration of such a heat exchanger will enhance the project substantially.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** As mentioned, it seems the project timeline is too ambitious.

**Reviewer 2:** The thermal stability of the technology's proposed structures may be inadequate for application to CSP. An initial material selected, tungsten, was shown to have inadequate oxidation resistance and required coatings or even materials substitution (Sandhage et al.).

**Reviewer 3:** Fabrication of meta materials is not so practical yet in many situations. Using coating to realize meta material could be a huge challenge.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** All needed entities are involved.

**Reviewer 2:** CSP system and component designers.

**Reviewer 3:** People working on optical meta material design and fabrication, in particular, the fabrication.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The proposed project schedule seems too ambitious for both design and demonstration. 2) The technical viability of this concept is yet unclear to this reviewer. 3) It is not clear to this reviewer whether a 25% reduction in the size of a sCO2-heat transfer fluid heat exchanger is a limiting factor in the pursuit of next-generation CSP systems. It is recognized that sCO2 heat exchangers is important.

**Reviewer 2:** 1) The team proposes an innovative approach to improving heat exchanger performance (reducing cost) via coatings with engineered structures for tailored optical properties. 2) There is significant risk that the approaches won't be applicable to CSP operating conditions or materials. 3) Additional interaction with CSP systems and component developers could accelerate implementation of a successful method based on this project's work.

**Reviewer 3:** 1) Whether coating can realize cavity-structure in metamaterial design. 2) This is a high-risk project. 3) Real challenge in the fabrication of desired metamaterial is not yet well identified.

## High-Toughness Cermets for Molten Salt Pumps – $1,326,384

*Powdermet | Euclid, OH | Principal Investigator: Joseph Hensel*

This project is developing high-toughness, ceramic-metal composite materials (cermets), which offer minimal friction in fluids with poor lubrication and are resistant to erosion and wear-and-tear. The team is building a liquid pump and a component test facility that analyzes these materials in a molten chloride salt environment, examines design allowances, and determines the cost-effectiveness of the cermets. This work could enable fabrication of low-maintenance, durable pumps for concentrating solar power systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 3 |
| Advance the U.S. solar industry substantially | 4 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project has studied the properties of developmental ceramic/metal composite coatings. In all testing reported, the coatings developed by Powdermet have met performance criteria relevant to protecting superalloys from corrosion by molten salt heat exchange fluids, a significant technical risk associated with long-term use of molten salts at the high temperatures required by CSP and sCO2 systems. The technology also likely has relevance to other high temperature uses of nickel-based superalloys where attack of grain boundary chromium is problematic. Critical challenges were set and the approach shown to successfully overcome them. This budget for the work appears to have been well matched to the tasks. Due to circumstances beyond the control of Powdermet, long term testing of the coatings in molten salt loops has not been performed. Despite the overall positive results of the project, this task is extremely important for determining whether the coatings are applicable to CSP applications. Fortunately, The PI has devised a mitigation plan to determine whether the coatings will have adequate long-term behavior.

**Reviewer 2:** The project is well laid out and structured for the new cermet material development. The team has the necessary laboratory testing, materials evaluation and development, and valve design expertise. If there is any weakness in the project, it may be over ambitious. But the initial work was done with prior funding and is being applied here. So, it is likely that the same rate of progress will be made and the goals will be achieved.

**Reviewer 3:** The project is in advanced stages of development; components had been either designed or built. The cermets appear to be an excellent material choice for Molten salt pumps. However, a true test of the material suitability can be proven on a much large scale than proposed in the project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Powdermet relied on a collaboration with The University of Wisconsin for molten-salt loop testing. Unfortunately, technical issues at The University of Wisconsin have prevented Powdermet from performing some of its tasks. All other tasks appear to have been completed on schedule and a thorough investigation of the microstructure and mechanical properties of the coatings has been performed. Powdermet has accomplished the non-trivial task of applying a uniform coating of material to the Wc particles and preserving that structure in coating deposition. The PI has communicated a mitigation plan to address the need for long-term, molten salt loop testing. Powdermet is well known in the industrial community, so it is expected that they communicate results with potential end-users of their coatings, although this was not made clear in their report.

**Reviewer 2:** A good team making good progress and so the performance is good. The over ambitious nature of the project suggests close watch by the project managers.

**Reviewer 3:** Good progress has been achieved from 2018 until now. The proposed solution to use high toughness cermets offers a better solution that current available metal materials for 750C cycles.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in this project is unique and essential to developing a corrosion resistant coating and verifying its behavior under the desired operating conditions.

**Reviewer 2:** Score: 5. Comments: The tasks are possibly over ambitious, but achievable. The past performance of the team is good and so, my assessment is that the tasks are well laid out and should be possible to be achieved.

**Reviewer 3:** Score: 5. Comments: Building a scaled down pump, this the only way to fully understand the interactions between the materials and fluid working conditions. Otherwise it will be another "analytic" exercise offering not a clear path to construction and testing of full scale pumps.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I would like to see data for thermal cycling of the coatings under start-up, shutdown, and unplanned events during operation.

**Reviewer 2:** The main concern (not a blind spot) of the project (and thus of the PI and the team) is the ability to complete all the objectives. The factors that they can control will be controlled but I am not sure how the PI will manage factors beyond his control. I think the PI is realistic, and his discussions with me through email were very good, and I have confidence in the success of this project.

**Reviewer 3:** Again, the investigators must evaluate the impact of the transition for a "scaled-down" model and the full-size applications. Heat transfer does not scale well.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Close collaboration between Powdermet, superalloy manufacturers and the projects involved with centrifugal casting or welding tubes would be beneficial.

**Reviewer 2:** I feel that this team has the requisite combination of resources, expertise and industry partners to make it a success. The key addition may be the technology users and I believe that can be facilitated by the program and project managers at SETO.

**Reviewer 3:** While Sulzer is a very reliable Pump Equipment manufacturer, it would be highly advisable to consider other suppliers.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) The coatings developed by Powdermet are very promising from a performance and fabricability perspective. The fact that this work has been performed by a commercial entity demonstrates that these coatings could be available to a CSP system fabricator. 2) Verification of the coating's performance requires long-term testing as planned. If the test loop issues can not be resolved, alternative approaches - such as those suggested by the PI - should be used. 3) Additional interaction between Powdermet, alloy producers, and the investigators developing low-cost methods of making superalloy components for SETO would be beneficial.

**Reviewer 2:** 1) Hold the team to the schedule; 2) Verify the metrics they have asked for in the materials development.

**Reviewer 3:** 1) Give serious consideration to allow the completion of the project until the fall of 2020. 2) Request before approval an update on the current status. 3) Explore utilization of this type of materials for other applications.

## Mechanically-, Thermally, and Chemically-Robust High-Temperature Ceramic Composites – $400,000

*Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage*

The purpose of this project is to increase the thermal-to-electrical conversion efficiency of concentrating solar power systems by developing new mechanically robust, thermally conductive, and thermally cyclable ceramic composites used to make chloride salt heat exchangers and piping. Currently, no cost-effective solution exists for either of these components at high temperatures. These composites will be stiffer and stronger than nickel-based superalloys at 550-750 degrees Celsius and also resistant to corrosion by supercritical carbon dioxide air, and heat transfer and storage fluids, such as molten chlorides. The team will also test the manufacturability of these robust ceramic composites in complex shapes via scalable, low-cost forming and thermal treatments.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project is well aligned with the goals of the CSP program. This project plans to investigate the ceramic/metal composites comprised of interconnected phases of both the ceramic phase and the metal phase. Critical challenges include milestones for oxidation resistance in both $sCO_2$ and air and also achieving sufficient hot strength at 750C. The project start date was 2/1/2019 and the end date is 7/31/2020. Since these are new structures that are being developed, the goals of the project are certainly high risk especially given the short duration and funding of this SIPS project. The project goals are well aligned with the program objectives and also with the funding level and duration.

**Reviewer 2:** This project addresses a critical weakness of earlier work by the PI on using displacement reactions to fabricate ZrC/W composites for high-temperature, compact heat exchangers, these materials were susceptible to oxidation and, as expected, coating them with a protection layer proved untenable. Therefore, the PI, Professor Sandhage, drew on his materials knowledge to identify another potential materials system applicable to the Displacive Compensation of Porosity approach: $Al_2O_3$/Cr. This project is focused on demonstrating proof of principle of this material system prior to developing HX components. Given the proposed fabrication method of compact HX, development of good bonding methods will be essential.

## 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 0 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project is structured with clear objectives and well-defined milestones. The project is ahead of schedule with respect to milestone completion. Both the Alumina-Chromium and the Silicon Carbide-Silicon composites have achieved the required oxidation resistance in both the sCO2 and air at 750C. The Alumina-Chromium composite samples have far exceeded the 200MPa, 750C strength requirement (value of 321 MPa achieved). The other two milestones appear to be well on their way to completion ahead of schedule also. Overall, the project performance appears to be excellent at this point in the project timeline.

**Reviewer 2:** Although the project appears to be almost halfway complete, only one milestone has been completed. Results indicate that the other milestones are on track, but bonding is a key to assembly of HX and is addressed toward the end of the project. There are no collaborations. Although this may be acceptable for a seed project, collaboration with CSP system and HX designers will be essential.

## 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Each task in this project is well designed and provides significant information necessary to gain an adequate picture of the feasibility of producing these metal/ceramic composites. Furthermore, the required property information generated will be essential in determining if the properties demonstrated by these materials will fit the application requirements.

**Reviewer 2:** Score: 5. Comments: Each task adds unique and important value to achieving the overall goals of the project.

## 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I did not find any blind spots in the project plan or execution. At some point which may be in the next phase of the project, if there is one, costing estimates should be generated to be able to compare to targets. This would be difficult at this point in the project however as the final compositions and fabrication techniques are still being determined.

**Reviewer 2:** A critical blind spot is the focus on a strength metric as opposed to a reliability metric for the material. The material fails in a brittle manner and therefore Weibull Statistics are the most appropriate for evaluating reliability.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I did not identify any additional organizations or stakeholders necessary based on the goals of the project and the stage of the project.

**Reviewer 2:** CSP system and component developers.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** The project is ahead of schedule on the milestones with no significant challenges identified to completion of all milestones on-time and on-budget. The project has demonstrated significant high temperature oxidation resistance and hot strength for the ceramic/metal composites fabricated to date. No significant challenges appear to be outstanding for successfully achieving all the project milestones.

**Reviewer 2:** 1) The project applies a fabrication approach that may have significant cost benefits for production of high-temperature HX. 2) Demonstration of robust bonding methods is critical in application of this technology. 3) It is recommended to apply Weibull, or other statistical based, reliability approaches to assessing mechanical reliability. Methodologies suitable for metals (or polymers) are not relevant and potentially unsafe.

## Mitigation of Molten Salt Corrosion – $400,000

*Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage*

When molten chloride salts are used for high-temperature heat transfer and storage, structural metal alloys, and ceramic composites, the materials used to store many tons of molten salt can experience corrosion at high temperatures if the chlorides are contaminated with dissolved oxygen or water vapor. Corrosion is the most likely source of failure for chloride salt heat transfer fluids in a concentrating solar-thermal power system. This project aims to dramatically reduce corrosion for a concentrating solar-thermal power systems by developing novel chemistries of the molten chloride salts, and will show that minimal corrosion can be achieved with appropriate containment materials.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The proposed work covers necessary, but not transformative work for corrosion in systems with high-temperature chloride salts. Results likely only apply to next generation CSP plants. Unclear how the proposed tasks would lead to an understanding of the actual corrosion mechanisms instead of just measuring the corrosion rate.

**Reviewer 2:** 1) Well aligned with SETOs goals. 2) These are well captured, clear, and complete. 3) The main challenge on this project was to ensure the coupling at high temperature has a good dielectric material and suited to the application. Rotating electrodes are used routinely in aqueous systems. 4) Timeline and budget are both very good. 5) Provides a similar value to other projects, with the exception of provide some ability to access mass transport. I would have provided a 6 if this system were not isothermal. 6) It will provide tools and underlying information for component designers.

**Reviewer 3:** The project has already created the tools for evaluating the impact of molten salt corrosion. The team has selected the appropriate equipment to demonstrate experimentally the impact of chosen materials on the operational capabilities and further path for implementation.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 6 | 3 |
| Collaborates with sufficient stakeholders | 4 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Team has made substantial progress towards the build of the testing rig. Some quantifiable targets indicated that allow for directed execution of the testing program.

**Reviewer 2:** Milestones are relatively clear with good time frames and budgets. Impact is clear based upon the metric. Purdue is the only institution on this proposal. Having an industrial partner to provide advise would be helpful in providing guidance. The fact that they are patenting information indicates that there will be a reluctance to fully inform the community, though their poster was pretty open about the design features. In general the patent situation can hinder technology deployment since any technology developer will need to work with Purdue and develop a licensing agreement -- this does the opposite of sharing information and puts a variety of restrictions on the application.

**Reviewer 3:** The project is in the middle of the evaluation. They developed and built the equipment necessary to conduct the experimental work. At this stage, the team must continue the work to see some actual results.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Program for proposed work is clearly stated, and is focused on measurable outcomes that can be applied directly to real power plant operation.

**Reviewer 2:** Score: 6. Comments: It's clear they are working through a logical sequence of activities to get to the final task of proving out the method while attempting to constrain conditions that are favorable for good material performance.

**Reviewer 3:** Score: 5. Comments: As mentioned above the project is halfway to completion. The coming steps are an absolute must or otherwise all the efforts and investment done until now will be wasted.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** There is no indication that liquid water will be included as an environmental factor in testing program. Ambient air humidity is likely to be a factor in real operating plants, and is also the source of stress corrosion cracking in lower temperature systems. The potential for SCC in the higher-temperature systems needs to be assessed as well.

**Reviewer 2:** The flow of the system is important, but so is differential temperatures within the system as mass flow and material transport (corrosion in the hot area and deposition in the cold areas) occurs in halide systems. This rotating electrode set up won't be able to catch that behavior and having representative corrosion rates (<30micron/yr) may not be correct based upon this behavior.

**Reviewer 3:** It must be relevant to the project team to fully understand the difference between studies and laboratory experiments and the potential large-scale implementation in the industry. Scaling up was always the most challenging aspect of any project. Look ahead how to do the conversion.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The targeted < 30 um/yr corrosion rate needs to be confirmed by equipment OEMs. Such a large corrosion rate will significantly limit design space. Engaging equipment OEM sooner will allow for a better understanding of if this is the correct corrosion rate to target given the practical considerations of equipment design.

**Reviewer 2:** Having an industrial partner to provide advice would be helpful in providing guidance.

**Reviewer 3:** Having an industrial partner with practical experience in different types of molten salt and impact on the containers materials would be extremely useful.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) work needs to focus specifically on identifying corrosion mechanisms, not just corrosion rate. 2) the role of liquid water on corrosion mechanisms needs to be included in this work. 3) proposed work has clear and actionable outcomes.

**Reviewer 2:** 1) Mass transport in chloride systems will likely matter, it certainly matters in fluoride systems. This system won't capture that behavior. 2) The idea of this project to to compare a rotating electrode to static samples. If mass transport (due to different temperatures) is not captured inherently in the set up the corrosion rates will be rendered not usable by industry and need to be repeated. 3) The speed and cost at which this work is being accomplished is impressive.

**Reviewer 3:** 1) The project is in the middle of development - results should be reviewed as soon as the experimental work will be completed. 2) The project must involve industry participation to provide input for future large-scale application. 3) As mentioned above, interrupting the process now, will only waste the effort and funding already spent on the project.

## Oxidation-Resistant, Thermomechanically-Robust Ceramic Composite Heat Exchangers – $3,500,000

*Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage*

This project team is developing cost-efficient ceramic-composite primary heat exchangers that are highly resistant to corrosion by supercritical carbon dioxide and molten salt and will not deform or fracture at temperatures as high as 800 degrees Celsius. These heat exchangers will last longer than conventional ones and improve the efficiency and lifetime of concentrating solar-thermal power plants.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Scope of proposed work is quite large and spans design, manufacturing, and testing of advanced HX design for very high temperature- and pressure-operation. Both the fabrication method of the proposed HXs as well as the physical design can be applied to a range of heat exchanger applications within CSP, but also within thermal energy storage, aerospace, and compact heat exchanger applications. If reliable high-temperature operation is possible, HX developed could allow for increased efficiencies in thermal energy systems across the energy sector.

**Reviewer 2:** This project will investigate the manufacturing of cermet printed circuit heat exchangers, for high temperature and high-pressure applications, required for sCO2 systems. A successful project will advance the solar energy industry by providing alternatives for reliable components to be used in sCO2 power systems. The findings from this project can also be used in other industries.

**Reviewer 3:** Professor Sandhage, and team, plan to conduct an ambitious development project that could have significant impact on solar energy technology, and many other areas of technology where heat recovery is important. The project is based on earlier work using displacement reactions whose products have greater molar volume than the reactants. In earlier work, Professor Sandhage, and team, proposed using ZrC/W composites, however these required coatings to prevent oxidation and application of these coatings was untenable for complex components required in HX. Therefore, Professor Sandhage, and team, investigated another displacement reaction pair with products exhibiting higher molar volume than the reactants. This pair Al/Cr2O3 is more likely to have corrosion resistance and oxidation resistance in the desired sCO2 HX application. Furthermore, the processing route developed by this group offers an elegant solution to fabricating and bonding components of complex shapes required for compact heat exchangers that can survive sCO2 pressures and temperatures. The team may be underestimating the technical issues involved with consistently producing components of the desired geometries at relevant dimensions due to the exothermic nature of the reaction, the potential for the reaction to seal off unreacted metal, and control of infiltration into plates with features of the dimension required for efficient heat transfer for the specific material's thermal properties. Nevertheless, the team is aware of these challenges and has demonstrated successful application of the approach and a thorough understanding of the fundamentals required. Since the proposed method is innovative, it should be compared at several steps to commercially available silicon-bonded silicon carbide or reaction-bonded silicon carbide.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 3 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 3 | 5 |
| Collaborates with sufficient stakeholders | 4 | 3 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Work has not yet started. Team includes Thar energy who is familiar with many novel HX designs. Team also leverages existing test facilities there. Team would benefit from the incorporation of a larger HX equipment OEM, potentially Heatric or Alfa Laval, to guide design-for-manufacturing activities.

**Reviewer 2:** Low scores were given as the project has not started.

**Reviewer 3:** Some of the milestones are vague. Why is a 3 mm-thick plate selected, for Milestone 1.2.1, and what are the dimensions of the" parallel channels"? Failure strength is not a sufficient criteria. Failure analysis based on stress modeling and material Weibull parameters should be used to show that a structure with adequate reliability for sCO2 operation and thermal efficiency can be designed and then fabricated. This applies to Milestone 2.1.3, 3.2.3, and 3.3.2. Why are hot-pressed components used in Milestone 1.2.2 when the processing conditions can affect surface composition, flatness, porosity and other parameters that can affect bonding. Since the materials are brittle, 85% bonding implies the presence of defects that can act as stress intensifiers. Silicon carbide and other ceramics have been joined meeting hermetic requirements. Why can't this material meet the same criteria? Hopefully, the investigators collaborate frequently, and early, with their collaborators from Thar Energy who have the capability to design HX components for specific material properties.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Tasks are ambitious and cover activities from design, to manufacturing, to testing. All are required for a compelling HX design. Unclear if timeline will be achievable given the high-risk nature of the tasks and metrics.

**Reviewer 2:** Score: 6. Comments: The project report included a list of tasks and milestones during each of the budget periods. The tasks are reasonable for achieving the goals of the project.

**Reviewer 3:** Score: 5. Comments: The tasks add unique and important value to achieving the overall project goals and address the key features of HX development: material oxidation and corrosion resistance, mechanical properties, component design and fabrication. The design aspect is somewhat weak. Instead of strength, Weibull statistics should be used to verify reliability.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** It is unclear how much time and effort is being dedicated to the evaluation of the design's resilience to thermal cycling. Some modeling activities are cited, but should be elaborated further to determine if simulations contain high enough fidelity to capture true failure modes for designs under real service conditions. This should be done before any serious manufacturing work to be sure that a design is possible that can reach target lifetimes of > 30 yrs.

**Reviewer 2:** It is important that the project gets to hardware testing, as this is where the assumptions and findings will be validated for the proposed cermet printed circuit heat exchangers.

**Reviewer 3:** The investigator selected strength as a metric for demonstrating the material and approach may be adequate. It is possible for a material with a strength significantly higher than 200 MPa to have an unacceptable failure rate under sCO2 pressures if its Weibull modulus is too low. A better approach is to do a parametric study of maximum tensile stresses as a function of HX component/channel geometry and service conditions (start-up, steady-state, etc.) and then use these stresses and the Weibull properties of the material to predict failure probability. The PI is familiar with this approach. The system designers should provide a relevant failure probability criteria consistent with the risks associated with HX channel or component failure.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Team would benefit from the incorporation of a larger HX equipment OEM, potentially Heatric or Alfa Laval, to guide design-for-manufacturing activities.

**Reviewer 2:** Involving commercial developers would provide information on the challenges for integrating these cermet printed circuit heat exchanges into overall solar power plants.

**Reviewer 3:** As described above, additional integrated thermal and mechanical design and analysis would accelerate evaluation of the approach.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Robust FEA simulations will be necessary to determine if > 30 year lifetime is possible under the thermal cycling conditions expected in real operation. 2) Proposal team is highly capable and likely to produce high-impact results. 3) Performance targets are quite challenging, but would lead to a HX design that could be disruptive across CSP and other thermal power applications.

**Reviewer 2:** 1) This project will investigate alternative materials and manufacturing methods for high temperature circuit-printed heat exchangers, to be used in sCO2 systems. 2) This project can accelerate the demonstration of high temperature sCO2 systems in commercial pilot plants.

**Reviewer 3:** 1) This is a high risk, high reward project led by a knowledgeable PI likely to develop an innovative solution to the requirements for a sCO2 HX and other applications. 2) The material strength criteria is insufficient and potentially unsafe. 3) A thermal and mechanical modeling and design component would accelerate successful development of the technology.

## Robust High-Temperature Heat Exchangers – $1,960,745

*Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage*

This team is developing a high-performance heat exchanger based on a new ceramic-metal composite material (cermet) for transfer of high-temperature molten chlorides, with supercritical carbon dioxide as the working fluid for energy conversion in the power block of a concentrating solar-thermal power system. The higher failure strengths and thermal conductivities at 800 degrees Celsius of these cermets instead of metal alloys will allow the team to design smaller, lower-cost heat exchangers than would otherwise be possible. By tailoring the cermet surface and fluid chemistry, the cermets also have the ability to withstand thermal cycling and thermal shock, as well as resist corrosion from molten salts and fluids based on supercritical carbon dioxide.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 4 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 6 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Scope of proposed work is quite large and spans design, manufacturing, and testing of advanced HX design for very high temperature- and pressure-operation. Both the fabrication method of the proposed HXs as well as the physical design can be applied to a range of heat exchanger applications within CSP, but also within thermal energy storage, aerospace, and compact heat exchanger applications. If reliable high-temperature operation is possible, HX developed could allow for increased efficiencies in thermal energy systems across the energy sector.

**Reviewer 2:** The project aligns strongly with the goals and supports SETO's mission. The project is nearing completion in September of this year. The critical challenges appear to have been met. The project will have a high impact in the development of high temperature heat exchangers. The level of DOE funding seems appropriate, as does the project duration, for a project of this size and scope. The HX technology that has been developed is impressive and can have broad applications. The project has good potential to advance the solar industry as well as other industries. Strengths: Impressive new HX fabrication technology for high-temperature applications. The materials have high thermal conductivities, and other properties that appear to be good. The scope of the research is broad and deep. Two patent applications and a publication in Nature have been discussed in the Report. Weaknesses: It is not clear whether the fluid flow and heat transfer analyses have led to a desirable (optimal?) design, and whether an optimal design could be fabricated with the techniques described. This is a minor weakness, in light of the strengths of the rest of the Report.

**Reviewer 3:** The project is well advanced and the team has demonstrated technical capability. It should be completed. The technical review must account for some additional review steps, particularly in the final experimental phase

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 5 | 3 |
| Collaborates with sufficient stakeholders | 6 | 4 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Team includes VPE who is familiar with many novel HX designs and experts in diffusion bonding processes. Team also leverages existing test facilities there. Considering the challenging nature of the proposed work, team has demonstrated considerable achievements during the timeline of the project.

**Reviewer 2:** The project is wrapping up, and it appears most of the milestones have been met. The projected heat transfer density of the HX appears to be excellent. However, actual thermal performance of the HX doesn't seem to have yet been measured. There have been two patent applications filed, and an article appearing in Nature is discussed. The quality of the disseminated work is noted including especially the article in Nature is noted; additional publications would be of interest to the HX research community. The discussion of Task 5, Manufacturing and Commercialization, did not give much attention to the commercialization. The performance appears to this reviewer to have been excellent. The new HX design is impressive, manufacturing methods have been identified, a broad array of technological issues have been addressed ranging from corrosion, to differential expansion during heating and cooling, to performing informative studies of the fluid flow distribution in the HX. The budget and spending appear to be in good agreement. Two patent applications have been filed, and a journal publication in one of the most premier journals has been reported.

**Reviewer 3:** The project is near completion and at this final stage it must followed for a successful outcome. The methodology and the technical approach are very convincing.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Tasks are ambitious and cover activities from design to manufacturing. All are required for a compelling HX design.

**Reviewer 2:** Score: 5. Comments: The tasks are effectively integrated. All of the tasks are important to the overall success of the project.

**Reviewer 3:** Score: 5. Comments: Yes, it is a chain process and each task must be followed and reviewed. As mentioned above, the project is in the final completion stage. The effort at this conjunction of development must be closely reviewed and the process of assessing both quantitative and qualitative to what extend the targets of the proposal are fulfilled.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1**: It is unclear how much time and effort are being dedicated to the evaluation of the design's resilience to thermal cycling. Some modeling activities are cited but should be elaborated further to determine if simulations contain high enough fidelity to capture true failure modes for designs under real service conditions. This should be done before any serious manufacturing work to be sure that a design is possible that can reach target lifetimes of > 30 yrs.

**Reviewer 2:** It is unclear whether fouling (due to debris entering the exchanger with the working fluids for example) could become an issue because of the small channel sizes. It is well known that small channel dimensions are desirable from the heat transfer perspective, but heat sinks and heat exchangers with small channels have been used infrequently in other applications because of their tendency to clog.

**Reviewer 3:** Alternatives in case of a major failure.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Team is appropriate for proposed tasks.

**Reviewer 2:** None noted. The project is ending in September.

**Reviewer 3:** The addition of an experienced HEX industrial partner might provide input on the future large commercial size application.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Robust FEA simulations will be necessary to determine if > 30 year lifetime is possible under the thermal cycling conditions expected in real operation. 2) Proposal team is highly capable and likely to produce high-impact results. 3) Performance targets are quite challenging, but would lead to a HX design that could be disruptive across CSP and other thermal power applications.

**Reviewer 2:** 1)The success of the project to date is evident, and the HX that has been developed is impressive. 2) It will be interesting to observe the measured performance of this HX under high temperature test conditions. From what I could glean from the Report, such testing would occur after the project is completed. 3) This is a comprehensive, nicely documented, and interesting Report on an advanced technology that can make a significant impact on numerous technologies in addition to CSP.

**Reviewer 3:** 1) Follow up closely the quality control of the demonstration unit. 2) Consider potential alternatives in case of major failures. 3) The challenges for conversion of a scaled demo into a true full size industrial product - this is one of the most common issues for projects.

## Development of In Situ Corrosion Kinetics and Salt Property Measurements – $1,799,892

*Rensselaer Polytechnic Institute | Troy, NY | Principal Investigator: Li Liu*

This project is developing in situ experimental techniques and methodologies to gain a fundamental understanding of the mechanisms of molten-salt surface corrosion kinetics and molten-salt properties. Four complementary approaches are under development to achieve these objectives: in situ transmission electron microscopy; neutron reflectometry of molten salt and alloy cells; macroscopic electrochemical studies; and vibrational spectroscopy analysis and modeling. By addressing the knowledge gaps in high-temperature molten-salt properties and corrosion mechanisms, this research can guide the selection of salts and containment materials.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 3 |
| Advance the U.S. solar industry substantially | 5 | 2 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Salt corrosion characterization is an important first step for the development of higher temperature CSP systems. Work is necessary to allow for appropriate materials selection. Salt properties and corrosion mechanisms will be invaluable for future development. Approach is valuable because it works on the development of multiple techniques for salt characterization. In-situ measurement capabilities can become impactful for real time salt corrosion monitoring.

**Reviewer 2:** This is a strong R&D team with broad materials experience. The different analysis methods compliment and are interesting scientific endeavors. Given the initial work of setting up cells is complete, and data has been generated this is a good result of the project. Provides fundamental information that may help inform performance behavior. It will be interesting work and will yield good publications and methods, which are valuable. I think there will be interesting science produced here and that is the primary challenge in making sure the specialized equipment is done to enable the measurements. If the challenges could better aligned to the technology deployment that would be best. This isn't particularly high-impact, which is why the score is low here. The risk is this project yields any conclusive evidence or value for commercial applications due to the nature of the work. It will be interesting work most certainly, but from a commercial perspective it would not make the list of work to be done at this time. No problems, but the funding seems relatively high with a long time frame on the project. Do not expect a high value add based on what is already funded. Do not expect this to advance the industry, it's too early stage of work. It may eventually be of use, but the methods are really the advancement.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 |
| Disseminates results frequently and actively engage partners | 4 | 6 |
| Collaborates with sufficient stakeholders | 4 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Multiple risks retired already. Important first results that pure ternary salts will not be corrosive to Fe-Ni-Cr alloys. Unclear what measurement accuracy is attained with new methods. Project is fairly early-stage with fully academic team. May need to engage with device manufacturers at some point during the project to make sure sensors are manufacturable at scale.

**Reviewer 2:** They have made fine progress, but at least for VT, this is something that they have done before and it seems as though the budget is a bit high for the task. New experimental capabilities, journal publications, training of students, and IP for lease are impacts identified. These are the impacts, but there are not obvious quantitative metrics that are being identified. Could use some further thought here. No technology developer is being partnered with, nor is a commercial salt supplier. Both are opportunity losses.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: A wide range of salt properties needs to be known in order to enable correct component development. Furthermore, understanding of corrosion mechanisms will be critical for appropriate salt system design. Providing first data on chloride salt properties also very important.

**Reviewer 2:** Score: 5. Comments: Development of in-situ techniques for fundamental understanding of the mechanisms of molten salt corrosion is an important and clear task. The application of techniques is also clear and independent. These are important and the real value in this project. Having a way to do this on small scale and relatively quickly is important and of value. Application to relevant combinations and development of simulation models seem to not be a clear stand-alone task and I think bears less usefulness unless directed to evaluate said combinations by a system integrator. The methods need to be clearly rolled up into faster ways to evaluate corrosion and this really should be coordinated by another team that is evaluating design cost. Material models, unfortunately, will yield little in these systems at present due to lack of certainty in operation.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** What specific corrosion mechanisms are identifiable with proposed devices? It will be necessary to evaluate multiple mechanisms including stress corrosion cracking, creep fatigue, base corrosion rate, formation of oxidation layers, etc. It is unclear which, of any, of these mechanisms can be captured with proposed work. What is the accuracy of measurements?

**Reviewer 2:** 1) Mass transport in a system with varying temperatures (hot to cold) likely to not understand the dynamic nature with the experiments as performed. The cells work as made, but value might not be realized given mass transport does not seem to be accounted for. 2) Work is very scientific and seems to be more academically driven vs. having obvious commercial implications and impacts. Decisions will be primarily guided from either interesting science or from alloy developer and might not go in the direction of a prototypical system. Simply put, there is a lack of technology developer to partner with.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Need to engage device manufacturers at a later stage in this project. Make sure that devices can be manufactured at scale to the tolerances required to realize good device accuracy. Need to engage ASME and/or other regulatory bodies. Data collected with proposed measurement techniques will serve as basis for future codes and standards, especially for components that will be undergoing unique thermal cycling conditions in CSP plants.

**Reviewer 2:** 1) Lack of technology developer partner. It is difficult to say if there is a big impact without a partner to guide the decisions being made from an R&D perspective. Having a system developer motivates the work being done and naturally helps guide the direction. 2) Raw material supplier for the HTF, though NREL seems to be standing in on this function.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Engage regulatory bodies now to allow for easier adoption of new materials into ASME codes, especially for thermal cycling service. 2) Focus on what measurement accuracy will be with proposed new methods. Will they be sufficient for subsequent design and manufacturing activities? 3) More clarity needed on which specific corrosion mechanisms will be captured with the new proposed methods.

**Reviewer 2:** 1) Work is very scientific and seems to be more academically driven vs. having obvious commercial implications and impacts. Decisions will be primarily guided from either interesting science or from alloy developer and might not go in the direction of a prototypical system. Some of the interesting science could be replaced with having the PIs exercise their corrosion cells for non-structural materials or welded materials to inform other projects. 2) This project seems isolated relative the broader community. 3) The goal of the work is to develop corrosion detecting methods - electrochemical is good enough for where the state of the technology is right now.

## Characterization of Radiative, Convective, and Particle Losses in High-Temperature Particle Receivers – $1,031,070

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Clifford Ho*

This project is working to reduce particle and heat losses in directly irradiated high-temperature (greater than 700 degrees Celsius) particle receiver systems, using a combination of computer simulations and measurements of particle fluid dynamics and heat transfer pathways. This enables increased receiver thermal efficiencies, reduces receiver costs, and mitigates potential health risks from inhalation of fine particles.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project addresses critical issues related to solar particle receivers. The information sought by this investigation is unique to particle receiver technology and has not been characterized previously. The result could have a significant impact on CSP system efficiency. Additionally, some of the techniques for measurement of heat losses in ambient environments may have application to other commercially significant technologies. Although there are fundamental challenges with the approach taken, the team has been very careful in their methodology and their measurements combined with strong modeling is likely to have a very positive impact on the development of solar particle receivers. The investigators should be encouraged to validate their work further by measuring other receivers and/or sources of combined thermal/particulate emissions.

**Reviewer 2:** 1. The goal of this work is to develop tools and methods to characterize particle and heat losses emitted from the aperture of a high-temperature particle receiver. Particle receivers are being pursued to enable higher temperatures (>700 °C) and greater power cycle efficiencies (≥50%) for concentrating solar power (CSP) plants. 2. Direct irradiance of falling particles enabled very high heating rates, but additional methods to reduce heat (convective and radiative) and particle losses are needed to increase receiver thermal efficiencies, reduce costs, and mitigate potential health risks from inhalation of particle fines. How to solve the inability to resolve the ejected particles using optical imaging methods. 3. (1) develop imaging methods to characterize particle and heat losses from open-aperture falling particle receiver systems, and (2) use conventional air sampling systems to determine inhalation and pollution risks. 4. Funding was necessary to develop the novel imaging instrumentation based on existing optical imaging and in-situ sensing technology. 5. The study has some fundamental impact beyond the current project. 6. It evaluates the effectiveness and efficiency of particle receivers and potential issues. 7. Strengths; Particle-image, particle-tracking, and image-correlation velocimetry methods were compared against one another to determine the best method to obtain particle velocities. A high-speed infrared camera was used to evaluate particle temperatures, and a model was developed to determine particle and convective heat losses. Weakness: lack quantification in system level.

**Reviewer 3:** This work seeks to develop methods for evaluating the performance of falling particle CSP reactors. Instrumentation has been applied, along with relatively simple models, for determining the particle heat loss during operation. In response to this reviewer's question the PI indicates that the high-speed IR camera is not able to resolve single-particle temperatures. There is thus some question in this reviewer's mind as to how accurate the measurement and dependent models are.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 4 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project has quantified data and results extremely carefully, despite significant uncertainty with the apparatus' sensitivity to ambient radiation. The team was careful in characterizing background signals and modeling results confirm data interpretation. This work has resulted in several papers to be disseminated to the technical community. The investigators should be encouraged to share their results directly, or through a focused workshop, with teams designing receivers and collectors to be sure that their results are translated into tangible improvements.

**Reviewer 2:** 1. In year 2, most milestones are not completed. 2. Imaging work is basically completed, but solutions that increase the receiver thermal efficiency while mitigating potential inhalation hazards of particulates are not provided. 3. Results are disseminated in conferences. 4. More collaboration with PIV and imaging expertise is required. 5. Camera-based imaging instrumentation was done in order to study particle and convective heat losses from the aperture of a high-temperature particle receiver. Particle-image, particle-tracking, and image-correlation velocimetry methods were compared against one another to determine the best method to obtain particle velocities. A high-speed infrared camera was used to evaluate particle temperatures, and a model was developed to determine particle and convective heat losses. Particle emissions from a high-temperature falling particle receiver with an open aperture were modeled using computational and analytical methods and compared to U.S. particle-emissions standards to assess potential pollution and health hazards. Several milestones were not achieved.

**Reviewer 3:**

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Task 1.6, "Scaling of imaging methods to a 100 MWe Plant," seems premature. It seems as if very little validation work has been done, i.e. tasks 1.3-1.5 and that results will require iterative modifications to the physical and numerical methodology.

**Reviewer 2:** Score: 4. Comments: Tasks in year 1 included imaging in lab-scale and demonstration in station test. These tasks were completed satisfactorily. Tasks in year 2 included in-situ imaging system on-sun testing, assessment of convective heat loss using in-situ imaging system, scaling of imaging methods to 100 MWe plant, and collection and analysis of samples during on-sun in tests. Those were basically incomplete. The task on modeling of particle dispersion in air was successful.

**Reviewer 3:** Score: 5. Comments: The project seeks to develop methods for determining the particle and heat losses from a falling particle CPS reactor. The PI has made progress in achieving that goal.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Based on the report and papers submitted by the Principal Investigator, and answers to follow-up questions, I don't think that there 'blind spots' that the Principal Investigator has overlooked.

**Reviewer 2:** In-situ imaging for on-sun testing in CSP tower is much more complicated than what expected and may require more synergistic efforts of a larger team.

**Reviewer 3:** The PI has acknowledged that the thermal imaging technique (and it was acknowledged that imaging would be the most challenging aspect of the work) has limitation.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This team should work more closely with those designing and fabricating receivers and collectors. This was not stated clearly in the material provided.

**Reviewer 2:** Complexity in Imaging instrumentation under harsh environment.

**Reviewer 3:** No additional collaborators needed.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The science and methodology applied by the PI and team is some of the most rigorous and careful of all the projects that I reviewed. 2) Substantial validation of the results is required to verify model interpretation of the results. 3) I would recommend funding additional verification work.

**Reviewer 2:** 1) Quantification of thermal efficiency of particles. 2) Potential health issues if small particles are not well contained. 3) Multi-phase fluid and particle flow and heat transfer.

**Reviewer 3:** 1) Good progress has been made in measuring the approximate temperature profiles and particle emissions from falling particle reactors. 2) The PIs have readily acknowledged the limitations of the approach.

## Development and Demonstration of a 1000 Degree Celsius Solid Particle Receiver – $750,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Christian*

The German Aerospace Center's advanced particle receiver concept, an inclined rotating drum where concentrated sunlight heats particles, is being tested at Sandia's National Solar-Thermal Test Facility at temperatures above 800 degrees Celsius, heat-throughput levels greater than five megawatts, and solar-concentration ratios greater than 1,000 suns.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 4 | 6 | 6 |
| Implement a high-risk, high-impact approach | 2 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** 1.1 The project aligns well with the goals of the topic and addresses an important opportunity to integrate work at DLR and SNL to acquire data regarding the performance of the DLR so that it can eventually be marketed commercially. 1.2 There were few scientific or technical details in the materials provided to review. Information was lacking regarding how the measurement of curtain uniformity, thermal efficiency, and outlet particle temperatures would be achieved. 1.3 Four and one-half of the six key outcomes and milestones describe rather mundane activities (develop a document, ship and receive the receiver, complete permitting and paperwork, design the support structure, and perform post-test inspections). The sixth of six key outcomes (measurements of performance) is of high risk and high reward, but details are lacking. Predicting lifetime (0.5 of 6 of the key outcomes) may also be challenging. 1.4 I have no reason to believe the budget and timeline are inappropriate. 1.5 The work involves other parties (DLR and HelioHeat) which suggestions that the work can be highly translational and important to parties beyond DOE. Application to technologies outside of CSP are probably limited. 1.6 If successful, the proposed activity represents a good opportunity to achieve this objective. Strengths: International involvement (DLR), private sector involvement (HelioHeat), and unique experimental facilities (SNL) are all present. The investigators are in a unique position to perform the work (as it is unclear who could undertake the work proposed other than these investigators). Weaknesses: Lack of scientific and technical detail in the report made assessment difficult. The poster is uninformative.

**Reviewer 2:** Interesting project in which an existing design for a particle receiver will be tested at Sandia's central receiver test facility.

**Reviewer 3:** 1) Performance information (at power levels closer to a small scale Concentrating Solar Power (CSP) plant) will be obtained at full load conditions (2MWt) and at 1000°C particle outlet temperatures at the National Solar Thermal Test Facility (NSTTF) located at SNL. 2) Cost reductions; Reliability; Repeatability - all target at commercialization. 3) Advanced particle receiver technology is still a research and development activity but is verging on being able to be a commercial product. 4) The project budget is reasonable. Duration is 2-year. 5) Sandia National Laboratories (SNL) and the German Aerospace Centre (DLR) are world leaders in the joint and separate development of very high temperature next generation solar concentrator systems using solid particles. This project will provide the critical performance information needed to commercialize the German Aerospace Centre (DLR) CentRec® receiver and ancillary particle systems (lifts, hoppers, valves) developed at Sandia National Laboratories (SNL). 6) The overall project objective is to deliver critical performance data for the particle receiver system at a 2MWt scale. Licensing SNL's particle receiver system components will be an end goal. Providing performance results for the CentRec receiver will provide HelioHeat with results to market the receiver they have licensed. An ideal commercial license will include a final design needed for solar plant operation. 7) Strengths: Strong team and world leaders in field. Test at full load conditions (2MWt) and at 1000°C particle outlet temperatures. Being able to be a commercial product. Weakness: not started yet because of contract issue.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 2 | 5 |
| Measures impact appropriately (e.g. quantitative) | 2 | 3 | 6 |
| Disseminates results frequently and actively engage partners | 2 | 3 | 6 |
| Collaborates with sufficient stakeholders | 5 | 4 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** 2.1 The project has not yet started, but there was not a clear indication of milestones to be met. 2.2 This was not discussed to any meaningful extent in the materials provided for review. 2.3 This was not discussed to any meaningful extent in the materials provided for review. 2.4 The collaboration with DLR and HelioHeat appears to be strong. 2.5 The project has not yet started, so there is no performance to be evaluated as of yet.

**Reviewer 2:** My main concern is the potential delays: the project is already 6 months late, before the delays by coronavirus. Although the budget is adequate for the propose scope, the scope of the project is too limited to demonstrate durability of components (e.g., 15 days of solar simulation). Low scores were assigned to several questions, as the execution of the project has not started.

**Reviewer 3:** 1) Milestones are listed; project is waiting to start. 2) The end state of this project is to provide the performance results of the particle receiver systems needed to prove that commercialization of the final product will be successful. The primary focus of the project is overcoming the testing and validation step needed during any commercialization process. An ideal commercial license will include a final design needed for solar plant operation. 3) Licensing SNL's particle receiver system components will be an end goal. Interactions with the commercial entity, HelioHeat, will be on-going to ensure commercialization will be successful. 4) Sandia National Laboratories in collaboration with the German Aerospace Centre (DLR). 5) The overall project objective is to deliver critical performance data for the particle receiver system at a 2MWt scale. Key milestones include the design and fabrication of the support structure that will accommodate the DLR receiver, site permitting and safety documentation, shipping and receiving the receiver at the test facility, and testing the receiver through an experimental test matrix to gain the performance data.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: As noted elsewhere, four and one-half of the six key outcomes and milestones describe mundane activities (develop a document, ship and receive the receiver, complete permitting and paperwork, design the support structure, and perform post-test inspections). The sixth of six key outcomes (measurements of performance) is of high risk and high reward, but details are lacking. Predicting lifetime (0.5 of 6 of the key outcomes) may also be challenging, depending on the level of scientific rigor applied to this task.

**Reviewer** 2: Score: 6. Comments: The project report included only a succinct summary of the tasks. Overall, the project organization is reasonable, for a technology transfer from DLR to Sandia.

**Reviewer 3:** Score: 6. Comments: Key milestones include the design and fabrication of the support structure that will accommodate the DLR receiver, site permitting and safety documentation, shipping and receiving the receiver at the test facility, and testing the receiver through an experimental test matrix to gain the performance data. Licensing SNL's particle receiver system components will be an end goal. Anticipated challenges for this project include: a. Cost reductions: This project will focus on receiver performance while keeping the costs low and integrating current low-cost systems identified by SNL and DLR. b. Reliability: The rotating feature of this receiver adds to the complexity of a CSP receiver, but there are industry examples of large machines rotating under extreme conditions to perform a task. The existing commercial equipment can be referenced for reliability in the scaled CSP plant designs. c. Repeatability: The CentRec was specifically tested for uniform particle outlet temperatures and determined that temperatures can be controlled with some simple control logic. The mass flow rate and rotational speed of the receiver is adjusted to achieve the required particle outlet temperatures and demonstrated to be successful. The ancillary systems can be adequately insulated to prevent inadvertent heat losses.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** None noted.

**Reviewer 2:** The goals of this project are to reduce risk for particle solar power towers by demonstrating a particle receiver. While there are many challenges to bring this technology to market, the fact that this project aims to operate the receiver in a solar facility will help remove blind spots that the industry as a whole may have regarding this technology.

**Reviewer 3**: Not sure if the DLR receiver will be purchased or constructed.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It is unclear what measurement methods have been developed, and who developed them. I assume these techniques have been developed and the experts who developed them are available to this project.

**Reviewer 2:** This project has a good balance of research institutes and technology provider. Commercial project developers need to be contacted in order to accelerate the deployment of this technology into a full pilot system.

**Reviewer 3:** The current collaborative team should be sufficient.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** There need to be clearer metrics put forth as to what would constitute a successful or unsuccessful outcome in order to provide meaningful comments. There needs to be a better explanation of the key scientific and technical challenges, along with identification of the individuals who would address them as well as their qualifications (publications, patents, etc.). There needs to be a clearer explanation of the timeline and key quantitative results.

**Reviewer 2:** 1) High impact project thanks to the actual demonstration of a particle receiver under solar concentration conditions, at 2MWth levels. 2) The main concerns are the potential delays, as the project is already late by 6 months before starting, and the limited scope with only 15 days of operation.

**Reviewer 3:** 1) World leaders with mature product target at commercialization. 2) To deliver critical performance data for the particle receiver system at a 2MWt scale. 3) The R&D performed with federal funds in the past can be leveraged to help test and push for commercialization for particle system components.

## High-Temperature Freeze and Leak Resistant Advanced Salt Valve – $2,000,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Kenneth Armijo*

This project team is developing a robust molten salt valve that can mitigate leaking and freezing in operating temperatures up to 750 degrees Celsius in concentrating solar-thermal power plants. The design uses passive and active heat management strategies suitable to different valve types. This will ensure long-term valve operation at high temperatures, promote a 30-year system lifetime, and reduce operation and management burdens due to freezing and downtime.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project plans to take an idea and design from TRL 1 through TRL 5 in three years, and that is high risk, challenging and ambitious. The ambitious comment is made because the project has not started and so it is not possible to gauge how well the team works and how productive the team is even over a short period. However, the team has written an excellent proposal, showing good knowledge of the space, and its needs and ways to meet such needs. The key question for the program managers will be how well they are delivering.

**Reviewer 2:** The project team has clear project goals and is limiting the efforts on the development to a single critical item, (FCV) which is critical for 750C operating systems. Scalability and risk assessment are well enunciated, but require more details about overcoming potential failures.Currently, there are no detailed milestones and project management, making very difficult for a proper review.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 1 |
| Measures impact appropriately (e.g. quantitative) | 5 | 1 |
| Disseminates results frequently and actively engage partners | 1 | 4 |
| Collaborates with sufficient stakeholders | 2 | 1 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This is a difficult question to answer or comment on, in view of the fact that the team is just getting started and not shown any progress or performance yet. However, based on the excellent proposal/report, my opinion is that the team should make good progress. Further comments cannot be made on this project on this topic.

**Reviewer 2:** While the scope and development processes for the project have been described, a more detailed task-oriented map must be created. It is imperative to involve more than one industrial partner, not only for the development but also for ensuring the quality of future manufacturing techniques for mass production. Many “one of a kind” successful lab prototypes failed to meet the large volume of manufacturing.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: In principle, the tasks do show good planning and thinking through the process. The success of these tasks will be proven after the project starts and the team works together. No further comment can be made on this aspect.

**Reviewer 2:** Score: 5. Comments: Yes, the project team had considered a very realistic and systematic process of assessing the material compatibility of various valve components. The other steps, of scaling up If followed properly, the analysis suggested in the proposal will make the experimental prototype successful.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Too early to comment on PI blind spots. However, the PI and team have written a good plan for the research, and brought the right scientific and technical people that should lead to success.

**Reviewer 2:** A review of competitive solutions offered by others for similar devices. A comprehensive analysis of mitigation solutions for each of the given steps in the development.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This team is well structured. At this time, no changes are suggested.

**Reviewer 2:** While Flowserve is an excellent partner/contributor, there are other National Laboratories as well as US organizations willing to be participants. In particular, manufacturers of high temperature pipes and valves. In addition, I would participate a team of experts in material compatibilities, as well as assessing the impact of wear and tear on hardware for these severe operating conditions.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Start the project; 2) Follow the timeline and see how they perform; 3) Make sure that they deliver the TRL 1 to TRL 5 transition -- that is a key aspect that makes this project so unique.

**Reviewer 2:** 1) Long term effects on hardware due to equipment operating at high temperatures. 2. There are large numbers of sub-components, such as packing gaskets, seals, bellows etc., which under high temperature conditions, behave differently. A careful review for the interaction between them and identification of the weakest link to failures. 3) In the end, the proof is in testing - a very detailed, comprehensive testing program is needed to insure that there are alternatives to overcome possible road blocks.

## Quantifying Thermophysical Properties and Durability of Particles and Materials for Direct and Indirect Heat Transfer Mechanisms – $445,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Kevin Albrecht*

This project seeks to improve the understanding of dense granular flow heat transfer through testing subscale prototype heat exchangers. Currently, data for prototype heat exchangers is limited due to uncertainties in inlet in outlet temperature. Acquiring this data will lead to input parameters for heat exchanger models used in the design process as well as identification of potential methods for improving the performance. The overall objective of this project is to supply other concentrating solar-thermal power projects with sufficient data for the design and optimization of particle-to-fluid heat exchangers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The goal of this project is to design and test a sub-scale moving packed bed heat exchanger system which demonstrates improved performance with respect to pressure drop and heat transfer characteristics. The project includes design, manufacturing (through procurement from outside vendor) and testing to validate model design results and demonstrate performance improvement. The overall goals of the project are aligned well with the goals of the program. Performance of the new heat exchanger design is expected to be enhanced by the implementation of narrower channels for the particles to travel thorough thus minimizing the heat diffusion length within the low conductivity particle bed. The project duration and planned work appear to match well with the level of DOE funding for the project.

**Reviewer 2:** 1.1 The research aligns well with the goals and clearly supports the SETO mission. 1.2 The challenges are noted in the report, primarily challenges associated with measuring the performance of the particle-sCO2 HX in terms of obtaining a high overall heat transfer coefficient.1.3 The proposed work is not of significantly high-risk, as it is mainly focused on improving measurement techniques. Accurate models of the particle-sCO2 HX would have a positive impact on the realization of such equipment.1.4 The duration and funding level appear to be appropriate, although details are missing.1.5 The proposed HX, with solid particles and sCO2 as the working material streams, might have limited applications beyond high temperature CSP. 1.6 The proposed HX is one of many individual components that have an important role in advancing high temperature CSP. Strengths: The research addresses an important problem, albeit somewhat limited to CSP. Unique opportunity to work with the Brayton cycle group at SNL. Weaknesses: Few scientific and technological details are in the report and poster. The internal configuration of the HX is unknown. Specific methodologies to address the possible challenges were not described.

**Reviewer 3:** The project, "Quantifying thermophysical properties and durability of particles and materials for direct and indirect heat transfer mechanisms," led by Dr. Albrecht at Sandia National Laboratory, addresses a critical need for SETO and the US solar industry. Efficient, economical heat exchangers are critical for thermal CSP systems. The project on particle-based heat exchangers is a necessary effort to understand whether this heat transfer approach offers economic benefits for CSP. The team has addressed issues such as hot-valve design and has a mitigation strategy for erosion., however the project is heavy on modeling as opposed to construction and testing of components. Modeling can be time and cost saving if it's assumptions and results are validated. Given the many unknowns in the technology overall, and especially of the heat exchanger component fabricator, shifting the balance of work toward testing from modeling seems appropriate.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 3 | 4 |
| Collaborates with sufficient stakeholders | 5 | 4 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project began on 10/1/2018 and ends on 10/1/2020. The report states that the milestones were renegotiated in November 2019 and that all new milestones are on track. Particle and sCO2 flow loop designs have been completed. Completion of the commissioning of these systems is expected in a few months (before July 1st when the procured heat exchanger system will arrive). Future efforts tied to milestones include procuring of one of the designed heat exchanger systems by the first of July. Another milestone includes testing of the procured heat exchanger system under various operating conditions to demonstrate performance improvement. Design of two different heat exchanger systems has been completed. Modeling of each of these designs is underway to determine the optimum design with respect to heat exchanger performance. The project appears to be significantly under budget; however, procurement of the system has not been accomplished yet. Manufacturing discussions are reportedly underway with Vacuum Process Engineering, however it is not clear from the report whether the external vendor has agreed to make the system (with the planned diffusion bonding, brazing, etc. features) and whether the costing and delivery terms will be consistent with the projects budget and timeline.

**Reviewer 2:** 2.1 Detailed timelines were not presented. 2.2 Technical and economic performance metrics seem to be missing altogether. No target values of the overall heat transfer coefficient were found. 2.3 There was no evidence of plans for dissemination of results or active engagement of a partner. 2.4 There is little evidence of this, although it is mentioned that additional support is being supplied from the Brayton cycle researchers within SNL without further detail. The project began in October of 2018 and progress seems to be limited to sizing experimental ancillary equipment and flow loops. More discussion of how high overall heat transfer coefficients or accurate particle temperature measurements will be achieved would have been helpful. There is little technical information in the Report or Poster.

**Reviewer 3:** Sandia National Laboratories has been involved in solar energy research for many years and has extensive in-house knowledge related to concentrated solar power and energy technology. Therefore, numerous external collaborators are not essential for the project to succeed. Erosion of heat exchanger components by flowing particles may be a significant issue for the technology. A separate project, at The University of Tulsa, has been funded by DOE to investigate this issue, but a more formal collaboration and/or communication method between Sandia and The University of Tulsa may be beneficial. For example, it's not clear that Sandia and Vacuum Process Engineering have communicated specific materials, flow rates, and other design requirements to The University of Tulsa, or that an iterative design process is in place to use the findings of The University of Tulsa results. The project report and poster didn't elucidate how project results were communicated to stakeholders.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Demonstration of the performance improvement for a new heat exchanger system will require development components which include design, numerical performance estimates, fabrication of the heat exchanger and testing of the heat exchanger to validate performance improvements. The work planned in this project includes each of these critical components and adds value to the overall goals of the project.

**Reviewer 2:** Score: 3. Comments: The tasks focus on hardware development, specifically hardware external to the particle-sCO2 HX. There is little information on how the thermal performance of the HX is defined, or quantified. The degree of accuracy to which these quantities of interest will be measured is not clear. The measurement challenges appear to be the most important aspects of the project, based on the information provided in Report.

**Reviewer 3:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I did not identify any blind spots for the project to progress toward the stated goals. Additional things to consider might be: The tendency for increased particle clogging in the heat exchanger system due to the smaller flow channels in the heat exchanger system should be evaluated. Similarly, the role of smaller channels on increasing particle erosion on the heat exchanger plates should be evaluated.

**Reviewer 2:** The budget could be more detailed. It is not clear how the measurements of the HX performance will be made. However, the project is ending in October.

**Reviewer 3:** Erosion is one of the key unknowns that hasn't been addressed by this project. Also, the PI seems to rely heavily on modeling without adequate verification.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** I did not identify any stakeholders, collaborators or organizations that are missing for completion of the planned work.

**Reviewer 2:** It is not clear who the experts are that will conduct the important measurements that are at the heart of building this experimental apparatus. However, the project is ending in October.

**Reviewer 3:** Materials scientists that can evaluate the selection of materials and their thermomechanical/environmental behavior.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** The goals of the project fits within the goals of the program. The project milestones are currently on track and the project is under-budget.

**Reviewer 2:** 1. Clearer metrics as to what would constitute a successful or unsuccessful outcome of the planned experiments would have been helpful. 2. A more detailed explanation of the key scientific and technical challenges, along with identification of the individuals who would address them as well as their qualifications (publications, patents, etc.) would be helpful. 3. There seems to be a disconnect between: (1) why the experiment is being built in the first place (to measure HX performance), and (2) the work that is being proposed which focuses on the experimental hardware external to the HX and spends little time on the HX itself or the measurements of HX performance.

**Reviewer 3:** 1) Prototype evaluation of this heat transfer approach at Gen 3 CSP relevant conditions is highly recommended. 2) The team has relied heavily on unvalidated modeling, whereas iterative modeling and verification can significantly reduce risk. 3) Closer collaboration with The University of Tulsa and/or other materials scientists may also provide benefit to the project's success.

## Solar-Thermal Energy Ammonia Production – $2,800,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Andrea Ambrosini*

This project enables the use of solar-thermal energy to produce ammonia, a common industrial chemical that requires a lot of energy to produce. First, sunlight will activate solid particles in a concentrating solar-thermal power system to isolate nitrogen from air. Then the nitrogen will be activated to form a metal nitride, which can react with hydrogen to generate ammonia. The project team is developing materials that can be reliably and cost-effectively cycled for both the nitrogen separation and ammonia generation steps in the process.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 3 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 2 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This is novel use of concentrated solar energy, in order to generate ammonia from renewable energy sources. This is a high risk / high reward project, with many technical challenges. DOE funding is key in order to develop and demonstrate this technology.

**Reviewer 2:** 1.1 This project proposes to use CSP to develop new chemical processes. 1.2 The project does not appear to have progressed at the rate that was initially proposed. The necessary nitride materials have apparently not been developed; it is not clear whether such materials will be successfully developed. The mitigation strategies noted in Item 10 lack necessary detail.1.3 Fundamental roadblocks have been encountered. Solar production of NH3 is an attractive proposition. 1.4 The project is expensive, and at this point it is questionable whether sufficient success will be achieved during the proposed duration of the project because of the difficulties encountered in producing the needed chemicals to proceed. 1.5 The difficulties encountered appear to be more fundamental in nature, and therefore one might anticipate fundamental solutions could be forthcoming. 1.6 Using CSP to produce NH3 seems peripheral to US solar industry. Strengths: The production of NH3 using CSP is an interesting and potentially economically and environmentally viable proposition. Weaknesses: The inability, to date, to produce the necessary chemicals for the project to succeed appears to be potentially fatal. Unfortunately, there are few scientific or technical details in the Report or the poster.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 2 |
| Measures impact appropriately (e.g. quantitative) | 6 | 2 |
| Disseminates results frequently and actively engage partners | 5 | 3 |
| Collaborates with sufficient stakeholders | 3 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The main concern is the lack of involvement of industry: technology providers and developers will be needed in order to demonstrate this concept at a commercial level. Involving an engineering firm could help understand key challenges, and start addressing them early on.

**Reviewer 2:** 2.1 The project started in October of 2018. The basic chemicals that are necessary for the project to progress have yet to be synthesized. The proposed mitigation strategies lack detail. 2.2 I did not note quantitative metrics in the Report. 2.3 There has been one journal article produced and one patent application submitted. Apparently, there is not an industrial partner. 2.4 It is not clear whether there would be an industry demand for the $NH_3$. Although the project started in October of 2018, progress is lacking because of difficulties in synthesizing the necessary nitrides. The mitigation strategies include "investigating alternative syntheses, leveraging ASU capabilities to perform these syntheses, and the purchase of a purge furnace to allow for higher throughput." There is little in these stated mitigation strategies that suggests that much thought has been given to how the difficulties will actually be addressed. Unfortunately, the performance of this project has been somewhat limited.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project is well thought out, with the right tasks in order to select materials and design key components in the system. The final task for system and thermo-economic analysis is key for defining the overall cost and government support.

**Reviewer 2:** Score: 3. Comments: It appears that the investigation has not progressed beyond Task 2 of the six tasks. It appears that Tasks 3 through 6 won't add much value unless Task 2 is achieved.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The TRL level of this technology is very low: not all steps in the reactor have been identified. While I wouldn't say blind spots, there will be many unknown unknowns as this technology is developed. It would be advantageous to involve engineering firms or commercial ammonia producers to get feedback on risks to make this technology a reality. From the solar side, key issues to consider would be: partial operation (low resource or cloud transients), system start up, and parasitic power consumption.

**Reviewer 2:** At this stage, without the nitride material successfully synthesized, it may be difficult to address additional unanticipated scientific and technological hurdles that will surely surface in the time left on the project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Engineering firms, ammonia producers and concentrating solar developers.

**Reviewer 2:** An individual or organization that can synthesize the necessary material in short order.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) High risk /high reward project. 2) Successful demonstration of this project could open the door for other industrial processes involving high temperatures, which could find a renewable energy source and reduce their carbon footprint. 3) Need to involve engineering firms, ammonia producers and concentrating solar developers to understand risks and a path towards commercial demonstration.

**Reviewer 2:** 1) This was, at the outset, a high-risk proposal. The investigators have encountered difficulties in completing Task 2, which is a critical activity. It is not clear if any value will be added by funding work on Tasks 3 through 6 unless Task 2 is achieved quickly. 2) The production of NH3 using CSP is an interesting concept, but perhaps not central to the interests of US CSP industry.

## Supercritical Carbon Dioxide Loop in Support of the Third Generation Concentrating Solar-Thermal Power Solid, Liquid, and Gas Pathways – $3,600,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Matt Carlson*

To achieve higher efficiencies, concentrating solar-thermal power plants can use the Brayton power cycle, an engine design that uses supercritical carbon dioxide as a fluid to transfer heat. Current concentrating solar-thermal power plants use steam Rankine cycles, in which 35-42 percent of the collected heat is converted to electricity. Brayton power cycles that use supercritical carbon dioxide as the working fluid could increase this efficiency to 50 percent or higher. This project will develop a supercritical carbon dioxide support loop to cool the main heat exchanger in a pilot plant project.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 3 |
| Advance the U.S. solar industry substantially | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This is a phase 2 type of project. It must be continued. However, a closer look and oversight concerning the efforts, cost and support of the subcontractors involved in the process must be established.

**Reviewer 2:** This project seeks to design and construct a mobile sCO2 cooling look capable of adapting to any DOE Gen3 CSP concept. In this sense the work is not research-oriented, but is engineering design needed to advance other projects in next-generation CSP effort.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 2 |
| Collaborates with sufficient stakeholders | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This is relative large-scale endeavor. Now is entering a significant phase. I wish it would provide a critical path for the hardware development and provides alternatives in case of components failures.

**Reviewer 2:** It is not clear whether there are results worthy of dissemination in this project, but it is needed to support other efforts.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: This project is very important for the future sCO2 power generation systems. It should provide more details on the oversight Sandia has over the design, quality and performance of all the system components.

**Reviewer 2:** Score: 5. Comments: The tasks and milestones seem reasonable, and the project is on schedule.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Oversight of subcontractors at their manufacturing facilities, to insure quality and performance of components.

**Reviewer 2:** No blind spots noted.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I would involve some equipment manufacturers as advisers, to ensure realistic and cost-effective options during the component fabrication stage.

**Reviewer 2:** The project appears to have involved those who will need the flow loop for testing their CSP concepts.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The project is critical in the overall scheme of the development of sCO2 based power generation systems. 2) They are in phase 2, therefore cancelling it now will be total unproductive 3) Explore option to accelerate the timeframe of the project. There were too many delays and the schedule might be negatively impacted.

**Reviewer 2:** 1) This work is supportive of other CSP projects, and the PIs are seeking to make the system adaptable. 2) The work is making good progress.

## High Temperature, Raman Spectroscopy Based, Inline, Molten Salt Composition Monitoring System for Concentrating Solar Power Systems – $1,154,849 ♦

*Sporian Microsystems | Lafayette, CO | Principal Investigator: Kevin Harsh*

In situ, real-time, and online monitoring of molten salt composition and chemistry could enable the next generation of concentrating solar-thermal power plants to achieve maximum thermal performance and reduce material damage due to corrosion. This project is developing and testing a lab-scale molten salt heat transfer fluid composition and contaminant monitoring system. Additionally, this project is developing and testing a fluid based on Raman spectroscopy, a precise method used to identify contaminants in the molten salt, and able to withstand high temperatures. Altogether, the proposed system will have the potential to improve the efficiency, reliability, and economic viability of concentrating solar-thermal power systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 3 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** In-situ, real-time monitoring of salt chemistry can be an important tool for early detection of unfavorable salt chemistries that may be detrimental to component life. Technology could also be used in nuclear industry to monitor quality of salts in MSRs. Unclear if real-time and in-situ monitoring is critical. Periodic sampling of molten salt for assessment of impurities may be sufficient to reach the performance goals of next generation CSP plants.

**Reviewer 2:** 1.1 The primary reason for this measurement is to detect changes to the melt that would result in corrosion. Raman allows a large swath of detection of varying elements. The focus of the overall work should primarily be to assess changes in the melt that would alter corrosion behavior, which is typically directly more measured by open circuit potential.

1.2 The one that I see as missing is a challenge around resolution of the technique to low enough impurity levels. I see this as both a large risk and challenge that is missing. 1.3 I think this is a high risk project, as the resolution of the technique may not be able to adequately resolve corrosion causing impurities, such as water or oxy-chlorides, at a low enough level to determine if system chemistry is “out of spec” (assumes there is a specification to begin with). Open circuit potential (i.e. electrochemical techniques in general) are more direct measurements of chemical changes to the melt -- very similar to pH changes in water systems. 1.4 Timing and funding seems appropriate. 1.5 I mentioned this above and in some of the other reviews, but standard electrochemical techniques are adequate. The spectroscopic techniques are interesting, but I think not needed for CSP systems 1.6 Similar to 1.5 - this is a nice to have, but not really going to make a huge impact.

**Reviewer 3:** The project is well defined and has budget and timelines that are in line with the proposed scope. The main weakness of the project is how much it will advance the solar industry: even with the successful completion of this project, the technology being developed (Raman spectroscopy) will only determine the presence of species in the heat transfer fluid. But, missing from these measurements is the concentration of those species, so that corrective measurements can be taken in order to alter the corrosion of pipes, heat exchangers and tanks.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 2 | 4 | 6 |
| Disseminates results frequently and actively engage partners | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Quantitative information is lacking. What accuracy of measurement is necessary to control salt chemistry appropriately, and can the given approach measure to that accuracy specification? Further, specifically what impurities need to be detected to fully monitor for all potential issues related to varying salt concentration and effect on equipment lifetimes?

**Reviewer 2:** 2.1 Milestones are good and clear. 2.2 It would have a been a bigger impact if the metric could focus on the impurities that (i.e. moisture) and the detection limits (min and max). As it stands condition monitoring makes sense, but is too broad. 2.3 No problems, clearly work is interrelated and milestones indicate the team is functioning well. 2.4 Sporian does reach out to various industrial contact, but it would be nice if there was a clear way to include material suppliers or system technology developers.

**Reviewer 3:** The project execution has been as planned, achieving most milestones to-date. The project budget and timeframe is commensurate with the proposed scope.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: All tasks are important for the completion of this work. Focus is on the ultimate development of a prototype system as a primary assessment of the technology’s viability.

**Reviewer 2:** Score: 6. Comments: Each milestone (as provided) shows a clear development path to de-risking the instrument and developing it. I think it looks good and is clear.

**Reviewer 3:** Score: 5. Comments: The project listed the milestones that have been achieved and the remaining ones; they are unique and show the progression to meet the project goals.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** At later stages of the project, the team will need to have an idea of how reliable this sensor is going to be. This will be critical to commercial adoption.

**Reviewer 2:** Characterization of detection limits - is it sensitive enough to detect low enough concentrations that system chemistry could be adjusted? That would be one area of concern I have as reading through this work.

**Reviewer 3:** It is not clear from the report, and a response was not received from the PI, on the following issues: 1) Are there limitations on the types of salts that can be monitored with this system? 2) Concentration information is needed in order to take action to prevent corrosion. 3) How is the system calibrated at high temperatures?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** OEMs of critical equipment that will be in contact with molten salt may be a helpful addition. They will be able to give input on how much fidelity or accuracy they may need to ensure the longevity of their equipment, and/or the specific impurities that are important to them for monitoring the health of that equipment.

**Reviewer 2:** This is a good team with NREL (chloride developer + Raman calculations) and UA (corrosion and test abilities).

**Reviewer 3:** The project results and development plan should be discussed with technology providers and commercial developers to understand that challenges to use this technology in commercial plants. It could be possible to apply this technology to existing concentrating solar plants, to gauge the benefit of having an inline diagnostic system and compare it with current methods.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) More quantitative information is needed on tolerable ranges for instrument accuracy for the proposed applications. 2) Emphasis should be placed on successful completion of system prototype at the end of project. 3) In-situ, real-time monitoring does not seem mission-critical for next generation CSP plants.

**Reviewer 2:** 1) As mentioned earlier, understanding the limits of detection is needed for this technique. 2) Cost, complexity, and resolution of the method vs. other electrochemical techniques should be compared to determine if there is any obvious advantage with this method. 3) Corrosion is typically the worst at gas/salt interfaces (there is a high concentration of impurities in these locations typically). If this technique could be used in the gas space then it might be helpful in diagnosing problems. Not clear what would need to be done to re-purpose the instrument but would be good to know if it was of interest to a developer.

**Reviewer 3:** 1) The project is advancing as proposed, achieving milestones, with a reasonable budget and time for the proposed scope. 2) Having determined the presence of certain species is only part of the answer; species concentration is needed to take action to prevent corrosion.

## Sensing and Arresting Metal Corrosion in Molten Chloride Salts at 800 Degrees Celsius – $800,000

*University of Arizona | Tempe, AZ | Principal Investigator: Dominic Gervasio*

This project proposes new approaches to mitigating corrosion from molten chloride salts in concentrating solar-thermal power systems. The team is investigating the potential of using metal salt additives to slow the loss of specific metals from piping; zirconium metal structures to remove impurities in the molten salt loop; and novel corrosion warning and controlling devices that can detect corrosion and switch salt flows. If successful, this project will show the feasibility of multiple new methods for sensing and stopping corrosion in advanced molten chloride salts for next-generation concentrated solar-thermal power thermal transport systems.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Proposed work is adapting a cathodic protection method to the inner surfaces of molten salt containment vessels, adopting this method from pipeline applications already existing in industry. If successful, this work could both provide a means to reduce corrosion rates in harsh environments, as well as serve as a measurement technique for the ingress of oxygen or water into a given salt system.

**Reviewer 2:** 1.1 This aligns well to the CSP goals. 1.2 The challenge is missing that it needs to be shown to be cost effective and that power supplied and the engineered features are not prohibitively expensive. This should be added to the final phase of the work. 1.3 If this is able to work well, then it's possible piping and other major components could be constructed from a lower cost alloy (i.e. a stainless steel). It is possible that it will be too expensive or complicated to implement. 1.4 It looks like the project has had some slow down in progress from the Raman work, which really is not critical or needed for project success. The current measurement should suffice to understand if there are chemical issues in the system. 1.5 If CP works well then this is another tool in the designer's toolbox to help make the system work and is unique relative. 1.6 It provides another system that could help move forward the industry. Right now most of the work is focused on monitoring for corrosive and this could provide options to actively protect critical components as needed.

**Reviewer 3:** The overall goal of the project is to develop a system which can detect when oxygen has entered the system and provide protection against oxidation of the metal after oxygen inclusion has occurred. The system is intended to serve as an early warning device for leaks and provide cathodic protection to the pipes during leak until it can be fixed. The project started on 4/1/2019 and ends 3/31/2022. Providing a cost effective system that can provide a continuous measure of the oxygen concentration in the system and could mitigate or eliminate the potentially deleterious effects of the oxygen could be of significant benefit to the CSP program and the overall goals of SETO. The project has as one of the goals, demonstrating a change in electrical characteristics can be observed for a negatively biased metal in a molten salt at elevated temperature when comparing without air and with air in the system. The goals appear to be written in more qualitative measures in the report as opposed to quantitative measures and therefore it is somewhat difficult to judge the impact of the project assuming the goals are achieved. The poster does give some indication of how the concept would be implemented in a real operating environment but the details of what material the ceramic couplers are envisioned to be that connect the pipe sections, how they would be joined to the metal pipes, what the characteristics of the porous plugs (material and pore characteristics), etc. which makes it difficult to determine if all of the appropriate testing is being included in this project to be able to project the potential for success in a real operational system.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 3 | 6 | 4 |
| Collaborates with sufficient stakeholders | 2 | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The existing team is not building upon existing knowledge and development within industry because it has not been able to effectively engage industry partners. Recommend bringing in industry partner as go-PI so they can contribute to development of the technology while protecting their IP. More quantitative information is needed on the needed sensitivity of the proposed method to detect impurities. Also, to what degree does power need to be controlled to only have the desired effect of mitigating corrosion? Unclear what the challenges are in scale-up of this technology from a small test sample to a full tank and piping system.

**Reviewer 2:** 2.1 No red flags. 2.2 Impact could be quantified better - it would have made sense to shoot for the 50 micron/yr corrosion rate under an air leak and then use experimental work to define a curve for air leak vs. current/area. That would be a great result that designers could use practically in design. 2.3 Doesn't apply - UA is the only partner and have not gotten any CP industries to help with system design. 2.4 Having an industrial partner to provide advise would be helpful in providing guidance, I'm sure that UA has interactions between their other projects, but it would still be good. The fact that they are patenting information indicates that there will be a reluctance to fully inform the community. This will greatly hinder technology deployment since any technology developer will need to work with UA and develop a licensing agreement -- this does the opposite of sharing information and puts a variety of restrictions on the application.

**Reviewer 3:** The due dates from the first milestone were apparently renegotiated. The milestone chart lists the first milestone being met on 10/30/2019 but then says the milestone is only 75% complete so it is not clear why there is a date listed for when it was completed if it hasn't been completed yet. Progress has been made in measuring the current change on a metal immersed in a molten salt with and without air present in the system. The project has experienced budget overruns in certain categories due primarily to unanticipated costs for purchasing optical components and for issues related to high temperature corrosion of the testing system and costs associated with obtaining materials/coupons for study. It is not clear if measuring the weight loss on coupons with and without air present will provide the requisite information to characterize whether the system will be able to mitigate the deleterious effects which might occur in a real system, including potential for localized corrosion in selected areas as opposed to uniform corrosion over the entire surface in large scale systems.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Last task focuses on development of a Raman spectroscopic detection of elements. Unclear how this fits in to the development of the CP development of earlier tasks.

**Reviewer 2:** Score: 5. Comments: I would have given a 6 except that the raman probe doesn't really fit into this work clearly - it looks like a real distraction to the prize of demonstrating the concept and then getting enough information to determine equipment sizing.

**Reviewer 3:** Score: 5. Comments: In general, measuring the effect of adding a negative bias to the metal and determining the corrosion rate with and without bias under various levels of oxygen concentration in the molten salt at operating temperature would be an important piece of information. Determining the long-term effects of negative biasing of the metal on the corrosion experienced would provide valuable information as to the viability of the system being investigated.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Likely appreciable development of the CP method in industry already. This industry partner should be brought in a co-PI so the project team is building upon an existing knowledge base, instead of re-inventing an existing technology. Why has CP method not been used in existing commercial molten salt systems today? Need to explore why, as the same reasons may make the CP method badly suited for future molten salt systems.

**Reviewer 2:** A great result would be a plot for air leak rate (or a air leak normalized by salt volume) vs. current/area to maintain a constant corrosion rate. This would help the designers - anything provided in literature has to be motivated to be written simply for the designer (a mechanical engineer, not material scientist) to use. Use of any metal as the anode other than Na, Mg, or K will result in changing chemistry of the overall melt. While this is likely to be low concentrations it will accumulate and have other impacts over time that might not be good from a systems perspective.

**Reviewer 3:** Some issues that may be considered if they are not part of the project plan already may include: characterizing the sensitivity of the oxygen sensing capability in light of the expected background noise in the system. Determination of the lower limit on the oxygen concentration that can be sensed and will that change with surface scale buildup, temperature changes, ion localization at the electrodes or salt flow conditions may be beneficial as may be determining what effects will the constant electrical bias have on other components/areas of the system - welds, other metals, etc. Another issue that could be addressed is: what is the potential for non-uniform corrosion morphologies to occur and how will the system (measurement and protection) be affected by these if they occur.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The existing team is not building upon existing knowledge and development within industry because it has not been able to effectively engage industry partners. Recommend bringing in industry partner as go-PI so they can contribute to development of the technology while protecting their IP.

**Reviewer 2:** A component or system designer might be helpful to help provide practical advice to UA during the development work.

**Reviewer 3:** Including system operators/designers may allow input on potential effects of the system being developed on other materials/components and allow understanding/measurement of fluctuation in background potentials, temperature fluctuations, flow patterns, etc.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1**: 1) Need to bring in industry partner as co-PI so current proposal isn't re-inventing existing technology. 2) Remove Raman spectroscopic portion of project; does not seem to fit. 3) CP method is a potentially compelling technology for its combined ability to detect and protect against sources of impurities.

**Reviewer 2:** 1) Raman is a distraction for this project. It is not needed as part of the overall goal of the project and, if anything, it detracts from the goals as they stand. 2) If the patent information is too restrictive then it will discourage use of this technology in industry. I've noticed many universities (PIs) are patenting ideas that they have no intention to get venture funding to work on after funding expires - this has only been done in an attempt to get more R&D funding from companies. Most solar companies do not have budget to do this kind of R&D at the levels universities what. I say this because I regularly get professors that would like me to fund $250k or greater projects - this just isn't something a small energy developer can do. All this is a long-winded way of suggesting this kind of activity be discouraged until there are viable technology developers that are making enough profit to enable follow up funding. 3) Use of anodes that are not carnalite (Na/Mg/K\\Cl2) should be discouraged as it will change the melt chemistry and might cause further issues. If the work concept works with Mg then that is probably good enough and it should be tested under a variety of transients.

**Reviewer 3:** The project is at the beginning of the second year. Progress has been made in measuring the change in current for a metal coupon immersed in molten salt with and without air present in the system. This project may be running a little over-budget and a little behind schedule, but it appears the issues have been identified and adjustments are being made in light of this.

## Additively-Manufactured Molten Salt and Supercritical Carbon Dioxide Heat Exchanger – $1,812,725

*University of California, Davis | Davis, CA | Principal Investigator: Vinod Narayanan*

This project seeks to develop an additively manufactured, nickel superalloy primary heat exchanger for advanced molten salt concentrated solar-thermal power systems. The primary heat exchanger will be made using nickel superalloys and laser powder bed 3-D printing, resulting in a compact design that is durable under cyclic operation at high temperatures and pressures in a corrosive salt environment. During the first phase of the project, different alloy powders are fabricated and characterized and then tested, both in conditions representative of Generation 3 concentrating solar-thermal power systems—720 degrees Celsius and supercritical carbon dioxide pressures of 200 bar—and at conditions relevant to current commercial systems—molten nitrate salt at temperatures up to 550 degrees Celsius. The team aims to validate a thermal model that can predict performance in a chloride salt environment and plans to use this model to develop a 20-kilowatt design to test the mechanical integrity of the fabricated primary heat exchanger.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Additive manufacturing of heat exchangers has potentially high impact for smaller HXs for niche applications where performance and/or compactness is at a premium. CSP plants may be one of these applications but given the large physical sizes of power cycle HXs, AM HXs are fairly early stage for next generation CSP plants. There is currently no evidence that AM methods are sufficient for making reliable HX units, especially considering that AM processes inherently include voids and discontinuities in the HX material structure that are sensitized sites for corrosion and fracture under thermal or pressure cycling conditions. That being said, this team has made an effort to address some of the most important parameters affecting corrosion characteristics and longevity like reaching > 99% part densities and methods to eliminate the formation of microcracks.

**Reviewer 2:** The project advances state of the art in AM for two specialized high temperature superalloys. Their application to the CSP sector is very appropriate. The project is well laid out, well developed and explained, and has the right teaming arrangement. It appears that there is a clear indication of the pathway to transition of this technology. The only part I am not sure is with their lopsided spending patterns -- if the project started last year about this time, the expenses should be around 30% but that is clearly not the case cumulatively to date. There was no explanation for the expenses. Also, it is not clear how the contract expenses are being used.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Tasks are very well-balanced covering cost modeling, manufacturing, design, design validation, and appropriate attention to corrosion characterization that takes into account detailed microstructure considerations. Work shows evidence of focus on attaining quantifiable goals, as well as incorporating many practical concerns related to design for salt drainage and factors influencing the longevity of units. Also, manufacturing scale-up plans.

**Reviewer 2:** The performance to date is satisfactory for a year's progress, but the expenses are not appropriate for the progress. Not sure if I can address this aspect. There is no good explanation for this discrepancy. The output from the project is good.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Team includes tasks to appropriately characterize the microstructure of fabricated parts. Tasks to work with appropriate partners who have long-standing experience making actual parts and dealing with standard AM manufacturing issues (like powder removal after part completion).

**Reviewer 2:** Score: 5. Comments: The project tasks are well planned and explained. The goals and metrics for the tasks are clear. I like the milestones and that they are able to meet them in the first year. However, as they progress with the additive manufacturing fabrication, their tasks will be more challenging to meet over the timeframes shown.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Commercial acceptance of AM HXs will be very challenging. Team needs to interface with ASME or other regulatory bodies to determine what needs to be qualified before such components will be accepted by local pressure vessel and boiler codes.

**Reviewer 2:** The PI needs to explain the expenses and balance it with respect to the accomplishments.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Commercial acceptance of AM HXs will be very challenging. Team needs to interface with ASME or other regulatory bodies to determine what needs to be qualified before such components will be accepted by local pressure vessel and boiler codes.

**Reviewer 2:** This project, in my opinion, has the right teamwork and future stakeholders for creating a new technology (materials science) and transition. It seems to be a three phase approach of design, development and validation, and future implementation through technology transition.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Team has made meaningful progress towards attaining acceptable part densities and microstructure qualification necessary for the mature development of AM HX units. 2) Team would benefit from more engagement from regulatory bodies and commercial off-takers to determine if AM manufactured HXs will ever realistically be accepted for power plant applications. 3) work has high potential to be effective in other industries where more compact and extreme high efficiency HXs are needed, i.e. aerospace and vehicles.

**Reviewer 2:** 1) Explanation of the budget. 2) If the material goals are not met, what are the alternatives?

## High-Entropy Ceramic Coatings: Transformative New Materials for Environmentally-Compatible Thin-Film Insulators against High-Temperature Molten Salts – $400,000

*University of California, San Diego | San Diego, CA | Principal Investigator: Jian Luo*

This project is developing high-entropy ceramics as a new type of insulating and protective coating material for metal alloys used in high-temperature piping and containment. High-entropy ceramics are a class of materials consisting of several elements in relatively equal proportions, whereas typical ceramics and alloys consist of one or two predominant elements. An effective, low-cost protective coating like high-entropy ceramics could substantially reduce the need for expensive, high-temperature superalloys. In order to develop and select the best material, the team will measure thermal conductivities of high-entropy ceramic compositions and examine their stabilities against molten nitrate, carbonate, and halide salts. This will optimize high-entropy ceramic composition and processing, helping to further reduce their thermal conductivities, which increases performance in high-temperature environments and lowers costs.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This is a good proposal for advancing high-temperature sensible heat storage, and high temperature low cost containers in general. The main weakness is that it may take a big and long development effort considering the unavoidable need for a cut-and-try method as well as long-term testing.

**Reviewer 2:** The project is focused on improving the coating efficiencies in the tubes used in CSP systems. The approach taken in this project, to evaluate and rank order the best high entropy coating materials will help the solar industry sector to provide better efficiency and meet or exceed the target per kWH cost target. The key exploration tasks for appropriate materials have been completed in the first year of the project. The goals are ambitious but realistic.

**Reviewer 3:** The project is focused on applying recent recognition of the impact of structural entropy on kinetic control and stabilization of solid state materials. As such, this project has the possibility of discovering new materials with previously unobtainable combinations of properties such as high stiffness to thermal conductivity ratio. A current limitation of the work is a universal lack of methodology for predicting structural entropy effects in multi-component materials with varying stoichiometry. Therefore, the approach to materials selection requires extensive empirical testing. Nevertheless, the Principal Investigator has focused on a highly relevant class of materials and elements. Understanding the thermal and mechanical properties of these material may lead to more universal understanding of basic materials behavior in addition to applications relevant to solar energy.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** I am unaware of the team's performance on this topic but it seems to be a competent team for this topic, NREL's reputation is very high.

**Reviewer 2:** A key aspect in this project is the two faculty member teaming for the materials search and classification. With the experience of this team, and the performance and publications to date, the project does not have a clear direct pathway to technology transition. The professors will need to reach out to industry collaborators and federal laboratories to make that happen. It is not insurmountable but needs to be done. As such the project has been making good progress and should finish on schedule and on budget.

**Reviewer 3:** Although this is a seed project to investigate a novel and unique class of materials, additional interaction with commercial coatings suppliers and providers could accelerate application of any discoveries.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**Reviewer 2:** Score: 5. Comments: The tasks are well laid out, and the responsible person for each task is described clearly. The only aspect I would have liked to see in this would be the possibility of intellectual properties and what would be the novel materials contribution beyond the solar industry, as this is a basic research project.

**Reviewer 3:** Score: 5. Comments: Each task in the project adds unique and important value to achieving the overall goals of the project.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Special attention must be paid to possible interactions between the different used materials, and behavior at the interfaces between them, especially over yeas of use. The Portland cement may be the weak link under extreme conditions. Inclusion of a company which is experienced in manufacturing somewhat similar containers, even for other applications, would be advisable.

**Reviewer 2:** The project is clearly defined and the productivity is good. The team has spent slightly over the budgeted amount to date, but I am sure they will be able to explain that and provide an explanation on how they can bring the project back on schedule. The productivity supports the slight overspending. I do not see any blind spots that the PI may have.

**Reviewer 3:** The PI is cognizant that this is a exploratory project aimed to determine the potential of the materials and the range of properties obtainable via the structural entropy approach. The main blind spot concerns how to apply the findings, but it is too early to consider this a blind spot.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Addition of at least one company which is experienced in manufacturing somewhat similar containers, even for other applications, would be advisable.

**Reviewer 2:** I would like to see some industry collaboration to be phased in-- even if the industry or federal laboratory members are brought in as advisers or for sharing the progress of this team. Subsequent to this project then, a new team comprising other members and other members from this team can address the technology transition aspects.

**Reviewer 3:** Interaction with component designers and coating providers could accelerate application of useful findings. Additional interaction or effort on high-throughput/machine-learning computational materials design could also accelerate development.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) How could they test the containers for long-term operation. 2) Which methods could they used to reduce the cut-and-try development process. 3) How to examine and understand materials' interfacial behavior over time under operating conditions.

**Reviewer 2:** 1) Discuss the budget expenditures; 2) Explore the transition plans; 3) Ask if there should be any IP disclosures.

**Reviewer 3:** 1) The materials proposed are novel and unique and offer potential for providing combinations of optical, thermal and mechanical properties that are not currently available. 2) Significant additional time and resources will be required to transfer findings to practical application. 3) Additional collaborations could provide useful in focusing work on specific requirements for Gen 3 CSP.

## Non-Contact Thermophysical Characterization of Solids and Fluids for Concentrating Solar Power – $1,180,000

*University of California, San Diego | San Diego, CA | Principal Investigator: Renkun Chen*

This project is developing a non-contact characterization technique called modulated photothermal radiometry. The technique measures the high-temperature thermophysical properties of heat transfer fluids and the associated solids, like tubing and solar absorbing coating, in various components and sub-systems used in concentrating solar-thermal power plants. The modulated photothermal radiometry technology can provide low-cost and fast characterization of heat transfer fluids and solids for third generation concentrating sola thermal power facilities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 3 |
| Advance the U.S. solar industry substantially | 5 | 6 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project seeks to apply an in situ, non-contact thermal characterization technique to measure thermophysical properties of heat transfer fluids relevant to CPS systems at high temperature. The presumption is that the thermophysical properties of molten salt and particulates proposed for use are not known at temperatures as high as 750C. The technique has the advantage that it is being developed for use in situ in the air--in an environment where it can be used readily in CSP applications. Further, the PI asserts that the technique can be used for bulk particulate and molten salt in both stagnant and flowing environments. To date, it appears that the work has focused on thermal characterization of coatings, and the work will now proceed to particulate beds and molten salt.

**Reviewer 2:** 1. The project develops a non-contact characterization technique called modulated photothermal radiometry (MPR). The technique will measure high-temperature (up to 800 oC) thermophysical properties of heat transfer fluids (HTFs) and the associated containment materials used in concentrating solar power (CSP) plants. It is especially suitable for in-situ diagnostics, for example, on moving particles in particle-sCO2 heat exchangers and molten salt in receivers and thermal storage units. 2. Challenges include large amount of radiative and convective heat losses. Moving turbid fluids, impeding laser penetration. Test the technique in near in-operando testing environments. 3. It is a high-risk high reward project. 4. A 4-yr $1.3M project in two Universities. 5. The MPR system developed by UCSD can provide a reliable non-contact, in-situ method for high-temperature thermophysical properties measurement of various materials, including bulk solids, fluids and particle media. 6. The MPR technique can provide fast and accurate characterization of materials for Gen3 CSP facilities, and is especially suitable for insitu diagnostics, for example, on moving particles in particle-sCO2 heat exchangers and molten salt in receivers and thermal storage units. These capabilities will provide accurate thermophysical data on relevant CSP materials. When used for in-situ diagnostics for flowing particles and fluids, the technique can obtain near-wall heat transfer coefficient. 7. Strengths: in-situ non-contact diagnostics. Made all the milestones so far. Weakness: interference of high temperature on signal and penetration issue of laser light in turbid media.

**Reviewer 3:** The project is well defined, with budget and timelines that are commensurate with the proposed scope. The main weakness of this project is that it won't substantially advance the US solar industry. Characterizing the thermophysical properties and heat transfer coefficients of components operating at Gen3-level temperatures will definitely help in designing the next generation solar plants. However, it does not mean that an in-situ measurement device for thermophysical properties and heat transfer coefficients will be needed.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 6 |
| Disseminates results frequently and actively engage partners | 6 | 6 | 6 |
| Collaborates with sufficient stakeholders | 6 | 5 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The milestones are reasonable and the project is on schedule. The necessary thermal characterization of coatings has been done. The most rigorous and beneficial work remains--the measurement of properties of molten chloride salt and particulates at high temperature.

**Reviewer 2:** 1. Budget and milestones are reasonable. 2. Impact is stated clearly, but not quantified. 3. Dissemination in journal publication. 4. The team have worked with Sandia, NREL. 5. The project has met all the milestones so far and is making good progress towards future milestones. Establishment of thermal conductivity database of materials. Development and demonstration of MPR technique for reliable measurement of bulk solids and thin coatings up to 750oC, with < 10% error. Design and assembly (on-going) of high-temperature MPR setup for moving particles and molten salt loop.

**Reviewer 3:** The project is well defined, with budget and timelines that are commensurate with the proposed scope. The project has been achieving its milestones in a timely fashion. The report indicates that Gen3 awardees are being contacted by the PI to deploy the measurement system; this is an area that SETO should look at, in order to make sure that technology providers and developers take advantage of this new measurement system.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: As mentioned previously, the project has completed the necessary measurement of coatings, and will now use that information in the next phase of the work focusing on characterization of CSP heat transfer materials (particulates and molten salt).

**Reviewer 2:** Score: 5. Comments: UCSD is in charge of the development of high-temperature MPR tool, model development, the development of the apparatus for flowing fluids and moving particles. UCSD is also responsible for thermal measurements of materials using standard techniques, including laser flash analyzer (LFA), transient hot-wire (THW) and differential scanning calorimetry (DSC). U. Arizona is responsible for the design and modification of their molten salts loop to be compatible with the MPR measurement. UCSD will work with SETO to identify two Gen3 performers to carry out in-situ thermal diagnostics of their heat transfer media. The project started in Oct. 2018 and expected to end in Spet. 2022.

**Reviewer 3:** Score: 5. Comments: The succinct tasks and responsibilities described in the project report are reasonable for achieving the goals of the project.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** I see no obvious blind spots.

**Reviewer 2:** The penetration of light in turbid media and uncertainty caused by high-temperature interference.

**Reviewer 3:** The main blind spot is whether an in-situ measurement system is needed: the accurate characterization of thermophysical properties is very important in order to accurately design the systems. Involving technology developers and project developers will help understand if this in-situ measurement method is valuable.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It appears the project is involving the appropriate entities.

**Reviewer 2:** Test in real working conditions.

**Reviewer 3:** Involving technology developers and project developers will help understand if this in-situ measurement method is valuable, the challenges for utilizing it and opportunities for testing in existing projects.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) An in situ non-contact measurement technique is being applied to the measurement of thermophysical properties of CSP materials at temperatures as high as 750C. 2) The required measurement of coatings for containment materials has been done, and the project is now ready to undertake measurement of bulk particulate flow and molten chloride salt.

**Reviewer 2:** 1) Remote non-contact diagnosis. 2) Wide applications to the CSP systems. 3) Stability and repeatability.

**Reviewer 3:** 1) The project is well defined, and is meeting milestones as planned. 2) The tasks that result in accurate thermophysical properties at high temperature are valuable for advancing the solar energy industry, in order to design high temperature systems and reduce margins and risks in designs. 3) However, the development of in-situ characterization is not so valuable to reduce risks to deploy Gen3 systems.

## Robust and Spectrally-Selective Aerogels for Solar Receivers – $363,999

*University of Michigan | Ann Arbor, MI | Principal Investigator: Andrej Lenert*

Efficient conversion of sunlight at high temperatures requires both absorption of sunlight and retention of heat from escaping in the form of radiation, convection, and conduction. The team is developing a transparent, thermally insulating aerogel cover that enables a concentrating solar-thermal-power receiver to operate more efficiently at high temperatures. This aerogel cover will be transparent to sunlight and able to absorb thermal radiation. The proposed aerogel would not require selective surfaces or a vacuum for attachment and would enable better thermal resistance at high temperatures. The aerogel cover will be developed and tested in order to minimize thermal losses and improve thermal stability.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 6 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project goals of this SIPS project are focused on development of multicomponent aerogels for use as a sunlight spectrum transparent insulator to promote retention of heat by the absorber by preventing heat loss through radiation, conduction and convection. Silica aerogels will be coated with an alumina layer by atomic layer deposition. The aerogels developed will allow a significant percentage of the sun's solar spectrum to pass through the aerogel to the absorber material. The absorber will become very hot due to absorption of the solar spectrum and will reradiate the energy according to the blackbody spectrum. The aerogel will be designed to have very low transmission in the expected wavelength range of the blackbody emission. In addition, the aerogel due to the high degree of nano-sized pores will provide excellent insulation against heat conduction. The goals of the project are well aligned with the overall goals of the program. The project sets critical challenges to overcome. The project funding level matches well with the planned duration and tasks to be completed.

**Reviewer 2:** 1.1 The idea and work on developing aerogels for reducing conductive heat losses from solar receivers at temperatures up to about 700C, in combination with coatings that increase solar-range absorptance and reduce IR emittance, deserve support. It of course must be evaluated for cost and long-term (many years) stability and robustness under extreme operating conditions. This would certainly improve the collector energy efficiency, hopefully at tolerable cost increase, the project's goals align well with this topic's goals and supports the SETO mission. 1.2 Expected challenges include long-term stability of the radiative and mechanical properties under extreme operating conditions, the same for conditions at the aerogel-absorber interface, need for the protection of the aerogel-absorber from environmental effects, and potential for irritating skin and eyes by the aerogel. Contingency plans are not shown. 1.3 It is a medium-risk high-impact approach, condition by the cost and successful long-term operation. 1.4 The project's goals, approach, and expected impact match well with the level of DOE funding and planned project duration. 1.5 They add significant value to existing research outside DOE-funded efforts. 1.6 If the goals are met, they would advance the US solar industry significantly.

**Reviewer 3:** The project addresses issues related silica aerogels for use in solar particle receivers. The project verifies solid hypotheses that alumina and hafnia, both with higher melting points (i.e. stronger interatomic bonding), coarsen less at elevated temperatures. The most relevant information is that the thermal and optical properties of the coated particles are nearly equivalent or surpass those of uncoated silica aerogels. Although it is assumed that aerogels are desired due to rapid heat transfer because of their small size, it is not clear whether coatings are superior to optimizing the size of the silica aerogel particle since a the coarsening rate and amount decreases with increasing size. Unfortunately, the project does not address the issue of a large mismatch in thermal expansion behavior between the silica core and its coating when rapidly heating the particles.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** All milestone to date have been achieved and the project is on track to meet the remaining milestones. Measurement of properties reported to data on samples prepared appear generally to meet the goals set out for the project. It does not appear that there have been any publications which have resulted from the project so far, but this is reasonable since the project just began about one year ago. It does not appear that there has been any significant collaboration outside of the PI/coPI.

**Reviewer 2:** The project just started so it is impossible to form a solid opinion yet. The PI-s and their past work and performance are good, but their current selection of stakeholders, and dissemination, if any, are unreported in the report we received.

**Reviewer 3:** The project has demonstrated successful coating of silica aerogel particles by both alumina and hafnia. This was possible due to the skill and knowledge of the Principal Investigator, Dr. Lenert. in ALD. This relatively short project has not only demonstrated that coarsening of silica aerogel can be reduced by certain ALD coatings, but that the coatings may also enhance infrared absorption, a desirable property. It is not clear how and to whom the results have been communicated, but it is likely that key findings will be published in the literature. Additional collaboration with technologists who have worked on particle-based receiver systems would likely be beneficial for verifying the applicability of the direction chosen and test methods.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The steps involved in the description of the work planned all appear to contribute significantly to achieving the goals of the project.

**Reviewer 2:** Score: 5. Comments: Yes, with the reservations expressed in 1.2, about lack in some areas.

**Reviewer 3:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** I did not identify any blind spots for completion of the project and achievement of the goals as stated. Some additional things which could be considered: It is not clear how the "friability" or mechanical properties will be evaluated and what the requirements will need to be for these aerogel insulators. It may be important to measure the change in thermal conductivity of the aerogels as a function of time at 700C to determine the extent of pore morphology or other changes. If the aerogels will be used in service in air, testing in the presence of moisture in the environment at 700C may be important to be able to project the property changes which may be expected in the real service environment.

**Reviewer 2:** A reminder (not necessarily blind spot) of the need to address carefully the long-term adhesion, aerogel and coating integrity, and their mechanical uniformity.

**Reviewer 3:** The coefficient of thermal expansion of alumina, 7-8 ppm/K, and hafnia, approx. 6 ppm/K, are significantly larger than that of silica, 0.5 ppm/K. Therefore, it is recommended that effects of this thermal mismatch on the integrity of the coatings and particles during heating and cooling are addressed. The effect of the additional weight of the particles, especially due to the use of hafnia, on flow and transport characteristics is not considered.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

Reviewer 1: I did not identify any additional stakeholders, collaborators or organizations critical for the success of the project in meeting the goals as written.

**Reviewer 2:** The report does not show PI-s collaboration with others, and it would be advisable to include experienced coating and aerogel manufacturers and users, as well as CSP systems experts.

**Reviewer 3:** CSP system and component designers and others familiar with particle receiver systems.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** The project goals are well aligned with the goals of the overall program. The project is on schedule with all milestones to date having been met. It appears that significant progress has been achieved in the project to date.

**Reviewer 2:** 1) Significantly address long-term (many years) stability of the radiative and mechanical properties under extreme operating conditions, the same for conditions at the aerogel-absorber interface, need for the protection of the aerogel-absorber from environmental effects, and potential for irritating skin and eyes by the aerogel, as well as economics 2) Contingency plans are needed but not shown. 3) It would be advisable to include experienced coating and aerogel manufacturers and users, as well as CSP systems experts.

**Reviewer 3:** 1) The results show that ALD coatings of alumina and hafnia can slow the coarsening of silica aerogels. 2) The ALD coatings can also be used to modify the optical/thermal properties of the materials. 3) It is recommendable to consider mismatches in thermal expansion between the coatings and the particles.

## Experimental and Numerical Development of Third Generation Concentrating Solar-Thermal Power Durability Life Models – $1,060,000

*University of Tulsa | Tulsa, OK | Principal Investigator: Michael Keller*

This project is developing a comprehensive particle and substrate durability model that will enable improved understanding of the performance of high-temperature components for the particle-based pathway. The team plans to advance existing research capabilities in erosion, corrosion, fracture mechanics, macro- and micro-scale materials characterization, and thermal and optical property characterization. The results will be used to develop a broad understanding of mechanical durability that can be used to determine component lifetime and performance degradation models.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 3 |
| Advance the U.S. solar industry substantially | 5 | 6 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project plans to determine the durability of particles and containment materials for CSP particulate based heat absorption/transfer media. The project plans to design and build facilities for testing of abrasion, attrition, impact erosion, and mechanical property characterization of both particles and containment materials. This data will be used to develop durability models which could be used for lifetime or service interval requirements for the list of containment materials tested and particle types tested. This could provide significant benefits if accurate models could be developed, especially if the model could be used to extrapolate to other materials systems as mentioned in the project description. Project began on 8/15/2018 and ends on 8/14/2021, so is a little over the halfway point. The project appears to have progressed well for the low temperature testing of the particles and containment materials. The progress report states the goal is to design and build facilities capable of 800C testing, however the responsibilities and later description say >700C. Significant challenges have been reported/encountered for long term testing at 800C. It is not clear what the number of hours is that would be considered long term demonstration in the progress report.

**Reviewer 2:** 1. The goal of the project is to design and build facilities capable of testing abrasion, attrition, and impact erosion, as well as mechanical properties characterization of particles and containment materials at 800°C. 2. The majority of problems faced to date have been long term operation of erosion test setups at 800°C. A second challenge was presented by lack of lubricants that could withstand 800°C. 3. Durability of particles and containment materials in GEN3 CSP operating environments is largely unknown and represents a risk to long-term cost-effective operation. 4. A three-year $1.666M project. 5. Relevant to coating technology. 6. The development of GEN3 CSP systems will require significant technological advances in the areas of durability, while maintaining, or even enhancing, thermophysical properties of the components operating within. 7. Strengths: Durability test is critical. Team is strong. Weakness: particles may not be spherical in real world.

**Reviewer 3:** This project studies key performance parameters needed for the development of particle solar receivers: abrasion, attrition and impact erosion. The project budget and timeframe is well structured for the level of effort. However, I am not convinced that this is a high reward project that will advance the solar industry substantially. The goal of a particle receiver is to be able to use cheap materials (e.g., sand) to achieve larger temperatures. Given the size of a central receiver system, the cost of the particles is going to be very small compared to the rest of the system. If particles degrade (i.e., optical properties, particle size, mechanical properties), the commercial project could include maintenance costs of replacing the particles every ~10 years or so, without being an onerous expense. This means that the only meaningful tasks consist of knowing the erosion on materials.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engage partners | 4 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 6 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The construction of the facility for room temperature testing of the particles and containment materials appear to be nearing completion according to the progress report. The operation of the high temperature testing facility at 800C has encountered significant challenges it appears for long term operation. Figure 2 shows a significant weight loss which begins after approximately 150 hrs, but the progress report does not clearly identify what the mechanism is that caused this weight change. In addition, the progress report does not adequately describe how this new data will affect the required number of hours of testing or the impact this may have on the durability model development. Figure 3 shows what appears to be a net weight gain after exposure testing, but what has caused this weight gain is not clearly presented, whether it is measurement error or a true weight gain due to oxidation of possible pickup of metallic impurities or other material.

**Reviewer 2:** 1. It seems milestones are well met. 2. A comprehensive particle and substrate durability model will allow comprehensive understanding of GEN3 CSP operating conditions on component durability (GEN3D Model). This will culminate with a GEN3 Durability model that will provide outputs that can model the optical degradation of particles over plant lifetime, total particle attrition, and substrate erosion. the durability data and capabilities developed here an asset to future CSP developers using particles, either as a receiver technology or for thermal storage. 3. This will be followed by publications in journals and presentations at key solar thermal conferences. 4. Boise State University, The University of Tulsa, Sandia National Laboratories. 5. A number of significant tests toward meeting our milestones have been completed.

**Reviewer 3:** From the report, it is not known how much the PI's are disseminating the results of the project. However, as both PI's belong to universities, I assume that they will publish the results in peer reviewed journals or conferences. The project lacks collaboration with industry members, perhaps at a consulting level at this early stage. A long-term view of commercialization could guide them towards the impact of these tasks.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks which are listed if completed successfully could provide unique and important value to the overall goals of the project.

**Reviewer 2:** Score: 6. Comments: The project has 5 primary objectives: 1) Evaluate effect of thermal cycling on the optical properties of candidate particles. 2) Evaluate impact erosion on candidate containment material from freely falling particles under GEN3 operating conditions. 3) Evaluate containment material abrasion and particle attrition erosion at GEN3 operating conditions. 4) Mechanical property characterization of individual particles. 5) Develop particle and containment material durability models that can effectively predict wear rates and life expectancy of the plant and various components.

**Reviewer 3:** Score: 6. Comments: The project report did not include the tasks that will be undertaken in this project. The succinct project description is reasonable for the level of proposed level effort and budget.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The project may benefit with more of an emphasis on chemical analysis of the particles, both the chemical and phase analysis of the surface layer before and after exposures and also the chemical and phase analysis of the bulk compositions. This may shed light on results in other areas such as mass loss/gain and optical property measurements. Likewise, the chemical analysis and phase analysis of the containment materials before and after exposures of different lengths of time could aid significantly in understanding the kinetics involved. This could significantly aid in the durability model development as well. Optical property characterization should consider the potential for contamination or reaction with the metallic substrates and the effect that these changes may have on the optical properties of the particles. Before and after pictures of the particles appear to show several particles that have been fractured. Based on this information, it would be beneficial to determine what effect this may have on the measure properties as a function of time and the durability model accuracy. The project is over halfway time-wise but it appears that only about 1/3 of the budget has been spent, however it appears that the investigators are aware of the underspent condition.

**Reviewer 2:** Commercialization.

**Reviewer 3:** The scope of this project is appropriately narrow, as it studies durability issues for particles and containment materials. The blind spot is whether studying particle degradation is a task that will provide actionable data for commercializing this technology: the cost of particles should be small for a commercial solar power tower system.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I think that all the relevant stakeholders, organization and collaborations appear to be in place. It is assumed that appropriate analytical services for chemical, optical and phase analysis exist in the organizations.

**Reviewer 2:** Eco-Analysis and Commercialization.

**Reviewer 3:** Commercial developers or engineering design firms could indicate whether this effort is valuable: the cost of one ton of sand is a few hundred dollars. The cost of the particles in a central receiver should be a very small cost of the total system.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** Project appears to be nearing completion for the room temperature testing phase. High temperature testing appears to be encountering significant challenges related to the testing system. Some chemical analysis combined with phase analysis for the particles may provide some insight into the other results obtained.

**Reviewer 2:** 1) Evaluation of erosion and abrasion. 2) Effect of thermal cycling on the optical properties of particles. 3) Develop particle and containment material durability models that can effectively predict wear rates and life expectancy of the plant and various components.

**Reviewer 3:** 1) Only the tasks on erosion of containment materials at high temperatures will significantly advance the solar energy industry. 2) Developers or engineering firms should be involved to start the process of planning for developing pilot plants.

## Carbonized Microvascular Composites for Gas Receivers – $1,277,345

*University of Tulsa | Tulsa, OK | Principal Investigator: Michael Keller*

This project aims to develop and characterize a novel carbonized microvascular composite intended for use in advanced, gas-phase concentrating solar power receiver. A polymer-fiber composite with directly integrated microchannels will be carbonized to form a light-weight, high-absorptivity material with a microvascular network of channels with an optimized topology that will enhance heat transfer to a supercritical carbon dioxide heat transfer fluid. This system is based on microVasc technology, which enables the formation of defined channels within a composite material through selective depolymerization of polymer fibers. The resulting composite can then be carbonized and coated for oxidative resistance, perhaps in situ, to form a highly adsorptive, mechanically robust carbon-carbon composite with high thermal conductivity.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** 1. This project is focused on the development and characterization of a novel carbonized microvascular composite intended for use in advanced, gas-phase Concentrating Solar Power (CSP) collectors, a muVASC receiver. These are polymer-fiber composites with directly integrated microchannels that will be carbonized to form a lightweight, highabsorptivity material that includes an embedded microvascular network of channels. The topology of these microchannels will be engineered to optimize heat transfer to a supercritical carbon dioxide ($sCO_2$) heat transfer fluid. 2. Performing the necessary high temperature carbonizations with the necessary densification steps is challenging. 3. These are polymer-fiber composites with directly integrated microchannels that will be carbonized to form a lightweight, highabsorptivity material that includes an embedded microvascular network of channels. 4. A 4-yr $1.6M project. 5. Not well described. 6. The proposed approach seeks to advance receiver technology in both areas by improving the thermal performance of the system with advanced materials and by harnessing the high thermal conductivities of carbon to reduce off-axis heating issues. 7. Strength: Analysis seems reasonable. Weakness: Fabrication and cost.

**Reviewer 2:** The goal of this project is to design, build and test a microvascular carbon composite receiver and validate performance of the receiver. Characterization of the thermal and flow properties will be conducted in an in-house test stand that will be constructed as part of the scope of the project. Development of a simplified model to simulate and optimize system performance will be accomplished to save model computational time when compared to commercial software packages such as ANSYS FLUENT. The goals of the project aimed at demonstrating significant improvement in receiver performance aligns well with the topic goals and the overall goals of the SETO program. It was not clear where this technology might benefit outside the DOE funded program research areas. The funding level, planned project duration, and goals appear to match well.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** 1. Pressure test milestone sounds good. Other milestones are not very clear. 2. The proposed approach seeks to advance receiver technology in both areas by improving the thermal performance of the system with advanced materials and by harnessing the high thermal conductivities of carbon to reduce off-axis heating issues. It is also expected that this approach will result in some savings in the structural requirements for the central tower since the composite systems will be lighter than their metallic counterparts. 3. Support students and researchers to publish their findings in reputable journals and travel to conferences in order to present results to the relevant research and technical communities. 4. It would be better to have a National Lab or some industry's involvement. 5. A model has been created to simulate flow and heat transfer through a solar receiver. Currently they are working on the production of a simple demonstrator object for initial testing.

**Reviewer 2:** The project appears to be making good progress in model development and validation as well as construction of the test stand. The model developed has been validated using ANSYS FLUENT and appears to be working properly. The anticipated benefits of the new model are reportedly that it can arrive at the solutions faster than using ANSYS, but no quantitative measure of amount of time saving accomplished or justification of why other commercial software such as ANSYS FLUENT could not be used, or if it were used what the cost/penalty would be. No publications were listed but this is reasonable since the project only began on 7/1/2019. There appears to be some confusion on the dates listed for project start, milestone due dates and project end dates. These do not seem to be consistent. All milestones reportedly have been met or are on track to be met. The project appears to be very significantly under budget. It seems that some of it may be related to the inability to hire a postdoc for the project, but it is not clear if the under budget situation has been remedied now or if the schedule for when it will be remedied has been developed. It appears that the modeling partner is being actively engaged and that sufficient collaboration is taking place between the participants.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Computational tasks seemed great. Fabrication and experimental testing are challenging.

**Reviewer 2:** Score: 5. Comments: The project tasks which include modeling/optimizing the system design performance, building the testing apparatus, fabricating the test receiver components, and demonstrating component performance all will significantly contribute toward the overall goal of demonstrating a significantly improved receiver performance.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** High-temperature and high-pressure testing.

**Reviewer 2:** I did not identify any blind spots for the project to progress toward achieving the stated goals.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Relevant industry.

**Reviewer 2:** I did not identify any missing collaborators, stakeholders or organizations critical to achieving the stated goals.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Novel idea on carbonization approach. 2) Performing the necessary high temperature carbonizations with the necessary densification steps is challenging. 3) Simplified modeling seems not necessary.

**Reviewer 2:** The project began on 7/1/2019 and so is still within the first year of performance. It appears that the project is significantly under budget at this point. Model development and validation have been successfully accomplished.

## Volumetrically Absorbing Thermal Insulator for Monolithic High-Temperature Microchannel Receiver Modules – $400,000

*University of Utah | Salt Lake City, UT | Principal Investigator: Sameer Rao*

The thermal efficiency of concentrating solar power receivers is limited by optical and thermal losses. This project is developing a novel, low-cost, high-temperature, and chemically stable receiver design based on a porous matrix of refractory ceramics that can absorb concentrated solar light throughout its three-dimensional volume. This design has the potential to substantially reduce optical and thermal losses relative to the two-dimensional surface of the tubes that are currently used as receivers. The team is developing a high-performance receiver that operates at over 720 degrees Celsius, has a thermal efficiency rate above 92 percent, and maintains excellent thermo-mechanical and thermo-chemical stability. The team will validate the design through computations and then experimentally at lab-scale.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 3 | 6 |
| Set critical challenges to overcome | 4 | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 3 | 4 |
| Advance the U.S. solar industry substantially | 3 | 3 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Proposed work is focused solely on the measurement of properties of a porous SiC structure. While this is necessary for the development of one specific type of receiver design, it is unclear if it services any other designs for next generation CSP plants, or applications outside of CSP. Proposed work is fairly narrow in scope and focused on relatively fundamental questions of material characterization.

**Reviewer 2:** 1.1 The project aims to increase the collector efficiency for CSP. This aligns with the goals and SETO mission. 1.2 The challenges, as stated in the Report, are straightforward. However, potential pitfalls as elaborated upon below. 1.3 The research, as proposed, is not of extremely high risk. If successful, the project can have a significant impact on CSP. 1.4 The project duration and budget appear to be reasonable. 1.5 The project, as stated, includes some interesting aspects, but incorporate well-known approaches that will likely have a modest impact on research outside of DOE. 1.6 Increasing the efficiency of the collector, at high operating temperatures, could advance the solar industry significantly. Strengths: The proposed approach, if successful could have a significant effect on increasing the collector efficiency. The approach is multi-pronged. The budget and timeline are reasonable. Weaknesses: The modeling approach, which is central to the project and from which relatively high anticipated figures-of-merit are obtained, employs assumptions that need to be considered carefully. The foam pore size (0.3 mm) is of the same order of magnitude as the foam thickness (1 mm), so it is doubtful that the foam and air inside the pores can be treated as a continuum using the RTE and an effective thermal conductivity modeling approach. It is possible that the foam, with open pores that allow air to pass through the foam layer (an effect that appears to have been neglected in the modeling), will increase convection heat losses from the receiver relative to a receiver having no foam in place. The thermal contact resistance between the foam and the CSP receiver surface, is presumably not accounted for in the model, and will add an undesirable and perhaps large thermal resistance between the hot foam and the cooler receiver, again degrading the thermal performance of the CSP system. The largest figure of merit shown in the graph in the poster occurs for L of about 0.5 mm, which is less than two pore diameters; this again suggests the model predictions need to be viewed with some scepticism. Finally, Figure 1a is supposed to show a L = 1 mm thick foam layer with pore dimensions of 0.3 mm. Looking at Figure 1a and considering these dimensions, something seems to be incorrect.

**Reviewer 3:** This work proposes to evaluate the use of porous silicon carbide as a volumetric absorber candidate for CSP receivers. It is proposed that the SiC volumetric absorber will not require the maintenance that the current technology (Pyromark) receivers require. The approach is to analytically and experimentally evaluate the radiation transport in such systems at operating conditions that simulate 1000 suns. The analytical approach is similar to previous published work, which was successful, but whose objective was different. The project seems promising.

## 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 6 |
| Disseminates results frequently and actively engage partners | 5 | 4 | 3 |
| Collaborates with sufficient stakeholders | 5 | 4 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Proposed work is comprehensive across fundamental modeling techniques and experimental validation.

**Reviewer 2:** 2.1 The project timeline is relatively short, it will require a concerted effort to have all the milestones completed by the end of the project. 2.2 I have concerns regarding the validity of the modeling approach, the assumptions used in the model, and the validity of the predictions that suggest the proposed approach will increase the collection efficiency. 2.3 The dissemination plans in terms of journal publications is good. The investigators are consulting with SNL on some aspects of the work. 2.4 Due to the consultation with SNL, I assume SNL will be interested in, and aware of the work done on this project. The performance has been good to date, but again, I have some concerns regarding the validity of the modeling approach and the model predictions. I believe a more rigorous analysis could show that the proposed approach could decrease collector efficiency, at least under certain circumstances.

**Reviewer 3:** The work appears to be on schedule, but it may be too early yet to produce results worthy of dissemination. The PIs reported to this reviewer that their predictions reveal FOM of 65% with a bare SiC absorber surface, 87% with the porous SiC volumetric absorber, which may be compared with 89% reported for the Pyromark surface

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Proposed work includes both experimental and fundamental modeling activities that complement each other. Work scope may benefit from some increased focus on full receiver system design, and how the use of porous media may affect the design or operation of such a receiver.

**Reviewer 2:** Score: 4. Comments: The tasks are all related, and there appears to be coordination among the researchers.

**Reviewer 3:** Score: 6. Comments: The theoretical and experimental approaches are complimentary and reasonable.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1**: How do properties change with temperature? Characterization is being performed at room temperature, but extreme high temperatures may warp the foam structure and lead to different properties.

**Reviewer 2:** Important aspects of the heat transfer processes seem to have been neglected or over-simplified. I suspect the predicted thermal performance of the proposed approach may be overly optimistic. The experimental measurements will be important.

**Reviewer 3:** No blind spots in the project noted.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** At a later stage in the project, would be beneficial to have people involved who have done full receiver design before. Should get input on how well foam structure stands up to typical thermal cycling seen in CSP plants.

**Reviewer 2:** None noted.

**Reviewer 3:** No additional collaborators needed.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Work seems based too much on fundamentals. Would benefit from more focus on full receiver design. 2) Need to determine if the use of porous materiel is possible under the thermal cycling conditions of real CSP plant operation. 3) Would be beneficial to tie this development work to applications outside of CSP receiver design.

**Reviewer 2:** 1) The budget and timeline for the project suggest that important experimental measurements of the efficacy of the proposed approach will soon be available and at relatively low cost. 2) If it behaves as described in the report, the approach could improve collection efficiency of the receiver and reduce the cost of solar-generated power for example. 3) Unfortunately, I have some doubts whether the modeling is properly accounting for heat transfer mechanisms that will reduce the efficacy of the proposed approach, and perhaps even decrease the collection efficiency.

**Reviewer 3:** If the FOM for the SiC volumetric absorber is promising, the PIs will need to undertake a careful economic analysis comparing the volumetric absorber with the Pyromark surface.

## Durable and Low-Cost Fractal Structured Multifunctional Coatings for Next Generation Concentrating Solar-Thermal Power – $400,000

*Virginia Polytechnic Institute and State University | Blacksburg, VA | Principal Investigator: Ranga Pitchumani*

This project team is developing fractal-textured barrier coatings for conventional, low-cost alloys like stainless steel to protect against corrosion from supercritical carbon dioxide, molten chloride, and carbonate salts used in concentrating solar-thermal power plants. Multiscaled, fractal textured surfaces can be fabricated directly on the underlying material using a process called electrodeposition, helping to create a robust and durable coating that preserves the thermal properties of the substrate. The textured surfaces of the coating will prevent wetting of the corrosive fluids with the surface, leading to a lower power requirement to pump fluids, less corrosion and wear, and reduced heat loss. This will help to increase the overall efficiency and lifetime of a concentrating solar-thermal power plant.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** 1. The overall goal of the project is to develop novel fractal textured coatings on various low-cost substrates such as SS316, SS347, In800H, In740H, etc., and demonstrate lower corrosion rate when exposed to high temperature heat transfer fluids (e.g., molten chlorides, carbonates and sCO2). 2. The challenge identified is mainly human resources. 3. The underlying scientific novelty of this project is that of generating multiscale surface topologies on metallic surfaces by tailoring the operating parameters of the industrially widely-used electrodeposition process. The innovative coating surfaces will be non-wetting to the heat transfer fluids, thereby deterring fouling, scaling and corrosion and allowing operation with high temperature heat transfer and storage fluids such as molten chlorides, carbonates. Developing fractal-textured multifunctional coatings is very novel. 4. The duration of the project is 1.5 year with reasonable budget. 5.Successful execution of this project can have far-reaching long-term benefits. 6. It offers potential to use low cost containment materials in high temperature CSP applications. 7. Strengths: Novel idea. Weakness: The figure showing in the poster is not in a high temperature range and personal hiring at the defined timeframe.

**Reviewer 2:** This project seeks to modify lower-cost metallic materials using fractal textured superhydrophobic structures to reduce heat transfer and raise operating temperature limits for CSP components. The work seeks to address the DOE desire to raise the operating temperature of CSP systems, thereby increasing thermal efficiency. The project has just begun, so progress to date is low. The work will assess the thermal and corrosion characteristics of such textured surfaces.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engage partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** 1) Budget is reasonable. Delayed start and is still in literature survey stage. 2) This research addresses the overall DOE/SETO mission to support early-stage research and development to improve the performance and flexibility of solar technologies that contribute to a reliable and resilient U.S. electric grid. Specifically, the project is focused on supporting advanced innovation in Advanced CSP Thermal Transport System and Components. Reliable, durable and cost-effective fractal structured multifunctional coatings prevent degradation of containment material and improve efficiency by reducing drag and heat loss for high temperature CSP plants, thus accelerating progress toward the 2030 SETO LCOE target of 5 cents/kWh. 3) Anticipate publishing a comprehensive review article based on the literature review. 4) Virginia Tech only. 5) The project started in February 2020. As per the first milestone, a detailed survey on high temperature corrosion and mitigation strategies in the literature is conducting. There is initial evidence that texturing of surfaces leads to reduced corrosion. The work in the coming months will build on the initial evidence to systematically achieve and demonstrate the project milestones.

**Reviewer 2:** This project was initiated in February 2020. Thus, there has been insufficient time for the PI to demonstrate progress. My scores in this section are thus quite irrelevant.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Task 1: Fabrication and Characterization of Fractal Textured Coatings; Task 2: Durability characterization; Task 3: Thermal Endurance and Corrosion Rate Characterization; Task 4: Flow Characterization; Task 5: Fouling Characterization; and Task 6: Technoeconomic Analysis.

**Reviewer 2:** Score: 5. Comments: The tasks proposed for this work follow a logical and reasonable sequence. Candidate materials for the textured surfaces will first be explored by applying the texturing and evaluating the surfaces corrosion and thermal stability. I would hope that the investigation of thermal stability would include thermal and hydrodynamic advantages that accrue from these surfaces (i.e., reduced heat loss to ambient, reduced pressure drop). This is not stated explicitly. Fouling of the surfaces will then be studied. Finally, a cost model for the implementation of textured surfaces on piping and containment component surfaces will be addressed.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Chemical aspects in corrosion and high temperature environment.

**Reviewer 2:** As stated previously, I would hope that the investigation of thermal stability would include thermal and hydrodynamic advantages that accrue from these surfaces (i.e., reduced heat loss to ambient, reduced pressure drop). This is not stated explicitly in the task list.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Expertise in chemical corrosion and reaction that may exist.

**Reviewer 2:** I see none missing.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Idea of fractal-textured multifunctional coatings which may provide for non-wetting of the corrosive fluids with the surface. 2) Mechanical durability, thermal stability, and fouling/scaling mitigation performances. 3) Heat transfer expert.

**Reviewer 2:** 1) This work holds promise for raising temperature limits, reducing heat loss to ambient, and reducing pressure drop in piping components of CSP systems. 2) The project has just begun and so there has understandably been little progress against the proposed milestones. 3) The PI has a strong track record of work in related areas.

## Fractal Nanostructured Solar Selective Surfaces for Next Generation Concentrating Solar Power – $936,326

*Virginia Polytechnic Institute and State University | Blacksburg, VA | Principal Investigator: Ranga Pitchumani*

This project aims to increase the thermal efficiency of solar receivers by fabricating multiscale fractal nano- and micro-structured, high-temperature coatings that can be applied to the receiver in a concentrating solar-thermal power system. Called a selective solar surface, this multiscale surface has texturing, which could enable the coating to enhance light trapping in the solar receiver, improve energy absorption, and eliminate the need for anti-reflection coatings. The team seeks to develop durable solar selective surfaces that enable absorption efficiency rates greater than 90 percent at temperatures higher than 750 degrees Celsius, and with a degradation rate of less than 0.2 percent per 1,000 hours.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 4 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Dr. Pitchumani at Virginia Tech is developing unique, nanostructured coatings to enhance the optical properties of receiver and collector components based on optics theory. He is applying coatings by electrodeposition, which is a commercially viable, economically feasible, scalable process. If successful, the project could have significant benefits to the US solar industry and other industries where thermal or optical control on metal components is important. Although a Figure of Merit including optical properties, thermal cycling and cost is proposed as a means of selecting coatings, it seems as if the key risk that the nanostructure of the coating, which is proposed to be the key feature to providing the system level cost benefits of the approach, are not emphasized adequately. An initial budget period focusing on this issue with a go-no go stage gate may be appropriate.

**Reviewer 2:** 1.1 Since lowering surface emittance while maintaining its high absorptance would certainly improve the collector energy efficiency, the project's goals align well with this topic's goals and supports SETO mission, but the proposal documents we received and follow-up response do not quite describe and evaluate sufficiently the explanation and justification of the approach of developing and applying fractal nanostructured solar selective surfaces for this purpose, nor of the robustness of the coatings under operating conditions, neither of their economic viability, relative to available coatings. 1.2 While the approach is generally sensible, insufficient information is provided to properly assess the ways to overcome the likely challenges in selection, application, thermal performance, and durability of the coating materials. Contingency plans are not shown. 1.3 In the absence of adequate assurances in the proposal, the approach is indeed a high-risk one, but could be of high impact if the prosed goals would be met. 1.4 They do if the proposed goals are met, which, based on my earlier comments, is impossible to predict. 1.5 They do. 1.6 If the goals are met, they would advance the US solar industry reasonably. Strengths: an innovative approach for developing high-absorptance low-emittance economical coatings that operate well at CSP high temperatures. Weaknesses: Strong uncertainties in the chances to meet these goals.

**Reviewer 3:** 1. In this project, we seek to significantly increase the thermal efficiency of solar receivers by fabricating multiscale fractal nano- and micro-structured high temperature solar selective surfaces with superior performance and air-stability. 2. The main difficulties experienced so far pertain to procuring the characterization instruments for measuring the solar absorptance and thermal emittance. 3. Durable solar selective surfaces with the ability to operate at >750oC enables high efficiency advanced sCO2 power cycle integration with CSP systems and decreases LCOE which, in turn, could help stabilize and reduce electricity rates to consumers. 4. A 2-year $1.17M project. 5. The proposed research will broaden both fundamental and applied scientific knowledge in the fields of optical transport phenomena in multiscale fractal surfaces and the robust, scalable fabrication process of the structures. 6. Successful development of the cost-effective coatings that maintain high absorptivity while minimizing emissivity and maintain prolonged stability at high temperatures in air (>750oC) will enable deployment of advanced, high temperature and high efficiency power cycles, reduction in receiver cost and solar field cost (reduction in number of heliostats), due to improved thermal efficiency. 7. Strength: Using electrodeposition for long durability. Weakness: Require expertise in Instrumentation and solar radiation.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 3 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** As mentioned above, although the milestone plan focusing on material comparison and selection initially, one of the most important features of the technology, the ability of the nanostructured surfaces to provide adequate benefit at high temperatures, could be emphasized more and earlier in the project. Likewise, the PI proposes a fairly large list of materials choices, due to the flexibility of electrodeposition, but materials compatible with those anticipated to meet CSP mechanical and thermal requirements should be a high priority. In this regard, the PI should be encouraged to collaborate with others working on fabricating low-cost superalloy components for CSP systems.

**Reviewer 2:** The project just started so it is impossible to form a solid opinion. The PI and his past work and performance are very good, but his current selection of stakeholders is insufficient.

**Reviewer 3:** 1) In literature review stage. No further milestones are identified yet. 2) Further it will have the following positive impacts: Security: Cost-effective and efficient solar thermal receiver technology would enable increased use of domestic solar energy resources strengthening the nation's energy security; Environment: Cost-effective and efficient solar thermal energy power generation could help decrease fossil fuel-based electricity use and harmful emissions from coal-burning power plants; Economy: Durable solar selective surfaces with the ability to operate at >750oC enables high efficiency advanced sCO2 power cycle integration with CSP systems and decreases LCOE which, in turn, could help stabilize and reduce electricity rates to consumers. 3) Publishing a comprehensive review article based on the literature review. 4) Virginia Tech with two partners on the technoeconomic analysis and tech-to-market evaluation. 5) The project has recently started. A literature review is being conducted per the project plan and preliminary studies on deposition of black cobalt oxides and copper oxides are being conducted on different substrates materials such as stainless steel, Inconel, copper, etc. with good adhesion property. Significant results will be forthcoming.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in this project adds unique and important value towards achieving the overall goals of the project, but it may be beneficial to select some tasks as go-no go gates.

**Reviewer 2:** Score: 5. Comments: Yes, with the reservations expressed in 1.2, about some lack of clarity of the justifications.

**Reviewer 3:** Score: 5. Comments: Task 1: Fabrication and Characterization of Solar Selective Surfaces; Task 2: Optical & Mechanical Characterization of Solar Selective Surfaces; Task 3: Thermal Endurance Characterization of Solar Selective Surfaces; Task 4: Technoeconomic Analysis (to be conducted in collaboration with Dr. Nithyanandam of Element16) and Task 5: Technology to Market Plan.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** As mentioned above, nanoscale structures are usually unstable at elevated temperatures. Although the specific, cauliflower-like, structures anticipated by this process may be more stable than other geometries, degradation will occur. Subsequent to the degradation, the cost-benefit result may change. In addition, by not focusing only on creep and oxidation resistant alloys, the project results may not be applicable to CSP system components.

**Reviewer 2:** A reminder (not necessarily blind spot) of the need to address carefully the long-term adhesion, coating integrity, and mechanical uniformity of the coating, not only its radiative properties.

**Reviewer 3**: Participation of experts in optical instrumentation and solar radiation.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Alloy and component designers and manufacturers.

**Reviewer 2:** The project has minimal collaboration, with 2 small companies that I don't know and that don't seem to be very engaged in key aspects of the proposal topic, and it would be advisable to include experienced manufacturers and users of CSP systems.

**Reviewer 3:** Optical imaging and radiation area.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The project is directed toward a theoretically, highly beneficial method of improving cost and efficiency of CSP systems. 2) It is important to demonstrate stability of the methods nanostructures and their application to relevant materials. 3) The project is just beginning so there is a lot of opportunity to modify the scope/budget/schedule of the tasks, including go-no go criteria, and address the potential weaknesses of the current plan.

**Reviewer 2:** 1) Significantly improve the explanation and justification of the approach of developing and applying fractal nanostructured solar selective surfaces for this purpose, for assuring the robustness of the coatings under operating conditions, and for their economic viability. 2) Significantly improve the evaluation and explanation of the impact of the proposed 'fractal' coating on the performance and economics of CSP systems, in comparison with existing coatings. 3) Address carefully the long-term adhesion, coating integrity, and mechanical uniformity of the coating, not only its radiative properties.

**Reviewer 3:** 1) Long-term air stability and durability. 2) Enable achieving > 90% receiver thermal efficiency for next gen CSP plants operating at temperature > 750oC. 3) Cost-effective coatings.

# CSP Systems

## Third Generation Gas-Phase System Development and Demonstration – $8,276,094

*Brayton Energy | Hampton, NY | Principal Investigator: Eric Vollnogle*

In this project, a commercial-scale gas-phase concentrating solar-thermal power system is being developed in the first two Gen3 phases and, if selected for the third phase, developed into a test facility. The megawatt-scale test system absorbs energy from a heliostat field and delivers it into a thermal energy storage system, storing nine megawatt-hours of heat at a temperature of 750 degrees Celsius for a minimum of ten hours. The energy then moves into a working fluid that could have a round-trip efficiency of 99 percent, creating a concentrating solar-thermal power solution that enables on-demand renewable energy.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 4 | 6 |
| Implement a high-risk, high-impact approach | 6 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This is a very large ambitious project that would provide a lot of advancement through a substantial demonstration. Many of the concepts explored have been studied in very small scales but this would allow a large advancement.

**Reviewer 2:** Strengths: 1) Gen3 needs an integrated receiver/working fluid/power cycle/thermal energy storage solution. This proposal addresses the receiver portion while keeping track of the other necessary components. 2) Several areas were discovered where the earlier approach was not sufficient and changes were made. 3) There are potentially a lot of knowledgeable eyes reviewing the results of this design effort. Weaknesses: 1) It is not clear who is checking Brayton Energy's work 2) A novel, untested SCO2/solid particle heat exchanger is evidently required. This is its own project by itself.

**Reviewer 3:** This project is properly conceived and includes a wide range of capable participants. It is pushing the boundaries of what has already been done in CSP by integrating higher temperatures, higher pressures, sCO2, and other innovations that represent a high-risk, high-impact approach. While the funding level is high, it appears to be in a reasonable range for the goals. Sub-components of this project are relevant to research in other areas including sCO2 in general as a power system for energy storage with other storage media, nickel alloys and advancing heat exchangers, improving receiver technology that could be beneficial for high-temperature process heat, etc.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 | 6 |
| Disseminates results frequently and actively engage partners | 5 | 4 | 6 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project includes a lot of different partners and stakeholders, leveraging a lot of industry knowledge and expertise.

**Reviewer 2:** There are multiple team members on this project, presumably to provide input and guidance to Brayton Energy's design work. How much input and checking has there been? It's unclear.

**Reviewer 3:** This project appears to be well managed and advancing according to its time frame and budget from the materials presented. It is also tracking the LCOE, consistent with measuring the impact appropriately. While the team is extensive, one stakeholder that appears to be missing is a partner to accurately provide O&M costs to confirm and make sure that the design is consistent with a low O&M cost strategy, an challenge that will stress the ability to get below the LCOE target. There may be some input in this area from Bright Source or Solar Dynamics but input from a project owner/operator would improve this.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Validating the designs up front is key to ensuring the full system can work as expected.

**Reviewer 2:** Score: 3. Comments: It isn't clear from the Poster or Report what the tasks were. There are high-level Gantt Chart one-liners.

**Reviewer 3:** Score: 6. Comments: All the tasks noted in the report appear to be aligned with achieving the overall goals of the project. There don't appear to be deficiencies in this area.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Although ultimately there is a cost goal and the system needs a path to meet that goal, focusing too much on optimizing the cost may detract from the project. The project includes some very risky systems that may be best to prove out before optimizing for cost. Heat transfer and efficiency of the particle to $sCO_2$ heat exchangers

**Reviewer 2:** Who is reviewing the designs? Brayton Energy says the design is fine and it will work, but who (amongst all the partners) is responsible for due diligence?

**Reviewer 3:** Decoupling the thermal energy collection to the dispatching of electricity will continue to be a growing need. Ensuring the design keeps this in mind is important to the technology's applicability. For the power cycle, being able to ramp quickly, start and stop, etc. will help make it more applicable to the market. A complete O&M buildup will be important to validate that the system can achieve the target LCOE. It may be useful to perform this analysis and find the threshold scale of commercial projects where this technology can be competitive.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project has a lot of collaborators and stakeholders already that provide a lot of expertise, there does not seem to be any missing.

**Reviewer 2:** There are multiple partners in this project already. What's missing is knowing who is responsible for what.

**Reviewer 3:** Additional participants with deep O&M experience could help the project team ensure both that the design is headed in a low-cost-to-operate direction and that the O&M costs are reasonable and include all life cycle costs. In addition it may be useful to have additional support on the team to address the storage tanks to ensure that this part of the overall system, which may seem simple, is addressed as it is critical to the success of CSP in general.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The project team includes a lot of resources and expertise that should aid in the project being successful. 2) The timeline will likely slip due to the large scale of the project and inevitable challenges (including the Coronavirus). 3) There is significant risk in the particle to sCO2 heat exchangers and this project relies on two of them.

**Reviewer 2:** Ask Brayton who is responsible for the design review? Has it been documented? Amongst the multiple partners, who did what?

**Reviewer 3:** 1) A review of the O&M costs and how those compare to the LCOE targets would be useful to be sure these are being managed in tandem with the rest of the project. 2) Storage tanks likely need to be addressed here or elsewhere. As seen in the industry, a failure on a tank is difficult to recover from. Tanks that went from 400C to 600C and now to 700C with this project are exceeding what has been done and to date hasn't been done with a lot of success. 3) Projects like these with high risk-high impact are clearly best funded through the SETO to advance the industry.

## Concentrating Solar-Thermal Power Plant Construction, Start-Up, and Operations and Maintenance Best Practices Study – $748,192

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Mark Mehos*

This project is determining best practices for the engineering, construction, commissioning, operations, and maintenance of concentrating solar-thermal power plants in the United States and abroad. The team is working to obtain and analyze input from operators, owners, developers, financers, and engineering, procurement, and construction contractors of these systems. At the end of the project, a best-practices document will be published to enable future plants to minimize costs and maximize energy production.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Strengths: 1) This synthesis and discussion of best practices will help guide the CSP industry in the future and also enable other industries to contribute to the CSP industry. Weaknesses: 1) Other than an OSTI report - how are comments going to be made available to the public? More useful than just a synthesis, it seems that specific, detailed comments from the individual contributors could also be useful. How would the public find those individual comments?

**Reviewer 2:** The project aims to gather and disseminate best practices through the lessons learned by CSP trough and tower owners, operators and major EPC contractors. The team consists of highly experienced individuals from the government (NREL), and commercial entities who have worked in the field for several decades in some cases. The team has worked very closely with the stakeholders through on-site visits, phone interviews and gathering data through questionnaires. The project's objectives are well thought out and aims to provide a solid database future implementors of CSP can drawn up.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engage partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 6 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The team is large with contributors from deployed plants.

**Reviewer 2:** From its inception, the project has laid out very well-designed objectives to engage as many of the 90 CSP (parabolic and power towers) plants operating worldwide. The goal of reaching >60% of current operational projects was exceeded to be almost 80% of CSP plants. The number of issues that they have gathered representing the different phases of the project were so exhaustive that the team had to move from a simpler Excel database to Access. The project has had the cost-sharing from a commercial entity )Solar Dynamics, SolarPaces as well World Bank through project direct funding and in-kind support help in data collection efforts and supporting dissemination of best practices and lessons learned following final report publication. Due to sheer reach of the team's effort, and outreach, the project shows high promise of success.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Other than a report, I don't see how the access database will be made available to the public.

**Reviewer 2:** Score: 6. Comments: The capital cost of CSP systems continues to decline worldwide. Anticipating continued cost reduction, future O&M will likely represent a growing percentage of CSP costs. As such, publication of best practices for design, construction, start-up, and O&M are critical to both continued near-term deployment of CSP technologies and long-term reduction in levelized cost of electricity (LCOE). The engagement of the major trough owners, operators and major EPC contracts is critical and the PI has been very successful in this effort. They have collected over 1000 issues related to technologies in trough and tower, as well as several project related issues. The combination of getting buy-in from the major players to participate and engage has proven to be a highly successful endeavor leading to some unexpected findings such relative importance of project implementation issues over technical challenges related to systems and components.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Other than a summary in the OSTI report, will the individual responses be made available, and how?

**Reviewer 2:** None. The team consists of very experienced engineers and project managers who understand the CSP technology and its applications quite well and have made connections to the right stakeholders.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No one is missing.

**Reviewer 2:** Very well thought through mix of stakeholders needed for practical implementation of CSP technologies.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Considering the enthusiastic participation of the industry, are their individual responses going to be made available? 2) This is an important project that will enable better CSP plants in the future. 3) For some, a detailed description of the problem (as obtained from the individual responses) could prove useful.

**Reviewer 2:** 1) Senior, experienced individuals engaged in the project ensures success. 2) Engagement of CSP stakeholders critical and buy-in has been very successful. 3) Cost-sharing from external non-US government agencies provide the assurance that the database will be put to good use.

## Liquid-Phase Pathway to SunShot – $8,067,661

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Craig Turchi*

This team is testing the next generation of liquid-phase concentrating solar-thermal power technology by advancing the current molten-salt power tower pathway to higher temperatures and efficiencies. The project is designing, developing, and testing a two megawatt thermal system consisting of the solar receiver, thermal energy storage tanks and associated pumps, heat exchangers, piping, valves, sensors, and heat tracing. If selected for the third phase, the system will be validated in a commercial-scale test facility.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Strengths: 1) Specifically targets improvement areas in existing technology. 2) Has found possible ways forward for those improvement areas. 3) Knowledgeable team that seems to have been consulted. Weaknesses: 1) Many of those associated with piping salt (but it's the devil that you know). 2) Requires a new salt. 3) May be expensive to protect piping surfaces.

**Reviewer 2:** The topic is well aligned with the SETO mission and has set critical challenges to overcome. The focus too on the storage tank and critical challenges around that are key to high-temperature thermal energy storage being widely commercially adopted in the US. The level of funding appears reasonable. For this to advance the US solar industry, tower technology overall has to grow or pumped thermal energy storage will need to adopt it. The latter may be a path that still can advance the US solar industry though.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 |
| Disseminates results frequently and actively engage partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project has met milestones and is in budget.

**Reviewer 2:** The project appears to be meeting its milestones however, the spend on personnel appears to be outweighing the spend in other categories (contractual). This may signal some delay in some areas or just a contracting/payment issue. The team is a diverse and capable team of partners and it appears that sufficient stakeholders are on board. It may be useful to get some additional consulting or some outreach to the different tank consultants/designers that have built molten salt tanks in the past for commercial projects. This isn't to say that the team isn't capable with the current stakeholders, but that issues in this area are complex and the industry lacks codes and standards that are directly applicable to the technology.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Not all tasks were listed, but I feel important ones were highlighted.

**Reviewer 2:** Score: 6. Comments: I agree that each task adds important value to the overall goals of the project. The milestones noted show a complex assembly of issues to overcome to advance the technology.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I think the PI has thought of more than I have.

**Reviewer 2:** While the work appears robust and complete, some areas to consider would be to not limit tank designs to flat-bottomed tanks. Other tanks such as a conical bottom tank or spherical tank may offer some advantages and flat bottom tanks haven't been the easiest to deal with in industry. Also, other tank concepts could be considered such as earthen tanks with liners. The liner to prevent or limit corrosion and reduce the metal requirement of the tank is an interesting one and should prove to be useful. While corrosion is a concern, another advantage may be that the temperature of the metal wall may be reduce and environmental issues such as rain may not cause the high thermal stresses that can occur, creating another benefit.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I'm not aware who's on the DOE Salt Collective, but they're a valuable resource for this project.

**Reviewer 2:** As previously noted, additional stakeholders in tank design may add value to widen the view of structural options. This may be the approach of the team already with the tank consultant/designer selected, so it can be discarded if it is the case.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Appreciate the attempt to find an enabling salt. 2) This approach is R&D, but it's also applied engineering. I think that makes it nearer to market.

**Reviewer 2:** 1) The advancement of molten salts to high temperatures is an important pathway to lowering LCOS. 2) This is an important project as it does focus also on the tank design, however additional work and research in this area is needed since it is often an overlooked aspect of the technology as simple. 3) Balancing the CapEx/OpEx with the improved efficiency is critical to the success of the project.

## Real Time Operations Optimization Software – $2,900,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Michael Wagner*

This project extends prior work on the National Renewable Energy Laboratory's System Advisor Model software for concentration solar-thermal power, focusing on dispatch optimization and solar irradiance forecasting. This software can automate certain decision-making processes at concentrating solar-thermal power facilities to execute real-time, optimal operational strategies in these areas. Automating these processes can simultaneously account for operational factors beyond the knowledge of human operators, generate consistent and improved plant performance, and reduce long-term maintenance costs. Prior work in the System Advisor Model has shown that optimized dispatch could increase a facility's revenue by 5-25 percent, depending on the market.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The proposed software sounds very useful to plant operators, but the main questions is if it will be adopted and actually used by operators.

**Reviewer 2:** The SAM tool is already a very comprehensive and feature-filled tool used in design of CSP fields. The authors are now aiming to significantly improve its usefulness by integrating engineering models to ensure model system performance at 1-minute fidelity as well as providing methods for optimizing operations taking into account plant component failure modes, heliostat soiling, power cycles availability etc. The tool is also envisioned to provide plant operators access to real-time predictions for performance based on existing environmental conditions. The team is implementing a multiple pronged approach where they develop detailed engineering models as well as optimization of plant start-up and shutdown taking into account wear and tear of the components. Complex interactions between receiver, power cycle and TES are modeled to determine cost/benefit results in real time. Solar and weather forecasting techniques are used to local plant conditions will assess operator decisions in the context of machine learning and characterizing soiling and failure rates over time.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engage partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project does a good job of quantifying the benefits with several different metrics. There are several collaborators on the project including an operator.

**Reviewer 2:** Methodical improvements of existing performance models have led to agreements between model results for enthalpy and pressure to industry data to within 2%. Optimization models have been demonstrated to perform accurately to within 99% within 10% of required time step. Solar forecasting errors have been reduced. The team is working on the remaining milestones and are working on machine learning-based algorithm tuning and overall system model validation. They are working with industry such as BrightSource Energy and Tonopah Solar Energy, two important players in this arena. The usefulness of the tool is expected to be significant as they share model results and compare actual data to help finetune the model parameters.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: All of the tasks listed appear to be valuable including engagement and outreach.

**Reviewer 2:** Score: 6. Comments: The project is multi-dimensional in the sense it tries to integrate various O&M related topics and can be used in different applications such as steam-Rankine power cycle off design, CSP-hybrid systems to improve PPA, transient thermal behavior of steam-salt heat exchangers. A separate planning and operations optimization model for mirror washing has also been developed that helps to improve revenue. There are other capabilities included in the model which make this a very comprehensive tool.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Adoption by end users, as each operator has their own unique system and typically does not trust outside software or parties to make key decisions even if proven more effective. The software makes a lot of sense, but will be an uphill battle to sell or get active engagement.

**Reviewer 2:** None. The project addresses plant operations from both the revenue and O&M cost perspectives by identifying concrete measures to maximize revenues and minimize costs.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** If possible to get additional operators involved with the project will help create buy-in and future adoption.

**Reviewer 2:** The PI has done a thorough job in engaging all relevant organizations.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Get additional end users involved early. 2) Good job on quantifying impact and progress. 3) Good job having a task related to engagement and outreach.

**Reviewer 2:** 1) Very ambitious project. 2) I expect there will be additional iterations on the optimization of operations to minimize costs. Machine learning will involve several data and there could be some site-dependent data that might be difficult to capture. 3) Very useful tool - learning may be difficult so learning modules on youtube or similar could be envisioned.

## Integrated Heat Pump Thermal Storage and Power Cycle for Concentrating Solar-Thermal Power – $756,466

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joshua McTigue*

This project investigates the thermal performance and economic feasibility of a new integrated technology that couples solar power generation and grid-connected storage. By using thermal energy storage, which can be easily incorporated into concentrating solar-thermal power plants, this work explores the effect of storing electricity from the grid by powering a heat pump that can charge a cold storage material. Cold storage could potentially enable very high net power cycle efficiencies. The team is developing techno-economic models to investigate several key variables in this new system design, including potential thermodynamic cycles, working fluids, and cold storage media. A study using California electricity market data will evaluate the economics of the new system and determine which performance metrics may make it economically feasible.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project is a unique look at expanding the value of CSP plants.

**Reviewer 2:** The proposed concept is a novel concept to improve the overall economics of CSP plants and also interesting from the perspective of adding grid flexibility since there may be a lot of excess energy that a CSP plant could effectively store and then deliver when needed, effectively utilizing the asset. The concept is well matched with the level of funding and can aid in helping to advance industry and other efforts in better understanding the flexibility of pumped thermal energy storage.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 |
| Disseminates results frequently and actively engage partners | 4 | 6 |
| Collaborates with sufficient stakeholders | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project includes several collaborators to dig deeper into various sub-components. The project could benefit from feedback from utilities in terms of actual value or additional soft benefits.

**Reviewer 2:** Some issues were noted in contracting and timing but appear to be manageable. The PI does show realistic LCOS targets and clear comparisons to accurately measure the technology against others. The work could benefit from more industry engagement on components such as turbomachinery, heat exchangers, and other critical components to confirm cost targets are realistic. This was noted to be completed in Milestone 2.1 but additional information on industry engagement would be helpful.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project is analysing several different scenarios to identify the strongest cases. Additionally, by making a tool available by the end the project provides additional future value.

**Reviewer 2:** Score: 6. Comments: The tasks/milestones in this project appear to align with the goal.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** As the PI indicated partial load cases pose the largest challenge in having an accurate model.

**Reviewer 2:** PTES is young and many variations will come out over time. Some areas to consider: 1) Is the cold side necessary? If integrating with CSP, the cold side isn't being used to charge the TES on the existing Rankine cycle and may just add unnecessary cost. 2) The size of the charge heat pump may be more important in the Plexos modeling than the discharge heat engine. Or at least the ability to decouple these. 3) Minimizing heat transfer surface area will be key to cost competitiveness along with having a high-performance heat exchanger. 4) If PTES is used outside of CSP to retrofit existing fossil plants, the cold side may not be useful (since a separate heat engine would be used for discharge and only the hot side is needed to run the existing plant as it already has heat rejection). 5) Provided that the heat engine and heat pump are synchronous, other grid services are possible while charging and discharging such has having physical inertia, providing circulating current, etc. Concepts like these should help add more renewables while maintaining a stable grid.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Feedback from a utility would be beneficial to this project.

**Reviewer 2:** Engagement and outreach with more of industry may help advance this concept. Given the variety of approaches being developed for PTES, this work is well-positioned to summarize the pros and cons of different approaches.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Would like to see how much this would affect the LCOE for a new plant, rather than just LCOS. 2) Get a utility stakeholder involved. 3) The concept is only marginally competitive with batteries, but much more complex of a solution.

**Reviewer 2:** 1) Modeling system configurations in Plexos is a very smart approach. Ultimately systems are not sold on LCOE/S but overall system value to the utility/ISO. This part of the work is very valuable and an interesting addition to simply developing a CSP concept. 2) This work appears to leverage advancements to date and has two directions, first it has the potential to improve CSP and second it has the potential to be relevant with PV or other renewable sources. 3) There are many in industry working to develop PTES solutions with a variety of configurations. Expanding this work to showcase different advances SETO has made and how they are applicable to this technology can help spur additional innovation.

## Full-Scale Hydrogen Mitigation Installation and Testing – $496,352

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Greg Glatzmaier*

This project aims to solve efficiency degradation that gradually reduces electricity output over the life of parabolic trough power plants due to hydrogen generation in receiver tubes. The lab and Acciona Energy USA Global will design, implement, and evaluate a full-scale hydrogen mitigation process at the Nevada Solar One power plant.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 |
| Advance the U.S. solar industry substantially | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project has done an excellent job in identifying a specific problem related to HTF which undergoes decomposition with release of H2 and causing performance to degrade by as much as 15% which translates to losses up to $3M/year for a plant such as NSO. The matching of a DOE lab and a commercial power supplier as large as NSO is an accomplishment by itself since the companies don't like taking the risk of down-time if challenges arise. To the credit of NREL, they were able to convince NSO to implement a test-scale system at NSO to demonstrate the concept. The team is well on its way to demonstrating it which will give confidence to other power supplier to also consider implementing such a process. With an estimated payback time of 2-4 months, it is hard to see why companies will not want to implement it.

**Reviewer 2:** The projects impact is proven by NSO decision to implement despite risks to energy production. 15% loss and 750MW worldwide on current plants is significant. Improving current solar plants greatly helps advance the solar industry.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 |
| Disseminates results frequently and actively engage partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The PI has implemented a staged approach to implementing the H2 removal process starting with lab-testing, winning the confidence of a commercial entity and working with them to implement a test-scale unit at their facility. This is highly commendable. They were slightly over cost ($253K) as they had to deal with unforeseen challenges but in the long run it is minor. The team had established clear goals in the requirement of continuous operation (5 days) and H2 partial pressure measurements in the headspace each day. The testbed was completed and the team should be in the process of testing at the time of this review.

**Reviewer 2:** Great collaboration with NSO and Acciona, including implementation in an active power plant.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project has clearly identified milestones of cost for installation, test-scale performance, H2 extraction rate and H2 target reduction. They were under cost for installation, but the cost for testing had to be augmented due to unforeseen challenges which they addressed with their partner, NSO.

**Reviewer 2:** Score: 5. Comments: The tasks are all important to the project.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** None. They are on their way to succeeding in their project.

**Reviewer 2:** No blind spots come to mind. Implementing at full scale may introduce new challenges, but the current trial is of significant size and in an active plant that most issues should arise with the trial.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None. The project addresses a problem with CSP plants where H2 evolution from the HTF is an issue. By partnering with the right entities, they are ensuring the problem will be addressed in the right manner.

**Reviewer 2:** Critical stakeholders look to be included, including HTF manufacture and support for further commercialization.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Importance of lab-testing and validating approach first (done). 2) Work with commercial sector and win their confidence in implement in their working field (done). 3) Engage another entity to take over infusion (done).

**Reviewer 2:** 1) Demonstration in an operating plant is a significant step and should illuminate more unforeseen challenges than an offline demonstration. 2) Collaborations with operators is very important and can provide insight that may spark additional projects. 3) Having a path to commercialization is significant and utilizing the HTF manufacture is a smart approach.

## Particle Pilot Plant: Integrated High-Temperature Particle System for Concentrating Solar-Thermal Power – $9,153,858

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Cliff Ho*

This project is designing and testing a multi-megawatt thermal falling particle receiver in a concentrating solar-thermal power system. It has the potential to operate for thousands of hours, provide six hours of energy storage, and heat a working fluid like supercritical carbon dioxide or air to a temperature of at least 700 degrees Celsius. If selected to continue into a third phase, the project team will validate the ability to meet the Solar Energy Technologies Office concentrating solar-thermal power cost and performance goals via a commercial-scale test facility.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1**: SNL led by Clifford Ho and in partnership with several institutions have laid out a very ambitious and impactful program that will significantly impact the CSP community. The team consisting of international electric utilities and CSP developers have laid out a detailed project plan for developing a pilot plant utilizing particles which can be heated to very high temperatures and transfer the heat to a high-temp $sCO_2$ or air heat exchangers. The key risk areas have been identified in great detail and have been addressed to convince this reviewer that there is a high probability of success and will advance US solar industry as well as globally.

**Reviewer 2:** Strengths: 1) Detailed report that provides granularity on the tasks required and their status. 2) This is a novel approach to CSP that avoids many of the difficulties of the liquid and air approaches. 3) Strong team that seems well organized.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project's goals are to design an integrated particle-based CSP system and address key component risks. In the R&D effort phase, they have de-risked the proposed G3P3 by simulating and testing key components. This is done in combination with their partners and it is clear that the level of communication is high amongst them. Over 20 peer-reviewed publications have been generated.

**Reviewer 2:** The tasks are detailed, along with milestones and state of completion.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: In Phase 1, the individual components such as receiver, storage, heat exchanger, particle lift etc. have been studied and designs optimized. In Phase 2 detailed drawings, piping and instrumentation diagrams have been generated. They have a 60% complete design package and are in a good position to have it ready for construction bid in Phase 3. All the activities have been conducted in a thorough manner.

**Reviewer 2:** Score: 5. Comments: Yes - tasks were reported with high granularity and were integral to the project being completed.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** None. The PI has done a thorough job in identifying the right stakeholders and working towards a solution that is feasible.

**Reviewer 2:** I believe the PI and the team have anticipated more than I have in this area.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** None. The PI has done a thorough job in identifying the right stakeholders and working towards a solution that is feasible.

**Reviewer 2:** There is already a large team, and they are collaborating with particle lift companies for particle transport.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Excellent attention to detail on the component R&D. 2) Outstanding international partnership. 3) Strong impact potential to CSP.

**Reviewer 2:** 1) There are so many "particles in the air" in this project that it is hard to determine which parts are absolutely critical to de-risk and attempt to solve before Phase 3. Ask Cliff to make a "5 things that must be de-risked" list for you. 2) There will almost certainly be delays in making the components - start early. 3) This particle approach has almost always stood on its own. What commercial entities are also involved in high temperature particle transport? I think Cliff has tried to make those connections, but it would be worth it to talk to him and try to help him out.

# Desalination and Other Thermal Processes

## Integrated Power Block Heat Exchanger and Thermal Energy Storage System for Concentrating Solar-Thermal Power Plants – $348,000 ♦

*Argonne National Laboratory | Lemont, IL | Principal Investigator: Dileep Singh*

Working with CFOAM, one of the world's largest carbon and graphite foam manufacturers, Argonne will develop and commercialize a low-cost integrated heat exchanger/thermal energy storage system for concentrating solar-thermal power plants, desalination applications, and waste-heat recovery. By loading up CFOAM's graphite foam with a salt designed to melt or freeze at an industrial process's operating temperature, Argonne hopes to store energy and reduce costs by combining the heat exchanger and the thermal energy storage into a single component.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 3 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at adapting the latent-heat thermal energy storage (TES) system initially developed at ANL for concentrated solar power (CSP) applications. The TES system is integrated with a heat exchanger (HX) using a high-thermal conductivity graphite foam infiltrated with phase-change material (developed by CFOAM). Both numerical and experimental work will be conducted to characterize and optimize the integrated HX/TES system for potential industrial applications. The proposed work uses the phase-change TES system to address the diurnal solar energy fluctuations. The thermal energy storage system is potentially useful for many systems driven by solar power. The proposed integration of the phase-change storage system with a thermally conducting medium can further improve the efficiency.

**Reviewer 2:** Strengths: The project is relevant to SETO's goals and mission. It targets storage, a component that is critical to enable efficient and cots-effective integration of the CSP and desalination. In my experience, less attention is being granted to storage relative to desalination technology; consequently, the research performed here could add value beyond DOE-funded efforts. Weaknesses: Storage requirements may differ as a function of geography (particularly related to available sunlight) and application (amount of up-time required to produce sufficient water for the end user. The public sector often requires continuous production, for example, while some industries can operate with fluctuating supplies). The team does not address the broader context that the technology would initially address, and any tasks that would be developed to address it.

**Reviewer 3:** Weakness is that the primary part of this work is based on the proprietary storage medium which requires commercialization by the owning entity or a licensee, otherwise, technology will not move forward and gathered data will be locked up in a binder.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 3 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 2 | 3 |
| Collaborates with sufficient stakeholders | 3 | 2 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project has not started yet. The proposed milestones are reasonable given the limited scope of the award, although milestones could benefit from more quantification.

**Reviewer 2:** The project has not yet started. Therefore, milestone achievements cannot be ascertained. The budget and timeline appears to be appropriate for the proposed work, however. Additionally, the team has not articulated its plans to disseminate results, nor engage with a variety of stakeholders.

**Reviewer 3:** Project has not started yet with CRADA partner so it requires more time to find out milestones are reasonable or not. Dissemination of project findings is unclear. I assume there are no other project partners other than the CRADA partner which for this level of work is fine. It would be beneficial to have end-user perspective if CRADA partner is early stage/startup.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 5. Comments: The tasks (articulated through milestones) are specific and logical. They are designed to establish the technology design, a place to test the design, fabricate the lab-scale equipment, test thermal performance, and establish databases. This should help advance the technology readiness level of the technology.

**Reviewer 3:** Score: 5. Comments: Tasks are fine.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** The effective thermal conductivity of the phase change material may change significantly depending on the extent of phase change. The varying thermal conductivity may complicate the optimization of the HX/TES integration.

**Reviewer 2:** The team should consider the context into which the integrated system would be delivered, in order to strengthen the quality of the goals articulated for storage and efficiency. For example, if a system were to be placed in an environment with limited sunlight and high production requirements (i.e. 24/7 continuous operation), storage efficiency and capacity KPIs may need to be very high compared to scenarios with ample sunlight and flexible operating requirements. Addressing this would help with the experimental design of future tasks, and help drive interest from potential end users.

**Reviewer 3:** Cost of proprietary TES is unknown and could be concerning. How is the sizing for the HX/TES plant done? Will it be based off of a certain desalination process or can it be adjusted to provide a power/heat output for the desal plant?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project may benefit from interactions with end users so the design parameters (such as the temperature of the fluid streams) are driven by real applications.

**Reviewer 2:** I would recommend that the team connect with technology providers associated with CSP and desalination approaches, in order to obtain input on storage capacity requirements that can help inform task objectives.

**Reviewer 3:** End user input will be required.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The proposed work uses the phase-change TES system to address the diurnal solar energy fluctuations. The thermal energy storage system is potentially useful for many systems driven by solar power. 2) This project has not started yet. The proposed milestones are reasonable given the limited scope of the award, although milestones could benefit from more quantification. 3) The project may benefit from interactions with end users so the design parameters (such as the temperature of the fluid streams) are driven by real applications.

**Reviewer 2:** 1) The project is relevant to SETO's goals and mission. It targets storage, a component that is critical to enable efficient and cost-effective integration of the CSP and desalination. 2) The team should consider the context into which the integrated system would be delivered, in order to strengthen the quality of the goals articulated for storage and efficiency. 3) Storage projects are worthy of funding. However, because this project has not yet started, and because the commercial partner is pending, it is difficult to determine whether this project should be included among others being considered.

**Reviewer 3:** 1) End-user and desal expertise is needed. 2) Proprietary TES and associated costs are unknown and could be a show-stopper. 3) Project milestones are dependent on CRADA completion thus requiring timely CRADA execution.

## Geographic Information System-Based Graphical User Interface Tool for Analyzing Solar-Thermal Desalination Systems and High-Potential Implementation Regions – $965,198 ♠

*Columbia University | New York, NY | Principal Investigator: Vasilis Fthenakis*

This project is developing software with state-of-the-art solar-thermal desalination models, verified with data from operating thermal desalination plants and data from solar-thermal desalination pilots at Plataforma Solar de Almeria in Tabernas, Spain. The software also incorporates newly developed geospatial databases of alternative water resources. By integrating desalination techno-economic models and geospatial data layers in one interface, the developed software will assist with the planning and valuation of solar-thermal and hybrid technologies.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at developing an open-access software that comparatively evaluates solar thermal and solar hybrid desalination technology options in different locations. The software not only combines techno-economic analysis with geospatial data, but also integrates open-source data/software with new concepts such as the utilization of multiple alternative water sources. The team is aided by an industry advisory board of diverse background and location. The proposed work fills an important gap because solar desalination options are not widely appreciated in the desalination industry, and there is not a comprehensive database for newcomers to assess solar desalination for specific applications at specific locations. If successful, it will promote wider adoption of solar desalination technologies.

**Reviewer 2:** This is a good project if similar other efforts have not been compiled. The data gathering part of this study is where the proof will be in this work. It must be validated by others beyond the advisory board.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engage partners | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project is well executed with project milestones completed as planned. There are multiple publications including an accepted review paper and two MS theses. An alpha-version of the software is scheduled to release for June 2020. The team has identified a few challenges, including the need to normalize the cost data and to gather performance data of new desalination technologies, and has proposed plans to address these challenges.

**Reviewer 2:** Team must collaborate with desal stakeholders to raise awareness of solar thermal energy. Data gathering will determine the impact of this tool.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 5. Comments: Yes, they add value.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Since the goal of this project is to provide a one-stop platform to evaluate solar desalination technologies, it might help for to engage current or recent SETO teams in addressing the challenges (e.g. in normalizing the cost data and gathering performance data of new desalination technologies) and testing the usefulness of the proposed platform.

**Reviewer 2:** Gathering or finding useful data is the major challenge here. Disseminating this information to the desal community in a manner that demonstrates the value of this tool to them is a hurdle that the team must overcome. I think the PIs should consider presenting this information at a multitude of desalination related conferences, such as AMTA, AWWA, AWS, etc.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See previous question.

**Reviewer 2:** Desalination consultants and desal plant designers would be great to partner with or present this data to, in a format that would provide the designers and planners to understand what type of thermal energy, at what grade and cost is available to them. This would provide beneficial info for desal plant design.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The proposed work fills an important gap because solar desalination options are not widely appreciated in the desalination industry. If successful, it will promote wider adoption of solar desalination technologies. 2) This project is well executed with project milestones completed as planned. There are multiple publications including an accepted review paper and two MS theses. 3) It might help for to engage current or recent SETO teams in addressing the challenges (in normalizing the cost data and gathering performance data of new desalination technologies) and testing the usefulness of the proposed platform.

**Reviewer 2:** This model is as good as the data that is built upon. Raising awareness of solar availability, especially for use in thermal desalination could allow desal plant designers to consider thermal desalination as opposed to electric energy intensive membrane processes

## Solar-Driven Desalination by Membrane Distillation using Ceramic Membranes – $873,648

*Fraunhofer Center for Energy Innovation | Plymouth, MI | Principal Investigator: Jeffery McCutcheon*

This project is developing and testing ceramic membranes for solar-driven membrane distillation systems for desalination. The challenges that ceramic membranes face for membrane distillation applications are mass and heat transfer, wetting, scaling, and fouling. These challenges are being addressed by designing and optimizing membranes at a small scale, and later applying the lessons learned to larger-scale elements that can be used with a solar-thermal test bed.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 4 | 4 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 2 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 5 |
| Advance the U.S. solar industry substantially | 5 | 3 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims to develop ceramic membrane for solar driven membrane distillation (MD) systems. Ceramic membranes are more durable than their polymeric counterpart and can be directly used to treat hot wastewaters. The ceramic membrane is treated with a hydrophobic coating to prevent flooding. The proposed approach retains the relative simplicity of membrane distillation compared to other desalination technologies. If successful, the project has the potential to expand the operating space for MD because the ceramic membrane provides chemical and thermal stability. The SETO funding is helpful in exploring a more robust membrane for MD desalination.

**Reviewer 2:** Strengths: Ceramic membranes have been identified as a promising technology for industrial treatment and desalination applications. Solar-driven distillation using ceramic membranes, if proven, may offer a useful tool in the industry's technology portfolio for challenging applications. Weaknesses: The team did not provide substantive (if any) updates to the milestone status, impact, project results, or budget tables. It is difficult to ascertain the team's progress in light of this. Project delays are also apparent due to contractual changes within the project team.

**Reviewer 3:** Scores partially derived from poster since Report was incomplete. A weakness with ceramic membranes is their cost and that is not captures as a challenge. MD requires low cost energy such as solar to make it competitive. High temp solar has not been a good solution since the traditional polymeric materials do not stand higher temperature thus a ceramic membranes that can provide a barrier to everything but vapor could be game changing for MD, if cost effective.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 1 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 1 | 3 |
| Disseminates results frequently and actively engage partners | 4 | 1 | 5 |
| Collaborates with sufficient stakeholders | 3 | 1 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The team has completed almost all BP1 milestones, including the development of a hydrophobic ceramic membrane that meets the technical specifications. The team has identified anti-wetting membrane as the primary challenge and has figured out a process to make the membrane structure hydrophobic to prevent spontaneous wetting. The project is currently going through a novation process, which caused a delay in validating the model for the membrane performance.

**Reviewer 2:** No information provided.

**Reviewer 3:** Impact not present in report deciphered from poster and parts of the report. Strong partnership and stakeholder presence on the team with academic and private sector company.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: BP1 tasks are appropriate.

**Reviewer 2:** Score: 3. Comments: The tasks (as described in the milestone table) are discrete and logical, particularly as relates to research and development of the ceramic membrane distillation technology. However, there do not appear to be any tasks associated with integration of a solar thermal component. The project seems to diverge from SETO objectives as a result.

**Reviewer 3:** Score: 3. Comments: Deciphered from poster.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The ceramic membrane is significantly more expensive than its polymeric counterpart. A technoeconomic analysis needs to be conducted early on to ensure economic viability.

**Reviewer 2:** The team must consider steps required to integrate the ceramic membranes with solar thermal components. It would also be beneficial for the team to identify a target application, in order to identify design factors that would make any integrated systems model more meaningful.

**Reviewer 3:** The cost of ceramic membranes is mentioned on the poster but is not captured as a challenge in the Report. It must be accounted for if MD is to be a viable option for desalination and concentrate management.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It will be helpful to engage end users of this technology as early as possible.

**Reviewer 2:** The team appears to be comprised of representatives from industry and academia. I recommend that the team interface with technical communities, via technical seminars or conferences, and potential end users to access market intelligence and data that could inform project tasks.

**Reviewer 3:** At this point, the project team needs to demonstrate the proof of concept of the ceramic membrane and do a technoeconomic analysis of it.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project aims to develop ceramic membrane for solar driven membrane distillation (MD) systems. If successful, the project has the potential to expand the operating space for MD because the ceramic membrane provides chemical and thermal stability. 2) The team has completed almost all BP1 milestones, including the development of a hydrophobic ceramic membrane that meets the technical specifications. 3) The ceramic membrane is significantly more expensive than its polymeric counterpart. A technoeconomic analysis needs to be conducted early on to ensure economic viability.

**Reviewer 2:** 1) Solar-driven distillation using ceramic membranes, if proven, may offer a useful tool in the industry's technology portfolio for challenging applications. 2) There do not appear to be any tasks associated with integration of a solar thermal component. The project seems to diverge from SETO objectives as a result. 3) I would not recommend offering additional funding for this project, due to an overall lack of information provided, an indication of significant project delays, and a lack of solar-related tasks.

**Reviewer 3:** Report was incomplete. I relied on poster for my scores. MD will most likely not replace RO as the primary desalination step. The PI should focus effort on produced water or concentrate management.

## High-Efficiency, Zero Liquid Discharge, Multiple-Effect Adsorption Distillation – $1,600,000

*Greenblu | Hamilton, NJ | Principal Investigator: Howard Yuh*

Adsorption distillation, a technology based on using materials that are able to adsorb large volumes of water vapor, is well-suited for zero liquid discharge applications where the incoming brine or waste water must be completely separated to produce only purified water and solid salt. This team is developing a multi-stage adsorption water distiller with the ability to use the same adsorbent beds for both a liquid-only distiller to concentrate brine and a liquid-solid crystallizer to generate solid salt by-products, by only altering only the input mechanics.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 4 | 5 |
| Set critical challenges to overcome | 5 | 4 | 3 |
| Implement a high-risk, high-impact approach | 6 | 4 | 2 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 1 |
| Advance the U.S. solar industry substantially | 5 | 5 | 1 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at developing a multi-effect adsorption distillation system enabled by a heat-activated adsorbent for water vapor. Compared to traditional MED techniques, the proposed technique incorporates an intermediate adsorbent to permit operation at higher temperatures and to treat high-salinity brines with zero liquid discharge. Zero liquid discharge (ZLD) desalination is desirable but rarely implemented in real-world systems. Based on GreenBlu's patented technology, the proposed work has the potential to achieve ZLD at a reduced cost. If successful, the proposed work may significantly advance desalination for areas that prohibit brine discharge. SETO funding is appropriate to bridge the gap between initial funding and prototype demonstration.

**Reviewer 2:** Strengths: 1) The project is rigorous and designed to address specific technical challenges that will raise the TRL from 3 to 5. 2) Milestones are tied to securing letters of support/intent from stakeholders, which incentivizes technology maturity. Weaknesses: 1) Alignment with SETO's mission is implied. Specific goals and progress related to parameters such as LCOW are noted, but not obvious to the reader. 2) The challenges to overcome are highly granular. While this specificity is appreciated, it is difficult to ascertain how overcoming them will lead to a progression toward testing stages.

**Reviewer 3:** The challenge and weakness that I see is that what happens with the mountains of salts that are created or the leftover brine and how they plan on doing selective precipitation. This missing piece is puzzling and maybe it is proprietary, but I cannot a positive review on this technology until I have a better understanding of what happens to the remaining solution/solute after evaporation and condensation occurs.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 2 |
| Disseminates results frequently and actively engage partners | 4 | 3 | 1 |
| Collaborates with sufficient stakeholders | 3 | 4 | 1 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The team has met all Phase 1 milestones to produce the adsorbent material with quantifiable metrics such as production weight and water uptake. The team has identified two challenges related to the thermal performance of graphite nanosheets and the volatile components within the adsorbent, but have figured out workarounds that met the milestone metrics. Since the proposed technology is still in its early stage, the potential project impacts are analyzed in mostly qualitative terms.

**Reviewer 2:** The team was able to successfully meet its milestone targets. Milestone results are provided in quantitative terms (primarily related to manufacturing success indicators). Broader impacts are qualitative, rather than quantitative (e.g. described in terms of how the technology addresses market trends). The team indicated that they communicate with potential customers frequently. However, they have not clearly engaged with technical communities, such as via presentations at technical seminars or conferences.

**Reviewer 3:** No publications or public information will be generated as everything will be proprietary and patented. There are no other stakeholders but this company. Economic assessment seems to be a number pulled out of the air by stating a 20x decrease in relation to another technology. There is no basis provided.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 5. Comments: The team indicated that they devised a long series of milestones to drive technology development from TRL 3 to 5. The tasks associated with each budget period are appropriate to enable this TRL progression, including adsorbent performance demonstration, mechanical stability and cycle testing, and prototype development.

**Reviewer 3:** Score: 4. Comments: The tasks are fine for the project as defined. The problem is the technology or possibly my lack of understanding of it in how they plan on dealing with waste (or how they plan to selectively separate salts) from the technology.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Although the proposed technology is still early in its development, it might be useful to start conducting techno-economic analysis so the team has rule-of-thumb guidelines for the costs tolerated for materials and components. Such guidelines are particularly useful as the team search for technical workarounds that may or may not be economically viable.

**Reviewer 2:** The team should begin focusing on design requirements to enable treatment for the target application, and the use of solar thermal energy to power it. The team should also ensure that it clearly resolves health and safety issues related to the production process, to assure viability from a manufacturing, safety, and industrial hygiene perspective.

**Reviewer 3:** Salt mass balance and where it ends up is not defined. Dissemination or diversity of project partners such as an end user would be beneficial.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See previous question.

**Reviewer 2:** The team should consider engaging with technical communities, in order to gain insight regarding challenges and opportunities related to the target application that can be used to inform scale-up tasks. Technical conferences, or smaller forums (such as academic seminars) would be worthwhile for this purpose.

**Reviewer 3:** Project partner(s) such as an end user would be beneficial.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The proposed work has the potential to achieve ZLD at a reduced cost. The proposed work may significantly advance desalination for areas that prohibit brine discharge. 2) The team has met all Phase 1 milestones to produce the adsorbent material with quantifiable metrics. They have figured out workarounds for technical challenges associated with the thermal performance and volatile components of the absorbent material. 3) It might be useful to start conducting techno-economic analysis so the team has rule-of-thumb guidelines for tolerable costs as the team search for technical workarounds.

**Reviewer 2:** 1) The project is rigorous, and structured to incentivize technology maturation by tying milestones to stakeholder support. 2) The team should focus on design requirements for the target application in order to facilitate further technology development. They should also resolve health and safety issues in order to confirm viability from a manufacturing and health and safety perspective. 3) The team should consider engaging with technical communities in order to gain insights to aid in future planning.

**Reviewer 3:** 1) Claim on 20x cost reduction in comparison to MVC is unsubstantiated. It needs to be verified. 2) If they can selectively precipitate different salts, this project could be significant not just for the solar field, but also the inland desalination field as it could a long ways into solving the concentrate issue from RO. However, there is not much information provided. 3) Dissemination or diversity of project partners such as an end user would be beneficial.

## Direct Solar-Thermal Forward Osmosis Desalination of Produced Waters – $800,000

*Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Robert Kostecki*

This project is developing a new integrated ionic liquid-based forward osmosis water treatment system for produced waters of high salinity that cannot be treated directly by reverse osmosis. This novel desalination system combines advanced forward osmosis membrane technology with the lab's unique ionic liquid forward osmosis draw solute chemistry and direct absorption of solar energy using photonic infrared heaters. The technology is being tested by project partner California Resources Corporation.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 4 | 3 |
| Set critical challenges to overcome | 5 | 5 | 1 |
| Implement a high-risk, high-impact approach | 6 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 2 |
| Advance the U.S. solar industry substantially | 5 | 4 | 2 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at combining forward osmosis with solar thermal energy to desalinate high-salinity produced water from oil and gas extraction. The forward osmosis process is enabled by a thermally responsive ionic liquid that shows lower critical solution temperature (LCST) phase behavior with water. The separation of water and ionic liquid is accomplished by a photonic heater that absorbs solar energy and emits in infrared wavelengths. The resulting water is further polished with nanofiltration for agricultural use. This is a highly innovative proposal that addresses an important area of application. The two major components (ionic liquid osmosis and photothermal converters) are both novel and carry significant risks. If successful, the proposed research may open up a new realm of applications of solar technology in the petroleum industry. The high-risk, high-impact nature is well suited for DOE funding.

**Reviewer 2:** Strengths: 1) Relevant Opportunity: the team has identified a challenging application (produced water treatment for agricultural use) that is in need of technically-sound, cost-efficient solutions. Forward osmosis is a valid candidate for this application, and solar energy may indeed enable it to overcome hurdles that are currently precluding its use. 2) Scale-up Approach: the team intends to partner with CRC, an industrial entity, to demonstrate the technology using real produced water samples. This is important to enable potential adoption of the technology in the long term, as end users tend to value data and experience from treatment evaluations that use representative water. 3) Milestone Progress: the team has achieved important initial milestones, and improved its benchmarks to capture findings from initial activities, indicating a good approach of continuous improvement. Weaknesses: 1) Market Reach: produced water salinity in the range of 20,000 mg/L as TDS is limited to few regions, primarily on the West Coast of the US. In other regions, this salinity is much higher (100,000+ mg/L in the Permian Basin in West Texas, 300,000 mg/L in the Marcellus Shale). If the technology is successfully demonstrated, it may experience challenges being translated to other regions with more complex produced water chemistry. 2) Pretreatment: the team's incorporation of pretreatment into the desalination process is unclear. Typically, pretreatment is necessary for desalination processes (including forward osmosis, despite its improved tolerance to scaling and fouling compared to reverse osmosis or thermal techniques). The presence or absence of pretreatment may significantly affect cost.

**Reviewer 3:** This project is very complex and the reward is limited. FO is currently not a favorable desalination process in the industry due to the need to draw water into a draw solution and then perform a separation to remove the draw solution. It is a two-step process that appears to provide savings of energy and have very limited application currently. This project rethinks the draw solution, the FO module and the separation step, each on their own being high risk to complete. It is very ambitious but the stated goals do not demonstrate high impact. The report does not provide metrics of success, thus the impact is really unknown. How much better will it be than today's FO?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 1 |
| Disseminates results frequently and actively engage partners | 6 | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Overall, the project is well executed with quantifiable intermediate results that are also scheduled for publications. The team has demonstrated feasibility for both major components. Their techno-economic analysis identified a need for a significantly higher water flux for the proposed technology to be competitive, and the team took the appropriate step to modify the related milestone. This high-flux requirement poses challenges for the development of a suitable ionic liquid and a more effective photothermal heater. There appears to be some catchup work to do to obtain an economically viable water flux.

**Reviewer 2:** The project is ambitious but still achieved key milestones within timeframes specified. The budget seems reasonable for modelling and testing of a complex technology on a challenging application. The engagement of a relevant industry partner (CRC) is an important enabler of the technology within the oil and gas space. The team has disseminated information in a variety of forums, including academic seminars, industry conferences, and is developing manuscripts for publication elsewhere.

**Reviewer 3:** At this point of this technology development, there is sufficient partner engagement and collaboration, however there is no measured impact provided. The only quantification provided is a flux of 5 LMH, which requires significant improvement for it to be competitive with existing technologies.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 5. Comments: The team has been focused on laboratory-scale modelling and testing of the technology, in order to address potential limiting factors that will affect its technical and economic viability. Prior to scaling up to a demonstration test, the team is conducting a techno-economic analysis. The overall approach appears to be constructed to enable the team to identify critical issues and address them before investing in potentially costly next steps.

**Reviewer 3:** Score: 3. Comments: Tasks are fine, timeline is aggressive.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Given the ultimate use of the product water for agricultural purposes, it may be prudent to investigate the product water quality (e.g. the effect of residual ionic liquid) against agricultural requirements early on.

**Reviewer 2:** Use of Pretreatment: the team has not indicated whether they have assumed the use of pretreatment. Pretreatment is necessary for produced water applications, including for forward osmosis, despite the fact that forward osmosis has a higher tolerance to scaling and fouling compared to other desalination approaches. Addressing pretreatment will enable the team to confirm system costs, as well as any technical challenges related to scaling and fouling that may impact the treatment process in this application. Market Reach: produced water containing 20,000 mg/L TDS is not widespread, and can be treated with other technologies. Addressing this will enable the team to ensure relevance of the solar-thermal forward osmosis system and future uptake. End Use: agricultural applications typically require enormous volumes of treated water. Produced water, in many regions, is also comprised of extremely large volumes. It would be worthwhile for the team to focus on maximizing flux in order to manage volume supply and demand across these sectors effectively.

**Reviewer 3:** Concentrate from NF and its management is not discussed in the report and would need to be thought about. Use of solar to spread heat into the FO system is ambitious and there is no discussion of how this will applied in larger scale systems. How much reactor footprint would be needed to treat how many gal/l/m3 of water? Development of Ionic liquid is in early stage and has significant gaps to overcome before it is commercial ready. Will there be health effects from this liquid in the product water?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** End user in the agricultural community.

**Reviewer 2:** I would recommend that the team engage with an agricultural end-user in order to understand key drivers (such as volume production requirements) that can be considered during the development and scale-up of the technology.

**Reviewer 3:** It would be beneficial to engage FO manufacturers of modules and membranes and draw solutions and build upon existing available technologies that best match up with the PI's vision as opposed to starting everything from scratch.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This is a highly innovative proposal. The high-risk approach may open up a new realm of applications of solar technology in the all-important petroleum industry. 2) Overall, the project is well executed with quantifiable intermediate results that are also scheduled for publications. The team has demonstrated feasibility for both major components. 3) There appears to be some catchup work to do to obtain an economically viable water flux. In addition, it may be prudent to investigate the product water quality against the intended agricultural application early on.

**Reviewer 2:** 1) Consider whether pretreatment is used, and its effect on cost and technical viability. 2) Consider market reach, and potential competition with existing technology, as it may impact long-term uptake. 3) Consider partnering with an agricultural entity to help drive technical needs, such as flux.

**Reviewer 3:** What is the overall benefit of this project if fully successful? Is there enough time and budget to advance this technology to where the PI envisions?

## Solar For Industrial Process Heat – $541,594 ♦

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis*

This project explores the potential role of solar energy technologies, including photovoltaic, solar-thermal, and hybrid approaches that produce electricity and/or heat, to meet a wide range of industrial process heat end uses in the U.S. manufacturing sector. The team is combining detailed information about the spatial-varying and time-varying patterns of industrial process heat demand with the availability of sunlight. They will estimate process parity—the point at which the levelized cost of energy from solar energy is equivalent to that from more traditional combustion sources when used for industrial process heat, based on specific times and geographical locations.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims to explore the potential role of solar technologies in addressing the industrial process heat (IPH) needs in the US. The team proposes to compile data on the spatiotemporal patterns of IPH demand and solar resource availability, and to estimate process parity between solar and combustion sources. The results will be published as data sets and review papers. This project addresses a gap in the data available for potential adopters of solar technologies, and is expected to greatly facilitate their decision making on a county by county, industry by industry basis. The national scope and open source aspects of the project justifies federal funding.

**Reviewer 2:** Strengths: The project is relevant and aligns with SETO's mission. The project addresses an important need to enable adoption of CSP technology for industrial water applications: the ability to identify markets and regions where these technologies are likely to be successful. The project has the potential to add value to a wide audience, and to advance research outside of DOE-funded efforts as well. Weaknesses: As the team indicates, there are many aspects of industrial applications that are considered proprietary by end users. It may be challenging to update the data sets to capture process-related changes in the future.

**Reviewer 3:** Challenges with data collection and availability is mitigated with a well thought out approach. There is not much risk and if similar analysis' have not been done, then it is high reward. A similar effort could be done for Solar for Desalination need.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project is well planned and well executed. The team not only took advantage of their complementary expertise, but also sought regular feedback from a technical review panel. The team has already published the first installment of their data set in the NREL data catalog and is on their way to publish a review paper documenting their findings. The team identified a significant challenge in finding certain data such as operating schedules, but developed approaches to estimate such data and checked their assumptions with industrial representatives.

**Reviewer 2:** The project appears to have achieved its milestones within reasonable timeframes and budgets. No issues were reported. The impacts of the project are qualitative in nature, as the intent is for the project to serve as a tool to others that are pursuing CSP research or applications. The impacts are described appropriately in light of this. The team collaborates with a robust group of stakeholders, including representatives from industry, research organizations, and academia. The team should be able to integrate a diverse set of ideas and information based on this.

**Reviewer 3:** Project can benefit from having additional stakeholders and partners to provide needed data and/or approaches to makes assumed or calculated data more accurate.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 5. Comments: The tasks are described in general terms, as part of the milestone status update. The tasks appear to be specific, robust, and logical, enabling the team to gather information, perform a literature review, and develop the data sets effectively.

**Reviewer 3:** Score: 5. Comments: Tasks are sufficient.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** This suggestion may be outside of the scope of the proposed work: While the large set of data is openly available, it is a bit difficult to visualize the data as intuitively as the cumulative energy graph and the heat demand map in the poster. It will be very helpful to develop an online graphic interface for plotting the data set in intuitive ways.

**Reviewer 2:** According to the Project Results, the team has gathered data related to IPH demands by county from 2014. Unfortunately, audiences may question the relevance of the data due to its age. The team might consider identifying newer data sets (if available). Alternatively, the team might consider communicating why the data is still useful, and how it can be utilized effectively in 2020 and in the future (for example, by publishing a paper that includes commentary on market trends, and any implications on data interpretation).

**Reviewer 3:** Data availability and validity are blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project has appropriately involved relevant parties, but see previous question for improving the outreach.

**Reviewer 2:** The team has engaged with a robust group of stakeholders for this project. No additions are recommended.

**Reviewer 3:** Professional organizations in various industries requiring industrial process heat should be contacted and pulsed for additional data and network that could provide any additional data.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project addresses a gap in the data available for potential adopters of solar technologies, and is expected to greatly facilitate their decision making on a county by county, industry by industry basis. 2) This project is well planned and well executed. The team not only took advantage of their complementary expertise, but also sought regular feedback from a technical review panel. 3) It will be very helpful to develop an online graphic interface for plotting the data set in intuitive ways (much like the cumulative energy graph and the heat demand map in the poster).

**Reviewer 2:** The project has the potential to add value to a wide audience, and to advance research outside of DOE-funded efforts. Audiences may question the relevance of the data due to its age. The team has engaged with a robust group of stakeholders for this project. No additions are recommended.

**Reviewer 3:** It would be interesting to do a similar project of solar availability vs desal water needs of regions/counties to match where desalination is needed, what kind of water is available and what sort of solar energy is available, and if that can be coupled with recommendation of various solar technologies.

## Hawaii Solar Desalination Project – $1,928,238

*Natural Energy Laboratory of Hawaii Authority | Honolulu, HI | Principal Investigator: Alexander Leonard*

This project advances the techno-economic viability of solar-powered forward osmosis by reducing the levelized cost of water 40 percent compared to current state-of-the-art technology. The team aims to demonstrate a system that incorporates a concentrating solar-thermal collector array delivering heat to a forward osmosis system. This system utilizes a new generation of membranes whose energy efficiency and durability will be demonstrated in this project. This system will then be installed and operated at an oceanic facility and the results will be used to scale up to a commercial-sized facility that can achieve the low targeted levelized cost of water.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 6 |
| Advance the U.S. solar industry substantially | 6 | 4 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at developing a solar powered forward osmosis technology for desalination. Forward osmosis has some potential advantages, including a higher water recovery compared to reverse osmosis, but has not yet been demonstrated with a competitive cost advantage. The team proposes to significantly lower the levelized cost of water (LCOW) by optimizing the nanofiltration membrane and the heat exchanger. The project team consists of Natural Energy Laboratory of Hawaii Authority (NELHA) which has access to an existing 2MW concentrated solar power array, Trevi Systems which has experience with forward-osmosis systems, and Cyanotech which serves as an end user for the consumption of water for microalgae production. If successful, the proposed project may be a game changer in demonstrating the commercial viability of the forward osmosis solar desalination.

**Reviewer 2:** Strengths: 1) The nature of the project is high-risk and high-impact. The team's goals to develop a commercial facility that reduces LCOW by 40% compared to the current state of the art approach would be highly visible to the industry, and encouraging of new technology uptake, if successful. 2) The team sets concrete challenges that must be addressed, and steps to overcome them. Weaknesses: 1) In order to address technical issues that arose during the implementation of the project, the team has begun turning to commercially-available options such as heat exchangers and membrane components, which are acknowledged as more costly and less efficient. This reduces the propensity for the solution to add significant value to existing research outside of DOE-funded efforts, and for it to help advance the US solar industry substantially as well.

**Reviewer 3:** This project could provide a breakthrough in solar desalination field of FO. This group is not re-inventing the FO wheel, which has been re-invented many times over, but it is enhancing it in areas where FO currently lacks, such as energy required to separate the draw solution from desalinated water by using solar power in modules that a commercial FO company is providing. The product water target is agriculture water so the quality probably does not need to be as stringent as drinking water standards.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 6 |
| Disseminates results frequently and actively engage partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project is well managed overall, despite some challenges in meeting the Phase 1 goal in terms of cost reduction. The team has demonstrated the feasibility for the end user, showing that the desalinated water has no adverse effect for the microalgal growth. The team has mitigated program risks by seeking both in-house and off-the-shelf solutions to reduce the cost of two key components (nanofiltration membrane and heat exchanger). Cost reduction remains a significant challenge because both components need substantial optimization.

**Reviewer 2:** The team has encountered technical issues related to heat exchangers and nanofilters that have prevented them from achieving some milestone targets. This includes the technical performance of these components, and subsequently engineering design and cost tasks that depend on the outcomes of the performance evaluation. The impacts are specific and quantitative, and address technical capability (recovery) and cost items (CAPEX, LCOE, LCOW). Promising results related to forward osmosis flux have been achieved, as well as demonstration costs. The team has disseminated results in several formats (including a television interview).

**Reviewer 3:** This project has the right stakeholder and plant for success.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 3. Comments: The tasks are generalized (e.g. "modeling, design, testing, sourcing, and pricing of key system components") but not articulated in discrete terms. It is a bit difficult to ascertain the uniqueness of these tasks as a result. The task combination is logical to drive toward the desired outcomes of the project, but would benefit from further explanation.

**Reviewer 3:** Score: 4. Comments: The tasks are sufficient.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Given the difficulty in the in-house development of both the nanofiltration membrane and the heat exchanger, the team might want to conduct an analysis to see if it is economically viable to use one of the components off the shelf. Doing so may also reduce project delay and improve system reliability down the road.

**Reviewer 2:** Volume Production: agricultural applications typically have a high water demand. While recovery is important to obtain high water yields from a treatment process, flux is another factor that is important for water volume generation. I would recommend that the team consider optimizing flux from the forward osmosis process, if possible, in order to ensure its relevance for this application and encourage future uptake. Pretreatment: the team does not address any requirement for pretreatment, which is important in order to manage scaling and fouling of the forward osmosis system (despite its increased tolerance for each compared to reverse osmosis). Managing scaling and fouling will optimize OPEX costs and drive higher water production.

**Reviewer 3:** If higher quality water could be provided so that it could be used for other purposes than just agriculture, that would be very beneficial to this field. They should be able to with both FO and NF in their process. The hot nanofiltration will be a challenge, but there are other solutions that can be used as a workaround.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The team is well balanced with an end user (Cyanotech) among the collaborators.

**Reviewer 2:** The project team is well-rounded, comprising a technical lead with access to a test site, a technology partner, agricultural end user, and consultant. I would suggest that the team engage with technical communities via conferences in order to gain market insight that can be used to inform technical and market challenges and opportunities, and ensure relevance.

**Reviewer 3:** This project has a diverse set of public and private collaborators and is outsourcing undeveloped parts to manufacturers that can provide the group with available components.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The proposed project may be a game changer in demonstrating the commercial viability of the forward osmosis solar desalination. 2) The project is well managed overall, despite some challenges in meeting the Phase 1 goal in terms of cost reduction. The team has demonstrated the feasibility for the end user, showing that the desalinated water has no adverse effect for the microalgal growth. 3) Given the difficulty in the in-house development of both the nanofiltration membrane and the heat exchanger, the team might want to conduct an analysis to see if it is economically viable to use one of the components off the shelf.

**Reviewer 2:** 1) The project is high-risk and high-impact, which could improve visibility and encourage future uptake if successful. 2) Tasks appear as generalized, and lacking in detail. Additional detail could help improve the ability for the team to identify and address challenges and scale-up effectively, while staying on schedule. 3) The team should be mindful of blind spots (related to volume production and pretreatment) in order to ensure relevance and capture potential issues that could drive up operating costs.

**Reviewer 3:** 1) This project has a diverse set of public and private collaborators and is outsourcing undeveloped parts to manufacturers that can provide the group with available components. 2) FO has been created and recreated multiple times, but it has never been optimized. This group is focusing on optimizing and using FO where it could actually be used, specially since it combines with solar energy. 3) The findings are beyond just FO and include the novel heat exchangers that could be beneficial to other fields.

## Zero Liquid Discharge Water Desalination Process Using Humidification-Dehumidification in a Thermally-Actuated Transport Reactor – $2,000,000

*Oregon State University | Corvallis, OR | Principal Investigator: Bahman Abbasi*

This project is developing a hybrid process to treat high-salinity water with zero liquid discharge. The cost and efficiency of energy consumption are targeted to be competitive with large reverse osmosis desalination plants at a fraction of the capital cost. This will be accomplished by using thermally actuated nozzles – components that operate in response to temperature changes – that are heated with low-grade solar heat. These hot air jets are humidified with brine and the solid particles can be separated out. By condensing the water vapor and recouping the heat, this process will target a highly energy efficient cycle.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 6 | 5 | 2 |
| Implement a high-risk, high-impact approach | 6 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 3 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at designing and demonstrating a modular desalination system driven by low grade heat to produce freshwater from high-salinity feed sources. The desalination is accomplished by a cyclonic spraying system combined with a phase change cycle. This new design eliminates the high operating pressure or temperature that is common in desalination technologies. In addition to the design and demonstration, the team will also provide a web-based simulation engine to aid the process optimization accounting for local conditions. The proposed approach is a significant deviation from common desalination technologies. It may offer important advantages in dealing with high-salinity water using low-grade heat. Another potential advantage is the possibility of zero liquid discharge. SETO funding will help establish the proof of concept for this potentially disruptive technology.

**Reviewer 2:** Strengths: Humidification-dehumidification has been identified as a promising technology for elevated salinity projects (primarily seen in industrial sectors, where salinity far exceeds that of seawater). Optimizing this technology and integrating a solar component could provide a useful tool to address these applications. Weaknesses: Tasks are defined in broad terms, and durations are not explicitly provided. It is difficult to determine whether the project matches well with DOE funding and planned project durations as a result. Industry entities such as Gradiant and Heartland Technologies are proactively developing and commercializing humidification-dehumidification and optimized thermal desalination approaches. It is difficult to determine whether the completed milestones add much to add value to research outside of DOE-funded efforts, or to advance the US solar industry substantially at this stage.

**Reviewer 3:** Separation of salt is questionable in the hydro cyclone and could use some more description.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 3 | 4 |
| Disseminates results frequently and actively engage partners | 6 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 2 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This is a well planned project with clearly quantifiable milestones. The team has delivered all phase 1 milestones, including the modeling and demonstration of the cyclonic separator, the design of the evaporator/condenser units, and the desalination simulation engine. A patent has been filed on the new design. The team has identified a few technical challenges, including the fixing of thermodynamic states in a complex system, and is working toward addressing these challenges.

**Reviewer 2:** Impacts are provided in broad, qualitative terms, rather than specific quantitative terms that would enable the reader to understand its relevance to SETO's mission. While the project team members appear to be actively engaged, the team has not provided an indication regarding whether results have been disseminated outside of it. A patent application was filed, however. The project team may benefit from engagement with additional stakeholders, particularly potential end users and industry representatives. This would enable the team to identify external progress related to humidification-dehumidification and ensure that the project they are pursuing is sufficiently differentiated.

**Reviewer 3:** Stakeholder engagement is lacking. Impact could be quantified more in this report.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 4. Comments: The tasks are described in broad terms, and generally include cycle design and operating simulations, component design, test facility design, and web application development. Each step is useful and practical to improve the technology readiness of the system. Additional detail (including KPIs) would be useful to determine whether the steps are sufficient to progress the technology efficiently and cost-effectively.

**Reviewer 3:** Score: 4. Comments: Tasks are sufficient.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The proposed system is highly innovative and also very complex. There may be significant challenges in putting different components together while avoiding unintended "cross talking" among different components. (The complexity of the overall desalination system also makes it challenging to fix the thermodynamic state, as the team has already noted.)

**Reviewer 2:** The team should consider integrating industry representatives into the project, in order to elevate the quality of the outcomes of planned project tasks by creating an opportunity to obtain feedback and potentially relevant data. For example, industry partners could help beta test the web application and offer feedback that aids its future adoption. Industry partners could also help the team plan for lab and demonstration tests by providing insight on water quality and site-specific conditions that are integral to the design process.

**Reviewer 3:** Desalination expertise is lacking with the PI.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Given the exploratory nature of the project, the team has adequately involved all stakeholders.

**Reviewer 2:** The team should consider engaging with industry partners and potential end users, in order to ensure that the technology is differentiated, and to support testing and demonstration with meaningful technical and market information.

**Reviewer 3:** Desal experts should be added to the team.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The proposed approach may offer important advantages in dealing with high-salinity water using low-grade heat. Another potential advantage is the possibility of zero liquid discharge. SETO funding will help establish the proof of concept for this potentially disruptive technology. 2) This is a well planned project with clearly quantifiable milestones. The team has delivered all phase 1 milestones. A patent has been filed on the new design. 3) The proposed system is highly innovative and also very complex. There may be significant challenges in putting different components together while avoiding unintended "cross talking" among different components.

**Reviewer 2:** 1) Humidification-dehumidification has been identified as a promising technology for elevated salinity projects (primarily seen in industrial sectors, where salinity far exceeds that of seawater). Optimizing this technology and integrating a solar component could provide a useful tool to address these applications. 2) It is difficult to determine whether the completed milestones add much to add value to research outside of DOE-funded efforts, or to advance the US solar industry substantially at this stage. 3) The team should consider integrating industry representatives into the project, in order to elevate the quality of the outcomes of planned project tasks by creating an opportunity to obtain feedback and potentially relevant data.

**Reviewer 3:** The desalination part of the technology is not well described or understood leading this reviewer to think that there is additional attention that it could require.

## Low-Cost Desalination Using Nanophotonics-Enhanced Direct Solar Membrane Distillation – $1,699,988

*Rice University | Houston, TX | Principal Investigator: Qilin Li*

This project is developing and testing a novel solar-thermal desalination process called Nanophotonics-Enabled Solar Membrane Distillation, which uses a porous, photothermal membrane to simultaneously convert sunlight to heat and desalinate water by membrane distillation with very high thermal efficiency. The Nanophotonics-Enabled Solar Membrane Distillation technology will go through a system-level integration and evaluation at the pilot-scale.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 6 | 5 | 3 |
| Implement a high-risk, high-impact approach | 5 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 2 |
| Advance the U.S. solar industry substantially | 6 | 5 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This projects aims at developing a pilot-scale solar desalination system using a photothermal membrane to simultaneously convert sunlight into heat and desalinate water by membrane distillation. The technology for the nanophotonics enhanced direct solar membrane distillation (NESMD) has already been demonstrate before. The goal of this award is to move the technology readiness level from TRL3 to TRL7. Both experimental and modeling work are proposed along with a technoeconomic analysis to determine commercial viability. The NESMD technology can significantly advance membrane distillation by directly integrating the solar heating element into the membrane. A successful demonstration of the pilot system will help push this technology toward commercial applications. Such a pilot system fits well into the core mission of SETO.

**Reviewer 2:** Strengths: 1) The project is relevant. It is high-risk and potentially high-impact, as it spans technology development stages from modeling through demonstration. The demonstration would occur at a site that is highly visible in the desalination industry. 2) Membrane distillation is compelling in the desalination industry but, to my knowledge, few entities in the industry are evaluating techniques to integrate solar energy to drive it. This project would add value to research outside of DOE-funded efforts. Weaknesses: 1) The team does not address expected requirements for pretreatment or ancillary equipment that may be required to enable scale-up of the technology.

**Reviewer 3:** Three challenges referenced in text and only two were introduced and discussed. Missing what the third challenge is. 0.75 LMH is practically unacceptable for any system other than emergency/disaster relief or community/HH drinking water needs. Cost of capital and/or land would be significant at that low of a flux. This technology at this flux is not applicable as stated in report for large scale (municipal sized) installations. While the risk is low, so is the impact. Technology is a bit undefined. What is the significance of nanophotonics for this technology? How are metrics for it quantified and described?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 3 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 2 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project is well executed overall. Most phase 1 milestones have been met, with the exception of the technoeconomic analysis because of the move of a co-PI. The demo unit has shown consistent performance that is accurately predicted by a reactor scale model. The validated model can be used for the cost analysis which has been moved to phase 2. The team has identified a technical challenge due to the sample-to-sample variation of NESMD membrane permeability. They have addressed this challenge by comparing the performance with traditional MD membrane, and the comparison has helped their model validation. However, the sample-to-sample variation still needs to be addressed for consistent desalination performance.

**Reviewer 2:** The team has offered a mix of qualitative and quantitative objectives for the project, from developing models to establishing specific numerical KPIs for performance testing. The objectives seem reasonable and feasible. The team is comprised of research and industry entities to develop and test the technology. The identification of the Kay Bailey Hutchinson Desalination Plant as the pilot site also shows promise to drive meaningful results.

**Reviewer 3:** What is the significance of nanophotonics for this technology? How are metrics for it quantified and described? User and technology provider partnership and stakeholder is severely lacking. Team needs that input sooner rather than later for technology development

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 5. Comments: The project tasks (organized by budget periods) are comprised of unique, discrete steps that are necessary to advance the technology from TRL 3 to 7. The objective to develop a cost-optimization model (during budget periods 1 and 2) that allows sensitivity testing as a function of geography and environmental conditions (assuming salinity is part of this) is compelling, as it will enable the team to ascertain viability for a range of markets.

**Reviewer 3:** Score: 4. Comments: Tasks are sufficient at achieving the goals.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The sample-to-sample variation of the NESMD membrane needs to be addressed for consistent desalination performance.

**Reviewer 2:** Blind spots the team should consider relate to potential pretreatment needs during scale-up to demonstration stage. This can impact technical efficiency and cost of the integrated system.

**Reviewer 3:** Team needs to clearly identify the use for this technology. Clearly, it is not intended for larger scale installations. Is it simple to use and easy to fix for smaller scale installation in off-grid areas and/or in disaster relief settings?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The team includes ES Engineering which will test the pilot system. This is a reasonable plan for a pilot study.

**Reviewer 2:** The project team appears to be well-rounded. It may be advantageous to include Kay Bailey Hutchinson plant staff in the project, to help the team identify challenges and opportunities that may be apparent or available in later stages of the project.

**Reviewer 3:** End users for the intended purpose of the technology that clearly needs to be defined by the team have to be engaged in this development. Thoughts must be given to commercialization.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The NESMD technology can significantly advance membrane distillation by directly integrating the solar heating element into the membrane. A successful demonstration of the pilot system will help push this technology toward commercial applications. 2) This project is well executed overall. The demo unit has shown consistent performance that is accurately predicted by a reactor scale model. The validated model can be used for the cost analysis which has been moved to phase 2. 3) The sample-to-sample variation of the NESMD membrane needs to be addressed for consistent desalination performance.

**Reviewer 2:** 1) The project is relevant, high-risk, and potentially high-impact, as it spans technology development stages. 2) Blind spots the team should consider relate to potential pretreatment needs during scale-up to demonstration stage, as it can impact technical efficiency and cost of the integrated system. 3) It may be advantageous to include Kay Bailey Hutchinson plant staff in the project, to help the team identify challenges and opportunities that may be apparent or available in later stages of the project.

**Reviewer 3:** 1) What is the intended use of this technology and at what size/setting? It will not be a solution at larger scale as claimed in the report. The flux is simply too low. 2) Will this technology meet stated desired LCOW or come close to it? 3) What problem is it trying to solve that other current desalination technologies coupled with solar energy are not solving currently, if the challenges of this technology are overcome?

## Low-Cost Buffer Storage for Solar Industrial Steam Applications – $2,500,000

*Sunvapor, Inc. | Livermore, CA | Principal Investigator: Philip Gleckman*

This project aims to demonstrate how using enormous tanks that normally store liquefied petroleum gas can be used to accumulate and store solar-generated steam—and use that steam for manufacturing processes. This technology should be cost-effective due to the low cost of pressurized water and the ability to operate at temperatures above 100 degrees Celsius. In addition, the project team will size the tanks to achieve a low cost of solar-thermal energy storage per gallon, and the solar steam will be able to be used in various industrial applications.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 2 |
| Set critical challenges to overcome | 6 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 2 |
| Advance the U.S. solar industry substantially | 5 | 5 | 2 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at developing a bullet steam accumulator (BSA) to provide cost-effective integration of solar pressurized steam with a typical manufacturing process. The BSA is envisioned to be 10X larger than traditional stream accumulator to even out supply and demand and drive down the cost. The prosed BSA system uses large-scale tanks that normally store liquefied petroleum gas. If successful, the proposed work will break the barrier for applying solar steam in various manufacturers such as food processors. The DOE funding is helpful in convincing initial adopters.

**Reviewer 2:** Strengths: The project is relevant, providing a steam storage solution for industrial applications, where the steam is generated using solar energy. Many industrial processes indeed face storage related challenges and have high steam demands. The team clearly articulates the challenges that they expect to face. They have also included specific mitigating actions to address them. Weaknesses: The team does not articulate any expected milestone outcomes or anticipated project results. While the project has not started yet, it would have been helpful to understand the team's intentions as relates items such as to knowledge sharing (publications) and pursuit of intellectual property.

**Reviewer 3:** Modularizing and mobilizing steam where it's not available is interesting but the team has a lot of work and many challenges and obstacle to overcome. Strength is understanding a lot of their challenges. Weakness is the view worth the climb? What is achieved if the claim of "a steam accumulator of a previously unimagined scale" is successful as opposed to modularizing and mobilizing solar energy steam generating technologies?

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 3 | 1 |
| Disseminates results frequently and actively engage partners | 5 | 3 | 1 |
| Collaborates with sufficient stakeholders | 4 | 3 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project has not started yet. The proposed milestones are reasonable and the risk mitigation plans are well prepared.

**Reviewer 2:** The schedule seems a bit aggressive for the tasks that the team has proposed. For example, during budget period 2, the team anticipates conducting a design review, completing a bid process, obtaining permits, and developing contracts within a year timeframe. Depending on the type of permits that are required, timelines to secure them may exceed a year. Additionally, the tasks anticipated for budget period 3 (procurement, mobilization, construction, startup and commissioning, and measurement and verification) seem potentially ambitious for a two-year timeline. Clarifying the expected capacity of the system and the intended operating environment may help address this. Impacts are primarily qualitative, rather than quantitative. It is difficult to understand how the project addresses DOE benchmarks as a result. The team does not articulate how they intend to disseminate results. The team has not identified specific stakeholders outside of the project team.

**Reviewer 3:** Impact is undefined quantitively. There is no discussed dissemination plan.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The proposed tasks are appropriate.

**Reviewer 2:** Score: 4. Comments: The task list is comprehensive, logical, and necessary to enable field-scale implementation of the technology. However, the current technology readiness level of the technology is unclear. The team may need to add steps to complete any preliminary models and laboratory tests that would inform field-scale applications.

**Reviewer 3:** Score: 3. Comments: Tasks are not provided, but score is based off challenges presented.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** There may be substantial difficulty in finding an initial adopter who is willing to take the risk. For BP1, it may be helpful to include some simulations along with the market study before securing a site host. If available, perhaps an existing (smaller) system at Sunvapor can be repurposed as a demo for the BSA?

**Reviewer 2:** After the team has identified promising markets for the technology, the team should focus on understanding industry-specific or geographic issues that may impact the design and implementation of the system. For example, different sectors often have unique codes and standards that must be followed. Different geographies may have different permit requirements. Site layout and accessibility may also present unique challenges. Understanding these issues early will help the team identify solutions and keep the budget and schedule on track.

**Reviewer 3:** Is there an actual demand for this? Vessel price too high as one of the challenges stated with a high risk has a mitigation action of "request multiple bids". If the price of vessel does not decrease via multiple bids, will this project be feasible? Other challenges and mitigation challenges have lowered the level of water in the vessel thus, lowering capacity but not the capital cost.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** See previous question.

**Reviewer 2:** Ideally, the team should engage with end users, in order to understand challenges and opportunities that could influence the design and implementation of the technology. The team might consider pursuing this type of collaboration after completing their first task (a market study).

**Reviewer 3:** Stakeholders should be engaged on how much they would be willing to pay for this technology and if the PIs can deliver for that price.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project aims at developing a bullet steam accumulator (BSA) to provide cost-effective integration of solar pressurized steam with a typical manufacturing process. If successful, the proposed work will break the barrier for applying solar steam in various manufacturers such as food processors. 2) This project has not started yet. The proposed milestones are reasonable and the risk mitigation plans are well prepared. 3) There may be substantial difficulty in finding an initial adopter who is willing to take the risk. For BP1, it may be helpful to include some simulations along with the market study before securing a site host.

**Reviewer 2:** 1) The schedule seems a bit aggressive for the tasks that the team has proposed. 2) The team may need to add steps to complete any preliminary models and laboratory tests that would inform field-scale applications. 3) The team does not articulate how they intend to disseminate results, and has not identified stakeholders outside of the project team. Doing so would improve the quality of the project.

**Reviewer 3:** 1) Future reporting should be cleaned up, otherwise, it will be difficult to understand progress. 2) Stakeholders should be engaged on how much they would be willing to pay for this technology and if they can deliver for that price. 3) A complete techno-economic assessment should be the first step in this project prior to any larger scale expenditures in the proof of concept.

## Energy Where it Matters: Delivering Heat to the Membrane/Water Interface for Enhanced Thermal Desalination – $1,709,744

*University of California, Los Angeles | Los Angeles, CA | Principal Investigator: David Jassby*

This project modifies a typical membrane distillation system by deploying layers of materials with high thermal and electrical conductivity at the membrane/water interface. These conductive materials will be able to deliver solar-thermal energy directly to where it's needed in the membrane distillation system. By directly coupling the membrane surface to a thermal input, this technology has the potential to be substantially more energy efficient than current membrane distillation systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at developing a thermally-driven membrane distillation technology. The key component is an anisotropic membrane that conducts heat (and electricity) primarily in the lateral direction. The anisotropic membrane is expected to reduce membrane fouling with the application of an electrical potential. The proposed topic of solar energy driven desalination is well aligned with SETO mission. If successful, the proposed membrane combines solar energy conversion with fouling prevention, a combination that will help advance the MD technology. With DOE funding, the proposed technology will hopefully be advanced to facilitate direct integration with end users.

**Reviewer 2:** Strengths: 1) Compelling Application: the team has identified a range of industrial applications that have valid needs for efficient desalination. Corrosion is a critical limiting factor to technical and economic viability. Addressing this issue may enable advanced approaches, such as membrane distillation, to become a tool that end users can use to address treatment challenges. 2) Sound Approach: the task structure and timeline is concrete and systematic, which should allow the team the opportunity to thoroughly vet the technology and address risks that arise. Weaknesses: 1)- Treatment Risks: the team has identified challenging applications (e.g. produced water treatment, flue gas desulfurization treatment) for this technology. The water quality in each poses scaling and fouling risk. Pretreatment will likely be necessary to mitigate these risks, which could subsequently add to the cost of the integrated system. It would be helpful for the team to identify how they intend to characterize and address these issues, particularly when they scale-up to a demonstration system. 2) Target Application: further to the point above, the team provides limited information regarding the market that will comprise their first area of focus (produced water treatment in the oil and gas sector). It would be helpful to understand the nature of the scaling and fouling issues that may arise, in order to characterize any pretreatment (and cost) required to allow for effective demonstration at a larger scale.

**Reviewer 3:** Strength are that it could have the potential to make MD more attractive as a desalination process. Demonstration of flux of 8 LMH is positive and in the right direction. There is room for improvement as the module is further developed. Weakness, currently is lack of test data with real water and effect on membrane and Aluminum Shims that are heated. Another weakness is the techno-economic assessment is making large assumptions that are not back up by the data to demonstrate an LCOW of 1.5/m3, such as a flux of 20 LMH and LCOH of $0.01/kWth. I assume this will be cleaned up further as more data comes in.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 2 | 5 |
| Collaborates with sufficient stakeholders | 3 | 3 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The team has met most of the milestones to date. They have successfully developed a composite membrane, and their MD system has achieved a water flux above target with a good thermal efficiency. There is some catchup work to do because of a corrosion problem of the thermally conducting layer, resulting in its relocation of from the feed stream to the permeate stream. The influence of this relocation on the overall system needs to be assessed, hopefully with the aid of a fully-developed finite volume model validated at the system level.

**Reviewer 2:** The team reported that it has completed most of its milestones, and that other milestones have neared completion. Impacts are specific and quantitative in nature (e.g. specific treatment costs, energy levels, and flux rates are identified). Results have not yet been circulated. The team did not report any engagement with stakeholders external to the project team. Doing so would be worthwhile, in order to gain application-specific insights that can be used to guide scale-up to a demonstration system.

**Reviewer 3:** The team is diverse and has good background in the tasks that they have been assigned.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 5. Comments: Each task is discrete, specific, and logical. For example, the team is clear with regard to expected timelines and responsibilities. The task structure should enable the team to gather sufficient data and information to inform subsequent activities.

**Reviewer 3:** Score: 5. Comments: Tasks are sufficient.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Anti-fouling is an important characteristic of the proposed composite membrane. Very little work is devoted in this regard so far. Along this line, it will be useful to target feed water of more well-defined characteristics (e.g. in a specific application).

**Reviewer 2:** Key blind spots relate to the target application and system integration. The team appears to have selected the oil and gas industry as the initial target market for the technology. Little information was provided regarding likely challenges in this sector (other than corrosion), including scale and fouling control. The team did not indicate whether they intend to use real water samples or indicative samples (i.e. a "recipe") to conduct treatment evaluations during later tasks. Consideration of these items is important, as it will inform any complementary or ancillary equipment needs (particularly pretreatment) and any facilities required (such as an oil and gas operator's site) for testing.

**Reviewer 3:** Getting flux from 8 LMH to 20 LMH is aggressive, but possible.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The end user needs to be narrowed down.

**Reviewer 2:** For the project to be successful, I recommend that the team pursue speaking engagements, in order to solicit feedback from technical communities related to challenges and opportunities that could inhibit or enable the success of this project. I also recommend that the team pursue a partnership with an oil and gas operator, in order to obtain representative water samples (if possible), or guidance regarding appropriate simulated water qualities, for testing. These activities would enable the team to sustain the relevance of the project, and support uptake of the technology in the future.

**Reviewer 3:** A commercial MD partner would significantly speed up the development and add additional know how.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1**: 1) The proposed membrane has the potential to combine solar energy conversion with fouling prevention, a combination that will help advance the MD technology. 2) The team has met most of the milestones to date. However, significant challenges are expected with the relocation of the thermally conducting layer to the permeate stream. 3) Anti-fouling is an important characteristic of the proposed composite membrane. Very little work is devoted in this regard.

**Reviewer 2:** 1) The technology is compelling and relevant for industrial water applications. The task structure and progress achieved to date are indicative that outcomes will likely be instructive or productive. 2) The team should consider disseminating information, as appropriate, in order to gain insights from technical communities and potential end users that will keep the project relevant. 3) The team should identify system integration requirements (pretreatment, scaling control, fouling control) as a function of their intended target application (oil and gas wastewater, real or simulated) in order to plan for scale-up logistics and associated costs.

**Reviewer 3:** Provide assumptions for techno-economic analysis and describe reasoning/source. Provide more information on how flux will be improved.

## Ultra-Compact and Efficient Heat Exchanger for Solar Desalination with Unprecedented Scaling Resistance – $980,875

*University of Illinois at Urbana-Champaign | Urbana, IL | Principal Investigator: Anthony Jacobi*

This project is designing, developing, and testing novel coatings for heat exchanger surfaces in high-temperature thermal desalination applications that aim to increase heat exchanger efficiency by 150 percent or more than current state-of-the-art technology. This will help address challenges like fouling and scaling as well as corrosion resistance that occurs at temperatures above 200 degrees Celsius.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project aims at developing a compact heat exchanger for solar desalination with higher thermal conductance and better fouling and corrosion resistance than the state of the art. The high thermal conductance is accomplished by polymer composites and the anti-fouling feature is accomplished by surface engineering that promotes nucleation of fragile crystal structures. The heat exchanger is then fabricated with additive manufacturing for use in a demo unit for sea-water desalination. The proposed technology can significantly improve the effectiveness of heat exchangers with a high-conductance, anti-fouling composite material, and also improve the desalination efficiency by enabling operation at elevated temperatures. Since heat exchangers account for about half of the capital costs for desalination systems, the proposed work can significantly improve the cost effectiveness of thermal desalination systems.

**Reviewer 2:** Strengths: The project offers an opportunity to advance thermal desalination technologies by addressing key limitations: scaling, fouling, and corrosion of heat exchangers. Combining improved heat exchanger/desalination technology with solar power, if successful, would add a useful tool to the industry's solution portfolio for complex applications. Weaknesses: The team articulates its challenges, but does not indicate the nature of the scale or fouling that it intends to address. Doing so is important, as it has implications on the ability for the system to perform self-cleaning, and overall OPEX. For example, some scales (such as calcium carbonate) are easier to remove compared to others (such as barium sulfate). It would be helpful to understand the type of scale that the team expects to encounter, and if the project is designed to address it.

**Reviewer 3:** The results from this study could be applied to other areas in thermal desalination, specially in regard to scaling.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 4 | 3 |
| Collaborates with sufficient stakeholders | 5 | 3 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This is a well-planned, well-executed project. The team has met phase 1 milestones in terms of material development and themofluid modeling, and is well into phase 2 tasks including a proof of concept for the self-cleaning surface design. The team has adapted quickly from the initial design with a single-phase, in-tube flow to the update design with a more complex system of in-tube condensation. In addition to validating their multi-physics model with existing literature in phase 1, the team will hopefully valid their model further with their own experimental measurements in phase 2.

**Reviewer 2:** The team has generally been able to achieve milestone and budget goals, including one approved six-month extension related to staffing. The impacts are qualitative, rather than quantitative. While the impacts are meaningful, it is a bit difficult to understand how the team's project ties back to SETO's core objectives (particularly quantitative ones). The team has not provided information related to dissemination of information. Engaged stakeholders appear to be limited to the project team and vendors.

**Reviewer 3:** Dissemination of results is currently lacking but the research is fairly early stage. I assume a manuscript is being prepared for publication.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are appropriate.

**Reviewer 2:** Score: 3. Comments: The project tasks are logical and important, as they primarily focus on modeling and manufacturing of the heat exchangers. However, it is unclear if the tasks (perhaps during Phase III, which are not provided) are sufficient to achieve the team's goals of progressing the technology from TRL 2 to 5.

**Reviewer 3:** Score: 5. Comments: Scaling studies and its reduction due to the design is unique and adds a lot of value.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** It is encouraging to see the proof of concept for anti-fouling surface design using a one-species test. It may be challenging to arrive at a surface design that handles sea water with complex constituents and varying salt concentration.

**Reviewer 2:** Unless they have already done so, the team should carefully consider the nature of the scale that is likely to form on the heat exchanger, in order to determine self-cleaning capabilities and OPEX implications. They might consider adding OPEX projections as a KPI to guide the technology development process. In preparation for lab testing, the team should consider whether they intend to use real or simulated samples of seawater, as each will contain different propensities for scale formation, fouling, and corrosion. This would enable the team to plan for subsequent technology development and demonstration tasks.

**Reviewer 3:** Various scalants can cause different effects. Scalants such as $CaCO_3$, $SiO_2$, and $CaSO_4$ all have different characteristics and should all be studied in this study.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** As a pilot study, the project has adequately involved relevant stake holders.

**Reviewer 2:** I recommend that the team engage with technical communities to gain insight on scale, fouling, and corrosion risks and data that could inform lab unit designs. Additionally, the team should consider engaging with potential end users, to potentially gain access to representative water for testing, and understand other constraints that could be addressed as the technology undergoes system design.

**Reviewer 3:** Project is in early stage and has proper to investigate. Upon successful completion and demonstration, additional stakeholders could be pulled in.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The proposed technology can significantly improve the effectiveness of heat exchangers with a high-conductance, anti-fouling composite material, and also improve the desalination efficiency by enabling operation at elevated temperatures. 2) This is a well-planned, well-executed project. The team has met phase 1 milestones in terms of material development and themofluid modeling, and is well into phase 2 tasks including a proof of concept for the self-cleaning surface design. 3) It is encouraging to see the proof of concept for anti-fouling surface design using a one-species test. It may be challenging to arrive at a surface design to handle sea water with complex constituents and varying salt concentration.

**Reviewer 2:** 1) Combining improved heat exchanger / desalination technology with solar power, if successful, would add a useful tool to the industry's solution portfolio for complex applications. 2) It is unclear if the tasks (perhaps during Phase III, which are not provided) are sufficient to achieve the team's goals of progressing the technology from TRL 2 to 5. 3) The team should engage with technical communities and end users to gain insights that could inform the development and implementation of lab and demonstration-scale tasks.

**Reviewer 3:** Various scalants can cause different effects. Scalants such as $CaCO_3$, $SiO_2$, and $CaSO_4$ all have different characteristics and should all be studied in this study.

## Low-Cost High Temperature Ceramic Heat Exchangers – $2,385,000

*Argonne National Laboratory | Lemont, IL | Principal Investigator: Dileep Singh*

As concentrating solar-thermal power systems move to power cycles with temperatures greater than 700 degrees Celsius, high-temperature metallic alloys become prone to degradation from corrosion and/or oxidation, which can increase costs. This project uses high-temperature, low-cost ceramic materials with new designs and 3-D printing to develop ceramic heat exchangers. Ceramic system components can potentially reduce corrosion issues created by molten salt heat-transfer fluids and oxidation from gas phases. As a result, high-performance, high-reliability ceramic heat exchangers could provide a cost-effective pathway for operating concentrating solar-thermal power systems at elevated temperatures and enhance overall system efficiency.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 4 | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths: 2) Novel approach to high temperature SiC heat exchangers for sCO2 power cycles that will help advance SETO's CSP goals. 2) Target strength and heat transfer properties have been attained. 3) Patent application filed. 4) Applicability beyond CSP. Project Weaknesses: Lack of chloride salt/SiC corrosion data.

**Reviewer 2:** Strengths: The project seeks to utilize a new material system that is less explored for CSP applications and has potential benefit for high-temperature, high-corrosion environment. Use of AM provides leverage to fabricate new shapes for the HX, and simplify design by integrating the header with HX module itself. In addition, the SiC powder development, optimized printing process to achieve high density parts, and metal joining techniques can also be useful for creating ceramic parts for other applications. The cost has been shown to be close to DOE target of $300/We. Weakness: Mechanical strength was characterized under room temperature and used in simulations for channel sizing. AM roughness has not been taken into account for the thermal-fluid simulations, so the simulation-based heat transfer and pressure drop characterization will vary from real world. The channel size is 4mm, which greatly diminishes the compactness factor compared to state of the art HX design. The achieved porosity was not mentioned.

**Reviewer 3:** High temperature heat exchangers that can operate in excess of 700 deg C and at pressures close to 20 MPa which are corrosion and creep resistant are needed to transfer heat from receiver to power block to achieve SETO's LCOE goals. The research project aims to develop ceramic material based HX technology for that purpose. Strengths: Ceramic matrix composites (CMC) such as Si-C has great potential for high temperature applications. The research project has identified the challenges appropriately and tasks and milestones have been defined to address the challenges. Weaknesses: Apart from the material properties such as fracture toughness etc, passage design and shaping are key challenges. Especially making intricate passages for molten-salt application means fouling and clogging can happen very easily. The inability to create smooth shapes and surfaces using Si-C and and challenges in machining CMC which is an inherently brittle material to the required shape are big challenges to overcome. How the ceramic material can withstand thermal gradients across the wall thickness need to be understood. So in summary this project has significant challenges as well as substantial benefits if the challenges are overcome.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** A journal paper is forthcoming. Preliminary techno-economic analysis is complete. Patent application filed.

Reviewer 2: The project has achieved important milestones during the BP1. A new binder-jetting printer has been installed and printing process for SiC powder has been optimized to attain high density parts. Conjugate simulations have been performed to calculate the appropriate channel geometry and size for the HX, as well as the strength requirement to withstand the target temperature and pressure. High temperature tests have been conducted to obtain the thermal conductivity of printed samples, however, the strength has only been measured at the room temperature. Overall, these results have been quantified, are relevant to the objectives, and form a good base for the next steps. A patent application has been filed for the proposed integrated HX-header module design, which depicts the innovativeness. Journal papers have been prepared, although not published yet.

**Reviewer 3:** From the summary report it appears the project is meeting the milestones clearly laid out. The reviewer believes right people are in the team working collaboratively. Based on the spending profile it looks like appropriate focus exists to execute the project.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the project tasks are unique and all appear to add important value to achieving the overall goals.

**Reviewer 2:** Score: 6. Comments: Each task is unique and essential for the subsequent goals. The execution order is systematic and the results for the milestones have been quantified.

**Reviewer 3:** Score: 5. Comments: The tasks have been defined after clearly outlining the objectives and challenges so as to address the challenges within the time frame of the project. And the tasks are defined in such a way they role up into the overall goals of the project.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** Not completely blind, but I think the project should have addressed ceramic to metal joints at some level in the first phase.

**Reviewer 2:** The investigators have not accounted for the effects of roughness in their heat transfer and pressure drop simulations. Hence, the channel sizing might change for a given heat transfer rate. The strength properties are based on room temperature measurements. However, high temperature strength estimation would be required to qualify the HX for real world application. The channel size is large compared to state-of-the-art printed circuit heat exchangers (PCHE) leading to large HX sizes. The stated 0.8 MW/m3 is lower than available high performance HX such as PCHE. The final HX size is to be achieved by aggregating 1m3 modules, however, the method of aggregation also needs to be developed. In addition, the effectiveness of the HX module was not clear from the report.

**Reviewer 3:** Much development has happened in developing ceramic HX using Si-C in aerospace industry. It will be wise to learn from Aerospace Industry on what worked and what did not. One note of caution is spending way too much time in modeling world as opposed to making prototypes and testing. In the reviewer's view, the project plan needs to put more emphasis on experimentation so the research can proceed faster. Though the modeling tools are very sophisticated they still do not bring out many real-world issues so a parallel experimentation is extremely necessary.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Perhaps a national lab partner to help validate the MOOSE FEA results in another commercial FEA package like LS-Dyna or Abaqus?

**Reviewer 2:** It is suggested to include a partner from CSP/sCO2 communities who can provide insight into final HX expectations and can accelerate the commercialization of the technology.

**Reviewer 3:** An industry partner would help in cross-checking some of the projects feasibilities and cost targets.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Need for additional corrosion data on SiC and other candidate working fluids / storage media. 2) Ceramic to metal joining might be tricky or problematic. 3) Better heat exchangers are a key need for sCO2 power cycles.

**Reviewer 2:** High temperature HX is a critical component for meeting SETO's mission for high cycle efficiency and low LCOE. The use of ceramic will provide an alternative to metal HX, thus, elevating the working temperature and mitigating issue of corrosion. The challenges encompass material processing to attain desired thermal and mechanical properties, achieve joining between ceramic and metals, optimum channel design for heat transfer, and cost. The proposed ceramic HX is to be made by the binder-jetting additive manufacturing which is highly susceptible to porosity and shrinkage of the built product. Due to the size limit of binder-jetting machine, the end product might need to stack up the additive-manufactured modules. These are critical to the success of the project. the current strength tests have been done at room temperatures, while the target working temperature is 750o C. As such, high temperature strength tests might be necessary. Also, the corrosion data is obtained from the literature. Some form of limited corrosion tests might provide further confidence in the capability of SiC, as well as, justify the funding.

**Reviewer 3:** 1) Bigger innovation/impact project with well defined tasks. Significant challenges as well as benefits 2) Tasks and milestones have been clearly defined and much quantification of targets have been given 3) With challenges surrounding fundamental material properties and passage design, there needs to be more experimentation along the modeling needs to happen instead of waiting at the end of modeling.

## 740H Diffusion Bonded Compact Heat Exchanger for High Temperature and Pressure Applications – $1,290,834

*Comprex | De Pere, WI | Principal Investigator: Zhijun Jia*

There is growing demand for high-temperature, high-pressure heat exchangers that can meet the stressful operating requirements of novel supercritical carbon dioxide Brayton cycles systems in a way that's cost-effective at commercial scale. CompRex has developed a heat exchanger design using 740H, a new alloy that can endure significantly higher stress at temperatures over 700 degrees Celsius, making it ideal for use with supercritical carbon dioxide cycles. In collaboration with Special Metals, the University of Wisconsin-Madison, and Advanced Vacuum Systems, CompRex seeks to develop a manufacturing process for producing 740H printed circuit heat exchangers using its proprietary ShimRex® flow path design. This design addresses the challenges that the material poses in etching and diffusion bonding that prevent the cost-effective manufacturing of 740H heat exchangers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths: 1) Very relevant to SETO's CSP goals as heat exchangers for sCO2 cycles remain underdeveloped. 2) Project takes applicable codes and standards into account. Project will produce a detailed quote for a prototype size heat exchanger. Project Weaknesses: Lack of an alternative bonding furnace plan/option.

**Reviewer 2**: Strengths: The objective of the proposed research, led by CompRex, is to apply IN740H to fabricate a compact PCHE compact heat exchanger using chemical etching followed by a diffusion bonding technique. IN740H is a new alloy that exhibits very high allowable stress and corrosion resistance, thus is suitable for high-temperature, high pressure applications. The project team intends to develop a 740H based primary heat exchanger for CSP sCO2 power block. The project overall consists of 6 tasks and these tasks are directed to the establishment of standards for 740H material properties and manufacturing processes to realize a PCHE prototype. This will lead to a TRL elevated from 2 to 6. Though this is a relatively high risk project, the impact on the advancement of CSP sCO2 technology can be significant, if successful.

Weakness: A notable weakness of the project is the schedule delay associated with the diffusion bonding furnace. The delay also pushes the Go/No-go decision further back, possibly to Q6; but the project has attained a 6-month no cost extension. It would be undesirable if such a check point is further delayed toward near the end of the project. Though the report submitted for review suggests that the project team has completed Task 1 and 2 and part of Task 3, the report offers no information concerning the results and findings of these tasks and associated milestones 1-5. The targeted product is a PCHE prototype where chemical etching is an important step of the fabrication process, preceding the diffusion bonding. Moreover, the microchannel patterns which dictate the heat transfer and pressure-loss characteristics in a PCHE are determined primarily by the etching process. The procedures of etching on a highly corrosion resistant 740H are expected to be significantly different from those of standard substrate material, such as SS316.

**Reviewer 3:** The proposed project attempts to utilize 740H material for making diffusion bonded Printed Circuit heat exchangers (PCHE) for use in high temperature (750 C) and high pressure sCO2 power block application. Though the material strength is superior whether a compact heat exchanger can be made of this material remains a challenge which is what the research project is tackling. The project is innovative in making use of high strength material for HX but whether the HX can be made in bigger scale (multi-mega watt) cost effectively has not been fully addressed. Diffusion bonding means special equipment (furnace) which may be a limiting factor when one tries to mass-produce heat exchangers at large scale.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 3 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** I lowered some scores due to the bonding furnace delays. Completion of pre-bonding manufacturing procedures is a notable and good achievement.

**Reviewer 2:** The project has a schedule delay caused by the establishment of a diffusion bonding furnace. The report offers little information concerning the completed tasks and milestones to date. Information pertaining to result dissemination and publication is also lacking. The PI at CompRex has a collaborative plan with Special Metal Corporation (SMC) for acquiring 740H material and University of Wisconsin –Madison for material and product characterization with sCO2 and molten salts. These are good teaming partners representing small business in power and manufacturing industry and academia.

**Reviewer 3:** The project has been ongoing for about a year and progress has been slower than expected. It was explained that the special bracing furnace took longer than anticipated. No details of the prototype HX module is given (dimensions & geometric features etc.). A discussion on HX performance metrics such as heat transfer effectiveness and pressure drop is also lacking. How will the the heat exchanger be tested? There was little information on the heat exchanger testing program. If a detailed testing program is in place that needs to be elaborated. Is diffusion bonding the only challenge for this project? A more detailed discussion on other challenges/risks for example, header designs, needs to be included. Some of the PROCEDURES or METHODS OF MAKING might be proprietary but design, performance still need to be discussed to provide the reviewer a sense of whether the project is headed in the right direction or not.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the project tasks are unique and all appear to add important value to achieving the overall goals.

**Reviewer 2:** Score: 4. Comments: The tasks and milestones have been defined and each appears to serve an important role in achieving the overall project goals. All tasks are directed to realizing two main project goals. First is to establish IN740H baseline material properties and relevant manufacturing steps for PCHE fabrication. The second goal is to attain ASME qualification for the manufacturing processes developed for meeting the first goal. However, in the report, the project team fails in providing a reasonable level of technical information for some of the tasks, such as etching and diffusion bonding for IN740H as a new high-temperature material.

**Reviewer 3:** Score: 5. Comments: If 740H material can be used to make heat exchangers for use in high temperature, high pressure cycles such as sCO2 that would mean a breakthrough in HX technology. So this project has a potential to significantly impact the technology development of a key component, heat exchangers.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Not sure if it's a true blind spot or not, but I found myself wondering if the project should evaluate additional candidate materials beyond 740H.

**Reviewer 2:** To this reviewer's knowledge, IN740H is expensive and has limited production and product forms. Besides technical challenges, cost concern would be an issue.

**Reviewer 3:** None at this point. Please see some of the review notes made in question 2.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** A national lab partner is missing and may have been able to help mitigate the bonding furnace delay.

**Reviewer 2:** For the current project needs, the teaming arrangement seems to be adequate which involves CompRex with heat exchanger expertise, Special Metal Corporation for material supply, and University of Wisconsin for material evaluation with sCO2 and molten salts. If the present project is successful and the IN740H based unit is available for testing in a realistic CSP setting, additional expertise might be included for better interface and dynamic match with the adjacent devices.

**Reviewer 3:** The project seems to have the right partners with another specialty metals organization and University partner for material testing.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** Project looks interesting and valuable since it addresses sCO2 cycle heat exchanger needs a back up plan for the original bonding furnace plan should be developed and pursued in parallel. Should alternate materials be considered?

**Reviewer 2:** 1) The motivation of the project on the technical aspect is good. IN740H could meet the operating requirements for the primary heat exchanger of CSP sCO2 cycle , if its material properties and anti-corrosion strengths under the realistic cycle conditions are systematically evaluated and confirmed. 2) IN740H built HEX can be expensive and cost would be a concern. 3) Optimal heat exchanger design and fabrication processes based on IN740H could be different from those of the state-of-the-art PCHEs. This could lead to further studies, if the present project shows promising results.

**Reviewer 3:** 1) High strength material 740H will be used to make diffusion bonded PCHX (Printed circuit HX) which can be a breakthrough in making HX that can withstand high temperatures/pressures encountered in sCO2 application. 2) The research team seems to have the right expertise to make HX modules and full scale HX (1 MW thermal scale) for testing. 3) Performance discussion (HX effectiveness, pressure drop), header design, cost, additional risks such as interaction of sCO2 working material interaction with 740H have not been adequately addressed.

## Additively Manufactured Supercritical Carbon Dioxide Power Cycle Heat Exchangers for Concentrating Solar-Thermal Power – $1,400,142

*GE Global Research | Niskayuna, NY | Principal Investigator: Bill Gerstler*

This project is developing additive manufacturing processes for the heat exchangers used in supercritical carbon dioxide power cycles in concentrating solar-thermal power plants. To overcome the expensive manufacturing process for heat exchangers, the team is using binder jet printing, a type of additive manufacturing, to significantly lower costs and enable new heat exchanger geometries, such as 3-D channels, and curved features not accessible using traditional fabrication processes. The team will then evaluate the new process and determine if it's capable of producing concentrating solar-thermal power compatible power cycles that cost $900 per kilowatt or less. The team will also perform mechanical tests to ensure that the resulting heat exchangers can withstand the high operating temperatures and pressures of the supercritical carbon dioxide power cycle. Finally, the team will create a risk reduction plan for scaling the heat exchanger design from lab-scale to a full-scale, including, a modular design.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths: 1) Modular heat exchanger concept is unique and interesting. 2) Better, cheaper heat exchangers are a key need for sCO2 power cycles and for achieving SETO's CSP goals. 3) Applicability beyond CSP/sCO2. Project Weaknesses:1) It is unclear to me how the project will ensure heat exchanger wall integrity and avoid flaws in thin channel walls. 2) Limited build envelope of the existing Binderjet machine.

**Reviewer 2:** Strengths: This project is to apply Binder Jetting AM technology, based on SS316L material, to develop a heat exchange device that are of potential applications for both high-temperature and low-temperature recuperators in sCO2 power cycle. The project has a cost target to reduce $175/KWe or 0.9 cents/KWh toward current SETO program goal. If successful, the project can render significant impacts on CSP technology as well as the general heat exchanger community, especially on cost reduction and manufacturing efficiency. (2) Teaming is strong within GE research. Project team is comprised of two interrelated groups of expertise, one focusing on heat exchanger design and the other on manufacturing. Weakness: Though additive manufacturing (AM) as a technology has been improving rapidly in recent years, binder jetting made products in general are of relatively lower mechanical strength, compared to other AM approaches involving direct melting and solidification. The shrinkage of built parts, i.e. dimension control, and surface roughness are critical and they need to be properly addressed. (2) The use of SS316 as the base-material for the proposed recuperator can meet the cost reduction goal. However, the corrosion resistance of SS316 in a sCO2 operating environment might be low, that could induce more costly operation and maintenance when the recuperator is operational. (3) Due partly to limited size of binder jetting machine, it is infeasible to build the entire recuperator core by a single AM process. Hence modular design and post-AM assembly procedures must be established. To a great extent, it makes the proposed project scalable in manufacturing. However, some of the physical phenomena and properties, such as surface roughness in small channels, are not scalable and could have adverse effects on the overall unit performance.

**Reviewer 3:** The research team aims to optimize the design of heat exchangers used for application at moderate range of temperatures (< 540 C) for use as recuperators in sCO2 applications using binderjet additive manufacturing technology using 316L material. The project was awarded in Oct 2019 and counting project delays is still in its initial phases. The phase I Go/No-Go decision is coming up on Sept 30, 2020. The weakness/challenge of the project was described well in the "challenges" section. Success in this project requires overcoming these challenges. Durability of the HX built will be an additional risk. Ultimately the surface area, compactness, pressure drop and costs are inter-related and governed by basic physics of heat transfer and fluid flow and surface area & material costs. Also it is not entirely clear why binderjet based additive manufacturing was chosen over other competing methods. But since the project was awarded in Oct 2019 the reviewer believes these questions have been asked by the selection team and were satisfactorily answered by the project team.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Project team has accomplished a lot so far but no publication of results yet?

**Reviewer 2:** If successful, the project could provide a low-cost manufacturing approach to fabricate recuperators in the sCO2 power cycle for CSP applications. The technology developed might render broader impacts on the general heat exchanger industry. As the project is relatively new, it has laid out a reasonable work plan and milestones for deliverables. It is also reasonable that no dissemination result is recorded to date. The project will be primarily pursued within GE Research, involving a heat exchanger design team and an additive manufacturing team. It might be useful to include collaborative activities with heat exchanger manufacturers, especially for product commercialization.

**Reviewer 3:** It is of some concern that the project spend rate is only 5% of the target spending. This pace needs to be picked up.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the project tasks are unique and all appear to add important value to achieving the overall goals.

**Reviewer 2:** Score: 5. Comments: The project focuses mainly on manufacturing for cost reduction. The project consists of two phases. The first phase is to characterize the viability of the binder-jetting process based on SS316L, which includes tasks concerning depowdering and control of shrinkage, dimension and surface roughness. This will be followed by a second phase focusing on heat exchanger performance, which includes tasks for heat transfer and pressure loss, as well as mechanical testing. A significant level of effort will be directed to assembly of modular components as typical binder-jetting produced parts are limited to a cubic-meter size. All tasks are designed to realize the final overall goal for a cost reduction of 90% from the current recuperator cost standard.

**Reviewer 3:** Score: 5. Comments: Tasks, milestones have been well defined to align with the overall goal of the project.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** PI may be underestimating the difficulty of joining the heat exchanger to process piping.

**Reviewer 2:** The scope of the project is primarily for cost reduction, by way of using inexpensive material and process. The report offers little information concerning the post-printing assembly/bonding process. A bonded system might exhibit compromised mechanical strength and performance compared to the original, pre-assembled parts. Overall, the project seems to place less emphasis on the performance aspect of the product. In addition, issues relevant to operation and maintenance, such as the effects of corrosion on binder-jetting made microchannels that could render downtime and costs over time.

**Reviewer 3**: None at this point.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** A national lab partner with additive manufacturing know-how would be a good addition to the team.

**Reviewer 2:** The project is being pursued within GE Research which is of abundant technical resources and expertise on many fronts. Establishing collaboration with sCO2 community and general heat exchanger community could strengthen the project.

**Reviewer 3:** It seems the team has the right people with right expertise. An industrial partner interested in commercializing the HX design/technology could be a good addition.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Low-cost, high-performance sCO2 power cycle recuperators are required help meet 2030 SETO CPS plant cost goals. 2) Binderjet is a new manufacturing technique that appears to enable economical sCO2 recuperators. 3) Blinder jet build size limitations - could these be addressed as part of the project or a follow-up project.

**Reviewer 2:** 1) The main scope of the project is to develop an additive manufacturing based process to produce recuperators for sCO2 power block that will lead to a 90% cost reduction from the current standard. While cost reduction is important, the project team should also direct a sufficient level of effort to optimize the performance and to address the issues pertaining to operation and maintenance. 2) Binder jetting is a relatively inexpensive and fast additive-manufacturing process. However, it has many known limits and technical challenges relating to depowdering, shrinkage, surface roughness, and mechanical strength. The modular assembly seems to benefit scalability; but it could be challenging to realize as well. 3. Though SS316L is inexpensive and widely used for additive-manufactured parts, it has significantly lower allowable stress and anti-corrosion properties compared to several AM compatible superalloys, such as IN718, IN617 and IN625. The cost of these Inconel alloys could be double the cost of SS316L or 316; but they could be potential alternatives to achieve better device performance.

**Reviewer 3:** 1) The work promises to increase the heat transfer effectiveness and at the same time reduce the size and cost of HX (recuperators) for sCO2 cycle. 2) Technical specifications in terms of passage size, tolerance, roughness values, powder use efficiency in the additive manufacturing process have been well defined as well as the objectives for phase 1 and phase 2. These well-quantified targets are a big plus for this research project. 3) The modules and concept geometries shows that the project team is making good progress.

## Gas Lubricated Bearings for Drivetrain in Supercritical Carbon Dioxide Cycle – $2,373,442

*GE Global Research | Niskayuna, NY | Principal Investigator: Jason Mortzheim*

This project is working to de-risk a novel bearing design for the turbines used in concentrating solar-thermal power plants with supercritical carbon dioxide power cycles. The bearing is a critical component that ensures the turbine, which converts heat into mechanical energy, performs reliably and at a high efficiency level. The turbine is the greatest single contributor to the supercritical carbon dioxide cycle's efficiency. These bearings must be durable and able to withstand the high temperatures and pressures associated with next generation supercritical carbon dioxide power cycles. The team will then perform mechanical tests and simulate rotor tests in order to optimize the design for concentrating solar-thermal power plants that provide consistent baseload power or operate as a rapidly-responding peaker plant. The team will perform technoeconomic analysis to determine if the design can achieve a 50 percent efficient power cycle in order to lower costs to $0.05 per kilowatt-hour.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths: 1) Broadly applicable for sCO2 cycles for CSP and other thermal energy sources. 2) Leverages existing GE gas bearing technology. 3) Project is timely with respect to sCO2 machinery development cycle. Project Weaknesses: Lack of a national lab additive manufacturing team member.

**Reviewer 2:** This GE-Research led, 3-year new project is aimed to elevate the GE's advanced gas bearing component technology from TRL 3 to TRL5. PI had previous DOE funding support to reach the current TRL, hence the team is experienced and well equipped for pursuing the current project. The project consists of two major tasks and they will be initiated soon and almost simultaneously. One is to perform a component test of thrust bearings in a sCO2 environment and the other is to test radial bearings using a GE in-house rotor rig and simulating the sCO2 turbine conditions. Data obtained from the first task will be used to validate a bearing design tool that will benefit the future research. Research results obtained from this research can render broad impacts on the general turbomachinery community. Weakness: As the project is new, no weakness is identified at this point.

**Reviewer 3:** This project aims to advance gas lubricated bearing technology which will enable oil-free drivetrains so hermetically sealed turbomachinery can be designed for sCO2 application to minimize losses and improve power block efficiency. More specifically the project's objective is to advance oil-free gas bearing technology to be used in high pressure, high temperature rotating machinery. If successful this technology has beneficial effects on turbomachinery beyond CSP application. Project summary has a minor mistake under "Project Schedule". It states the "Project initiation" date as 9/1/2020, the reviewer believes it is 9/1/2019. Spelling mistake in section 9 "Federal funds re required to OFFSET the commercial risk.." Weaknesses: A key risk has been identified by the author (ability to measure gas-bearing design validation data). Reliable gas bearing performance measurements could not be obtained as capability of the measuring instrument is not adequate. Bearing design and performance evaluation is a key component of the research project and the team is trying to come up with a measurable metric so different candidate solutions can be measured and evaluated.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Inclusion of a national lab with additive manufacturing acumen or SWRI in the project would be beneficial. The project has just recently started so spending is low and few milestones have been met, as expected at this point. Simulated rotor design is ahead of schedule.

**Reviewer 2:** The project is new and there is no data concerning task performance and milestone. GE Research is the project lead and will be conducting all the design and testing. Only collaborator is GE Additive who will provide additively manufactured gas bearings for testing.

**Reviewer 3:** The milestones have been clearly laid out to aid Go/No-Go decisions. The research funding was awarded in Oct 2019 and the work seems to have started only recently presumably due to contract delays. The reviewer believes there are no issues in communication within the team as well as with stakeholders. Considering all factors adequate progress is being made towards the project goals.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the project tasks are unique and all appear to add important value to achieving the overall goals.

**Reviewer 2:** Score: 6. Comments: All the tasks planned seem to be directed to two primary goals: (1) component test for the thrust bearing in sCO2 environment, and (2) development of an air-supported rotor capable of simulating the CSP sCO2 turbine loading dynamics to test radial gas bearings in the GE Research spin test facilities.

**Reviewer 3:** Score: 5. Comments: The project is unique in the sense it is trying to replace the oil-based bearing technology with gas bearings (oil-free) so hermetically sealed turbomachinery concepts can be developed to reduce windage and other losses.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Radial bearings exceeded the GE Research additive capacity - will they also exceed the capacity of GE Additive? Perhaps the national labs could assist? Is the 27 rpm / 85 bar proposed test rig targeting high enough test parameters? Is 27 rpm listed on the poster a typo?

**Reviewer 2:** First, assuming sCO2 will be the working fluid for the gas bearing, the tribological behaviors of sCO2 under relevant operating conditions will need be systematically investigated. Second, scalability of the additive manufacturing process for the intended testing and the level of dynamic loading under the realistic turbine conditions should be addressed.

**Reviewer 3:** The tasks are appropriately defined to align with milestones and overall project goals. So at this point, the reviewer does not find any "blind spots" according to the reviewer.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** National lab(s) with additive manufacturing acumen

**Reviewer 2:** Potential stakeholders might include the potential end users of gas bearings. For the present project, GE's own power generation and/or aviation divisions would be good candidates for collaboration.

**Reviewer 3:** The current project team seems to be have right expertise. At this point the reviewer does not find and shortcomings in collaborations.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** Possibility to include national lab(s) with additive manufacturing know-how. Is the proposed test rig flexible enough to be used for future work?

**Reviewer 2:** 1) Though the idea of using gas (air) bearing for turbine power train is not new, technical barriers remain significant before practical applications can come to fruition. The impact would be huge and broad, if the technology can be realized. 2) If the application is directed to CSP power block, tribological database for the working fluid, assuming it is sCO2, needs to be established. 3) Possibly to support a rotor dynamic or rotating research facilities with sCO2 as working fluid.

**Reviewer 3:** 1) Advancing oil-free gas bearing technology from TRL3 to TRL5 is an enabling technology to design hermetically sealed turbomachinery for sCO2 application with its high pressure and temperature application. 2) Complexity introduced at the system level to provide process gas to the bearing need to be addressed. The process gas system will replace the oil system but oil is used for other purposes also, so the researchers need to address how the overall system will change from oil-based to oil-free system and what are the merits and demerits. 3) Recently identified risk to validate gas bearing design tool needs to be addressed and a viable solution needs to be identified. 4). The research team is bringing GE Additive as a partner to make gas bearings. But for production cost needs to be addressed as one of the main objectives is to reduce costs and additive manufacturing may not be cost-competitive for production parts. 5) The spending is well below the budgeted amount from the time project started in Sept 2019. But there could be contract related delays but the progress needs to be tracked closely to make sure adequate resources are applied to complete the tasks per project plan.

## Vertically-Aligned Carbon Nanotube Arrays as Novel Self-Lubricating High-Efficiency Brush Seal for Concentrating Solar-Thermal Power Turbomachinery – $1,400,000

*Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Jun Qu*

In advanced turbines for concentrating solar-thermal power plants that use supercritical carbon dioxide as a working fluid, metal brush seals prevent internal energy leakage. This project is developing a new scalable seal brush on a flexible base that will improve the seal's efficiency and durability. The seal will be made of a vertically aligned carbon nanotube array and use a chemical vapor deposition process without a catalyst. The project aims to improve turbine efficiency and reduce the manufacturing cost by at least half.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 5 |
| Advance the U.S. solar industry substantially | 3 | 4 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths: Unique and potentially cheaper and better brush seal design with wide applicability beyond CSP. Modest cost. Solid Project team. Project Weaknesses: The overall impact on LCOE is small since leakage flows are only a 1-3% energy loss in most power cycles.

**Reviewer 2:** This ORNL-led, 3-year new project is to develop a new seal brush technology based on carbon nanotube (CNT). ORNL will employ its patented, catalyst-free chemical vapor deposition (CVD) process to grow arrays of vertically-aligned, multi-wall CNTs on a metal substrate (start with SS316). The project team has sufficient expertise and support to manage the project. As an actively researched topic in the tribology community, CNT based seal or brush is self-lubricating and capable of preventing leakage flow with reduced friction and better service life, compared to the commercial metal-based bristle brushes. The proposed CVD process for fabricating CNT brush has little geometric restrictions and is scalable. As reducing leakage flow has always been a universal engineering challenge, this project, if successful, can have a broad impact on the general sealing technology beyond CSP applications. The project targets to render a 1-3% energy saving and >60% manufacturing cost reduction in benefitting the SETO program. Weakness: Study of tribological behaviors of CNT-metal composites has been active for nearly two decades. However, the realistic application is still lacking. The project could be strengthened by including emphases on practical aspects relevant to this shortcoming.

**Reviewer 3:** Strengths: The research project aims to utilize carbon nano tube (CNT) based seals for better sealing of the turbomachinery used in CSP applications and at the same time reduce costs. This is a novel approach and could offer a breakthrough in sealing technology. Weaknesses: In reviewer's view CNTs do not seem to have been used in large scale in turbo machinery sealing. Durability, costs, ability to grow carbon nano tubes on different types of metallic surfaces would be some of the risks. Summary: The research project has been funded recently (3rd quarter of last year) and work is just starting. It meets all requirements, such as innovation and impact, quality of the research team and likelihood of success. The tasks, milestones and project plan are well-laid out. the interest from a turbomachinery sealing company is an additional plus.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 4 |
| Collaborates with sufficient stakeholders | 4 | 5 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Would be good to have other power equipment (e.g. steam turbine OEM) industrial partner(s) involved in addition to Danfoss who I see mainly as a compressor manufacturer.

**Reviewer 2:** The project is new and no data concerning task performance and milestone are available. The collaboration plan between ORNL and Danfoss seems to be adequate and complementary. ORNL will focus on the development of CNT seal brushes and material characterization, and Danfoss will utilize its in-house capabilities to perform seal modeling, design and fabrication of base structures, and prototype validation.

**Reviewer 3:** Appropriate tasks and milestones have been set to match the project deliverables. Since the project is just starting it is not possible to ascertain how things are going. Initial project delays due to contract negotiations have possibly contributed to the delay.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Project tasks listed are logical and executed in a reasonable order. Each step adds unique and important value towards achieving the overall project goals.

**Reviewer 2:** Score: 5. Comments: All the tasks planned are directed to resolving three technical challenges so that the overall project goals can be achieved. The three challenges are: (1) growing CNTs on different seal base materials, (2) growing longer (30mm baseline, up to 100mm) CNTs suitable for seal applications, and (3) improving bonding strength onto the seal base. A techno-econo analysis will be performed near the conclusion of the project. First Go-No-go check point exists as the 4th milestone about a year into the project.

**Reviewer 3:** Score: 4. Comments: Carbon Nano Tube (CNT) based seals are unique. If successfully implemented it can be a breakthrough in sealing of turbomachinery applications.

#### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** It's not clear to me which specific working fluids the PI plans to test for compatibility with the proposed CNT seals. Some additional tasks to study the seal interaction with common working fluids like sCO2, steam, air, Nitrogen, He, or various ORC working fluids would be of interest.

**Reviewer 2:** When CNT reaches 100mm long as the project intends to accomplish for brush seal application, it, in essence, becomes a carbon fiber. The growth density over the substrate as well as the tribological properties and durability could be substantially different from the CNT properties generally perceived with shorter growth lengths.

**Reviewer 3:** None at this point.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** A steam turbine or expander/gas turbine OEM partner would improve the quality of the project team. Perhaps SWRI too?

**Reviewer 2:** If the proposed study is proven to be feasible, the stakeholders and collaborators should include the end users or turbomachinery manufacturers on both component and system levels. This would be useful for product development toward commercialization.

**Reviewer 3:** It appears everything is in place. Considering this is a new project it is too early to say whether this will be a problem or not.

#### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Overall impact on SETO goals is probably too small given the impact of sealing losses on power cycle efficiency. 2) The working fluids that will be tested should be called out explicitly and include more than just one working fluid. 3) Good project team.

**Reviewer 2:** 1) CNT has low coefficient of friction. However, as a seal brush, its mechanical strength needs to be qualified. Also, its service life or durability needs to be examined. 2) Assuming the project is successful, how does the CNT-based seal brush compared to the state-of-the-art metal brush in performance and cost? 3) Brush loading comes with several different forms, e.g. shear, compression and torsion, how does the bonding strength between CNTs and the substrate correlate with different types of loading?

**Reviewer 3:** 1) Unique CNT based seals and could become a breakthrough technology. Carbon nanotubes have to be "grown" on substrates. It is not clear how to mass-manufacture such sealing for production. 2) The project has many challenges to overcome such as producing enough seals of consistent quality for testing, scaling up to production, cost of seals etc. 3) This project represents high risk/high reward proposal and has applicability far beyond the sCO2 turbo machinery.

## Development of a High-Efficiency Hybrid Dry Cooler System for Supercritical Carbon Dioxide Power Cycles in Concentrating Solar-Thermal Power Applications – $1,790,000

*Southwest Research Institute | San Antonio, TX | Principal Investigator: Kelsi Katcher*

This project aims to develop a compact dry cooling heat exchanger for supercritical carbon dioxide power cycles in concentrating solar-thermal power plants. Dry cooling drastically reduces the water used by power plants. However, it can reduce the thermal-to-electric conversion efficiency of the power cycle. An efficient heat exchange between supercritical carbon dioxide and ambient air can both conserve water while maintaining peak power cycle performance. The team is working to create and optimize a dry cooling heat exchanger with microchannels on the supercritical carbon dioxide side and a geometry that uses plates and finned chambers on the air side. The team will test the dry cooling system at the megawatt-scale with a supercritical carbon dioxide test loop, in order to determine the reliability of the fabrication method, validate the performance of the heat exchanger geometry, and show that the new dry cooling concept is compatible with an efficient concentrating solar-thermal power plant. These improvements could reduce the cooler cost from $168 per kilowatt to $95 per kilowatt and reduce cooling power consumption in concentrating solar-thermal power plants by 14 percent.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 3 |
| Advance the U.S. solar industry substantially | 5 | 5 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths:Very applicable to SETO CSP goals, relevant beyond CSP. Project Weaknesses: Project may not fully explore important off-design performance impacts on the design of such heat exchangers. This oversight has been a problem for other sCO2 cycle studies in the past.

**Reviewer 2:** The project brings a new approach to design of HX by marrying microchannel cooling with finned channels. At the same time, different material is used for each type and joining process for dissimilar metals is being developed. This approach aims at 50% reduction in capital cost, which is a significant saving. The research has a systematic approach to bring the technology from TRL2 to TRL7 which will speed up commercialization. Off-design performance for different dry-cooler configuration and operating conditions is also being considered based on turbomachinery maps from published data. A MW scalable prototype will be developed and tested with the existing sCO2 loop, thus, accurate cost prediction for utility-scale system could be done. In addition, the team has partnered with well-known HX manufacturer, making it possible to commercialize the developed technology. Weakness: As stated in the report, the project is running slightly behind on budget and schedule at current stage but is expected to meet the milestones and planned completion dates. The effect of corrosion on the microchannels and associated maintenance downtime and costs will be important for a realistic estimate in performance over time, and some corresponding task should be defined.

**Reviewer 3:** Strength: Compact dry coolers for the CSP sCO2 power cycle are key components. A significant effectiveness improvement and cost reduction will help achieve LCOE cost targets. Weakness: The proposal aims to using chemically-etched micro-channels for sCO2 and formed fins for the air-side to achieve 90% effectiveness (from the present 80 to 82%) for the pre-cooler & 50% capital cost reduction from present while maintaining key parameters such as pressure drop. Is this supported by heat transfer modeling? The limiting heat transfer is on the air side which is still using the bonded plate-fin channels (same as the state of the art) so how can the effectiveness be dramatically improved? Usually both sides of the fins are used for two fluids, with the thin walls separating the two fluids. With heat transfer through thin walls and large contact area between the two fluids are used to achieve high heat transfer. It is unclear how the micro-channels and finned surfaces with a parting sheet in between can achieve a better heat transfer. The reviewer is also skeptical whether a 50% cost reduction can be achieved.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 3 |
| Disseminates results frequently and actively engage partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 4 | 6 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Unclear if the project will adequately evaluate off-design performance. More collaboration with existing dry cooling equipment suppliers is recommended.

**Reviewer 2:** Currently, the project is in its early phase. As such, only preliminary results are available. The team has clearly laid out the benchmark performance to beat, using standard simulation tools, published data, and commercial quotes.

**Reviewer 3:** The end of budget period 1 is only about 6 months away (Aug 31, 2020) and only 2% budget has been spent with less than 7% of personnel time allocated. Even adjusting for contract negotiation delays, it seems adequate resources have not been applied to progress the project at the right level. It is difficult for the reviewer how key milestones can be achieved especially in budget period 1. The project team needs to address the execution gap fully.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the project tasks are unique and all appear to add important value to achieving the overall goals.

**Reviewer 2:** Score: 5. Comments: The project is divided in two phases. The first phase evaluates the concepts and performs reduced scale tests. A benchmark power block contribution to LCOE is stablished using data from commercial systems and SAM analysis. This will be followed by cycle performance studies (using NPSS and SAM) to analyze sensitivity of LCOE with respect to various system parameters. In this regard, several systematic sub-tasks have been defined pertaining to establishing the benchmark, selection of HX geometries, optimization of the fabrication processes, and validation through prototype trials and testing in an existing sCO2 loop. The second phase fabricates a MW scale HX and tests in the sOC2 loop. Thus, the tasks lead to the final overall goals of the project.

**Reviewer 3:** Score: 4. Comments: Judging from the summary of the project the reviewer has to assume appropriate tasks have been defined leading to milestones which are aligned with the overall project goals.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** It's not clear to me that the PI plans to take a detailed look at off-design performance of the proposed hybrid cooler using typical meteorological data for a representative CSP plant site. The project might also benefit from modeling in a commercial heat balance modeling package like EBSILON professional to address this.

**Reviewer 2:** The effects of corrosion on the microchannels and associated maintenance downtime and costs will be important for a realistic estimate in performance over time.

**Reviewer 3:** Fundamental heat transfer analysis need to support the significant increase in heat transfer effectiveness.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Inclusion of a dry cooling equipment supplier like SPX Dry Cooling would increase the likelihood of this project's success.

**Reviewer 2:** The project, though focusing primarily on product performance and manufacturing costs, doesn't seem to address the potential operation and maintenance issues of heat exchanger, such as corrosion and fouling. Data as such relevant to SCO2 as working fluid are limited. Establishing collaboration in these areas would strengthen the technical aspects of the project.

**Reviewer 3:** Judging from the summary the reviewer believes appropriate stakeholders have been included in the project.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) Off design performance across and entire year's (8760 hours) worth of typical meteorological conditions should be a part of this project. 2) Additional input from dry cooling equipment suppliers (beyond the equipment quotations mentioned) should be sought. 3) Good overall project topic that aligns well with SETO's CSP goals for lower cost and lower environmental impact CSP plants.

**Reviewer 2:** 1) The main goal of this project is to design and demonstrate a MW-scalable dry cooler with 50% reduction in capital costs compared to the current state-of-the-art finned-tubes crossflow cooler. This is to be achieved by combining enhanced heat transfer, compact size, dissimilar materials in the HX, and both reduced and full-scale prototype testing. The project aims at improving the proposed hybrid HX and high-efficiency blower system from TRL-2 (i.e., technology concept and/or application formulated) to TRL-7 (i.e., system prototype demonstration) within 2 years. Overall, it matches well with the level of DOE funding and planned project duration. 2) The project has several technical challenges. First challenge is to realize an effective design of heat exchanger core with microchannels on the hot (sCO2) side and formed fins on the cold (air) side. Down selection of optimal heat transfer enhancement features with affordable pressure loss is important to the success of the project. The second challenge is related to the joining processes for the proposed dissimilar material on the two streams. If these challenges work out, the gains will be significant due to reduction in HX capital costs and increased performance. 3) Compared to the current state-of-the-art dry cooler, the proposed hybrid dry cooler will likely induce much higher pressure penalty and require more pumping power to drive the flows. The operation and maintenance cost associated with corrosion and fouling could be more expensive as well. These are important issues that need to be addressed in the design and product development stage.

**Reviewer 3:** 1) This project aims to address key technical and cost challenges of hybrid dry cooler which is an important component for sCO2 power cycle to achieve SETO goals. Many challenged need to be resolved to achieve the project goals. 2) It is not clear whether limiting side heat transfer (air side) can be improved dramatically using the heat transfer design proposed. Though SAM (system advisor model) is used to predict LCOE, it is not clear what assumptions were used. 3) Project plan seems to be reasonable with appropriate tasks and goals but the project is progressing slower than expected which is a cause of concern. There is only approximately 18 months to complete the entire project (phase 1 and phase 2).

## Development of an Integrally Geared Compressor-Expander for Supercritical Carbon Dioxide Brayton Cycle Power Generation Applications – $5,350,000

*Southwest Research Institute | San Antonio, TX | Principal Investigator: Jason Wilkes*

The team of Southwest Research Institute and Samsung Techwin is developing an integrally-geared compressor-expander (compander) and a novel centrifugal compressor impeller design for use in 10 megawatt scale concentrating solar-thermal power applications utilizing a supercritical carbon dioxide cycle. This integrally-geared compander has the potential to improve efficiency, modularity, and process control over other proposed concentrating solar-thermal power turbomachinery configurations utilizing a supercritical carbon dioxide cycle power cycle.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths: Project's aim for a 50% cycle efficiency at $670/kW is impressive; Good team; Applicability beyond CSP if successful. Project Weaknesses: Lacking a larger turbomachinery partner like GE or Tosihiba.

**Reviewer 2:** Strengths: The project proposes a new IGC type compander design to be used for CSP applications, which aims at reducing the associated costs by 2.5 times. Performance targets and challenges are well defined at the component levels, such as the isentropic efficiency and aerodynamic losses for the impeller, mechanical integrity of components, hydrostatic testing of casings, validation of instrumentation, etc. The team has access to in-house sCO2 loop with a 2.5 MWth heater capacity, which is advantageous for the proposed tests. The fabricated compander can directly be scaled to 10MW capacity, providing a more realistic estimate of the performance and also shortening the path to commercialization. The project has already passed the Go/No Go for the first two budget periods. FMEA at operational and procurement level has been implemented. The partner, Hanwha Power Systems Americas, is a manufacturer of compressors for sCO2 cycle plants. Weakness: The project has some minor weaknesses. It seems that it is running slightly behind schedule. In addition, the current LCOE target for SETO is 5¢/kWh while the project proposes a LCOE of 6¢/kWh. Some tests for high temperature corrosion on the fabricated components exposed to sCO2 might be helpful.

**Reviewer 3:** The project is to develop integrally geared compander (compressor-expander) for use in 10 MW scale CSP sCO2 plant application with a demonstrator at the scale of 2.6MW thermal input at SwRI's facilities. Strengths: Ability to integrate multiple turbomachinery components (compressors and expanders) into a multi-shaft unique architecture to optimize the different components for cost and efficiency improvements. MW scale test rig was built to test out component and system efficiencies. The competencies of SWRI (PI) and Kanhwa Power systems have been complementary. Weakness: Complexity of the system increases using the multi-shaft system as also is the difficulty in maintaining reliability of such a system. Much remains to be seen as the test facility becomes operational at design and off-design conditions. Were degradation characteristics of the components (compressors, turbines) taken into account in estimating LCOE costs over the lifetime of the plant?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 6 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Project lacks a larger turbomachinery partner like GE or Tosihiba.

**Reviewer 2:** The project has completed the stated milestones for the BP 1 and 2, and has passed the corresponding Go/No Go check points. The duration for BP2 is twice as much as BP1, indicating some delay. The design of the compander with required performance criteria in terms of turbine efficiency, compressor range, mechanical integrity, and overall LCOE of 6¢/kWh has been achieved. In summary, the team has already designed a scalable compander with 50% thermal-to-electric efficiency, 6 ¢/kWh LCOE, 86% compressor efficiency, and 50,000-hour turbine life with 92% efficiency. The results have been distributed with conference papers, and a patent has been filed.

**Reviewer 3:** The project started in Oct 2015 and passed budget periods 1, 2 and 3 while passing the Go/No-Go criteria for each one of the budget periods. This is definitely a great accomplishment. Though it is not available in the summary document, the reviewer assumes scalability to full scale operation and LCOE estimates have been addressed thoroughly.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the project tasks are unique and all appear to add important value to achieving the overall goals.

**Reviewer 2:** Score: 6. Comments: The tasks and milestones have been systematically defined and each serves an important role in achieving the overall project goals. In summary, the work starts with selection of appropriate cycle which is suitable for IGC. During the BP1, design of the IGC is first conceptually analyzed and then experimentally validated to establish that the isentropic and aerodynamic efficiencies are above the desired values. In addition, mechanical integrity tests are conducted on the prototype to check for cracks, fractures, and plastic deformation. BP2 consists of tasks related to FMEA from operational and procurement points of view. In addition, tests are conducted to validate pressure ratings, instrumentation, and that the equipment passes vibrational and tear-down inspections. The final BP3 consists of aero-mechanical tests for individual components at warm and hot conditions.

**Reviewer 3:** Score: 5. Comments: The multi-shaft internally geared compander is a unique architecture that aims to optimize individual component efficiencies at the same time well integrated to drive down the costs. However, the seemingly overly complex design might make the manufacturing, operation and servicing of this unique turbo machinery complicated and hence drive up the life-time operating costs which in turn may potentially affect the life cycle LCOE.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** None that I see or can think of at this time.

**Reviewer 2:** The project has well covered the uncertainties through FMEA analysis and seem to have covered the possible blind spots. Although, some study on the corrosion due to sCO2 might be included.

**Reviewer 3**: None from a reviewer's point of view.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project lacks a larger turbomachinery partner like GE or Tosihiba.

**Reviewer 2:** The inclusion of an industry partner from advanced manufacturing community might further accelerate the product development.

**Reviewer 3:** It seems the right stakeholders and collaborations have been in place.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Project goals are ambitious with high impact on CSP if attained. 2) Integrally geared approach offers promise and potential optimizations over other approaches. 3) The project lacks a larger turbomachinery partner like GE or Tosihiba.

**Reviewer 2:** The application of the proposed IGC compander aims at reducing the current costs associated with the sCO2 turbomachinery by 2.5 times. In addition, the ability to increase the range of the compressor while maintaining the peak isentropic efficiencies, and modularity in the power block will lead to savings and fast-track to achieve the LOCE goals. This can significantly advance the US solar sustainability. The project has identified the critical challenges necessary to achieve the stated goals. The challenges identified include thermal management of the components to keep them within their working envelope, shaft rotor dynamics considerations, and prevention of thermal losses to the ambient. The project also incorporates FMEA from technology as well as procurement point of view. The project will develop an IGC for a reduced flow model but using a full frame, so that, it can easily be scaled up to 10 MW power cycle. This approach reduces the path to reach commercialization. In addition, various numerical and experimental tests is conducted at each phase for validating the mechanical integrity, aerodynamic losses and efficiency, and targeted wide impeller range while maintain peak isentropic efficiencies. In the final stages, the project will validate the performance of each component (within compressor and expander) under warm and hot conditions. This approach justifies the DOE funding for the given budget period.

**Reviewer 3:** 1) The project is big in scope and in impact. It started in 2015 and scheduled to end in Oct 2020. The project seemed to have a comprehensive project plan with tasks and milestones well defined. 2) The strength of this project is definitely system level prototype/hardware validation. 3) The project is enhanced by collaboration with a motivated partner (Hanhwa Power systems) with substantial cost share (nearly 40%) which affirmed the partner is serious about the technology development and commercialization. Are concrete plans available for full commercialization? What is the TRL this is in and what is the plan to make this a commercially viable product.

## High-Temperature Dry-Gas Seal Development and Testing for Supercritical Carbon Dioxide Power Cycle Turbomachinery – $1,999,985

*Southwest Research Institute | San Antonio, TX | Principal Investigator: Jason Wilkes*

Concentrating solar-thermal power plants with supercritical carbon dioxide power cycles require a mechanical seal to prevent working fluid leaks and support efficient operations. The increased temperatures and pressures of the supercritical carbon dioxide power cycle requires a novel seal design to support a target thermal-to-electric power conversion efficiency of 50 percent. This project is developing a high-temperature dry gas seal by replacing the temperature sensitive elements with more durable components, enabling the dry gas seal to reach operating temperatures over 500 degrees Celsius and enable the higher efficiency levels. Because the dry gas seal design would also be significantly smaller in size, it would reduce the complexity of the supercritical carbon dioxide turbine design, helping to increase operation reliability and improve turbine efficiency.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 4 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 4 |
| Advance the U.S. solar industry substantially | 4 | 6 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Project Strengths: Good evaluation criteria has already eliminated a number of candidate designs; Project seeks to build full scale seals and a full-scale test rig. Project Weaknesses: Only a 1 - 2 % Cycle Efficiency improvement potential.

**Reviewer 2:** Strengths: This SWRI-led, 3-year new project is to develop a high-temperature dry-gas seal (DGS) for sCO2 power turbine applications. Collaborating with other two project partners, i.e. EagleBurgmann and Virginia Tech, the proposed work will involve strong interaction between modeling and experimental efforts. One unique strength of this project is the capabilities of performing full scale tests under the realistic sCO2 turbine operating condition, which is targeted at 500C, 7.4 MPa and 18000 rpm. Realization of such DGS product would minimize the seal needed axial length and allow possible implementation of additional turbine stages, resulting in a potential increase in turbine efficiency up to 2%. The success in developing a high-temperature DGS would render a positive impact on commercialization of sCO2 power systems. Weakness: As the project is new, no weakness is identified at this point.

**Reviewer 3:** The project aims to improve the design and capability of dry gas seals (DGS) used in sCO2 turbines which will reduce the complexity of seal design which in turn would improve the overall turbine system design. The approach will be in two steps, first development of the temperature limited balance sealing element, and second, the full-scale DGS. The overall objective of the project will be to test a full-scale DGS in sCO2 at the design temperature, pressure, and shaft speed with the nominal parameters selected as 500 °C metal temperature, 7.4 MPa pressure, and 18000 rpm. Strengths: The effort is to reduce the complexity of turbine design dictated by the low temperature capability of balance sealing element/ DGS by developing high temperature capability DGS. The project aims to improve the turbine isentropic efficiency by 2-4% which will traslate to 1-2% of cycle efficiency. The projects is still early stages as it has been awarded only in Oct 2019. Weakness: With the design of high temperature capable DGS the project claims additional shaft lengths may be available to enable adding more turbine stages leading to turbine isentropic efficiency improvement of 2-4% but adding turbine stages also increases the cost and complexity of the design. It is also not clear whether the improvement of the cycle efficiency is substantial. Any improvement in cycle efficiency will definitely help but the benefits need to be quantified in a way to show that it is the most cost-effective way to achieve the SETO goals. It is unclear whether such a case can be discerned from the summary.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engage partners | 4 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1**: No publications to date lowered my score for "Disseminates results frequently and actively engage partners."

Reviewer 2: The project is new and no data concerning task performance and milestone are available for review. The collaboration plan between SWRI, EagleBurgmann and Virginia Tech seems to be adequate and complementary. EagleBurgmann will focus primarily on facilitating and conducting stationary DGS testing while SWRI will pursue the dynamic and full-scale testing. Virginia Tech will provide CFD simulation and modeling support for full scale DGS.

**Reviewer 3:** The project has been awarded in Oct 2019 but judging by the balance seal element downselect process it seems much progress has been made. But one notable piece of information that is missing is allocated budgets for budget period 1, 2, 3 and the amount that have spent till date to give an idea of what % of resources are applied to the project. The attached budget table has very limited data for some reason and it only shows the amount spent to date only so it is difficult to understand whether appropriate resources are being applied. It will be beneficial to show the % of budget spent.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, the project tasks are unique and all appear to add important value to achieving the overall goals.

**Reviewer 2:** Score: 6. Comments: All the tasks planned are directed to resolving the technical challenges for the development of a DGS that is suitable for high-temperature, sCO2 turbine. The initial phase of the effort is to identify the potential replacement of Balance Sealing Element in the conventional DGS, which is temperature sensitive. The project team has started with 19 replacement candidates with 11 selection criteria to narrow down the final 4 choices. This will be followed by a series of DGS tests under stationary and dynamic conditions.

**Reviewer 3:** Score: 5. Comments: The phased approach calls for testing the temperature limiting component (balance seal element) leading to full scale DGS design and test. The tasks and milestones were defined appropriately to reach this overall goal.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** No blind spots that I can see at this time.

**Reviewer 2:** None at this point.

**Reviewer 3:** None from the reviewer's point of view.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Project team lacks a turbomachinery OEM.

**Reviewer 2:** None at this point. The research along with the technical information would interest the general tribology and turbomachinery community. Timely dissemination of technical findings via journal publication and conference presentation is encouraged.

**Reviewer 3:** The partners seem to have appropriate background and expertise.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Project has already down selected 4 designs from 19 original candidates - good. 2) Dry gas seals appear to hold promise. 3) Is there the possibility to test all 4 down selected candidates with the requested funding rather than making a further cut?

**Reviewer 2:** This is one of the strongest projects in the CSP group. More feedback might be added after the review discussion.

**Reviewer 3:** 1) It is estimated developing a higher capability dry gas seal system can potentially result in 2-4% turbine efficiency which in turn will lead to a cycle efficiency improvement of 1-2%. But the efficiency improvements are predicated on not only high capability DGS development but also adding more stages to the turbine and possibly other improvements.
2) The overall budget & milestones seemed to be defined appropriately and the project teams do have the requisite expertise.
3) The project seemed to have gotten of a good start with the downselect process for balance seal element. However, many developmental steps outlined needed to be achieved before testing the new DGS system. The timeline of 2 years for the overall project, with more than 6 months already past, seems to be too short.

## Loop Thermosyphon Enhanced Solar Collector – $1,500,000

*Advanced Cooling Technology | Lancaster, PA | Principal Investigator: Nathan Van Velson*

This team is developing a loop thermosyphon solar collection system for efficient, low-cost solar-thermal desalination that does not require fluid to be actively pumped throughout the system. The design takes advantage of nanofluids with higher solar absorptivity and a two-phase thermosyphon to improve the system's efficiency and simplify the collection of solar-thermal energy used in desalination processes.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 4 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 3 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The subcontract expenses for developing the GO nanofluid are a disproportionately large portion of the budget. Continuing the project with the dye solution and removing the subcontract looks to be a better alternative. Prove out the concept with a workable fluid first then optimize the fluid later.

**Reviewer 2:** Strengths: Addresses desalination - may be more appropriate for the developing world or for temporary water after disasters; Has modeled and prototyped system. Weaknesses: What were the design specifications for the volume of water it needs to make? How does the size scale with the water volume requirement?

**Reviewer 3:** ACT has long experience in two-phase flow and thermal management which they have leveraged to developing a thermosyphon loop system to generate low-cost steam for solar desalination of brackish water. The solar-to-steam efficiencies are projected to be ~ 80% which helps to keep LCOH < $0.01/kWth. The key challenges have been identified and have been partially met. The primary challenge the team faced was in the performance of the Graphene Oxide material which was selected for high thermal absorptivity but turned out be coagulating and settling down in the loop. Fortunately, the tam was able to recover by finding an alternate commercial which seems to be stable and has similar optical properties to the GO. The project if successful will help move the needle in low-cost steam production.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 3 | 5 |
| Collaborates with sufficient stakeholders | 4 | 3 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The PI and the other collaborators worked together to tackle the issues with the nanofluid, even though ultimately unsuccessful.

**Reviewer 2:** What is the market for this product? Who are the clients?

**Reviewer 3:** The PI and his team focused on developing the design and modeling efforts of the thermosyphon. The original concept of using GO as nanofluid had to be shelved leading to a delay in meeting original milestones. They have fortunately found an alternate which seems to meet their requirements. They have also addressed issues related to glass/metal transition joints and have demonstrated its capability to handle relatively high pressures. Characterization of the long-term stability of the working fluid was addressed by designing and fabricating a small loop thermosyphon made of glass. The model developed for this effort seems to indicate that they are on track to meeting the cost metrics.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The tasks related to developing the nanofluid look to be unnecessary. The value of the nanofluid vs commercially available products should have been evaluated early on to justify including the nanofluid investigation in the project.

**Reviewer 2:** Score: 4. Comments: It's to the project's credit that numerical modeling has lead to design, engineering, fabrication and a working prototype. Now it would be useful to put it in the hands of an end-user and refine it.

**Reviewer 3:** Score: 5. Comments: The project has well-defined milestones for the first budget period. The LTSC system performance model has been developed and has integrated capital costs and operations cost to predict LCOH delivered to the desalination process. Nanofluid performance was impacted due to instability of the original selection of GO, but the team has recovered by using another fluid. Development of evacuated tube glass receiver and evaluation metrics has been met. In addition, they have partially addressed the transition joint between metal and glass. Further evaluation is needed to understand long-term corrosion impact if any.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The thermal cycling or potential for glass receiver sag over time due to extended time at elevated temperatures. Finding any fluid to last with minimal degradation over the life of a plant may be very difficult and fluid conditioning may be required. Off conditions, such as start up and cloud conditions may prove difficult.

**Reviewer 2:** Who is the client? How much water should your Thermosyphon be providing each day?

Reviewer 3: ACT has some real bright engineers but they have taken on the position of developing the loop heat-pipe system components in-house. In my opinion, they will find it difficult, because they will not have the bandwidth needed as they are a small company. They will risk going under. A better strategy would be to partner with a large company to help build components on a large scale once the technical aspects are all fully understood and addressed in their design.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Additional stakeholders related to the water treatment side would be beneficial to evaluate any constraints to the working fluid conditions.

**Reviewer 2:** End-users would help constrain the design.

**Reviewer 3:** The base technology is well within their capability of developing and demonstrating. However, they are taking on a position of wanting to manufacture the components themselves which is a risky proposition. Better to partner with a larger company.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The inclusion of the high-tech nano fluid in the project looks to be unnecessary as a commercially available product looks to be good enough for evaluating the concept. The risk to reward of the nanofluid portion of the project was not adequately evaluated upfront. 2) The value of direct absorption fluid vs standard CSP receivers is not clear. 3) Evaluating the concept is more important than optimizing the working fluid with nanofluids. Improvements to the fluid can be evaluated in a follow-on project once the concept is proven.

**Reviewer 2:** 1) Successful modeling -> design -> prototype project. 2) An eye-brow raising budget (on the high end). 3) How will this beat reverse osmosis?

**Reviewer 3:** 1) Good plan for large scale production and infusion is needed. 2) Keep track of progress in field transition joints. 3) Since the proposed system is only part of the solution for a solar distillation system, the interface to the distillation system needs to be understood well and captured in a user manual.

## Polarimetry-Enhanced Imaging towards Autonomous Solar Field and Receiver Inspections – $2,000,000

*Arizona State University | Tempe, AZ | Principal Investigator: Yu Yao*

This project is developing imaging systems using polarimetry, which is the measurement of how light rays are aligned, or polarized. Measuring polarization has the potential to be much more sensitive than conventional optical measurements. The imaging systems are small enough to attach to drones and deploy to evaluate the performance of concentrating solar-thermal power collector systems. They can also be attached to concentrating solar-thermal power plant power towers. Autonomous imaging will reveal damage and soiling on collector mirrors, and reduce errors in mirror alignment, resulting in improved efficiency.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 4 | 5 |
| Set critical challenges to overcome | 6 | 4 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 | 0 |
| Match well with the level of DOE funding and planned project duration | 4 | 0 | 0 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 4 |
| Advance the U.S. solar industry substantially | 5 | 3 | 0 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This project appears well aligned with the SETO mission. The approach appears to not have been used previously on CSP plants and has the potential to advance the solar industry. CSP projects do suffer from high O&M which leads to a high LCOE and being able to do widespread inspection over a large solar field to identify soiling and receiver tube damage can help focus O&M costs better without more labor-intensive inspection.

**Reviewer 2:** The proposal's goal is to develop a UAV-based polarimetric imaging technology to detect mirror edges, corners, scratches, etc. It can be also used to determine level of mirror soiling, etc. However, this technique cannot be used to determine surface errors, canting errors, etc which are the dominant sources of heliostat performance.

**Reviewer 3:** With the development of new drone cameras technologies this project may be significant for the CSP industry. With the development of new drone cameras technologies this project may be significant for the CSP industry. Over the years aerial techniques have been tested to verify reflective panels alignment, soilng etc.…but because of the high cost these techniques could not be implemented in the daily operation of CSP projects.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 0 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 0 |
| Disseminates results frequently and actively engage partners | 6 | 4 | 0 |
| Collaborates with sufficient stakeholders | 5 | 4 | 0 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The budget and time frame were marked as 3 since it was omitted from the report (apparently due to the project just starting) and couldn't be considered. The impacts appear to be referencing prior reports, which make sense. What would be helpful is to have a goal (if not already established) that shows the accuracy of the inspection (say cleanliness or degraded receiver tubes) compared to the state of the art method (visual-manual-handheld inspection) and the time it takes do these resulting in a cost savings that could be applied to repairing the issues. It isn't clear that the project is collaborating with current project owners. This would be helpful in getting up-to-date cost/benefit information.

**Reviewer 2:** Inadequate info due to the maturity of the project.

**Reviewer 3:** No comment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks appear to build up to meeting the project objectives but give the limited amount of space allowed, it isn't laid out in a way that helps me understand if >5fps and <2% DOP, etc. can result in a reduction in the cost of maintenance compared to the improved operating efficiency compared to current methods. Assuming the intermediate tasks that lead to achieving these objectives results in the overall goal of the project, then I agree with the plan.

**Reviewer 2:** Score: 4. Comments: Inadequate info. In Phase 1 the team expects to build visible full Stokes polarimetric imaging sensors with speed >5fps and polarization measurement error.

**Reviewer 3:** Score: 0. Comments: No comment.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** I wouldn't focus too much on canting and slope issues unless these can be corrected easily with software. One would assume that given the focus area, that much of this is better addressed through aiming strategies instead of extensive rework of a heliostat field. Of course if there is a widespread issue that can't be addressed through aiming strategies, then it would be useful. Where this has the most immediate value is in cleanliness and damage such as cracked or missing mirrors. Also, minor scratches likely wouldn't be addressed and may not be the highest value issue to try to illuminate.

**Reviewer 2:** Not enough data to evaluate blind spots. The primary caution is the advanced technology infusion they are proposing will need a significant systems level thinking which is not clear they possess.

**Reviewer 3:** No comment.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It would be useful to get CSP plant owners/operators collaborating on this to fully understand how they may focus their limited funds and where this work could help with that.

**Reviewer 2:** Not enough info. As a project, it appears to be very complex requiring fabrication of sensors which then needs to be implemented into a system and flown.

**Reviewer 3:** No comment.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This is likely useful in identifying mirror cleanliness and receiver damage to focus O&M resources. 2) There appears to be at least three projects with similar value, perhaps too much spending in this area. 3) Place-based innovation would have this work more closely tied to project owners/operators and as such these sorts of work should have be in collaboration with existing project owners/operators.

**Reviewer 2:** Not enough info. But key take-aways. 1) Very complex technology with uncertain benefits (goals can be met with laser-based systems). 2) Complexity at subsystem as well as system level. 3) Integrating in UAV is another level of complication.

**Reviewer 3:** No comment.

## Flat Focusing Mirrors for Concentrating Solar Power – $400,000

*Lucent Optics | Sacramento, CA | Principal Investigator: Sergey Vasylyev*

To reduce the cost and improve the performance of concentrating solar-thermal power plants, Lucent Optics will investigate the feasibility of making flat focusing mirrors using a thin light-focusing film on a planar reflective substrate. The team will produce a fully functional pilot-prototype of a flat focusing mirror measuring 0.5 meters by 0.5 meters that can be scaled to full-size concentrating solar-thermal power collectors. Planar focusing mirrors that use light-focusing film can replace many types of traditional collectors, providing a new pathway for further concentrating solar-thermal power cost reduction and performance improvement.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 4 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 4 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Unique project with potential impact. May impact concepts that require improved focusing at low cost.

**Reviewer 2:** Strengths: CSP would like to not have to curve its reflectors, and this would allow that. The proposal mentions that the LFOF could be "internal" to the mirror, this is important from a cleaning perspective otherwise the film would be a cleaning dealbreaker. Budget is modest for a proof-of-concept. Weaknesses: Much of the initial work was modeling that was validated by a 15 cm x 15 cm "interim" prototype - it would have been nice to have an initial prototype in year 1. It's unclear from the proposal if the prototypes developed have the LFOF internal to the mirror or on the surface. As mentioned before, the surface would be subjected to cleaning abrasion.

**Reviewer 3:** This is an interesting approach that is different than conventional methods to focus light. It appears aligned with the SETO mission. For the challenges to overcome, the project appears to set out clear objectives. What isn't clear is the level of focusing that is targeted and overall reflectivity of the surface. If the latter is significantly degraded it could result in a tradeoff instead of an improvement. That said, it still has the possibility of substantially advancing the US solar industry since it may lead to simplification in the overall design and construction of a project. The concept may have additional value outside of DOE-funded efforts too.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 | 4 |
| Disseminates results frequently and actively engage partners | 3 | 4 | 6 |
| Collaborates with sufficient stakeholders | 3 | 5 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** Good project success thus far. There do not appear to be additional stakeholders or partners involved.

**Reviewer 2:** Based on budget and scope of work this seems more of a proof-of-concept project at this point than a large-scale demonstration. For that, the team and scope is appropriate, though I would have appreciated more of a focus on the internal Fresnel structure that is protected from cleaning. My be is that the "interim" and "final" prototypes have the film on the front surface which will not be a viable plant solution.

**Reviewer 3:** This project could benefit from a stakeholder that could provide system-level input so that the impact could be measured more quantitatively. While the innovation is very interesting, how it would result in an overall LCOE improvement is important.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks build well, starting with evaluating requirements and modeling, then prototype and assessing against the model.

**Reviewer 2:** Score: 3. Comments: Many of the tasks are modeling - more physical prototypes demonstrating the internal Fresnel structure and performance would have been appreciated.

**Reviewer 3:** Score: 5. Comments: The tasks/objectives build up and add to the overall concept in a valuable way. The tasks include getting target optical parameters for the development of the concept. Once step that would be useful is to include reflectivity measurements at varying incident angles.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Getting perfectly flat mirrors is almost as difficult as canting the mirrors, so there will be some variability in terms of flatness. Transmission loss and durability to scrub cleaning will be additional critical factors. The adhesive issues may be a larger issue than currently expected in terms of life time durability or loss of performance.

**Reviewer 2:** If the LFOF is applied externally - abrasion of the film due to cleaning.

**Reviewer 3:** The surface may not be as reflective as other mirrors and may reduce the overall benefit of the technique. The micro structure may shadow portions of the mirror surfaces at different angles that may reduce the overall reflectivity. Whether a mirror is flat or curved on a heliostat, it will need to still be held in a proper orientation. This may eliminate the need for curved mirrors but still requires accurate placement of the mirror I don't see a savings in eliminating the need of "curving and/or canting the mirrors." I see the benefit as getting curved performance while reducing the cost of the facet closer to the cost of a flat mirror.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** There are no collaborators listed, so any additional stakeholders or collaborators would be beneficial. Substrate manufactures, heliostat designer, thin film manufacturing etc.

**Reviewer 2:** A plant operator or National Lab with experience in the industry to talk about the importance of cleaning (and difficulty of external polymers to stand up to it.)

**Reviewer 3:** At this stage having a heliostat field designer on board to weigh the benefits of the concept would have some value but the proof of the initial concept is likely better to prove out first. Given the efficient cost to benefit of the project, it is likely better to not add anyone else until it is further developed and proven.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Great progress and results so far on high risk project. 2) Evaluated typical high-volume production capability on facet flatness and add to the optical model. 3) Add stakeholders or collaborators.

**Reviewer 2:** Please focus development work on the internal LFOF. A polymer film on the surface of the reflector will be abraded.

**Reviewer 3:** 1) This is an interesting innovation that appears to get between the cost/benefit analysis of curved vs. flat mirrors for heliostats and there is likely a benefit here. 2) The overall reflectivity for all incident angles needs to be considered. 3) The optical performance (focus) for all incident angles needs to be considered.

## Aerodynamic Analysis and Validation of Wind Loading on Concentrating Solar-Thermal Power Collectors Using High-Fidelity Computational Fluid Dynamics Modeling – $195,412

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Shreyas Ananthan*

This project is working to validate high-fidelity computations of wind loading on concentrating solar-thermal power structures using wind-tunnel test data provided by SolarDynamics LLC. The team is addressing the progressively complex issue by validating the loading on a single-parabolic-trough-collector assembly to understand the meshing requirements and simulation best practices, predicting and validating wind loading on waked collectors by simulating multiple rows in different configurations, and simulating wind-loading characteristics of large arrays that are not possible to test in wind tunnels.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 4 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project is looking at impacting 15% of the cost of a system. Although the modeling is valuable, the real risk lies in a demonstration that relies on the lower wind loads expected, as that will be a contentious point for any bank funding a plant.

**Reviewer 2:** This work is well aligned with the SETO mission and can help socialize wind modeling for trough projects, arriving at methods to reduce the overall cost required to build a large solar field. The cost of the solar field is driven both by the need to have an optically correct collector and to survive wind loading without damage. The duration and the funding appear to match well; not a large spend to advance in this area.

**Reviewer 3:** The authors have proposed to use a highly advanced CFD code developed by NREL to analyze the effect of wind dynamics on the loading of heliostats. Commercial codes are not able to capture the dynamics or they are not validated to the extent needed to be useful. The project plan calls for working with commercial partners (one identified) to gather data and compare them to the results from the simulation. Once validated, the code will be made available in the public sector for general use.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 3 | 6 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 6 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project is collaborating with a commercial partner on both existing data and guidance on projected impact.

**Reviewer 2:** The project appears to be collaborating with a stakeholder to validate results against wind tunnel data. This is a reasonable approach. I would suggest also checking data against other data sources too in order to get a complete view of wind tunnel data available as some of these results may vary. It appears that the project is advancing according to time frames and budgets.

**Reviewer 3:** The project is in its infancy since it has just been awarded a few months ago. However, they have provided confidence of their approach as they have shown the ability to simulate the turbulent inflow wind conditions of interest when determining wind-loading on CSP collectors. Based on specific conditions the simulated results of mean-velocity profile and turbulent intensity matched experimental values to within 5% of measured values.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The project could benefit from additional industry outreach to get early buy in for adoption.

**Reviewer 2:** Score: 6. Comments: The task laid out appear to be structured in a way that will build up to the overall goals of the project.

**Reviewer 3:** Score: 4. Comments: The project leverages off the existing high fidelity code developed by NREL to develop parametric data that can be used by interested stakeholders to develop reduced-order models for estimating wind-loads in their design optimizations, which can have implications on design of the solar field.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** It is unclear how much of a benefit modeling 12 rows vs the current 6 rows actually provides. Engaging additional stakeholder such as banks in terms of what level of due diligence is required to have an impact on a production plant.

**Reviewer 2:** The overall cost of the solar field will be a factor of the deep collectors and the perimeter collectors. In some cases the design may be the same and other methods may be employed to minimize edge effects. Also, the code requirement for the design needs to be considered in this process to understand what loading is acceptable.

**Reviewer 3:** The results from the runs need to be expansive covering several field sizes and configurations. The PI needs to have a good understanding of layouts, locations, to bound the problem.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Engaging additional stakeholder such as banks in terms of what level of due diligence is required to have an impact on a production plant. Additional end users would also be valuable to get buy in and feedback early.

**Reviewer 2**: The stakeholder may want to consult with ASCE to get input on the methodology and its applicability to code compliance.

**Reviewer 3:** Project seems to be analysis focused with downstream users and use-cases not well defined.

### 6. What are the three most important pieces of feedback for this project you would SETO to consider?

**Reviewer 1:** 1) engage additional stakeholders. 2) Define the value of the current model with 12 rows vs the previous model with 6. 3) Gather validation data from operating plants.

**Reviewer 2:** 1) This is useful work that can help the industry as a whole from cost to design, cost to construct, cost to insure, etc. 2) There are differences in the industry with respect to wind tunnel results and then the application of those to what is acceptable for design. 3) More work like this that helps the industry as a whole through developing information that anyone can utilize is very beneficial to the industry.

**Reviewer 3:** 1) Very analysis centric. Didn't get a feel for gauging how much work the PI has done to ensure the results can be made useful 2) Dependence on NREL supercomputer could hamper timely analysis runs 3) Analysis results could be fortified by making recommendations on how best to address winds - where and how should wind barriers be erected, etc.

## Development and Validation of a Xenon Arc Lamp Accelerated Aging Method for Concentrating Solar-Thermal Power Mirrors – $653,607

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Tirawat*

In order to better understand concentrating solar-thermal power mirror degradation and minimize operations and maintenance costs, this project is developing and validating an accelerated aging method for testing solar reflectors using a xenon arc lamp exposure chamber to simulate the effects of sunlight. This evaluation method will ensure that mirror performance testing is standardized and user-friendly. As part of this effort, several databases containing information on the degradation of mirror performance are being updated and consolidated into one platform to help develop the accelerated aging model and the experimental aging method for reflective surfaces.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 5 |
| Set critical challenges to overcome | 3 | 5 |
| Implement a high-risk, high-impact approach | 3 | 5 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 |
| Advance the U.S. solar industry substantially | 3 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project will provide a valuable database and evaluation of mirror degradation. Although the degradation contributes to plant O&M, the actual value is not well defined. A use case of some existing plants that could have benefitted from this would be helpful.

**Reviewer 2:** The project has identified an area that needs to be addressed in terms of guiding solar concentrators on expected lifetimes and reflector aging characteristics. Developing low cost concentrators are driven by the cost of the reflecting surface to a large extent and since they see on-going abuse it is important to understand and predict future performance after undergoing environmental challenges. The PI has taken a multi-pronged approach to meet the challenge which involves developing a materials database which is searchable for available reflectance data and also provide material-specific guidelines for accelerated aging methods using xenon lamp exposure. The project is well designed and will add value to researchers in this area. The challenge that the project faces is the question of completeness and usefulness of the data since it relies on scanning data from files and developing routines to query them.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 4 |
| Collaborates with sufficient stakeholders | 3 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project could benefit from feedback of potential end users.

**Reviewer 2:** The project appears to have made progress in extracting reflectance data from scan files and also data acquired from industry partners. They have also made progress in making publicly available materials database. They indicate progress on all the milestones they have set out to do. They have assembled an international team with SMEs from Europe primarily for developing XALE guidelines.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The tasks are reasonable and provide value. The publicly accessible database needs user engagement and feedback.

**Reviewer 2:** Score: 4. Comments: The project has 4 main tasks of which 2 are well-defined - a) the outdoor exposure campaign for testing materials of different classes of solar mirrors and b) development of solar reflector database. The two other tasks are more challenging of which one is more than the other. Defining a proper accelerated exposure parameter space is hard and tied to that, the validation program to correlate the accelerated aging conditions to degradation mechanisms is even harder.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The use of machine learning is very interesting and could highlight important factors to degradation, but may have limitations on the actual value. The publicly accessible database needs user feedback and engagement.

**Reviewer 2:** The PI needs to engage actual solar field operators and capture their insights on what are their personal experiences. These people are likely quite advanced in age and it is important to capture their experiences. It is not clear if the PI is engaged in such activities.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Engaging end users of both the database and the published guideline would be beneficial.

**Reviewer 2:** Since this is a project designed to help concentrator performance which is dependent on materials that are highly reflective and age gracefully, the PI should be actively seeking out materials experts in the academia to see where progress is being made.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Provide a use case of a few existing plants in terms of benefit if available up front. I.e. if the guidelines for evaluating the degradation of mirrors for a plant were used, $X in O&M costs could have been avoided. 2) As pointed out in the challenges, reproducing natural degradation mechanisms is quite difficult. 3) Making a searchable database that is usable and is actually used can be quite difficult. The publicly accessible database needs user feedback and engagement.

**Reviewer 2:** While the task is not particularly novel, it is valuable. However, it remains to be seen how well it can be implemented.

## Solar Field Layout and Aimpoint Strategy Optimization – $309,616

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Alexander Zolan*

Using existing software packages to obtain a layout of the solar collection field of a concentrating solar-thermal power plant without accounting for the aiming strategy may yield solutions with heliostats that cannot be used efficiently without compromising the receiver's designed operating limits. This project develops a model that co-optimizes the layout and aiming strategies of a solar field to maximize the thermal energy generated by the field while operating within the design specifications of the receiver. The team utilizes state-of-the-art tools developed in its previous to characterize the thermal input to the receiver when provided a heliostat location and aiming strategy as input. This data is then used as input to an optimization model to obtain the best strategy within given limits. Advanced optimization techniques allow the model to obtain layouts and aiming strategies for commercial-scale plants.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** This work is aligned well with the SETO mission. While individual companies have optimization methods for heliostat layout and aiming strategy, it would be helpful for companies to have access to opensource information, especially if their primary focus isn't this and they are focused on other innovations this can become a standardized tool. Perhaps the industry may not adopt it as they may feel their methods are better but this would be a good benchmark too. The milestone of obtaining feedback from at least three beta testers by the end of the project could be advanced to help with this.

**Reviewer 2:** Strengths: NREL continues to make software tools that are useful for the CSP industry. This tool, as an open source tool, will likely continue to live on in other domains besides CSP. The team is knowledgeable and focused on making a usable tool for practitioners. As a software project, it is a relative deal funding-wise. Weaknesses: The tool being developed may help with making slightly more efficient fields, but it's not going to affect the LCOE very much. The number of people that need this tool, compared to the number of people that can get a reasonable profile from SolarPilot, is very small.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 4 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The start of the project seems to have been delayed due to hiring. It was noted in the report that the project can still be on track. What isn't clear is how a proper benchmark will be made for comparison. If existing commercial layouts will be compared to using the same aiming strategy, that might be useful to measure against instead of SolarPILOT since these were funded. Also, it is noted that the metric is 5% improvement in efficiency during peak DNI periods. It might be better to consider annualized values or something more like capacity factor. During the peak DNI periods there may be too many heliostats as it is and defocusing may be needed so adding efficiency during this period may not result in an overall benefit.

**Reviewer 2:** It's a one-year project half-way to completion. There aren't many results to date but the project has reasonable goals with a staff that has produced quality work in the past.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks/objectives appear to add value to the overall project and nothing appears out of place.

**Reviewer 2:** Score: 3. Comments: I did not see a detailed task list, but the narrative describes a sequence of steps required to complete the task.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Nothing that isn't already noted. My view of how to improve the LCOE of a tower project with respect to this innovation is to improve the annual utilization of the receiver and heliostat field. If peak output is a metric, then the field may be sized to 1.0 for that case and the receiver significantly over sized for all other times. If those cases align with the best delivery of energy to the utility for the best price, then perhaps it could be useful. However, balancing between having extra heliostats and the right size receiver should result in the best LCOE. Then maximizing the utilization of the heliostats as the project appears to be attempting to do is best viewed on an annualized basis.

**Reviewer 2:** Assumptions regarding in-field optical characteristics of heliostats. How much do these assumptions affect aimpoint strategy and intercept factor?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Engaging industry earlier, especially those that have done optimizations for commercial facilities solar field layouts and plant optimizations could be helpful to firm up the approach to be sure the optimization strategy is best.

**Reviewer 2:** They've found a few beta-testers. Getting the tool in the hands of these testers earlier rather than later.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This is valuable since it would be opensource and new entrants in the industry wouldn't have to build up this capability. 2) It is a reasonable amount of spend to get opensource information out into industry. 3) It would be useful to double check the optimization strategy to ensure it is driving to a lower LCOE and not an optimization for a single point at the highest DNI period, which may not be valuable.

**Reviewer 2:** 1) Get the tool deployed and into the hands of the beta testers as soon as possible. 2) Perform a sensitivity analysis showing how heliostat optical characteristics affect aimpoint strategy - what aimpoint strategies are beneficial for 2 mrad, 3 mrad, 4 mrad, and 5 mrad heliostats? And how much does each aimpoint strategy really affect field efficiency?

## Development of an Unmanned, Aerial, System-Driven, Universal Field Assessment, Correction, and Enhancement Tool Adopting Non-Intrusive Optics – $1,500,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Julius Yellowhair*

In collaboration with the National Renewable Energy Laboratory, this project is working to develop a new optical characterization tool for solar collectors. An automated aerial drone carrying a high-resolution camera will survey a large-scale heliostat field to compare the heliostats to their original structural geometry. The images will reveal problematic mirror angles and so that maintenance crews can quickly repair and calibrate underperforming heliostats. This new technology has the potential to reduce operations and maintenance efforts and increase power production, helping to reduce the levelized cost of energy of a concentrating solar-thermal power plant.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 4 | 6 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 2 | 6 |
| Advance the U.S. solar industry substantially | 3 | 2 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project appears to align well with the DOE SETO mission and sets critical challenges to overcome in optical measurement. The overall cost in not clear in the report and lacks the cost share and does appear to represent a relatively high cost but may have high value in other applications beyond DOE-funded efforts such as rapid measurement of structural integrity of other infrastructures to identify deviations from design or reference conditions. It isn't clear though, with the limited deployment of tower technology in the US, that this advancement will advance the US solar industry substantially. The report does note power-tower plants around the world, which isn't the scope of the US DOE.

**Reviewer 2:** From an O&M perspective it's important to know where you have problems in the field. Also from an O&M perspective, it's important to be able to figure this out quickly and easily. The scale of a CSP field means that, bluntly, there is limited time to handle problems in the field. In that optimization process, it has proven best to try to ensure that the heliostats are installed and are optically correct upon installation. The idea of "coming back to fix it later" is a tremendous O&M burden. This project proposes to "reduce O&M costs." If there are significant problems in the field, it will increase O&M costs. Supposedly the improved intercept factor will justify it. But the increase in performance (if it occurs) will not be free. This tool needs to fly over a whole field, and then the data processed and reports made, before useful information is given to plant operators. It would be better to have a tower mounted system that is always looking at the field and not wait for a drone to do an aerial survey. Strengths: Proposes a tool to determine alignment issues that allows continued plant operation. Weaknesses: UAS will only gather data on portions of the field at a time - will be slow; For existing plants expect little influence on LCOE; Does not affect initial plant cost.

**Reviewer 3:** The proposal leverages off current advances in UAV technologies to help solve issues with calibration of multiple heliostats in a field. The project has correctly identified the impact of imperfections in reflected sunlight on the downstream costs of operating a large CSP plant. The UAV is designed to have 2 independent measuring systems developed by SNL and NREL and have demonstrated the capability of measuring optical errors with hand-held cameras in the 0.25 mrad range with both approaches (UFACET and NIO) which is a significant achievement.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 3 | 4 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** From the reported information, it appears that the impacts are being measured appropriately and that the project is advancing within the time frame and budget. Where the project could benefit is from additional stakeholders on the O&M of a solar power-tower facility. Demonstrating how the results of this measurement technique would translate to reducing the LCOE of a solar-tower power project would help make sure that this innovation will be valuable for project owners. See blind spot notes for more explanation.

**Reviewer 2:** Team is meeting milestones as proposed, though budgets are large. Results are published. Reason for low score on “impact” is belief that this system is too slow and infrequent for use in a solar field. A tower mounted system would have been better.

**Reviewer 3:** In the first phase, the team has demonstrated the field performance of both approaches; i.e. UFACET and NIO using hand-held cameras. They have talked about the implementation of UAVs, but the progress is hard to determine as nothing has been shown. The discussion of moving from TRL 3 to 6 hard to evaluate because almost nothing on the progress of implementing the 2 systems on a UAV platform has been shown. They briefly mention “configuring a UAS system with sophisticated requirements”. Subsequent e-mails from the PI has overcome this concern.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The tasks appear to align well with determining surface slope errors and canting errors. Where the tasks appear light is in determining pointing errors and soiling. The latter two may be more immediately useful.

**Reviewer 2:** Score: 4. Comments: Project is appropriately staged.

**Reviewer 3:** Score: 5. Comments: The project identifies 5 subtasks related to demonstrating the techniques of measuring and performing data analysis to determine optical errors in facets of heliostats using hand-held camera. The progress shown using hand-hand cameras have been good. However, there is scant details on the UAS system. There are undoubtedly several milestones just for the UAS system itself which have no details presented.

**4. What ‘blind spots’ the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** While knowing the canting error and slope error of the heliostats appears important, it can be costly to then go into the field and make physical corrections to this. The cost to make these corrections would likely be much higher than other techniques to improve the performance of a field due to this. What is more immediately addressable by a project is knowing the soiling of the field and where to focus the limited funds an operator has to address the right locations while also making a quick assessment of the pointing errors of the field since that can be corrected in software, resulting in a lower cost-higher impact result.

**Reviewer 2:** The length of time to fly a solar field.

**Reviewer 3:** The team seems to have some members who are highly experienced in the measurement techniques but it is not clear if they have a solid team who can help meet their final end-goal of implementing a UAS system to perform entire field-level measurements.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** To be successful it would benefit the project to engage project owners. Two areas are important, the cost/benefit of the approach and method to deploy the technology. The first is already covered in the other comments. The second, proposing a licensing structure, may not be the most effective way to do this. Project owners and operators have a limited staff and the training of the staff to do this function may not be effective and this technology may be better deployed through a service model. An investigation into this may be helpful, including which approach is more scalable.

**Reviewer 2:** A plant operator.

**Reviewer 3:** Since this is a system implementation, the team needs to understand the importance of system-level thinking, imposing requirements on the subsystems and have a rigorous verification and validation program. This might mean the involvement of someone from the Aerospace or Automobile industries on a consultation basis.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Consider if the cost/benefit is realizable given the cost to mechanically correct surface slope and canting errors. 2) Consider if this can also be applied to trough projects and if cleanliness can be addressed, something that can help projects now. 3) Consider how this technology would be adopted by project owners (licensed or a service).

**Reviewer 2:** 1) This tool will be slow. 2) The intercept factor (which this tool addresses) is only one of many losses that a CSP plant experiences from sunlight to power production. An improvement in intercept factor of 10% will affect plant efficiency and LCOE by a much smaller amount (like 1-3%). 3) Field correction of mirror canting will increase O&M costs, not decrease it. What is the payback of O&M labor versus improved intercept factor?

**Reviewer 3:** 1) More details on the milestones transitioning from hand-held system to airborne system. 2) Ensure the team is well trained in systems thinking. 3) Conduct rigorous verification and validation to cover all sorts of field configurations and sizes.

## LiDAR for Autonomous Heliostat Optical Error Assessment – $320,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Daniel Small*

This project seeks to develop new uses for three-dimensional scanning Light Detecting and Ranging (LiDAR) sensors in the automatic/autonomous assessment of the optical errors in large-scale concentrating solar-thermal power heliostat fields. Experiments have demonstrated the ability of a 3D-LiDAR to acquire highly accurate point cloud measurements of facet mirrors across several heliostats at the National Solar-Thermal Test Facility and derive their facet canting angles and errors. The team is writing software for autonomous segmentation and error analysis and conducting in situ testing and evaluation at the National Solar-Thermal Test Facility.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 4 | 6 | 4 |
| Implement a high-risk, high-impact approach | 3 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 3 |
| Advance the U.S. solar industry substantially | 3 | 4 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** While the project looks to be useful in maintaining a calibrated solar field, the impact looks to be minimal. The fact that the commercial plant is not interested in allowing the scans currently shows the limited need or impact of this tool.

**Reviewer 2:** The approach is interesting and innovative. It also could have value in other areas outside of DOE-funded efforts in rapid measurement of structures. For the US solar industry, the challenge is the applicability over a small number of heliostat fields in commercial operation. However, if the edge technique can be adapted to troughs, it could be used to assess the health of trough fields too and assess the torsion of collectors at different tracking angles to arrive at better offsets and improve efficiency.

**Reviewer 3:** Strengths: Proof-of-concept using a widely available instrument and methodology to characterize mirror canting. Relatively small budget resulting in a tool that industry may use. Weaknesses: Speed - as envisioned hard to see how more than 1 or 2 heliostats are done at time. Assumes the solar field O&M staff has time to go around looking for and fixing canting errors. Fixing existing canting errors will increase intercept factor, but by how much? Will likely be small benefit is to LCOE.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 2 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 3 | 6 | 4 |
| Collaborates with sufficient stakeholders | 3 | 6 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** There is no quantitative estimation of the impact of the project. The commercial partner does not seem to be engaged in the project.

**Reviewer 2:** The project appears to be having issues with access to commercial heliostat fields in the US, speaking to the applicability generally at the moment. Where the report seems less elaborated is in the impact, tracking it from the measurement capability to a reduction in operating cost. However, the concept appears like it would be adaptable to being able to integrate with a heliostat field control system to provide feedback and correction to the tracking algorithms. I would avoid trying to adapt such a system to only identifying physical adjustments to heliostat facets that could otherwise be corrected in software.

**Reviewer 3:** This is a nice proof of concept developed by Sandia staff. There was an attempt to go deploy and test at Crescent Dunes.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: The tasks focus only on the tool and validating accuracy, none of the tasks look at logistics or impact of using the tool. Several similar type tools have been developed previously with limited commercial adoption. A look at the expected accuracy of the field vs the measured accuracy would help quantify the value of the tool.

**Reviewer 2:** Score: 6. Comments: The project appears to be well structured and advances with the tasks aligned to the goal.

**Reviewer 3:** Score: 5. Comments: Project is well scoped.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Quantifying the value of the tool. The reasoning for the lack of interest from the commercial partner would provide feedback on what is needed to better sell the tool.

**Reviewer 2:** The only blind spot I can see is that the benefits of such an innovation are maximized when both the O&M cost and the construction cost can be reduced while improving performance. If this innovation can be placed in between those two constraints, it has good potential.

**Reviewer 3:** How much is the LCOE in present solar fields being affected by poor canting?

What is the trade-off between O&M time needed to fix canting issues and the benefit from increased intercept factor?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** An end user commercial plant is the ideal collaborator for a tool like this. The project does have a commercial partner, but with limited interest or participation. Identifying another commercial partner that can provide feedback and testing would be valuable.

**Reviewer 2:** It would be useful to have industry participation to understand how this work could be integrated with a heliostat field control system. Also, to better understand the tradeoffs between trying to essentially rebuild or adjust 10,000 heliostats instead of making corrections based on measurement in software.

**Reviewer 3:** Use at a commercial field. Training of O&M staff in its use.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The value proposition is not clear. 2) The reasoning for the commercial partners limited interest needs to be understood. Are there other solutions that work well enough? 3) Logistic of actual use across a very large plant need to be understood

**Reviewer 2:** 1) The work is interesting and it see what from it can be applied to troughs would be useful. 2) Claims of improved performance from recanting and correcting errors manually on heliostats is not the most efficient approach to benefit from this innovation. 3) This work would fit well with improved heliostat field control systems.

**Reviewer 3:** 1) Project potentially useful to industry. 2) Low budget. 3) Shows usefulness of National Labs.

## Concentrating Optics for Lower Levelized Energy Costs – $2,061,865

*Solar Dynamics | Broomfield, CO | Principal Investigator: Kyle Kattke*

This project builds on heliostat technology developed under a previous award to develop the DROP C (Drop-in, Ring-Of-Power Heliostat). The new design allows the heliostats to be dropped into a location with drastic reduction of the preparation of the site location, which enables a reduction in costs and improves financing terms. The addition of a wide base and protected drives, which permit heliostats to move and reflect sun at the best angle, allows lower manufacturing costs, reduced costs for the structure's support, and increased protection from high winds. These improvements, coupled with wireless control of the heliostats, support lower cost targets.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project appears to align with the SETO mission very well and has elaborated clearly the critical challenges to overcome and demonstrates a clear understanding of the overall cost of a heliostat when setting a high-risk/high impact approach. The cost targets set could be expected to advance the US solar industry substantially.

**Reviewer 2:** Solar Dynamics has built upon prior funding from DOE to reduce the cost of installed heliostats by adopting a drop-in design which has several elements to make the goal close to achieving. The design is supposedly represents an evolution to Abengoa's "Ring of Power" concept. In addition to the heliostat design, the team has also proposed a) to develop low-cost solutions to mesh wireless networking in the field with capability of communication between heliostats and controllers (up to a max of 50000), and b) low-cost, rapid calibration of the heliostats using 4 cameras on the central tower.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 |
| Disseminates results frequently and actively engage partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project appears to have sufficient stakeholders and partners to understand the innovation it is pursuing. In addition, the impacts are appropriately measured. Where the project is struggling is in meeting the cost target, significant reductions from the state-of-the-art have been shown though. The work appears to be a complete buildup of the cost so it is likely that the cost achieved can be relied upon.

**Reviewer 2:** In the first phase, the project has demonstrated progress but has had to shift gears to make changes in their design to a less aggressive (moved from friction-based azimuth drive to positive engagement geared azimuth drive which increased their costs. However, the installed cost $75 per m2 is still very respectable and well under the costs of SOA heliostats which are closer to $120m2. On the mesh controller, the team has demonstrated proof-of-concept success with 30 nodes with very good response times, but it is unclear how well it will scale to 500+ heliostats which they will demonstrate in Phase 2. On the calibration system, the performance so far doesn't meet projected goals and it is unclear what sort of changes they will adopt going forward.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project has three main areas, each advancing the technology. Each area appears to build up in a way that drives to the overall targets in cost and performance.

**Reviewer 2:** Score: 5. Comments: The project has 3 distinct tasks they are addressing - 1) low-cost drop-in heliostats, 2) low-cost scalable mesh wireless communication for controls, 3) rapid calibration using Google's published multiscopic photometric approach using 4 cameras. All the tasks are consistent to meeting overall goals of reducing costs; however, progress on the tasks are uniformly successful. In particular, the calibration approach is way off from the project goals. It is unclear what the impact will be on LCOE and if the team will consider alternate approaches to overcome the shortcomings.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** This project doesn't appear to have any blind spots and appears to be advancing in a holistic way.

**Reviewer 2:** The PI has taken the approach of adopting and modifying existing designs such as the Abengoa's ROP heliostat design, the Google's approach for calibration and even the azimuth drive approach is not novel - it appears to have heritage from prior designs from DLR for example. Also, mesh networking is a logical approach and has been used by other PIs (NREL, DLR for example). The key focus on cost is good, but it should not blind them to considering novel approaches which may be still early TRL which may come out from the universities and not necessarily from the large institutions.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project could have a benefit from engaging a civil engineer to do some 3rd party reviews of the system. It is noted that a 3rd party validation was done for the wireless mesh network. It could also be useful to engage insurers and/or an independent engineer to help move the product closer to a commercial one.

**Reviewer 2:** The PI and team have a good understanding of the state of practice and have even adopted some of the approaches. However, it would behoove them to look around in universities particularly for solutions in calibration and even mesh networking.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project appears to demonstrate a complete view and full understanding of the technology being developed. 2) The project is struggling to get to the cost targets but has advanced the technology in a way that appears to be complete and not missing costs. 3) The project is utilizing an automated calibration method for the field that should help reduce the future O&M costs too, helping to reduce the LCOE.

**Reviewer 2:** 1) The team has identified and is trying to address the "tall tent-poles" in implementing low cost heliostats. 2) Drop in heliostats with no foundations to worry about is a good approach. 3) They need to focus on calibration as that could drive LCOE if not implemented well.

## Development of a Front-Surface Concentrating Solar-Thermal Power Reflector Using Ultra-Barrier Technology – $323,428

*Sundog Solar Technology | Searsport, ME | Principal Investigator: Randy Gee*

Sundog Solar Technology and its project partners, Helicon Thin Film Systems, Erickson International, and the National Renewable Energy Laboratory, is developing a high-performance, lower-cost solar reflector for concentrating solar-thermal power systems. The design of this new reflector moves the silver from the back of the glass to the front of it, allowing for more efficient reflection without sacrificing product lifetime. The reflector also has a novel coating that can withstand both ultraviolet radiation from the sun and impact from scrubbing the mirrors clean. High-volume manufacturability is critical to achieving low costs, so this reflector will be constructed using roll-to-roll manufacturing methods. The team is creating laboratory-scale reflector specimens and will then develop the manufacturing techniques for these reflectors.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 | 4 |
| Set critical challenges to overcome | 4 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 4 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** A cheap, durable, high reflectance mirror for CSP has been a "holy grail" for some time. Silver is an excellent reflector, but when placed behind glass refraction causes losses that would be nice to avoid - therefore look to a front surface reflector, but then soiling and cleaning mar the reflective surface. This project seeks to develop a durable barrier coating, with imperfections sealed with a polymer, that would enable a front surface reflector made with roll-to-roll manufacturing methods. Strengths: Goal relevant to CSP industry; Milestones on track; Solid team - (Sundog, Helicon, NREL). Weaknesses: Polymer as of yet hasn't shown abrasion resistance; Quality control at required throughput for cost savings in the roll-to-roll vacuum deposition process.

**Reviewer 2:** The project appears to align well with and supports the SETO mission. It correctly notes that significant improvements to achieve the cost goal of $50/m2 for the collector could be achieved through the reflector. What is unclear is if the front surface reflector film alone could achieve significant cost reductions and if it would enable cheaper architectures for supporting the film or if new architectures would be needed that bring new challenges and costs. This project does address an opportunity to increase the reflectivity of mirrors used in CSP. The approach appears sound with respect to measurement of the reflectivity and is noting a significant reduction to the LCOE. The project is likely to advance the US solar industry when coupled with other advancements.

**Reviewer 3:** The project references a 4.4% LCOE reduction potential, but thin films have been around for quite a while with limited adoption. The impact of the project is limited as it focuses on scrubbing durability, but that is only 1 aspect of why thin film has not been adopted.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engage partners | 5 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The assembled team is appropriate.

**Reviewer 2:** From the data presented, it appears that the project is advancing according to the time frame and budget provided. The impact, the reduction to the LCOE, reference prior publications from 2013 and should be updated to be sure that the innovation still is expected to have the noted impact, but it is likely still to be the case. Some suggested improvements include that a known standard should be used to determine the scrub-abrasion resistance (one may be used, it just isn't noted). It would also be useful to have testing to measure the adhesion of the intermediate layers over time with thermal cycling. The cost per square meter would be useful to compare to the state-of-the-art including assumptions to the fully replaced part, meaning if the thin film will be bonded to another substrate or edge supported, the total cost of the replaced part is needed for a full comparison. It doesn't need to be all developed in this project, just shown that this advancement isn't conceived in isolation

**Reviewer 3:** The project seems to be on track despite some challenges. The project does not appear to have input from potential customers.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: As described previously, a cheap durable high performance reflector would help all CSP technologies.

**Reviewer 2:** Score: 5. Comments: The project consists of two tasks with the second task scaling up from results of the first. Given that the first task is directly addressing the first goal and the second task addressing the second goal, it appears that the project is properly aligned. As previously noted though, with an overall goal to reduce the LCOE of CSP, it would help to have a task in this project that clearly showed the other technology needed to realized the overall goal of the project and how the thin film alone achieves this.

**Reviewer 3:** Score: 5. Comments: The tasks are directly aligned with the goals. Lab scale test and validation, then scale up prototypes.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** The time and effort it takes to get good quality control out of a roll-to-roll vacuum deposition process, and perhaps the durability of the polymer hole filler.

**Reviewer 2:** While I doubt that the PI has a blind spot to the overall cost of integrating this innovation into existing or new collector or heliostat platforms, it isn't elaborated. It would also be useful to understand how this innovation is integrated into a collector or heliostat to understand if other issues that degrade the focus like superimposed surface imperfections if overlaid on a substrate, flatness issues if used as a stretched membrane and environmental resistance such as wind loading if not used on a substrate. All of these may negate the improvements and need to be considered holistically when considering the reflective surface.

**Reviewer 3:** Scale up challenges are underestimated. The current lab scale challenges and additional effort required will be even more in scale up.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I think they have a good team, but I believe they will need more time.

**Reviewer 2:** The project could benefit from a stakeholder that would integrate this innovation into a structure so that the advancement is progressing in a way that it doesn't become stranded and without a way to be used in a collector or heliostat.

**Reviewer 3:** There is no collaboration with potential customers or end users to determine requirements and viability.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Project has good goal. 2) Project is on track. 3) The vacuum deposition roll-to-roll portion (the second half) is unlikely to be successful.

**Reviewer 2:** 1) This project could use a stakeholder that would use the technology. 2) Having a hypothetical buildup of the collector cost with this innovation included would be helpful. 3) It would be useful to see how this innovation results in more US solar jobs and content compared to others.

**Reviewer 3:** 1) Scale up risk is underestimated. 2) Are there additional hurdles to adoption that are not part of this project and how will those be overcome. 3) This project is not critical to enabling gen 3 plants.

## Metrology-Assisted Robotic Mirror Alignment for Troughs – $1,150,000 ♦

*Sunvapor | Livermore, CA | Principal Investigator: Philip Gleckman*

Parabolic trough solar collectors are well-suited to generating industrial steam, but their assembly has significant labor costs. This project is developing a mobile, automated assembly method that is derived from advanced aerospace techniques. This method will lower labor costs, improve safety and quality, and enable the assemblies to be easily transported to new project sites.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 2 | 4 | 4 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 3 |
| Advance the U.S. solar industry substantially | 4 | 5 | 3 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** Deploying CSP in smaller commercial applications has the potential to advance the solar industry if cost competitive. Particularly in California and the US utilizing a mobile robotic unit to minimize labor is a good path to cost savings. The savings of $6/m2 is substantial and the risks of the concept are fairly low as robotic arms are fairly common place.

**Reviewer 2:** Strengths: Projects attempts automated manufacture of a PTC from a company in the business of making and selling troughs; Seems to have found appropriate deployment partner in iARobotics; Reasonable budget. Weaknesses: How will the automated assembly be evaluated? What rate of installation is required? What's the payoff compared to manual construction?

**Reviewer 3:** The project appears aligned with the SETO goals, to get the LCOH below the target. It isn't clear that adding a robot to field assembly will drive to this target alone. There doesn't seem to be a high-risk associated with this approach. Items such as weather ratings (IP65) and other aspects would appear to be issues of standard design while the focus alone should be how the system reduces the cost of assembly and alignment. Robotics are used throughout almost every industry and it isn't clear how this work would advance research outside of DOE-funded efforts nor is it clear that this innovation would advance the US solar industry substantially. To make that assessment one would need to understand the architecture of the collector first to better understand if inserting a robot in one step would significantly change the trajectory of the overall technology.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 4 |
| Disseminates results frequently and actively engage partners | 4 | 4 | 6 |
| Collaborates with sufficient stakeholders | 4 | 5 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The main collaborators on this project are the robotics firm developing the system, beyond that there is no additional collaboration. For the size and scope of the project the level of collaboration seems appropriate.

**Reviewer 2:** So far the project seems to be on track, though it is mostly specifications and weatherizing of the equipment.

**Reviewer 3:** The project appears to be advancing according to its budget while noting that no results are shown yet. Regarding measuring impact appropriately, it would be helpful to see the complete buildup of the collector cost and how this innovation reduces the overall cost. It is noted that the reduction sought is approximately the same as the structural material needed but this still leaves it unclear for me with respect to achieving the goals. It would appear from what is presented that the project could benefit from engaging other stakeholders to understand the overall viability of this technology and its competitiveness in both competing structures for low-temperature heat and for overall process heat.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The individual tasks are not identified in the report, just general discussion of the work.

**Reviewer 2:** Score: 3. Comments: A detailed task list was not provided.

**Reviewer 3:** Score: 3. Comments: The challenges noted in the project report primarily related to weatherizing and safety. Tasks related to these areas, while important, would be expected to be addressed after demonstrating key performance on assembly and alignment to tolerances. It isn't clear that the work is focusing in this area given the challenges noted.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** Sufficient anchoring of the equipment may be difficult in certain weather conditions.

**Reviewer 2:** I don't see a plan to evaluate the optical performance of the collector after the robot assembles it.

**Reviewer 3:** First, one would want to compare how process heat at this temperature could be achieved with other technologies to be sure that competition isn't already ahead with a solution that can be assembled. Also, the assembly and alignment of structural members is only a part of the overall construction of collectors. Since personnel may be needed to bring the material, insert fasteners, move the robot, etc. it appears that the robot may be too much for use in this step. Comparing this to photovoltaics and rapid assembly of photovoltaic fields, humans are still in the last assembly step while robots are used to make simple parts that assemble. To get the high precision needed, it would appear that high quality parts manufactured in a robotic environment and assembled in the field by humans may be an approach that needs to be compared against this approach. In addition, comparing this approach to the use of an assembly jig would also help establish a baseline for comparison.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1**: The end user is managing the project, so there is little need for additional stakeholders.

**Reviewer 2:** None - though some way to evaluate the optical performance of the collector is required.

**Reviewer 3:** The project appears to be using a robot for a step that may or may not lead to a clear cost reduction. It isn't clear that a reduction in labor will be achieved by this innovation and other stakeholders with experience in CSP process heat could add value in helping to ensure the innovation can realize the desired benefit.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The concept seems relatively low risk. 2) Modifying existing standard equipment used outdoors may be a lower cost solution that designing from scratch. 3) Few challenges to overcome.

**Reviewer 2:** 1) Project seems underspent. 2) Unclear that solar steam has relevance in today's market. 3) Budget seems appropriate.

**Reviewer 3:** 1) Process heat is a large market that will be addressable with a cost-competitive solution. 2) Many companies have tried to enter this market with solar-thermal technologies, even with competitive pricing against natural gas (with California's incentives), and haven't been successful. The obstacles aren't simply cost. 3) There doesn't appear to be a lot of innovation in this project and it appears to be forcing a robot in a step without a reason.

## Solar Steam on Demand – $1,000,165

*Sunvapor | Livermore, CA | Principal Investigator: Philip Gleckman*

The most efficient water distillation processes for desalination that use heat recovery require a steam source at a temperature around 180 degrees Celsius. This project is developing and testing a novel solution for generating steam by using solar-thermal energy as the primary source of heat and developing thermal-energy storage using a phase-change material. This solution will be combined with a previously developed low-cost, high-performance solar collector, creating a system that has the potential to operate water distillation equipment and meet the heat requirements of many industrial heating applications day or night.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 3 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** While the project started out with high risk, ultimately the failure of the storage system now limits the value of the project.

**Reviewer 2:** The projects correctly identifies the need for infusing solar technologies into process heating needs which account for 25% of the GHG emissions. Most of the process heat needs are in the 200-300 oC and parabolic dish technology is ideally suited for generating process steam. The technology has been demonstrated in a prior DOE-funded SunShot program. In order to reduce cost of collector, the PI has chosen to use lumbar as the support for the parabolic dishes and has shown it can substantially reduce cost of installed collectors. For this award, they have leveraged the prior success and propose to scale by a factor of 12.

**Reviewer 3:** The project is aligned with the SETO mission and does set out the critical challenge to overcome, a low LCOH for process heat and to be able to provide that on demand. It isn't clear though if the project has an LOI or an actual steam purchase agreement as the report cites this differently in two different places. In any case, getting additional commercial structures to provide heat to process heat facilities could spur additional research and development in process heat, advancing the industry as a whole.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 | 2 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 6 |
| Disseminates results frequently and actively engage partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 3 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** The project does include an end customer and a steam purchase agreement, helping to validate the market for such a product.

**Reviewer 2:** In the first budget period, the team has performed well. They have cross some important milestones such as securing an interested customer in solar process heat, permitting to build the plant, improving maturity of the technology and plant engineering. However, one of their tasks to build a TES has not been successful. It is not clear what is the impact on the overall cost of implementing the technology.

**Reviewer 3:** The project doesn't appear to have additional project partners that could help realize the goals and appears to be having difficulty with the storage price targets. Also, it isn't clear that Milestone 1.2 was to be a commercial agreement or just an LOI. Also, it isn't clear if Milestone 1.3 is to represent permits to construct or just one permit. From the report, it isn't clear that the project is progressing as originally planned. Given the level of spend, it isn't clear if the task and goals will be met.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: All of the tasks look to add value to the project. Big risks were tackled up front such as the storage system which proved to be much less economical than expected.

**Reviewer 2:** Score: 5. Comments: Sunvapor has taken on the challenge of producing low-cost solar steam and has demonstrated that it is a viable approach which is sustainable and low-cost. The payback periods are in the 2-4 years. The team has been very practical in their approach and worked with all the relevant stakeholders to move the technology forward. Nonwithstanding the low cost of gas currently, this approach is bound to make inroads as long as the primary challenges of getting permitted sites, and guaranteeing customers a steady supply.

**Reviewer 3:** Score: 3. Comments: The tasks appear to be more execution based with some R&D aspects in PCM that have been removed due to not meeting project estimates. However, it is hard to follow if the Letter of Intent is the same as the Letter of Commitment and if this is building up properly to the overall goals of the project. Similarly it is unclear if the intent of the permitting task was to get a permit from the Community & Economic Development Building & Fire Safety Division and if this is the definitive permit to construct and operate the facility. The general build up of the tasks make sense however it isn't clear if the actual accomplishments are lining up to meeting the goals.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** The value of the project needs to be re-assessed in light of the lack of storage solution.

**Reviewer 2:** It appears they have not identified alternate storage solutions. Abandoning thermal storage might impact overall LCOH.

**Reviewer 3:** The project doesn't appear to have tasks related to O&M and may be excluding that cost.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The project has input from several stakeholders including an end user for the steam supplied.

**Reviewer 2:** None. They have made progress in raising the technology maturity, complete plant engineering and permitting. These are critical to future success.

**Reviewer 3:** The project could benefit from reaching out to others in the industry that have attempted process heat and perform some lessons learned due diligence. Also, the project appears to be relying on published data for PCM storage and then noting a failure to achieve targets as a failure of NREL estimates. This suggests that the project is relying too heavily on published data rather than rigorous engineering or outreach to others in the industry.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) The project should be reassessed without the storage component in terms of the value it provides. 2) Good job in tackling the high risks first and identifying the drawbacks of the storage system. 3) Although the steam purchase agreement is valuable, the project should be judged on value proposition rather than sunk costs.

**Reviewer 2:** 1) Low cost solar collectors is important - the team has addressed it. 2) Team didn't plan for a failure in TES; they need to assume that trying to minimize degradation with purging H2/N2 to reverse direction of reaction is not reliable. 3) Need to understand what is impact of not having TES - which type of customers would be impacted in case they want to go ahead with no TES.

**Reviewer 3:** 1) Low cost projects that are connected to a customer are interesting and if done inexpensively enough, can pry out cost issues and realities in deployment that can be used to advance the industry. 2) Where the project cites inadequacies in NREL estimates, future awards should have backup when a company is relying on other people's work. 3) It isn't perfectly clear that the milestones relate to actual advancement of the project and should be further verified that the project can advance.

## The Internal Compound Parabolic Concentrator: A Novel Low Cost Solar-Thermal Collection System for Desalination Processes – $1,081,793

*University of California, Merced | Merced, CA | Principal Investigator: Roland Winston*

This project is designing and building a prototype, then testing a novel, low-cost solar-thermal energy system that can reduce the levelized cost of heat to below 1.5 cents per kilowatt-hour thermal, while also incorporating dispatchability and portability features. The project includes the design and development of a new collector or concentrator, called the Integrated Compound Parabolic Concentrator, as well as the design and development of an accompanying thermal energy storage system.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 6 |
| Set critical challenges to overcome | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 0 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 0 | 6 |
| Advance the U.S. solar industry substantially | 0 | 5 |

Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.

**Reviewer 1:** The project documents did not include a status report. The PI has not answered my emails yet so It's difficult to score this project at the moment.

**Reviewer 2:** The UCMerced has been known for developing the compound parabolic trough. In the current configuration, the compound parabolic mirror is implemented internally in a glass tube with heat pipes gathering the reflected light on the back and direct incident light on the top surface of the heat pipes. The approach is novel and provides a potentially cheap solution for a solar collector with TES. Since the TES is in direct contact with HTF, there is no need for heat exchangers which can drive up the system costs. The primary challenges which are being addressed include a) the metal/glass vacuum seal and b) integrating the heat pipes with the tubes c) manifold plumbing, d) thermal cycling of the TES. The team is university-based with the usual challenges of finding continuous support and transitioning it to the commercial sector.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 | 6 |
| Measures impact appropriately (e.g. quantitative) | 0 | 6 |
| Disseminates results frequently and actively engage partners | 0 | 6 |
| Collaborates with sufficient stakeholders | 0 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** No comment.

**Reviewer 2:** The university has a long history with compound parabolic mirrors. The current project has shown significant progress in modeling of systems, heat transfer analyses. The system has shown > 64% solar-to-thermal efficiency at 150C. The team has demonstrated several of the proposed milestones such stability of seals to thermal cycles, tension on the metal-glass seals. The prototype storage media has been thermally cycled at 130C and the thermal storage capacities are higher than minimum requirements. The bench scale prototype system has shown > 500 kJ with a delta-T of less than 15 K. These are important milestones, but long-term testing has to be done to demonstrate long-life in real world conditions.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 0. Comments: No comment.

**Reviewer 2:** Score: 6. Comments: The team has a well-developed program keeping performance and costs in mind. If the project is successful in meeting long-term stability and performance requirements, it stands a good chance of being commercialized and employed in different scenarios including residential heating systems.

**4. What ‘blind spots’ the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** Need to look beyond demonstrating a good technology. They need to be aggressively courting commercial sector.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No comment.

**Reviewer 2:** The team needs to be aggressively courting commercial sector.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** 1) Engage commercial sector more aggressively. 2) Have a solid plan for licensing and infusion - a market survey needs to back it up. 3) More cycles on TES needed. Also, what happens if it is not stable.

# Systems Integration

# List of Reviewers

**Sebastian Achilles**, General Electric

**Rich Bauer**, North American Electric Reliability Corporation

**Rajni Burra**, First Solar

**Antonio Conejo**, Ohio State University

**Lisa Dangelmaier**, Hawaiian Electric

**Pengwei Du**, Electric Reliability Council of Texas

**Ananda Hartzell**, Fimer Spa

**Will Hobbs**, Southern Company

**Andrew Issacs**, Electranix

**Fran Li**, The University of Tennessee

**Clyde Loutan**, California Independent System Operator

**Julia Matevosjana**, Electric Reliability Council of Texas

**Mahesh Morjaria CEO**, REPlantSolutions, LLC

**Sandeep Narla**, Tesla

**Sid Pant**, General Electric

**Ken Pennock**, AWS Truepower

**Miaolei Shao**, General Electric

**Bruce Tshuchida**, The Brattle Group

**Vijay Vittal**, Arizona State University

**Dan Woodfin**, Senior Director of System Operations, Electric Reliability Council of Texas

# Analysis Methodology

Reviewers had evaluation criteria for each project and scored them on a 1–6 scale:

**1** – Strongly Disagree

**2** – Disagree

**3** – Slightly Disagree

**4** – Slightly Agree

**5** – Agree

**6** – Strongly Agree

In addition to numeric scores, reviewers were asked to provide qualitative comments and feedback to justify the scores awarded to projects. Other criteria only required qualitative feedback.

# Project Evaluation Form

**1. The project's goals, approach, and expected impact:**

a. Align well with this topic's goals and support SETO's mission (1-6)

b. Set critical challenges to overcome (1-6)

c. Implement a high-risk, high-impact approach (1-6)

d. Match well with the level of DOE funding and planned project duration (1-6)

e. Add significant value to existing research outside DOE-funded efforts (1-6)

f. Advance the US solar industry substantially (1-6)

*Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.*

**2. Based on performance to date, the project team:**

a. Meets important milestones within reasonable timeframes and budgets (1-6)

b. Measures impact appropriately (e.g. quantitative) (1-6)

c. Disseminates results frequently and actively engages partners (1-6)

d. Collaborates with sufficient stakeholders (1-6)

*Using the above criteria, please summarize the performance of this project in 100-200 words.*

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

*Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.*

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

# Project Reviews

Independent review is an important part of SETO's overall portfolio management process, as it provides alternative viewpoints from leaders in industry and academia on current project activities and strategies. Reviewers who participated in the virtual peer review evaluated projects by assessing project reports and posters written by each project's principal investigator. Any questions about the project were addressed via email exchange between the principal investigator and the reviewer. Each project was assigned two or three reviewers.

Below, you will find a list of the projects reviewed organized by track and topic. Projects are alphabetized by the awardee name and represented in the following format:

**Project Title – Funding Program, Amount Awarded**

*Awardee Name | Awardee Location | Principal Investigator*

Project Description

Project evaluations completed by reviewers are found after the descriptions.

# Photovoltaics for Resilient Distribution Systems

### Reconfigurable and Resilient Operation of Network-Controlled Building Microgrids with Solar Integration – $2,221,000

*Argonne National Laboratory | Lemont, IL | Principal Investigator: Bo Chen*

This project is developing a reconfigurable distribution grid framework for reliable and isolated operation through the dynamic integration of neighboring microgrids. This is one of the first steps toward creating a grid of microgrids. Researchers are focused on the load, storage, and solar photovoltaic device level to enable frequency- and voltage-regulating capabilities in buildings that have solar energy storage with grid-forming inverters and controllable loads. The team plans to further develop these technologies and work toward the dynamic integration and separation of neighboring microgrids, which will be tested in the field.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is very relevant project to address the problem of resiliency in the BTM scenario and finding from this project can be potentially can be potentially extended to the larger distribution network as well. The modelling of Solar + X and the evaluation of dynamic micro-grids approach is very appropriate way to look at this problem. Building energy management combined with inverter controls while maintaining the frequency and voltage is fundamental to the success of this program. The team is good job of meeting some of the voltage frequency criteria and optimizing the use of storage. It will be interesting to see how this work for the rural and Urban BTM micro-grids.

**Reviewer 2:** I believe that the project is aligned with the SETO goals. The algorithm developed by the project team will enhance the resiliency of the distribution grids by maintaining frequency and voltage within the required limits thanks to centralized control of micro-grids in buildings. It integrates energy efficient resources, such as solar into the grid, and at the same time will allow micro-grids to operate as islands and continue the power supply without being connected to the grid. The optimization algorithm proposed by the authors seems to be innovating and promising. The weakness of the project may be in the difficulty of validation of the model and the algorithm under real-time conditions, thus it is unclear if the parameters for voltage and frequency control set in the model can be achieved. Align well with this topic's goals and supports SETO mission – I gave the highest score because I believe that the project supports the SETO goal of enhancing resilience and reliability of the grid with high penetration of solar energy. Set critical challenges to overcome – The project is challenging, it is important for the industry, and part of it is already successfully accomplished. Implement a high-risk, high-impact approach – I don't think that the implementation of this project will be unsuccessful. Since half of it is already done. Impact on the industry seems to be average. Thus gave the medium score. Match well with the level of DOE funding and planned project duration – based on the complexity and challenges to implement the project, the funding and duration seemed reasonable, although the cost seemed a little bit high. Add significant value to existing research outside DOE-funded efforts – there are several organizations participating in the project and performing the research, including universities and research centers, and the project seems valuable to add to their efforts. Advance the US solar industry substantially – the project will contribute to the solar industry, but it is rather local and deals with a narrow subject, which includes not only solar.

**Reviewer 3:** The project objectives are directly aligned and consistent with the goals of leveraging distributed resources to improve resiliency of the distribution networks through the ability in both microgrid autonomous mode and interconnected mode. The performance objectives of the networks are well defined in terms of frequency and voltage performance, and sizing of supplemental storage. The ability to integrate with a variety of energy resources provides flexibility to the solution. The project appears to have had limited interaction with utility or distribution operators which could enhance its visibility and identify possible operational realities that might be included. While a utility advisory team is referenced, the membership was not and details not provided. Thus far the communication and work are primarily investigative and lab-based.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 4 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The milestones are on target. There is bit of under-spending on the budget front which the PI is investigating and will catch-up with the partners. The overall performance is good and expanding it to larger BTM loads and lab validation are key next steps. Certainly there a some key challenges like understanding the flexibility of a given microgrid and delays impacting the control performance in meeting voltage frequency criteria. The team is highlighting the challenges well and also has a mitigation plan.

**Reviewer 2:** From the project description, it seems that there were significant achievements in implementation of the project. Coordinated control diagram is developed for two operating modes. System restoration and energy management framework is developed. Measures of the project impact were specified. control diagram is developed to dynamically regulate frequency and voltage in the entire distribution feeders using a pinning consensus algorithm. Milestones were achieved.

**Reviewer 3:** The project concepts are interesting and the project described in the report has clear objectives and goals. The challenges are well articulated. The project is directly aligned with the objective of evaluating resiliency benefits from DER. The project is essentially academic and research based at this time and might benefit from additional inputs or contributions from both utility operators and large building systems operations.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: I tasks are well aligned to meet the goal. The team should present a view of applicability of this solution to different kinds of BTM loads. What kind of BTM loads are better served and where does this approach have a poor performance or not meet the proposed criteria.

**Reviewer 2**: Score: 6. Comments: The project has several tasks: Develop the coordinated control diagram in a single building microgrid. Develop the optimization model and solution algorithms of reconfigurable dynamic microgrids framework. Develop the frequency and voltage regulation algorithm using a pinning consensus algorithm. Validate the work on IIT's microgrid and ensure the same criteria. Each of these tasks adds unique and important value to the goal of the project.

**Reviewer 3:** Score: 5. Comments: The progression of tasks is reasonable in terms of meeting the state objectives.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The blind spot really may be baked into the assumptions of building load and generation flexibility which are built into the models. Also, the team should get guidance from the IAB on applicability of this solution to BTM loads. What percentage of the US BTM load can be served by this solution?

**Reviewer 2:** I think that validation of the model and the proposed algorithm is important. So far, it is not clear will the model perform in the real-life conditions as well as it is expected. Validation may also appear to be cumbersome.

**Reviewer 3:** In addition to voltage and frequency control, protection from faults would need to be addressed. A challenging question is the criteria for formulating a microgrid, versus remaining interconnected. Good to evaluate the potential scenarios and characterize the resiliency benefit versus traditional utility operation.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Cannot comment without knowing who is on the current IAB.

**Reviewer 2:** The project needs to collaborate with electric utilities and with the owners of the buildings where the microgrids that the project is striving to improve are. Industrial and other commercial customers that may be considered as microgrids may bring more to the project success if they collaborate with the project.

**Reviewer 3:** Building energy management systems and operators, utility operations, manufacturers, and protection.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** SETO must seek answers from this team on the applicability of this solution of the program meets their milestones. If this solutions can serve only 5% of the US BTM market can that be called success? What kind of retrofits need to happen to the current buildings in rural and urban communities for this to be widely applicable.

**Reviewer 2:** The project brings innovated approach to control of microgrids. It will achieve reduction in outage time for the loads, and thus increase resiliency of the grid and also improve frequency and voltage regulation especially for operating in an islanding mode. The project may bring cost savings by decreasing the size of required battery storage.

**Reviewer 3:** 1) Highly aligned with the research area objectives with clear objectives and tasks. 2) Interesting concepts being proven in test environments. 3) Could benefit from expanding stakeholder representation.

## Enhancing Grid Reliability and Resilience through Novel Distributed Energy Resource Control, Total Situational Awareness, and Integrated Distribution-Transmission Representation – $3,002,085

*Arizona State University | Tempe, AZ | Principal Investigator: Raja Ayyanar*

This project is building enhanced grid models by integrating transmission and distribution analyses. Using sensors and communications equipment, this tool can enable coordinated distributed resource responses, which can help increase the amount of renewable power operating in the distribution system.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 4 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 4 | 4 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project aligns relatively well with the SETO missions, focusing on communications and controls, along with cyber security means. The same technology can be applied to other DERs, storage, and smart devices, however, its use outside of DOE is unclear. The project duration (36 months from August 2019 through July 2022) and budget ($3.0 million DOE and $0.9 million cost share) is commensurate with other projects. The overall project schedule and milestone targets also appear to be adequate. The project kicked off in August 2019 and the first milestone is set for April 2020 so it may be too early to speculate if these are achievable targets. One concern is that the project bundles transmission and distribution together. This may have been an appropriate approach when utilities were still vertically integrated with limited external transactions, however, it may be a much more complex issue today than the project team recognizes. For example, Arizona Public Service will be participating in the CAISO Energy Imbalance Market where real-time inter-state transactions occur WECC-wide. Real-time is also where the products developed by the project come in play. Integrating these two different assets that have different regulatory jurisdictions (as an approximation, federal for transmission, state for distribution) will be a challenge that perhaps the engineering focused team may not be prepared for.

**Reviewer 2:** Strength: The program proposes a comprehensive end to end system optimization approach to assess the situational awareness at very high levels of penetration. By streaming 1 sec data from a large number of DER devices into a cloud based central platform, with the objective of making Planning and Operational decisions with a complete situational awareness (of the distribution system and the nearby transmission it is connected to) is a big and a bold strategy. Such a high fidelity data driven approach supported by a real time analytics engine will demonstrate the merits and challenges on this approach. Weakness: This approach from a real world implementation point of view also presents a few challenges: 1) Viability of the approach from the implementation cost point of view 2) Often there are several stakeholders and owners on the distribution systems and getting data from these entities could be challenge. 3) Some of the legacy systems do not support smart data exchange and hence may not be visible and loss of communication could be a common problem. Broad Scope: The Scope of the project seems to spill into 2 of the sub areas: 1) PV for Resilient Distribution Systems and2) Power electronic devices and controls. This could make this program largely academic in nature, which should be construed in a -ve sense. Future programs may be needed to pick smaller portions of the project with a goal to enable large scale adoption and commercialization of the technologies developed.

**Reviewer 3:** The project investigates some interesting approaches to managing the distribution system and has a reasonable contribution from various stakeholders and some actual field data. The approaches are modeling intensive and complex which would be a challenge for widespread deployment.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The milestones and associated schedules for the first year are identified in the report. However, while the report indicates a Go/NoGo decision in May 2020, there are no milestones or decision criteria discussion. Milestones for year two and three are not discussed. While the project only started in August 2019 and they only spent 3 quarters to date, the report indicates that the team is generally on track. Externally, the team appears to have been sending surveys to industry participants to get input and seem to have been discussing them along with their interim results among team members.

**Reviewer 2:** As mentioned above this project has a very broad scope from 2 different systems sub-groups. There are 4-5 different aspects of the project that need to come together. The project partners have the right competencies and can potentially accomplish this successfully. At this point it seems like the project is a bit delayed.

**Reviewer 3:** The project involves academic, research, developer and industry representatives. The project progress seems reasonable for this point and may be impacted by current supply chain issues. The measures are quantified but, how these measures relate to distribution system performance is not entirely clear (i.e.; hosting capacity accuracy within 90%, does this prevent issues?).

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: While the tasks are described in the report, the schedule is not and even if one assumes the tasks will be executed in the order of the task numbers, it is difficult to understand how each task feeds into others, and at what timing this occurs. The tasks discussions are largely focused on the technicality (which is necessary to some degree) of each task and fails to demonstrate the connectivity of each task and the role they play towards the overall project. The report could be improved if the larger narrative of the tasks and milestones could be provided, rather than discuss the technical details that the current report focuses on.

**Reviewer 2:** Score: 6. Comments: The tasks in the project add significant value to the overall project and are well defined. However, the timelines may have to be adjusted.

**Reviewer 3:** Score: 5. Comments: The tasks are reasonable and in accordance with the goals.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** One concern is that the project bundles transmission and distribution together. This may have been an appropriate approach when utilities were still vertically integrated with limited external transactions, however, it may be a much more complex issue today than the project team recognizes. For example, Arizona Public Service will be participating in the CAISO Energy Imbalance Market where real-time inter-state transactions occur WECC-wide. Real-time is also where the products developed by the project come in play. Integrating these two different assets that have different regulatory jurisdictions (as an approximation, federal for transmission, state for distribution) will be a challenge that perhaps the engineering focused team may not be prepared for.

**Reviewer 2:** Please reassess the timelines and the funding requirement to align with the scope.

**Reviewer 3:** The data requirements and complexity of the project are substantial. Does the approach provide significant benefits in terms of DER potential over existing and proven methods, to make the investment worthwhile?

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The potential weakness of the team is that it lacks a balanced leader and a commercialization expert. The report style also focuses heavily on the technicality while not so much to the overall picture (for example, the task description does not hint on how each task flows into others, at what timing). A well-versed leader could perhaps balance this bias and help coordinate the product launch with a commercialization expert (which the team is lacking).

**Reviewer 2:** The current scope makes this project academic. Please identify the key technologies that can adapted for commercialization in the short term. Once we have that we can make a determination on the key stakeholders that are needed and may be mission.

**Reviewer 3:** Does this project compete with existing distribution management systems?

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** The project aligns relatively well with the SETO missions focusing on communications and controls, along with cyber security means. The same technology can potentially be applied to other inverter-based technologies as well. However, the potential weakness of the team is that it lacks a commercialization expert and a leader who can balance the technical side and commercial side. There is also concern that the team may not necessarily appreciate the jurisdictional and functional difference that exists between transmission and distribution.

**Reviewer 2:** The Scope of this program probably needs to reduced. For example, the smart inverter control can be removed and could be allocated to different program. If that is not possible the timelines and budget may have to be adjusted. Viability of the approach needs to presented. What does this approach cost? Trade-of between cost and reliability could be key outcome that may be needed. If this is data driven approach, what happens when the data is lost due to loss of comms or attack?

**Reviewer 3:** 1) The project has a good mix of contribution from developer, industry, and research contributors. 2) The approaches are interesting but require complex modeling and communications. 3) The incremental benefit in terms of DER integration over more simple and proven approaches would be a useful measure.

## Solar Critical infrastructure Energization System – $5,792,342

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Brian Seal*

This project is developing a pre-planning analysis technique, using new communications standards and advanced inverters, to determine how to methodically supply power to critical infrastructure with any resource available on the grid. To validate this technique, the team is working with several partners, including Austin Energy and Pecan Street.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aligns well with the SETO mission—the project develops an approach where DERs, including solar, are utilized in advanced ways to remedy the critical infrastructure during emergency conditions. It enhances the role of solar while addressing resiliency of the electric power system in an agile way. The team appears to be well-balanced with different expertise, including a utility, solar developer, national labs, academia, operation system developers, and others. The product developed could potentially help research activity beyond DOE—for example it could be applied in designing remote bases for military or mining industry. The project duration (37 months from December 2019 through December 2022) is commensurate to other projects. The budget ($5.6 million DOE and $2.7 million cost share), with more than adequate cost share, is among the highest. However the benefits, if realized, appear to justify the higher budget. The schedule and milestones also appear to be well thought through. The key challenge may be how to get the industry to use the technology developed after it is launched.

**Reviewer 2:** This project is directly aligned with the SETO objective to leverage DER for improved resiliency. The project benefits from a comprehensive representation of stakeholders: research, inverter developers, utility, The approach is novel as compared to other reviewed microgrid studies in that it leverages existing resources to supply resilience rather than requiring investment up front in specific resources to support potential microgrids that would only be used in a rare circumstance. This provides for a more complex, but also, likely more feasible (affordable) mechanism to supply key sites and infrastructure with energy during major disruption events. The project will culminate in field testing in partnership with the participating utility. The project also engages various types of DER including load-management, which enhances the viability and applicability in real-world application. The differentiation between critical and non-critical loads is also a key factor in leveraging available DER to serve critical needs.

**Reviewer 3:** This project develops a new process and control system that locally operates solar and storage resources, the grid, and manageable load to provide energy to critical infrastructure during emergencies. The project is well thought of and has ambitious goals. It has diverse tasks including assessment method, developing new control methods, and control functions of the inverters, cyber-secure technology and architecture for resilient communication systems. The weakness may be that with such ambitious tasks, it is not clear if the project will be completed in time and how validation of the project will work. Validation is planned in one system by testing and/or actual events. It is also not clear which criteria is used in determination which loads are critical and need to be continued to be served from DER and which loads need to be curtailed, so far it is planned to be done manually. The project reconfigures the grid to route the energy to critical loads, but doesn't have a backup plan in case the route to critical loads is not available. Another weakness may be that to expand the project to be used by other electric utilities, an interest group that includes other entities should be formed. Although the project seems to be valuable, is unclear how wide the interest will be.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 0 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 0 | 5 | 6 |
| Collaborates with sufficient stakeholders | 0 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team started working in December 2019. Given that there has been less than a quarter spent to date, these questions may not be applicable to this project at this time. The report does outline their milestones in detail.

**Reviewer 2:** The project is at its inception, but the theory appears quite promising and the project team has a very complete representation of researchers, der developer, and industry. The objectives are well described however the measures of success were not quantified in specific measured terms, instead being on stakeholder feedback. The project has a well-defined plan for dissemination of the learnings to industry.

**Reviewer 3:** The project requires large, although reasonable budget, and has an aggressive schedule. Expected impact of the project is significant, since it can be widely used, and it will allow to continue to serve critical loads in cases of emergency and disasters. It will allow to achieve a more resilient distribution system. The project performance was not evaluated in sense of numbers, but it is hard to estimate quantitatively. The project proponents provided a list of milestones and schedule of deliverables which is reasonable, although quite tight with many tasks to be accomplished in a relatively short time. There are several collaborators on the project that include an energy company, a company that performs modeling and also energy management company, research labs and inverter company.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: While the report does not provide a schedule with tasks, it does list the milestones, their scheduled due date, and their evaluation criteria. The report also discusses the overall scope and schedule by year. This helps the reader understand the overall scope and steps needed. However, without the task descriptions, assessing whether each task adds unique and important value to achieving the overall goals of the project, with the current report, is not feasible without speculation.

**Reviewer 2:** Score: 6. Comments: This apparently novel approach would provide methods and tools to assess if in-place DER can be leveraged to support critical infrastructure, and configure and operate these systems. The project is comprised of a good mix of contributors that seem well qualified to complete the objectives. This approach holds promise in being able to leverage DER for resiliency, consistent with SETO objectives, without requiring extensive investment to locate DER specifically for the resiliency benefit.

**Reviewer 3:** Score: 6. Comments: The project consists of five tasks, which are different in nature, but each brings value to the project, and the project couldn't be implemented without all these tasks.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project team should think through what success means. Success should not simply be a good software but include commercialization and/or deployment by utilities. Expanding the role of the utility team member and reflecting on NREL's experience in launching spin-off business should be planned as part of the larger goal.

**Reviewer 2:** In addition to evaluating operability the protection of the systems is important. It might be important to identify if the in-place DER typically provide the flexibility to be used in the manner needed to support this theory. The owners/operations of DER would need to be willing to have their resources used to serve the objective of providing energy to critical loads.

**Reviewer 3:** It is not clear what method will be used to determine which loads are more critical and which can be curtailed and will it be performed automatically. Also, if there are any backup plans if pathway from DER to critical loads cannot be identified. The project requires grid-forming inverters, which are not in wide use yet.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The team is a diverse team that is relatively well-balanced. If anyone, a commercialization lead that can balance the varying needs of the team members may help. For example, the utility member may want to withhold certain parts of the technology developed from being commercialized siting security issues while other members may want to head towards full commercialization. With that said, if team dynamics can be managed within the current team, for example, NREL acting as the neutral middleman in such cases, there may not be a need to extend the team beyond what it is today.

**Reviewer 2:** It could be useful to survey existing DER owners/operators to evaluate the willingness to participate in the resilience microgrid for the purpose of serving critical infrastructure (which may not be their own load).

**Reviewer 3:** I think that the project authors can also collaborate with more electric utilities.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project aligns well with the SETO missions in multiple ways and appears to be well thought-through. However, the project team should think through what success means beyond developing a suite of good software. Commercialization of the software suite (or deployment by utilities) should be in sight. This can be done by harnessing the experience that exists within the team (for example, NREL's experience in launching spin-off business) or by adding a neutral expert. The project team appears to be a large and diverse team that is relatively well-balanced at the moment but they should be aware that team dynamics could lead to either the success or failure of the project.

**Reviewer 2:** 1) The project is a novel and very interesting approach to utilize existing DER to meet the country's resilience objectives during disturbances and outages, rather than designing microgrids with additional emergency use resources. 2) The project is well defined, with a good mix of contributors, to support the technical developments, modeling and field testing. 3) The project has a well-defined and complete plan for sharing the learnings from the project to the general industry.

**Reviewer 3:** The project is important to enhance resilience of the grid and allow to serve critical loads in cases of crisis and emergencies. It is innovated and will use a new process and a new operation system. The project needs more avenues for its validation then just one energy company where they plan to validate it. Since the project is intended to be used only in critical emergencies and during crisis, it may be used very rarely.

## Faster-than-Real-Time Simulation with Demonstration for Resilient Distributed Energy Resource Integration – $3,115,048

*Electrical Distribution Design | Blacksburg, VA | Principal Investigator: Dan Zhu*

This project team is developing a technique to speed analysis of power flow using graphic trace analysis, or outputs from a bar graph instead of complex calculations, and then validate it in the field with its project partner, Pepco. The goal is to enable evaluation of the distribution network down to the secondary network and allow for rapid detection of power system abnormalities caused by instability, cyber intrusion, or other factors.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 5 |
| Set critical challenges to overcome | 4 | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 3 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 2 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project somewhat aligns with the SETO missions but only in a limited way—communication among the different segments of the power system (transmission and subtransmission and various components of the distribution network) including DERs, and associated cyber security. While solar has a large share of the DERs, this can be any technology—for example, it can be communication between EVs and storage, or smart appliances, and the utility. SEPA is part of the team and hopefully this will not sway the team away from looking at opportunities beyond PVs. The project focuses on integrating the different segments within the power system electric and therefore the applicability beyond DOE associated research is also questionable. The project duration (36 months from November 2019 through October 2022) and budget ($3.5 million DOE and $1.4 million cost share, most of the cost share appears in the last year) is commensurate to other projects. The overall schedule and milestones are not described with sufficient details and are unclear. The milestones reached to date (noting that the project was just kicked off in November 2019) appear to be rather in the preparation phase than the actual analysis phase and is hard to assess without further details.

**Reviewer 2:** Firstly, I would like to thank and congratulate the project supporting groups for taking up on a great subject of focus. Given the increased penetration of DER and their adoption, it is time for in-depth system level dynamics study involved in end to end process of generation, transmission, distribution and controls. While multiple supporting groups already realized part of the algorithms they developed over the years and bringing that knowledge together for a purpose, it will definitely be a challenge and high risk to prove the integration of these algorithms into function. The project scope of DER is limited to Solar and would have been useful to include Wind as it is also a bigger part of DER today and as its forecast is also dependent on weather. More details on the use-cases and abnormalities would have been useful to understand the extent of study. In specific regards to the solar smart inverter and ability to control for grid stability has been very much proven in the last 5 years and hence in that regards, this project will not be providing much advancement. It will be interesting to see if the load forecast considers EV (electric vehicles) as part of the study to be useful and contemporary to today's world. Great work!

**Reviewer 3:** The project approach seems to be novel, designed to leverage existing available data from meters, adms, scada/ems; and articulates the reasons an adaptive integration tool is required to adjust for changes in demand and weather. It is especially appreciated that the project includes comparison of the integrated control to the (existing) local autonomous control. Acknowledges real-world challenges of modeling and data from different sources and organizational entities.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project only started in November 2019 so it is just in their second quarter. So far, the report indicates they have met their milestones to date, although it isn't clear if any were not met and simply not discussed. The report also indicates the team members are aware of the current status and lessons learned from the work to date. The team has engaged SEPA as an outside industry group, however, SEPA's involvement to date is also unclear.

**Reviewer 2:** Since there is a lot of models and algorithm integration work needed, there will be challenges and pose risk to the project. The yearly reviews planned will be a good opportunity to check on the progress of the milestones provided. The project scope is broad and an interlink to many critical functions of the technology. I recommend for a quantitative observation during the project study as that will help drive the further study when this project concludes. The results were expected to be more subjective. The study definitely covers the appropriate stakeholders needed for the completion of the project. Recommend to allot more budget for equipment and supplies, the allocation seem very low than needed.

**Reviewer 3:** The project is in its early stages so it is difficult to characterize performance at this point, but is has engaged with SEPA to leverage information sharing. The project includes a good mix of research an industry, including a utility partner, SEPA, lab and academic research entities. The objects and purpose are well articulated and utilize typically available models and data, while recognizing the challenges in created integrated models.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The report does not articulate any tasks. Rather it discusses the project objectives and associated timelines—which at a high level is; design the product in year one, develop the actual product in year two, then field tests the product in year three. If that is the case, these steps are likely adequate. The report also identifies four milestones without indicating when they are to be achieved (one can perhaps guess the numbering of the milestones could be corresponding to the three years discussed, however no description that suggests so is provided). The report could be improved if the larger roadmap and milestones could be provided.

**Reviewer 2:** Score: 5. Comments: The project adds to the importance of managing dynamics of DER penetration with the 100year old Utility grid system and next generation SCADA controls. The industry is still very new to Cyber security and estimating the abnormalities that can happen in the future. Identifying the specific use-cases, gathering accurate real-time data and integration is the right approach and much needed. With the experienced supporting groups, this study will lay foundation to more in-depth analysis.

**Reviewer 3:** Score: 6. Comments: The tasks are grouped in logical progression and focused on specific issues. 1) Testing and comparison of the centralized approach used in the project with autonomous controls. 2) Testing methods and impacts on voltage instabilities and cyber issues in the field. 3) Field demonstration of the methods based on lab results.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The diverse team is relatively well-balanced. The larger question may be which member leads the commercialization effort after the product is successfully developed. The diverse team, by nature, may find some internal conflicts. A key question is whether PEPCO would deploy the technology, and how to find other potential customers afterwards. The team may not be fully appreciating the efforts needed for commercialization.

**Reviewer 2:** Need more focus in the model and algorithm integration from various groups. Regular interactions with SME (subject matter experts) are a must-have for this project as much of the part models or algorithm are already realized. Recommend for more budget allocation to the equipment and supplies. Include results to be quantitative and that can make the project tasks varied from what is highlighted in this report.

**Reviewer 3:** The project might benefit from a more formal strategy for sharing of results.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The team is a diverse team that is relatively well-balanced. If anyone, a commercialization lead that can balance the varying needs of the team members may help. For example, PEPCO may want to withhold certain parts of the technology developed from being commercialized siting security issues while EDD may want to head towards full commercialization. With that said, if team dynamics can be managed within the current team, for example, as SEPA becoming the middleman in such cases, there may not be a need to extend the team beyond what it is today.

**Reviewer 2:** This selection of supporting groups seems appropriate and good for this study. Universities, Utilities and Industry alliance.

**Reviewer 3:** The project has a good mix of stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project only aligns with the SETO missions in a limited way and, therefore, the contribution to the US solar industry advancement may not be so high. However, the technology developed could be applied to a broader range—for example, it can be communication between EVs and storage, or smart appliances, and the utility. The team appears to be a large and diverse team that is relatively well-balanced at the moment but the team should be aware that team dynamics could lead to either the success or failure of the project. The role of SEPA, beyond advertising the technology developed, is unclear and perhaps it could be expanded to guide the diverse team to a common goal, especially during as the project enters the commercialization phase.

**Reviewer 2:** 1) More milestones be focused on the integration progress. 2) Evaluating sub-section validation in the early stages, rather than wait till the end. 3) Allocate more budget to equipment and supplies.

**Reviewer 3:** 1) The project objectives and potential benefits are clearly articulated. 2) The project appears to have a novel approach to the problem which is based upon leveraging existing sources of data in today's utility operations, while recognizing the challenges of creating an integrated source. 3) The project provides useful insights by comparing approaches against existing, simpler autonomous control and including field trials.

## Low-Cost, Plug-and-Play Data Diodes for Solar Equipment Cybersecurity – $1,200,000

*Fend Incorporated | Falls Church, VA | Principal Investigator: Colin Dunn*

Solar energy equipment is made by a small number of manufacturers, increasing the risk of economic disruption from a widespread, distributed cyberattack on industrial photovoltaic control systems. This project is developing the "Data Valve," a low-cost, plug-and-play information transfer device that provides unhackable, physically-enforced security with real-time equipment monitoring. This tool could prevent the large economic disruption that could be caused by a distributed cyberattack on industrial control systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 | 6 |
| Set critical challenges to overcome | 4 | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 3 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 4 | 6 |
| Advance the U.S. solar industry substantially | 2 | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** First, I would like to thank and congratulate Fend for taking the responsibility in improving cyber security for solar systems via hardware. This topic is very important to the solar technology in general. Even though the solar deployments are happening for the last 40yrs, most of the grid-tied or micro-grid systems are designed to operate autonomously and relies very less on external controls. But with the recent advancements of smart inverter functions and desired monitoring of the systems for performance makes it vulnerable as the dependency on the remote control and access has increased. However, the cyber security for IT services, data centers, cloud platforms has been established for years and continuously improving. Most of these are based on software protocols, and other mechanisms built on top of the hardware. Solar industry is very new to security protocols and is incorporated with the recent IEEE and smart inverter functions development. Relying solely based on hardware and with limited supported to specific communication protocols will stand as a weakness to this product.

**Reviewer 2:** The project is aligned with the SETO missions in that it has developed a communication means tailored for solar assets. The underlying technology can likely be used for other applications (in fact this project was more of refining that product to be useful for solar assets) and has the potential to add values beyond DOE research activities. However, it may not directly contribute in advancing the US solar industry, nor lowering the LCOE in general—although providing situational awareness to the operators could potentially reduce curtailment and therefore lower the LCOE. The project duration (38 months from July 2018 through August 2021) is commensurate with other projects while the budget ($1.1 million DOE), despite having no cost share, is significantly lower than others. The team appears to be checking the milestones, however, their forward schedules and milestones are somewhat unclear. For example, the report indicates a Go/NoGo decision scheduled for summer of 2020 but no specific milestones are assigned to it.

**Reviewer 3:** This project presents a novel hardware solution to cyber security. The data diode presents an optical separation there by literally creates a physical firewall. This is paradigm shift in the cyber security. This could be a game changer for the solar industry and IoT in general. A two way communication is typically required in a solar field and scalability could be challenge as well since a solar plant potentially needs to exchange a huge about controller and SCADA data.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 2 | 5 | 5 |
| Collaborates with sufficient stakeholders | 2 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Given that this is hardware product development and emphasize on the scalability of the product for greater cost reduction compared to other products. The budget proposed seem less and can be boosted for support. Also, the development group could not summarize the level of testing that is done against the common cyber threats possible or tried on. This is a product from a sole company and visibility of product acceptance with industry wide utilities is a weakness. A good portion of the budget shall be allocated for testing to specific use-cases and conditions expected. A review and recommendations from country wide IOU's, ISO's, IEEE, Sandia labs, NREL and Cyber security testing labs will be helpful.

**Reviewer 2:** The project has two phases and the second phase started in August 2019. The report discusses the milestones and achievements to date, indicating the team is on track. The team appears to have been collaborating heavily with other industry participants, and also utilizing their connections for disseminating internal results, creating a very positive feedback cycle.

**Reviewer 3:** Phase I was completed on time and within the budget, and Phase II is on track to perform similarly. Fend has achieved its expected Phase I results and are on track to successfully complete Phase II with the successful commercialization of its data diode hardware and optional cloud-based data platform. Fend has created a low-cost data diode for the solar energy market that is in use in the field today and has resulted in commercial sales. Fend successfully completed all of its Phase I milestones, including field testing at two local commercial-scale solar installations.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Since this is product development and scalability factor is the most critical element. Defining use-cases and conditions, validating and certifying with the cyber security standards at labs, review from industry wide utility experts is needed. Manufacturing and product adoption need to be very simple and low cost to achieve that.

**Reviewer 2:** Score: 3. Comments: The report does not articulate any tasks. Rather it discusses the project achievements to date including milestones. The reading suggests the project to be on track. However, assessing whether each task adds unique and important value to achieving the overall goals of the project, with the current report, is not feasible without speculation.

**Reviewer 3:** Score: 6. Comments: Fend is in the process of completing Phase 1 tasks. Field tests of phase 1 diode, two-way diode prototype are all scheduled for this year. Fend is also working on making the diode robust. The project seems to be on target in all respects.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Need to gain knowledge of industry wide Cyber security standards and use cases. Even with 90% cost reduction still leaves the product to be very expensive and hard to adopt. Need to compare again the standard software based security protocols implemented in IT industry, data centers and cloud platforms.

**Reviewer 2:** The project seems to be well under control—however, the detailed plans for field testing is unclear. For example, will a NRECA member utility be a host for the field test, or will it solely be performed within the existing team members? What would be the criterion for field test? Also the interface with the ultimate user (likely utilities and solar customers?) is unclear.

**Reviewer 3:** Applicability to a large-scale vs a small scale PV program. Do the costs scale well for a 5kW project to a 50MW project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** A review and recommendations from country wide IOU’s, ISO’s, IEEE, Sandia labs, NREL and Cyber security testing labs will be helpful.

**Reviewer 2:** The team seems to be well-diverse and balanced, including several commercialization experts (which many project teams lack). A host for the field testing (such as a utility) could greatly benefit the project.

**Reviewer 3:** Fend is approaching all the relevant stakeholders at this point.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** SETO should continue to encourage more cyber security advancement in the solar industry. SETO should try to collaborate experts from other industries to Solar technology on this topic. SETO could encourage more hardware, software and mixed solutions to defend cyber security threats.

**Reviewer 2:** To date the project appears to be on track. However, the tasks to date have been focused on designing and developing the technology. The plans for the upcoming field tests and commercialization of the technology afterwards are unclear and would benefit from further review.

**Reviewer 3:** 1) Cost. 2) Scalability. 3) Large scale adaption by the solar industry. 4) Reliability of this new component on small vs large PV project. SETO should look evidence on these items and a compare it with the state of art cyber security measures. For example compare the FEND technology on the SHINES project installation.

## Integrating System to Edge-of-Network Architecture and Management – $2,400,566

*Hawaiian Electric Company | Honolulu, HI | Principal Investigator: Shari Ishikawa*

This project is working to validate the system-level benefits of enhanced utility visibility and control of distribution system and edge-of-network electricity resources. This project aims to enable proliferation of a reliable base of solar-plus-storage distributed technologies that offer more plug-and-play customer options for grid participation, and provide cost-effective grid response capabilities to system operators.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 6 |
| Set critical challenges to overcome | 3 | 5 | 6 |
| Implement a high-risk, high-impact approach | 3 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 3 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 3 | 4 |
| Advance the U.S. solar industry substantially | 3 | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aligns with the SETO mission in that it demonstrates one particular configuration of a hybrid system that enables and enhances DER (storage and solar) operations from the utility. The application appears to be tailored towards the utilities' specific systems so there may be limitations on how they can be applied to others, including its contribution to research activities beyond DOE. The project is almost completed and the duration (39 months from March 2016 through May 2020) and budget ($2.4 million DOE and $2.4 million cost share) are both on the higher side, although still comparable to other projects. The cost share of 50% is much higher than other projects but perhaps it is associated with the various hardware/software specific to this project. The project appears to have been run on schedule meeting all the interim milestones, although the scope of some of the milestones were modified to meet budget constraints. While the project did demonstrate the technical feasibility of a given system configuration, it is unclear if the product developed is economically advantageous, or if it will help advance the US solar industry, in general. The LCOE calculation, which is one of the tasks the remaining, should help clarify it.

**Reviewer 2:** The project demonstrated successful SHINES (Sustainable and Holistic Integration of Energy Storage and Solar PV) deployments and showed the system-level benefits of enhanced utility visibility and control of distribution system electricity resources. It achieved visibility of DER resources and control of single and multiple DER resources with a single command and implemented several technologies. The project will be useful for the utilities with high penetration of distributed solar PV. The DER data is refreshed every 15 minutes, which seems too much time between the data. The project authors are working towards of less time between the data. The forecast for the DER output is currently in 1-2 hour timeframe. Day-ahead forecast accuracy is low because of the island system with a limitation on where irradiance and wind sensors can be placed. Satellite information doesn't always provide high accuracy near the ground. Thus, decisions on unit commitments of renewable resources cannot be made enough in advance. The project can control DER active power, but it doesn't control other values such as voltage and frequency. It seems that the project has rather limited applicability.

**Reviewer 3:** This project presents a Grid EDGE technology template for communication and control of various DER devices using commercially available equipment. Real time visibility of DER devices has been demonstrated in this project and can be expanded to other DER equipment on the distribution network into a central analytics platform to assess the situational awareness. A network architecture with several DMZs (with multiple firewalls) like the Hawaii Electric DMZ and the HECO DMZ can quickly add to the cost of IT infrastructure in a high DER penetration network.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 2 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 2 | 3 | 6 |
| Disseminates results frequently and actively engages partners | 2 | 6 | 6 |
| Collaborates with sufficient stakeholders | 2 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is almost complete. It appears that the scope has been changed a number of times to comply with budget constraints or vendor changes, rather than technical discoveries. This may indicate communication issues, or inadequate planning upfront. The fact that the LCOE calculation is still not available at this timing (two months before project completion date) is also alarming. While there appears to have been internal discussions within the team, and a two-day workshop attended by the Utility/Balancing Authority Advisory Team (UBAT) with 22 utility and Balancing Authority members, any outreach beyond this is unclear (the report suggests a few options but does not say the outreaches were executed, despite the fact that the project is almost at its end) and there is no discussion about sharing interim results with external parties.

**Reviewer 2:** The project is almost completed, however the final completion date was postponed. The part that is left is the Least Cost analysis. The budget allocated for the remaining part seems too large. The project results were reported on a frequent basis. Advisory team was formed to monitor the project. The impact of the project can be significant, but only for utilities that have high penetration of distributed solar PV. There were multiple challenges, including several vendors dropping out of the project. It seems that the project performed satisfactorily. One of the tasks was to determine the pros and cons for utilizing OpenADR versus IEEE 2030.5 protocol. These protocols were recently tested and the IEEE 2030.5 protocol appeared preferable because it allows to control voltage and frequency set points. The OpenADR allowed only to perform simple commands, however, is was easier to implement it compared to IEEE 2030.5. The testing results were not included in the project report because they were performed only recently.

**Reviewer 3:** The project seems to have implemented the following: 1)IEEE 2030.5 protocol across all devices. 2) OpenADR integration between the WebSDK to the Energy IP DEMS and the STEM batteries and ConnectDER aggregated systems.
3) 4 SHINES devices in the field including storage, PV emulator and demonstration of the demand response program.
4) LCOE calculations. A very good and practical demonstration of DER on the grid edge.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: The report does not articulate any tasks. Rather it discusses the project achievements to date (note that the project is almost complete), which indicates that the project team went through a lot of scope adjustments throughout the project. This may indicate that the planning, including the task definition and how each task respectively added unique and important value to achieving the overall goals of the project, could have been improved. A review of how it could have been done with 100% hindsight may be valuable to the SETO awardee community as a whole.

**Reviewer 2:** Score: 6. Comments: The project has four tasks: 1) Design "grid response" control capabilities involving SHINES technology providers, customer and utility perspectives; 2) Develop and deploy integrated SHINES technologies with edge-of-network data, communication and forecasting support; 3) Demonstrate SEAMS intelligence via SHINES to "practically" manage distribution level issues introduced by high penetration PV and solar variability; and 4) Evaluate cost effectiveness of SHINES and integrated SEAMS capabilities to support reliable grid transformation needs. Each of them adds unique value to the project.

**Reviewer 3:** Score: 6. Comments: All the tasks are complete and the projects end in May 2020

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project team seemingly went through a lot of scope adjustments and member changes throughout the project. A review of how it could have been done with 100% hindsight may be valuable to the SETO awardee community as a whole. Also, an evaluation of how the technologies developed can be easily applied to other inverter based technologies and other systems would be beneficial.

**Reviewer 2:** The project provides visibility for DER, but time intervals are too large. The project authors need to work on having data delivered at shorter intervals. It can control output of the DER, but to control voltage and frequency more complicated protocol, that has some technical challenges needs to be used.

**Reviewer 3:** I don't see any blind spot at this time. The project is almost complete.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project is led by the utility and with the sub-contract structure, the decision making process may have also been dominated by the utility. An independent project manager that balances the overall team would have been beneficial. This project manager could also help evaluate how the technologies developed can be easily applied to other inverter based technologies and other systems would be beneficial.

**Reviewer 2:** I think that the project needs to collaborate with more vendors of smart inverters, and engage more electric utilities that could use the project.

**Reviewer 3:** All the current SETO systems program PIs can learn from this project. Also, the report should be disseminated to all the DER working groups and beachhead distribution utilities that are in the process of adding grid edge technology.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project is at its wrap-up phase and yet a lot of things are not tied up (for example, the LCOE calculation is still not available, there is nothing to suggest adequate outreach has been execute, or any indications of reflecting the lessons learnt from the multiple hurdles experienced through the project). A review of how it could have been done with 100% hindsight may be valuable to the SETO awardee community as a whole. An evaluation of how the technologies developed can be easily applied to other inverter based technologies and other systems would be beneficial.

**Reviewer 2:** The project develops and deploys integrated SHINES (Sustainable and Holistic Integration of Energy Storage and Solar PV) technologies with edge-of-network data, communication and forecasting support and an architecture linking devices to associated operating system for the electrical grid. The project will provide visibility of the distributed energy resources and will allow for their centralized control. However, it has rather narrow applicability and its economic benefits are unclear.

**Reviewer 3:** Each of the systems program PIs can learn from this project and build on the outcomes. This will allow them to evaluate the pros and cons of this implementation and build on this.

## Enabling Cyber Security, Situational Awareness and Resilience in Distribution Grids with High Penetration of Photovoltaics – $2,110,790

*Kansas State University | Manhattan, KS | Principal Investigator: Bala Natarajan*

This project is developing a compressive sensing method that requires fewer inputs than usual so grid operators can observe quickly-changing grid conditions and determine vulnerabilities in critical infrastructure. The team is developing smart inverter controls to detect cyber intrusions and initiate network defenses.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 4 | 4 | 4 |
| Implement a high-risk, high-impact approach | 4 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 4 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project aligns relatively well with the SETO missions and helps reduce curtailment (which effectively lowers the LCOE). The same technology can potentially be applied to other inverter-based technologies, however, its use outside DOE is unclear. The project duration (36 months from August 2019 through July 2022) and budget ($2.1 million DOE and $0.7 million cost share) is commensurate to other projects. The overall schedule and milestone targets from the technical side appear adequate. One point that may be missing is a critical review towards their achievements. For example, will they be comparing the performance of their self-learning PV inverters against the traditional passive inverters even after the testing phase, and if so, would they consider switching off the "self-learning" function if they find it may not be adequate under certain circumstances? The project also claims the self-learning inverters can help with the operations of the distribution grid. This may well be a potential, however, the project members may want to look into how much information the utility operators can absorb and process.

**Reviewer 2:** The project as defined has three objectives and it wasn't clear to this reviewer how these objectives were linked with each other: intrusion detection, lack of visibility points, and detection of stable operation. While cyber secure, stable distribution resources are important, detecting intrusion requires some means to resolve the issue once detected and this reviewer is unsure if stability and lack of data points is a major hindrance to DER integration at present. Perhaps this would be more clear upon reading the cited references and linked web page. These comments are based solely on the report material. The approaches seem to involve a high degree of complexity that might be challenging for the typical utility to implement, as well as the industry to adopt the inverter capabilities.

**Reviewer 3:** I would like to thank and congratulate the project supporting groups for taking on this focused topic. The approach of modeling to experimental validation is commendable. It is not clear on what level of fundamental blocks were already developed and ready for use to system integration. Since the experimental validation comes later in the period, the equipment costs seem low and need to be boosted. This research mostly focusses on the automated optimized control of PV systems response behavior to abnormalities and less dependent on other ways to enhance or boost the grid resilience. The quantitative expectations on how much the enhancement can be made is missing in the conclusion. The risks of the project are not mentioned for clarity. This project seem more apt for a academia focus rather than commercialization and scalability in the wide platform.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project started in August 2019. While there is only 3 quarters-worth of time spent to date, the report discusses the project status as a percentage of completion. However, it does not evaluate the progress against any milestone, nor does it explain what these completion level means (such as ahead of schedule, on-target, delayed, or others). The report does discuss the team's findings and suggests the team is aware of their achievements and potential shortfalls observed through the work to date. The team has released several papers about their interim results and has plans for presenting in industry conferences. It appears that they have an industry advisory board but details are not discussed.

**Reviewer 2:** It seems the project is primarily a research and proof of concept or academic type of project conducted in a laboratory environment. It is difficult to concretely measure the progress of this type of project which is heavily model based and much of the work to date is in developing the models and performing analytics. There have been several published findings to date, at various industry forums. It is not clear if there has been any interaction with DER developers or utilities for feedback on these issues and methods of solving them.

**Reviewer 3:** More universities and national labs might add value to the research done here. The simulations may depend on the assumptions made in the fundamental algorithms. The quantitative expectations on how much the enhancement can be made is missing in the conclusion. The risks of the project is not mentioned for clarity. This project seems more apt for a academia focus rather than commercialization and scalability in the wide platform.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The tasks are not articulated in the report but it appears as the team is planning, at a high level, to design the product in year one, develop the actual product in year two, then field tests the product in year three. If that is the case, these steps are likely adequate. The report could be improved if the larger roadmap and milestones could be provided, rather than discuss the technical details as the current report has focused on.

**Reviewer 2:** Score: 5. Comments: The tasks are to develop the models, methods, algorithms, and designs.

**Reviewer 3:** Score: 4. Comments: Yes, tasks are well defined but the scope seem narrow and conclusive on the objectives.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** One point that may be missing is a critical review towards their achievements. For example, will they be comparing the performance of their self-learning PV inverters against the traditional passive inverters even after the testing phase, and if so, would they consider switching off the "self-learning" function if they find it may not be adequate under certain circumstances? The project also claims the self-learning inverters can help with the operations of the distribution grid. This may well be a potential, however, the project members may want to look into how much information the utility operators can absorb and process.

**Reviewer 2:** Evaluate if the issues identified are of substantial concern for DER integration today. Are there simpler approaches to meeting the needs, than the ones proposed, and would DER be willing to participate in the manner described? Wasn't clear what is the action taken if cyber intrusion is detected.

**Reviewer 3:** Assumptions of algorithms and models used. Minimal dependency on the real-time use cases and data. Limited to PV systems self-control and no clear visibility of the quantitative improvements expected.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The potential weakness of the team is that it lacks a balanced leader, a field expert (such as an actual operator) and a commercialization expert. The report style also focuses heavily on the technicality while not so much to the rest (for example, the milestone section discusses "milestones 3.3 through 3.6" without indicating what they are). A well-versed leader could perhaps balance this bias and help coordinate the product launch with a commercialization expert (which the team is lacking).

**Reviewer 2:** It would be good to have commercial industry perspective on the issues studied being concerns and the feasibility of utilizing the proposed solution approaches. It's not clear why new solutions are required to supplement existing local voltage response/control? How does state estimation improve system performance?

**Reviewer 3:** More national labs and universities along DER standard working groups.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project aligns relatively well with the SETO missions and helps reduce curtailment (which effectively lowers the LCOE). The same technology can potentially be applied to other inverter-based technologies so the impact can be meaningful. However, the team appears to be very focused on the technicality, and largely in the research arena, rather than having actual field experience. This may lead the project to struggle later when the field test and commercialization become the main tasks. The team also lacks an internal critique, who can also help to improve the quality of the product, and later launch it.

**Reviewer 2:** It would be good to articulate in the findings and report: 1) how these three objectives are related (if they are) i.e. intrusion detection, state estimation with low data resolution, and voltage control issues; 2) identify the prevalence or relevance of these issues in present day systems, and 3) how the approaches used in this project compare with possibly less complex and/or commercially proven methods of local response and control by smart inverters.

**Reviewer 3:** SETO can encourage projects like these as they may contribute to the improvements of the existing DER standards. SETO can help the project supporting groups to involve more organizations.

## Artificial-Intelligence-Driven Smart Community Control for Accelerating Photovoltaic Adoption and Enhancing Grid Resilience – $2,419,912

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Xin Jin*

This project addresses challenges in community-scale coordination of behind-the-meter resources by building on the National Renewable Energy Laboratory's efforts on home energy management, grid hosting capacity, and device characterization for grid services. Using smart meter data, the team is developing artificial intelligence that can learn to identify homeowner preferences and enable day-ahead planning. The project aims to evaluate how to best use solar energy paired with flexible building loads like electric water heating or electric vehicle charging. Since solar energy is intermittent, the algorithms will try to schedule the loads when the sun is out. When there is excess solar energy, the project will determine the smallest battery energy storage system so the community can use that energy later in the day. This analysis will provide insight into cost-effective ways to minimize the need for battery energy storage systems. The team will validate the solution using hardware-in-the-loop laboratory testing, which simulates real-time embedded systems, and field demonstration in a net-zero-energy community.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 6 | 3 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 2 | 5 |
| Advance the U.S. solar industry substantially | 6 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a very well-defined program with clear targets, very relevant to SETO mission and will impact utilities, homeowners, builders etc. This will establish a template for developing smart communities. The plan to demonstrate at a Colorado community makes this whole program very robust.

**Reviewer 2:** Firstly, I would like to thank NREL for contributing to this research and study of optimizing generation and consumption basing artificial intelligence. This topic is essential because with increased penetration of PV on to the grid, the utilities are scaling down from providing any generation credits to no credits in some cases. So, it is on the homeowners to utilize other ways to efficiently use the generated green energy. Energy storage comes into picture here and has been helping a lot in utilization during day and night. However, because of the ESS costs, it is not always possible to scale ESS easily. This is where smart home load control comes into picture. As part of home load control, this study selects home water heater, thermostat controls for proof of concept. These two are weak picks due to limitations. Water heater is selectively needs at peak times when sun is not around and is hard to time. Thermostat controls vary based on the home owner preference from time to time and external controls are not desired. Lot of inverter and energy storage manufacturers already sell products that can perform site control and home load control at high efficiently over the last 5 years. The innovation and need from NREL to focus on this topic seems very redundant and unnecessary. Rather recommend to focus on reducing costs for micro-grid inverters and energy storage. EV(Electric vehicles) and flexible home loads such as Dishwasher/Dryer/Washer are great examples as there is great flexibility beyond the home owners.

**Reviewer 3:** The project had a unique focus among the projects assessed by focusing on community based networked use of DER working with residential developer. The objective of the designs are to optimize PV usage and control for NZE communities and consider use of the community resources as non-wires alternatives for distribution impacts of DER. The project has encountered some challenges and workarounds in the aggregator design due to computational burden.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 3 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 4 | 5 |
| Collaborates with sufficient stakeholders | 6 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The program has no delays and is on budget. The performance of the team and the value delivered to the research community and Community in general is phenomenal.

**Reviewer 2:** Lot of inverter and energy storage manufacturers already sell products that can perform site control and home load control at high efficiently over the last 5 years. The innovation and need from NREL to focus on this topic seems very redundant and unnecessary. Rather recommend to focus on reducing costs for micro-grid inverters and energy storage.

**Reviewer 3:** The project has completed demonstration of the control system, with challenges overcome; and provided seven publications to share findings with industry. The project had to adjust its contributors based on delay of the original housing project over water rates, but was able to find other participants. There are developer, research, and industry participants.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project is very well defined and executed and is delivering enormous value.

**Reviewer 2:** Score: 3. Comments: Lot of inverter and energy storage manufacturers already sell products that can perform site control and home load control at high efficiently over the last 5 years. The innovation and need from NREL to focus on this topic seems very redundant and unnecessary. Rather recommend to focus on reducing costs for micro-grid inverters and energy storage.

**Reviewer 3:** Score: 5. Comments: The tasks and activities are well planned and logical to achieving the project objectives, culminating in field proving.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None that I can think of.

**Reviewer 2:** As part of home load control, this study selects home water heater, thermostat controls for proof of concept. These two are weak picks due to limitations. Water heater is selectively needed at peak times when sun is not around and is hard to time. Thermostat controls vary based on the homeowner preference from time to time and external controls are not desired. EV (Electric vehicles) and flexible home loads such as Dishwasher/Dryer/Washer are great examples as there is great flexibility beyond the homeowners.

**Reviewer 3:** It might be important to determine, in the utility findings, if the community project places additional balancing requirements or other service needs upon the power system when operating in an interconnected mode; and also, consider he possible impact of separation if such systems are common and separate during grid disturbances.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

Reviewer 1: None that I can think of.

**Reviewer 2:** Inverter manufacturers, System integrators, Utility Grid representatives.

**Reviewer 3:** The composition of the team seems to have a good mix of perspectives of developer, customer, researcher, and utility.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** SETO should encourage other projects working on BTM resiliency to coordinate with the PIs of this project Xin Jin and Fei Ding. They would benefit from this.

**Reviewer 2:** This research work is extremely redundant as there are many, many commercially available products at scale doing the same. Rather SETO should encourage to reduce costs on energy storage and micro-grid inverters SETO and NREL should encourage utilities to accept the already working models on systems deployed without restrictions (Utilities today create massive permit and interconnection delays as they don't understand the smart site controls at this level).

**Reviewer 3:** 1) The project is unique amongst the projects reviewed, in evaluating community DER control and requirements. 2) The project has completed milestones and is making progress despite the impact of a construction delay. 3) Seven communications have been issued to share findings of the project work with industry.

## Rapid, Rural, and Resilient Interconnect Toolkit – $240,000

*National Rural Electric Cooperative Association | Arlington, VA | Principal Investigator: David Pinney*

This project is developing simplified interconnection evaluation software to help rural communities and small utilities deploy solar energy systems more easily. Solar applications are on the rise in these areas, and managing the interconnection approval process in a timely, effective manner is challenging. The tool kit will help utilities address interconnection queueing and processing.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 3 | 6 |
| Set critical challenges to overcome | 4 | 6 | 6 |
| Implement a high-risk, high-impact approach | 2 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project proposes to develop and field test new rapid tools for interconnection analysis, by leveraging rapid application development on top of NRECA's Open Modeling Framework (OMF), to help rural communities and utilities deploy, more easily, solar energy systems through streamlined interconnection processes. Thus, it will support businesses and allows better integration of solar into the grid. The tool will be publicly available. The project applies to small or medium rural utilities and because of that, may not have wide application. Cost of the project is not high and the implementation time is relatively short (one year). The authors state that the project will be an innovation since currently interconnection process is either not automatic, or if automatic, is expensive. However, it is not clear if indeed comparable programs don't exist. DOE funding is critical for the project since there is no funding from any other sources.

**Reviewer 2:** This appears to be a very useful project to facilitate DER interconnection at lower cost and effort while still ensuring technical thoroughness of the interconnection process. This would reduce interconnection costs for utility ad DER and could result in shorter lead-times especially for smaller systems with low population density, which often have limited staff and budgets. This project may not be in the proper topic area as it is not clearly related to resiliency, unless one takes the point of view that the interconnection evaluation ensure that there is no negative impact on reliability and resiliency, and increased adoption of DER may provide some resiliency options.

**Reviewer 3:** This is a very relevant problem and the right partners NRECA and APPA have stepped up to address the problem and provide a solution. Cost is key concern for developers on the distribution networks. Projects below 5MWs typically get a fast track permitting but having a tool like this can potentially larger community and industrial projects as well. A similar approach can work for distributed wind as well. For wind the such a tool can provide a larger benefit.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 6 |
| Collaborates with sufficient stakeholders | 6 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project goal is by the end of the project to reduce average interconnection analysis time from 2-3 hours to 15 minutes, or more than an 80% reduction in analysis time. This improvement will be measured using data from the partner utilities, and gather data from other utilities recruited as advisors to make sure these metrics are valid for the large small utility community. The project duration is one year and the cost is reasonable. The results are disseminated every quarter and several utilities involved in the project are actively engaged. A comprehensive guidebook on how to use the tool developed by the project will be released. In the course of the project development, the tool will be used and validated in the partner utilities.

**Reviewer 2:** The project anticipates sharing the process created with many rural utilities, via guidebooks and software. The timeline is relatively short to develop these tools. There is vetting by utility testing included in the project.

**Reviewer 3:** The project started and has a good mission and vision. Not much to report in terms of performance.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks are to develop the requirement and specification document, develop the intermediate and then final versions of the software, to validate the tool in the member utilities, to issue the guidebook and to implement the tool in other rural utilities and cooperatives. Each tasks add value to the project.

**Reviewer 2:** Score: 5. Comments: The tasks are logical progression in development, bench testing, field testing, and distributing to users.

**Reviewer 3:** Score: 6. Comments: The tasks are well constructed and involves a lot 4 rounds of testing and validation with utility partners. Also the interconnection guide book will also be created in accordance with the Utilities criteria for interconnection.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Since the project hasn't been started yet, it is not exactly clear how it will be developed. The tool will be applied to small retail-scale solar PV projects. In my opinion it makes sense to also expand it to utility-scale projects, if any are interconnecting in rural cooperatives. Also, there should be plan how to disseminate the tool to all rural utilities and to other utilities for which it may be beneficial.

**Reviewer 2:** The essential key is to ensure that the tool actually provides the necessary analysis to reliably integrate systems. Rural systems can have some special considerations due to long feeders and light loads.

**Reviewer 3:** The team probably needs to consider to build a state/national level database of available interconnect facility and needs to updated and maintained as project permits get awarded and built.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I think that it should include more partner utilities where the tool can be tested and validated.

**Reviewer 2:** None identified.

**Reviewer 3:** None that I can think of at this point.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project will give wider access to solar for rural utilities and reduce cost of solar. By implementing the automatic tool for solar interconnections, the time of distribution engineers will be saved and possible human errors will be avoided. However, the project is applicable only to small or medium size rural utilities. This project is a part of Innovations in Manufacturing and Competitiveness.

**Reviewer 2:** 1) The project works to address an issue that limits ability for rural utilities to rapidly connect DER. 2) The results could be very helpful to rural utilities if the product performs equally in evaluating interconnection constraints and solutions. 3) The project may not be the proper category as it is not directly addressing a resiliency issue but rather an interconnection analysis bottleneck issue.

**Reviewer 3:** SETO definitely needs to support this program. SETO can also let the wind office and other Distribution related offices start similar projects. This could very vital to DER future of the country. These tools can be combined with resource assessment tools to accelerate the development of DERs and a modern grid.

## Photovoltaic Analysis and Response Support Platform for Solar Situational Awareness and Resiliency Services – $2,271,130

*North Carolina State University | Raleigh, NC | Principal Investigator: Ning Lu*

This project is designing a modeling tool to determine the optimal response of renewables on transmission and distribution systems, as well as behind-the-meter response for small-scale solar energy systems. With real-time sensor readings and a cost-benefit analysis, this tool can be used for grid planning and to help restore power during an outage.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aligns well with the SETO mission—the project not only delivers means to enhance the operation of solar assets but also includes a model to assess the economic benefits of such options. If used appropriately, the combined product could certainly help solar developers or utilities identify further opportunities for solar (or other) hybrid technologies. However, the potential for contributing to research beyond DOE may not be as high. The project duration (36 months from November 2019 through October 2022) is commensurate with other projects. The budget ($1.5 million DOE and $0.8 million cost share), with more than adequate cost share, is at the lower end, increasing the performance/cost ratio of this project above others (i.e., it indicates higher cost performance). Understanding that the project just started in November 2019, there are no significant milestones achieved to date, and future schedules and milestones are not articulated in the report. One point that may be missing within the team is how to get the industry to use the software developed. The ultimate goal may be to have it in the control room, however, that will take years to convince the operators, even if it is a stand-alone software not interfering with other control tools.

**Reviewer 2:** The project develops a platform that provides real-time situational awareness and optimal response plan selection. It does steady-state and dynamic simulations in faster-than-real-time for real-time issues. The project's operation platform can be used to monitor, and develop optimal response plans for hybrid PV systems both in transmission and distribution, including behind-the-meter. It is done both for normal and emergency conditions. The project can also be used as a planning platform to design and test PV-based grid support functions and perform cost-benefit studies. It has several technical challenges to overcome, and since it is just started, the outcome is not very clear. The project requires funding from utilities, private sector, and software vendors and is a high risk. The impact may be high, but only for small grids with high PV penetration.

**Reviewer 3:** This project tackles the topic of situational awareness in a very appropriate way. The Operation Model Tool, Model Parameterization Tool, a real-time Situational Awareness Tool, an Optimal Response Tool and a Cost-Benefit Tool provides the right structure to assess situational awareness, cost and estimate the efficacy of the approach.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 0 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 0 | 3 | 4 |
| Collaborates with sufficient stakeholders | 0 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team started working on January 2020. Given that there has been less than a quarter spent to date, these questions may not be applicable to this project at this time.

**Reviewer 2:** The project started in January 2020, and is planned to last for three years. Therefore, its performance is hard to estimate yet. The milestones include developing the prototype of each of the five tools and preparation of a real-time simulation test, which will be done in year 1. In Year 2, the project will focus on the integration of the tools on realistic transmission and distribution models. In Year 3, the technology transfer and project implementation on the selected facility is planned. The project's impact will include real-time simulation tools enabling situational awareness and optimal response selection and making PV-based hybrid systems visible and controllable in both normal and emergency operation conditions. The project stakeholders were identified, but they are not involved in participation yet. The success of this project will ensure the economical, secure, reliable, and resilient operation of future electricity grids with high PV penetration.

**Reviewer 3:** There is not much to report at this point since the project started later than the expected date. The team is expected make some progress on Grid Support Functions by end of Q1 and perform project setup activity with its partners.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The report does not articulate any tasks. It also does not discuss milestones. This may be because the project was just kicked off earlier this year. The report does provide a nice figure that illustrates the flow of the different tasks, responsible team members, and by year. This figure suggests that each respective task adds unique and important value to achieving the overall goals of the project.

**Reviewer 2:** Score: 5. Comments: There are five tasks that the project needs to accomplish and each adds unique and important value to the project. 1) Development of operation models of hybrid PV systems that bind steady-state and dynamic simulations on a real-time platform considering communication protocols. This approach guarantees the scalability of the platform. 2) Development of model parameterization algorithms that allow parameters to be updated close to real-time using field measurements for real-time situational awareness. This approach guarantees the replicability and sustainability of the model. 3) Development of anomaly detection algorithms. 4) Development of a modeling mechanism that allows faster-than-real-time scenario simulations for preparing emergency operation and selecting optimal response and restoration plans. This technology is essential when prompt actions to fast changing operating conditions are required. 5) Development of a cost-benefit assessment tool that will use the actual field data to estimate the economic benefits for the services provided under both normal and emergency conditions. It will estimate the economic value in integrating PV systems with other resources.

**Reviewer 3:** Score: 6. Comments: My feedback is Same as provided in Question 1.This project tackles the topic of situational awareness in a very appropriate way. The Operation Model Tool, Model Parameterization Tool, a real-time Situational Awareness Tool, an Optimal Response Tool and a Cost-Benefit Tool provides the right structure to assess situational awareness, cost and estimate the efficacy of the approach.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project is developing software that can be used for both operations and planning. One point that may be missing within the team is how to get the industry to use the software developed. The ultimate goal may be to have it in the control room, however, that will take years to convince the operators, even if it is a stand-alone software not interfering with other control tools.

**Reviewer 2:** The project mainly counts on the DOE funding. I think that it should more actively involve other sponsors. The project platform consists of five tools that are developed also by entities other than the North Carolina State University. In my opinion, the project authors need to have a backup plan if some of the project participants are behind schedule or don't complete their tasks as it was planned.

**Reviewer 3:** None at this point. The project started later than the expected date. The team seems to have the right competencies to accomplish the goals and objective. There are some challenges that were identified with respect to availability of real time models but once the team gets going we may get a view of the potential blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project does list utilities as team members. Expanding the role of these members to help identify the potential flaws or roadblocks, and potential areas for improvement would help. Another point to consider is the backup plan in case the team member utilities decide against deploying the technology developed. These should be reflected into the team's future plans.

**Reviewer 2:** The project collaborates with one National Lab, one electric utility, software development company, several distribution companies and solar developers. Other stakeholders may include more electric utilities where the project may be tested.

**Reviewer 3:** None at this point. The project started later than the expected date. The team seems to have the right competencies to accomplish the goals and objective. There are some challenges that were identified with respect to availability of real time models but once the team gets going we may get a view of the potential stakeholders who can add value to this project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** While the project is still young, it appears as a rough gem that aligns well with the SETO missions and can benefit the solar industry in many ways. The project team needs demonstrates a successful track of execution, and further think of what success of the project would look like. Success should not simply be a good software but include commercialization and/or deployment by utilities. Expanding the role of utilities within the team may help.

**Reviewer 2:** The project will provide real-time situational awareness and response plan and enhance grid reliability and resiliency by early detection of abnormal operation conditions. It will enhance grid restoration practice by integrating PV, storage and other DERs into the black-start and cold-load pick up process. The project will reduce the amount of unsupplied load and shorten the fault restoration time. However, the project just started, has high risk of not being successful and the set milestones are not reached yet. Whether or not grid services provided by hybrid PV systems developed by the project can meet service requirements compatible with existing grid services and if they are also economically viable is largely unknown.

**Reviewer 3:** None at this point. The project started later than the expected date. The team seems to have the right competencies to accomplish the goals and objective. The modelling framework looks robust. This project has the potential to set a benchmark on situational awareness. We can provide more appropriate feedback at the end of the year.

## Cybersecure Utility Distributed Energy Resource Networking with Integrated Multi-Party Trust – $2,600,000

*Operant Networks Incorporated | Santa Rosa, CA | Principal Investigator: Randy King*

This project team is working with the power company Exelon to develop and deploy communications technology that securely shares information about solar and other distributed energy resources with multiple parties across multiple connections, including the internet. With new capabilities and protections, the technology is able to connect to existing utility software platforms. This allows utilities to comply with new regulations requiring direct communication with distributed energy resources, restrict access to trusted partners, and improve cybersecurity.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 6 | 5 |
| Set critical challenges to overcome | 3 | 5 | 5 |
| Implement a high-risk, high-impact approach | 3 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 2 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project somewhat aligns with the SETO missions but only in a limited way—communication between the utility and DERs. In some ways it does not have to be solar—for example it can be for communication between EVs (and they do touch on storage) and the utility. Therefore, the contribution to the US solar industry advancement is not so high. However, the communication-focused project can benefit many other fields outside of DOE and can become one form of Internet of Things, if applied appropriately. The project duration (36 months from May 2020 through April 2022) and budget ($2.6 million DOE and $0.9 million cost share) is commensurate to other projects. The overall schedule and milestone targets from the technical side appear adequate. The expected impact, as far as what is in the scope here, is optimistic at best. If the market size and associated benefits were as big as claimed, private entities would certainly try to take advantage of it. This observation suggests that the project's technology to market approach needs improvement, including market research and cost/pricing analysis.

**Reviewer 2:** Strength: The program objectives are very relevant and the proposed approach and the partners supporting on this program can accomplish this objective. Operant networks seems to have previously developed base libraries for a DER gateway under a SETO program. It is important for this team to build on the DER gateway effort. Suggestion: The team could plan to include a utility advisory board during the 2nd BP to get better feedback and make MPT viable out of the gate.

**Reviewer 3:** The positive aspects of the project are with its proposal to work to address a critical need for control and monitoring and that it has strong partners. The need is establishing a cyber secure possible method for interfacing with DER by multiple parties. It is to be field proven, with a utility partner and strives to achieve compatibility with industry tools (ADMS/DMS) and standards (IEEE 2030.5 and 1547, NERC CIP, The need for identified common approaches for control that also allow customer interested interface, with security for the utility control is definitely needed. Concerns with the project are what seems to be a fundamental assumption that developing such an approach is the only way to achieve the goals of secure DER monitoring and control. It seems other approaches could be to segregate communication on the DER side, similar to a DMZ approach. Control enacted through others means such as inverter relays or metering, or disconnects, would also work. The model seems to suggest a middle-man aggregate in between the utility and DER which will increase costs. The impact of the protocol security measures on performance should also be considered. This would seem to be a project to evaluate one possible solution so that the costs and feasibility can be weighed against other approaches and not be a mandated approach. It would be concerning if utilizes are forced to interface to DER solely through third parties which can increases costs and inevitably introduce additional operational concerns and complexities as compared to other approaches that do not require intermediaries. This aspect concerns me as we would not want research to benefit a particular market segment inappropriately.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 0 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 0 | 5 | 6 |
| Collaborates with sufficient stakeholders | 0 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project starts in May 2020 so all questions are not applicable. The report indicates that there will be a good amount of stakeholder involvement in the design and also testing of the product, along with a substantial target contact list for commercialization. Therefore, if scored, the project may have received higher points for these.

**Reviewer 2:** This program has a start date of 5/1/2020. Hence cannot comment on the performance yet.

**Reviewer 3:** Project is just getting started. It has clearly articulated objectives and goals and has a utility partner identified and an outreach to the standards groups. The objectives look quite ambitious however. It may be difficult to achieve consensus required in the time frame for some of the objectives especially compliance with several standards and regulatory requirements which would require input from those entities which is not typically a rapid process.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The project has not started yet, however, the report description suggests the project team has a good plan with the timelines well thought through. At a high level, the project designs the product in year one, develops the actual product in year two, then field tests the product in year three, and these steps are adequate. The tasks (or rather "tracks") described in the report appears adequately corresponding with the timelines, although it could be articulated further.

**Reviewer 2:** Score: 5. Comments: The Tasks look appropriate and the team can potentially refine the task list and scope once the program starts.

**Reviewer 3:** Score: 5. Comments: The tasks and goals are well laid out. The objectives look ambitious particularly where consensus from working groups and other entities is required.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The potential shortfall of this project may be at the last stage after the field testing is done, i.e., commercialization. There is no guarantee that Exelon would deploy the new technology developed, and even if it did, there are no guarantees that other users (largely utilities?) would deploy the technology. Even if they do, there may be a need to customize the product and go through a similar testing phase. And there is no estimate of how much of the total market can be captured, nor how long it may take to achieve such market share. NREL may have some insights as it has spun off a number of new business, and have seen some succeed while others fail.

**Reviewer 2:** Feedback from multiple utilities would be needed so that the final solution can meet their requirements and cost targets.

**Reviewer 3:** Is there consensus that a shared communication is the likely approach, requiring a multi-party trust protocol? Or might other solutions be preferred which are based upon segregation techniques eliminating the need to interface to a common source? Does this project potentially support a particular commercial platform that could force utilities to engage with third-party providers in lieu of other options that might be lower cost?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team members appear to be centered on developing a new technology, which in itself is fine and aligns well with the project goals and needs. However, it may be short on expertise to commercialize the final product beyond Exelon.

**Reviewer 2:** Multiple forward utilities which are facing DER problems. Alliant Energy in the Midwest is one of the forward-looking utilities that has expressed concerns with expanding DERs.

**Reviewer 3:** The project would benefit from some partnering with solar inverter suppliers and suppliers of larger DER systems. This may be somewhat provided by the standards review but there may be innovative approaches no the DER side that could be useful.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project scope only aligns with the SETO mission in a limited way and, therefore, the contribution to the US solar industry advancement is not so high. However, the communication-focused project has the potential to benefit many other fields beyond the scope of DOE and that should be given adequate consideration. The potential weakness of the team is the lack of a commercialization expert and plan. This can be seen from the report—the description of the technology development is very well thought-through while that for commercialization is much more abstract with optimistic numbers that may not reflect the actual market the team can reach into.

**Reviewer 2:** The team should leverage previous work on libraries built for DER Gateway. Build a broader consortium of utilities to get good feedback on the MPT method, interoperability protocols, standards and cost targets etc. Build a robust set of requirements for commercialization. Down selection of vendors/OEMs who can meet the above requirements.

**Reviewer 3:** 1) The positive aspects of the project are its engagement with industry and utility with development of field-proven solutions. 2) Need further assessment of the problem definition and proposed solutions by people more qualified than myself. Are there other communication and control approaches that might not require this protocol-based solution? Does this approach potentially force the industry into a middle-man arrangement to communicate to DER, or does it leave open other options? 3) Evaluate whether the aggressive timeline is feasible considering working with standards working groups.

## Grid Resiliency with a 100 Percent Renewable Microgrid – $4,500,000

*San Diego Gas & Electric Company | San Diego, CA | Principal Investigator: Thomas Bialek*

This project is working to research and validate microgrid technologies that enable the use of solar and other distributed energy resources with grid-forming photovoltaic and battery inverters. These devices can improve grid stability and resilience by maintaining voltage and frequency during changing conditions, especially microgrid islanding, which independently provides power. The team is developing new controls and software for smart photovoltaic inverters and distributed energy resource management systems that may allow more flexibility for the interconnection and operation of small-scale photovoltaic and other distributed energy resource systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 5 | 4 | 4 |
| Implement a high-risk, high-impact approach | 4 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 3 | 2 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The Project will enhance resilience of micro-grids with a 100% renewable generation. It researches and validates innovative technologies that enable DERs with grid-forming inverters to contribute to grid stability and resilience by maintaining voltage and frequency during transient conditions, especially islanding. The project evaluates and designs an interface between a DER management system (DERMS) and the grid. It would expand control capabilities and operating experience via development and deployment of significant new capabilities. The project will allow to overcome challenges such as black-starting a 100% renewable-based micro-grid. It will demonstrate how intelligent control of DERs can improve local system reliability and resilience, and reduce PV curtailment due to islanding operations. The level of requested DOE funding ($3,807,796 as specified by the PI) from DOE seems to be too high. The project is going to be applied only to one substation and it is applicable only to micro-grids with extremely high solar PV penetration. Also it has to involve many participants to make it successful. Attempting to island a micro-grid in a low-inertia environment while keeping frequency within limits require a fully developed simulation environment and may appear to be challenging. It may be too expensive to expand it to other substations.

**Reviewer 2:** Firstly, I would like to thank and congratulate the teams and organizations supporting this experimental study. With increased Solar adoption and dynamics around Utility grid causing stability issues may result in black out or similar situations. The study is helpful in terms of deep-dive in to islanding a section of the community with the help of micro-grid system under grid fluctuation scenarios. this definitely helps the regions where the Utility grid is weak or impedance is low due to excess generation. Another useful case would the cases of natural disasters like hurricanes, tornadoes, storms and wildfires, this micro-grid system able to separate a community or region to isolate and separate and self-sustain with the solar. I believe this project is not adding much innovation or proving that is not already on the common marketplace. The level of development needed here is limited.

**Reviewer 3:** This is a well-balanced project that aligns with the SETO mission while also providing potential applicability to research beyond those of DOE—for example islanding of an electric system can be used for military bases. Using a real system as a testbed will certainly help demonstrate the ability and limits of what solar (and other associated equipment) can do, although it may not do much to lower solar costs—one of SETO's key goal. However, the insights gained from the actual system including the controls and associated communication means would be very valuable to the industry as a whole. While the project has not yet started, the project duration (36 months from April 2020 through March 2023) and budget ($3.8 million DOE and $2.1 million cost share, note that the total cost share percentage value reported is off) appear to be commensurate to other projects. The schedule and associated milestones are not clearly described. Therefore any further assessment at this point would simply be speculative.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 0 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 0 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 0 |
| Collaborates with sufficient stakeholders | 4 | 4 | 0 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project hasn't been started yet, so its performance cannot be evaluated at this point, but the plan seems reasonable and achievable. Based on the project's plan, its performance seems acceptable. The project includes three tasks with sub-tasks if further detail of the breakdown of the work will be needed. A Project Schedule has been developed for the entire project, including task and subtask durations, milestones, and go/no-go decision points. A Milestone Summary Table has also been developed to ensure the project remains on track and achieves the desired outcomes. The measure of impact will be performance of micro-grid in an islanding condition. Impact will be measured in voltage and frequency. During the project duration, the project will be tracked and the results will be disseminated through regular meetings and review of measurable deliverables. The project participants include several departments of SDG&E, also ABB and NREL.

**Reviewer 2:** I believe the author is making assumptions that sizing of the Solar, ESS and the load usage in the area to be proportional for stability. However, in reality the communities could have various generations of the solar that may or may not able to perform smart inverter functions. With smart PV inverters, when grid fluctuations in voltage and frequency happen, they have the ability to curtail rather than abrupt turn-off. So, the need for micro-grid to provide stability in this case is very less. The legacy PV inverters may or may not be able to operate in parallel to micro-grid systems due to weakness in ability to differentiate Grid vs. micro-Grid. Modeling is the key to this project and is neither much done by the inverter partner nor the utility grid and is managed by the national lab. Seeing this as a risk. The development group is already utilizing the micro-grid capable inverter and ESS, with pre-defined advance controls. Leaving the integration alone to simulations and study of transfer time from fluctuation to a stable situation. While the ESS can achieve up to a fraction of second transition, the simulation shows multiple seconds for stability in this small system.

**Reviewer 3:** The project starts in April 2020 so all questions are not applicable.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The overall project objective has been broken into separate task sections that are clearly linked to, and combine to result in, the project's final objective. The tasks for the project seems reasonable and achievable. Each adds value to the project. The tasks include: Research and validate, via laboratory and field tests, innovative micro-grid technologies that enable DERs with grid-forming inverters to contribute to grid stability and resilience by maintaining voltage and frequency during transient conditions, especially micro-grid islanding. Evaluate and design a standard interface for various DERs to decrease the complexity of interfacing between a DERMS and grid edge devices. Evaluate past islanding attempts coupled with the development of controls for an appropriately sized battery to decrease the variability of frequency and voltage within the island to avoid activation of protection equipment.

**Reviewer 2:** Score: 2. Comments: The project scope fails to contradict the smart PV inverters that can already do much of the control to avoid impact to grid stability in fluctuations. The project fails to narrow down the scope of development that needs to be done from the work that is ready to use. The level of innovation is minimal although the topic adds lot of value to the SETO long-term goals.

**Reviewer 3:** Score: 2. Comments: The report does not articulate tasks, timelines, and associated milestones. Therefore assessing whether each task adds unique and important value to achieving the overall goals of the project, with the current report, is not feasible without speculation.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The project will be applied only to one substation, thus it is not clear how it may be applied to other substations and conditions. I think that other stakeholders, such as electric utilities other than SDG&E may be also be reached to.

**Reviewer 2:** More details or focus needs to be present of PV inverters compatibility and transfer time to micro-grid. Justify solid reasons to contradict why smart PV inverters cannot solve this problem. Fail to identify the best use-cases that this idea is useful as highlighted above. Need to include Generators as part of the study for accurate dynamic behavior study.

**Reviewer 3:** Given that the utility is the lead, the project may become too focused on the specific system and not provide enough general insights that can be applied widely after the project. There is nothing wrong with developing technology specific for the Borrego Springs microgrid (in fact, having a real test-bed is one of the advantages of this project), however, the project would benefit the general industry even more if results and observations could be grouped into general and asset specific buckets.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** I think that it will make sense to involve other electric utilities with high solar PV penetration.

**Reviewer 2:** Although appropriate stakeholders are part of this study, the simulation which is key part of the study is neither done by inverter partner nor the utility grid, which may cause some gaps on the result.

**Reviewer 3:** The project is focused on enhancing an existing microgrid and the team appears to have all the technical expertise needed. The organization chart lists one member for a non-technical role—a regulatory lead. However, the team may benefit from adding a few more non-technical roles, such as roles looking at the benefits from the consumer end, or a role looking at sharing or commercialization of the technologies developed and lessons learnt. These non-engineering roles could help evaluate the technologies developed beyond the engineering benefits the project seems to be focused on.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** The project will provide grid resilience for a micro-grid with a 100% renewable generation through the addition of advanced grid-forming inverters and other control features, and it is important for reliability of the grid. The project will be applied to one substation in SDG&E, and expanding it to other substations and micro-grids as part of this project may appear to be too expensive. It is applicable only to micro-grids with high solar PV penetration. The budget funding requested from DOE appears to be too high.

**Reviewer 2:** I highly recommend SETO to look at this topic and promote micro-grid systems that are either solar compatible or operate as a multi-mode system. This is extremely useful in times of natural disasters like storms, wildfires, hurricanes, tornadoes and such. the cost of solar panels and grid-tied inverters are in great shape but the micro-grid systems are disproportionately expensive and the amount of industry research is minimal in comparison.

**Reviewer 3:** This is a well-balanced project that aligns with the SETO mission while also providing potential applicability to research beyond those of DOE. The insights gained from the actual system including the controls and associated communication means would be very valuable to the industry as a whole. However, the project can fall into a potential of putting SDGE's interest too high above the interest of the general industry—for example, if the technologies developed are too specific to the Borrego Springs microgrid and cannot deployed elsewhere, it would not serve the industry well. Maintaining this balance is very important. Another important factor may be how to evaluate the technology developed beyond the engineering needs.

## Distributed Energy Resource Cyber Security Standards Developments – $1,200,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Jay Johnson*

This project is creating cybersecurity standards for distributed energy resources, including solar inverters, for new products entering the market and operating in the field. Specific distributed energy resource cybersecurity requirements will be included in communication protocol standards, interconnection and interoperability standards, and grid operator and aggregator architecture requirements. Sandia National Laboratories and the National Renewable Energy Laboratory are coordinating standards development with stakeholders, leading working groups, and accelerating codes and standards development through in-person and virtual participation. Researchers are also conducting the technical research and development required to validate the test procedures and recommendations within these standards.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 6 | 6 |
| Set critical challenges to overcome | 4 | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 2 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 6 | 6 |
| Advance the U.S. solar industry substantially | 3 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** In this project, recommendations for DER cybersecurity standards are being created to establish a minimum level of performance for products entering the market and operating in the field. Specific DER cybersecurity requirements will be included in communication protocol standards, interconnection and interoperability standards, and grid operator/aggregator architecture requirements. The project funding is intended to lead working groups, and accelerate codes and standards development. Also, the funding is for technical R&D activities to validate test procedures and recommendations. This project has a high impact for the solar/DER industry because it is establishing benchmarks for secure operations for a healthy cyber ecosystem. New standards developed by the project when they become mandatory, will also have high impact. Although the project is important for the industry, it doesn't exactly follow the mission and goals of SETO, since it is not directly connected with the development and application of technology to advance low-cost, reliable solar energy in the U.S. The project will advance cyber security by establishing mandatory standards, but not US solar industry. The project requests full funding from DOE and the level of funding seems to be high.

**Reviewer 2:** The project has contributed to industry by several publications of best practices and benchmarks being used as a foundation for standards. The project is hindered by the nature of developing new standards and practices which involves many stakeholders through voluntary participation. Until such time as industry reaches consensus the work products contribute to industry as guidelines and best practices. Raising the awareness of the number of entities involved and establishing ownership within targeted industry standards group is a useful outcome in itself.

**Reviewer 3:** This program is fundamental and critical to Cyber-security of the future grids with large scale penetration of DERs. It lays out the basic DER requirements including communication protocol standards, interconnection and interoperability standards, and grid operator/aggregator architecture requirements. This program needs to continue beyond 2021 to provide oversight and support the industry in the implementation of the proposed standards.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 6 |
| Collaborates with sufficient stakeholders | 4 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project milestones are being met within reasonable timeframes. Some of them are already accomplished, such as standardized procedure for DER vulnerability assessments and a workshop on the project. Other milestones are in progress or planned. In the last year, several papers were published by NREL, EPRI and Sandia that will be used for standard development. The status of the project is regularly reported at DOE workshops, IEEE conferences, and on DER Cybersecurity Workgroup webinars. There are active working groups working on the project. There are no quantitative measures of the project impact. The impact will be new CIP standards developed by the project group. The results are disseminated frequently through working groups, reports and papers. Currently, the project team is engaged in conversation with UL 2900 Software Cybersecurity for Network-Connectable Products Standards Technical Panel, IEEE, and International Electro-technical Commission (IEC) to improve and harmonize standards across these organizations. There are still many standard developing organizations that are not included.

**Reviewer 2:** Based on the cited reference documents that were the outcome of the project to date, the project appears to have brought together industry and research entities to develop useful work products providing foundation for DER network practices and cyber security standards. The participants include labs, EPRI, and solar interests. The work is important in furthering the common practices and requirements for distributed resources. The project next steps are to move guidelines and best practice works into requirements and auditing practices.

**Reviewer 3:** Sandia is on target with their 2nd year spending, but NREL is slightly under spent while they setup the lab testbed for validating the certification procedures. The team is performing well in accomplishing the key tasks.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The goal of the project is to advance cybersecurity in the DER and utility community by creating consensus DER cybersecurity standards, best practices, or guidelines. Specifically, the team is creating: 1) DER equipment standards and associated certification protocols. 2) Communication (data-in-transit) requirements. 3) Network architectures guidelines. 4) Access control requirements. 5) Patching requirements. 6) Auditing best practices. The development of each task provides DER vendors, utilities and third parties with a cyber-secure reference for implementation. These are intended to be used as the basis for cybersecurity standards drafted by UL, IEEE, IEC, NIST, or other Standard Development Organizations.

**Reviewer 2:** Score: 6. Comments: Each milestone identifies step progression from developing guidelines, to formalizing requirements, to verifying performance through audits. The milestones also include regular sharing of findings with industry, as well as interfacing with the entities that will need to develop formal requirement.

**Reviewer 3:** Score: 6. Comments: The tasks are well defined and I believe the team is performing very well and need to continue to do so over the next year and beyond.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Although the project is important for the industry, it is not directly related to the SETO mission of accelerating the development and application of technology to advance low-cost, reliable solar energy in the U.S and its goals of improving the affordability, performance, and value of solar technologies on the grid. In my opinion, the project is not related to the means of advancing solar technology to lead innovation and reductions in solar electricity costs, or to enabling solar to support grid reliability and pair with storage to provide resilience, and it also doesn't provide technical information on solar technologies to stakeholders. I consider these to be the "blind spots" of the project.

**Reviewer 2:** The achievements and collaboration so far have been very good considering the diverse stakeholder interests and opinions and the natural challenges of standards development. EPRI has been involved, so the following might already be incorporated: but it might be worthwhile to involve the viewpoints of utilities that have an extensive ADMS/DMS and/or smart grid deployment in the development of requirements to ensure compatibility. (This may have been done; was not able to review all the reference material).

**Reviewer 3:** The team could play an extended role beyond 2021 in providing the right guidance to State public service commissions and regulatory bodies for the implementation and enforcement of these standards. or it may be good to involve them at this time.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Since the project is related to development of the new standards, it will benefit from collaboration with more standard development organizations. Other stakeholders may include electric utilities who will use this standard.

**Reviewer 2:** As mentioned in item 5, it may be good to incorporate perspectives from a utility viewpoint that has already a large amount of interconnected DER and communications. This may be achieved through EPRI. The challenge will be to find a way to move requirements forward and achieve buy-in from all the stakeholders.

**Reviewer 3:** National Association of Regulatory Utility Commissioners (NARUC) and State electricity commissions and regulatory bodies may be need to brought into the loop as well.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project is creating cybersecurity standards for distributed energy resources, including solar inverters that will establish a minimum level of performance. Since it is related to development of standards, it is not directly related to the DOE SETO mission and goals. The funding requested for the project is exclusively from DOE and the level of funding seems to be high.

**Reviewer 2:** This type of work is important and necessary to standardize requirements for secure DER networking. It seems that there have been some important contributions so far, as characterized in this report - three reference works serving as foundation for standards development. The work products will need to be reviewed and accepted by industry stakeholders in order to move the work into requirements. The challenge in getting agreement and finding the proper certifying entity is appreciated due to different opinions and lack of clarity as to the overarching responsible entity.

**Reviewer 3:** Bring the National Association of Regulatory Utility Commissioners (NARUC) and State electricity commissions and regulatory bodies into the loop. This program could be extended beyond 2021 to provide oversight and support to the utilities and industry in the implementation of the proposed standards.

## Securing Inverter Communication: Proactive Intrusion Detection System Sensor to Tap, Analyze, and Act – $1,930,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Shamina Hossain-Mckenzie*

Inverters, which connect solar energy systems to the grid, can improve the hosting capacity of distribution grids, but interoperability, access interfaces, and the proliferation of third-party software applications have made smart inverters more susceptible to cyberattacks. This project is designing a distributed monitoring system to observe a wide range of cyberattack paths, detect various attack methods, predict adversarial movements, and implement controls that mitigate damage to distributed energy resources, like solar energy systems and other devices connected to the grid. The team is also developing and testing a cost-effective, device-level solution called the Proactive Intrusion Detection and Mitigation System in order to effectively protect and defend distributed energy resources.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 5 |
| Set critical challenges to overcome | 3 | 6 | 5 |
| Implement a high-risk, high-impact approach | 3 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 2 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project somewhat aligns with the SETO mission but only in a limited way—it enhances the cyber security of solar inverters and help expand their usefulness. Therefore, the contribution to the US solar industry is indirect and not so high. However, as the project team recognizes, the technology developed could be applies to other inverter technologies and perhaps could help research outside of the DOE scope. The project duration (36 months from October 2018 through September 2021) is commensurate with other projects. The budget ($1.9 million DOE and almost no cost share) is at the lower end making the performance/cost ratio look attractive. However, as discussed earlier, the project does not improve solar technology by itself but rather the peripheral technology that may help enhance the application of solar. And there is very little cost share.

**Reviewer 2:** Strengths seen in laying out the sensors, detection methods, use-cases and intentional attack methods. Hardware validation of the full system setup is the appropriate way to go.

**Reviewer 3:** The project has created low cost prototype sensors for cyber intrusion detection which can be layered upon existing detections. The project is promising in terms of cost and abilities; to date the validation and testing has been in a purely model environment.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 3 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project started in October 2018 and is just around its mid-point. The report discusses the immediate milestone and achievements clearly and indicates the team has a good grip on the findings and reflecting that to future project work. Interim results have been published in several papers, and there appears to be a very collaborative team dynamic. However, stakeholder engagement may be missing. Overall the team appears to be on track.

**Reviewer 2:** While the level of complexity in development and analysis is great, the national labs and security organizations should include Utilities, ISO (independent service operators) and standard organizations like IEEE and UL to be part of the supporting groups.

**Reviewer 3:** The project has created a prototype sensor which can be utilized for detection of cyber intrusion issues at the inverter, and layered upon existing network protections. The prototype testing has to date been conducted in a model environment to evaluate computational burdens and performance. Findings to date have been shared at three industry forums: IEEE cyber security, Smart grid, and power and energy.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The report does not articulate any tasks. It does discuss milestones but only immediate ones. The report does provide an overview of the scope in the Goals section helping the reader understand the general scope and steps. However, assessing whether each task adds unique and important value to achieving the overall goals of the project, with the current report, is not feasible without speculation.

**Reviewer 2:** Score: 5. Comments: Yes, the tasks for individual milestones along the program is very well laid out.

**Reviewer 3:** Score: 5. Comments: The specific tasks were directly listed in the text of report, but can be surmised from figure 3 were the research approach to meet the goals are illustrated.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The report focuses on the technical aspects and does not discuss much about testing, or commercialization. And the project does not list a team member who can lead the testing and/or commercialization. Given the similarity of skillsets of the current team members (all in the technical field), the project does risk the potential of ending up as another research that is technically valid but practically not useful and therefore not deployed.

**Reviewer 2:** Do not see any blind spots in the plan presented in the report.

**Reviewer 3:** The prototype evaluation is primarily based on emulations with some work to be based on system models. However real-life systems are subject to dynamics and infrequent, but expected conditions such as faults and contingencies, or aberrations in weather conditions, telemetry failures, etc. It is important to verify performance in these conditions when it is most important to collect data. false detections are important to identify in addition to percentage of actual intrusions detected.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** A utility partner to help with the field test and identify the potential flaws or roadblocks, and potential areas for improvement would certainly benefit the team. Another potential weakness of the team is that it lacks a commercialization expert and a leader who can balance the technical side and commercial side. This may lead the project to struggle later when the field test and commercialization become the main tasks. A neutral leader (who is not from a research institute) to balance the team that is composed of members with similar research backgrounds may also help.

**Reviewer 2:** Utilities; ISO's (independent system operators); and organizations like IEEE/UL technical panels.

**Reviewer 3:** A utility partner to provide ability to evaluate impact on performance during normal and abnormal operating conditions.

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** This project enhances the cyber security of solar inverters and help expand their usefulness. Therefore, the contribution to the US solar industry is indirect and perhaps not so high. The technology developed could be applies to other inverter technologies and perhaps could help research outside of the DOE scope. What is critically missing is the way for the technology being developed to be commercialized or deployed in the industry. For that purpose, a utility partner, a commercialization expert, and a neutral leader who can balance the technical side and commercial side would greatly benefit the current project team.

**Reviewer 2:** SETO should continue to encourage advancements in this area, recommend to include the missing supporting groups stated, and understand that this project has potential to evolve into a commonly applicable standard for safety on a scale.

**Reviewer 3:** 1) The project produces a prototype detection device that can be layered upon other network intrusions methods. 2) The device is low cost and initial testing shows the data burden is reasonable. 3) The validation and testing is based on modeling and emulations. Field testing or use of data collected from field might provide additional insights into performance during abnormal operating conditions.

## AURORA: Autonomous and Resilient Operation of Energy Systems with Renewables – $4,999,999

*Siemens Corporation | Princeton, NJ | Principal Investigator: Ulrich Muenz*

This project is creating a microgrid control system that can coordinate distributed microgrids to work together. The system will include a communications-free method to increase grid resilience and autonomously restore power during a blackout using smart inverters.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 6 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The AURORA project demonstrates innovative technologies for Security Situational Awareness by assessing and optimizing resiliency against physical threats and detecting and localizing cyber- attacks. It also will provide distributed micro-grid coordination and continuity of service after attack on control center or communication network. In addition, the project will secure autonomous micro-grid restoration after blackouts by robust parallel grid-forming inverters. This project addresses key power system challenges, such as scalability in physical situation awareness, data scarcity on cyber-attacks and complex dynamics during islanding and restoration. It implements a high risk, high impact approach, since innovation on such a large scale is a high risk. Also there is scarcity of data which is difficult to obtain, optimization algorithms for physical security situational awareness may not be scalable to large systems, and massive parallel grid forming with that many inverters hasn't been tested before. The project will add significant value to research with a large team of expert working on the project. Weaknesses of the project may be that it is going to be tested on one small system and it may not be clear how it will work on larger systems, or how it can be replicated to other systems. Also, the project budget seems not to be finalized yet.

**Reviewer 2:** The project has clearly defined goals. The 3 level EMS is deployed on HECs power system with Siemens Micro-grid controller and Micro-grid manager to simulate grid resiliency and grid restoration and cyber and physical threats. The demonstration of grid restoration with 50 simulated inverters is a good validation strategy to demonstrate grid forming capability.

**Reviewer 3:** Firstly, I would like to thank and congratulate the project supporting groups who is taking up this herculean task. The goal/ motive of this project is extremely important to understand and implement well for success on long term. The level of PV penetration and electric loads usage has exponentially went up multi-fold in the recent decade. Hence leading to grid instability and blackouts. There are various natural disasters or usage abnormalities that are happening around to make micro-grid more essential part of the ecosystem. The micro-grid will be heart of the system when the Utility grid drops out and be able to restore from blackout and operate DER in parallel safely. The interconnection and communication between sectional micro-grids are crucial to the future. However, the scope of the project is extremely wide and the goal seem aggressive with the project duration and support system present. It is unclear on how much of the fundamental blocks are already realized and how much of development is left out to achieve the results.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 6 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project duration is three years, out of which only one quarter has passed. The milestones in this quarter are related to project management as well as requirements and use cases for the different technologies. No results were disseminated yet. Detailed Project Management plan and Technology to Market are under development and not submitted yet. The project report doesn't include milestones and their completion dates past the first quarter. Although impact of the project is high, it cannot be measured quantitatively. The outcome of the project will be a demonstrator for new multi-layer resiliency framework in a simulated operational environment for one power system and hardware demonstrator for parallel grid-forming with 50 software defined inverters. The project will enhance resilience of the grid with high solar PV penetration. Collaborators on this project are NREL, Columbia University, Holy Cross Energy and Siemens Digital Grid. The last two advise and support the project by providing real-world requirements and use cases based on their operational experience as well as field data. In my opinion, the project could include also other electric utilities as stakeholders because the project if implemented, it will have a high impact on the industry.

**Reviewer 2:** The project seems to be on target and Siemens is working on getting subcontractors into the project. Detailed Project Management plan and Technology to Market are under development and will be submitted by end of Q1. Budget seems to on target as well.

**Reviewer 3:** However, the scope of the project is extremely wide and the goal seem aggressive with the project duration and support system present. It is unclear on how much of the fundamental blocks are already realized and how much of development is left out to achieve the results. The focus of implementation is on a small-scale system and the assumptions made here may not apply well to different configurations possible at medium and large scale. The part of the development efforts are within Universities and Siemens research divisions. The collaboration requires and missing other stakeholders such as ISO(independent system operators), IEEE or Sandia labs and medium-large scale utilities.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project includes several layers of tasks, each of them adds important value to the project goal. The first layer includes security situational awareness, and its tasks are assessing and optimizing resiliency against physical threats and detection and localization of cyber-attacks. The second layer includes distributed micro-grid coordination where the project will work on continuity of service after attack on control center or communication network. The third layer of tasks includes autonomous micro-grid restoration that increase resilience against cyber and physical threats in a simulated operational environment and works with fast restoration after blackouts with the help of robust parallel grid-forming inverters. Although these tasks are important and will add value to the project, the project report doesn't explain how and in which timeframe they will be achieved.

**Reviewer 2:** Score: 3. Comments: The project tasks are not very well defined at this time. But the 2 key major outcomes to be expected of this project are: 1) Demonstration of physical and cyber security situational awareness as well as distributed microgrid coordination in NREL's ADMS testbed running HCE's power system; and 2) Hardware demonstration of parallel grid-forming and autonomous blackstart with 50 inverters. I would ask this team to put more detail around the tasks and timelines.

**Reviewer 3:** Score: 6. Comments: There are various natural disasters or usage abnormalities that are happening around to make micro-grid more essential part of the ecosystem. The micro-grid will be heart of the system when the Utility grid drops out and be able to restore from blackout in a timely fashion and operate DER in parallel safely. The interconnection and communication between sectional micro-grids are crucial to the future.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** My concern is that the budget for the project is not developed yet, so the cost is not clear. Another "blind spot" may be that the project will be validated and tested on one small system and it is not clear how it can be scaled to large systems and how it will be applicable to other systems.

**Reviewer 2:** Although it is not clearly stated in the submitted reports, the team is undertaking substantial scope. The Budget, tasks and timelines are not available from the reports. this makes it difficult to assess any potential blind spots. However, the team has partners with the right competencies. This gives me confidence they will be able to deliver.

**Reviewer 3:** The focus of implementation is on a small-scale system and the assumptions made here may not apply well to different configurations possible at medium and large scale. The part of the development efforts are within Universities and Siemens research divisions.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I think that the project authors need to collaborate with more electric utilities that may use this project.

**Reviewer 2:** The project team includes, Siemens Research, Siemens Digital Grid, NREL, Columbia university and Holy Cross Energy. The project outcome is well defined. It looks like all the bases are well covered.

**Reviewer 3:** The collaboration requires and missing other stakeholders such as ISO (independent system operators), IEEE or Sandia labs and medium-large scale utilities.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) This project is creating a micro-grid control system that can coordinate distributed micro-grids to work together. The system will include a communications-free method to increase grid resilience and autonomously restore power during a blackout using smart inverters. The grid forming and distributed control developed in this project will be of great value also to rural/remote areas, which can be powered by solar generation. Also, the physical and cyber security situational awareness developed in this project assures the resiliency of power grid and could inform grid operators the best actions to mitigate large-scale failures in power systems. 2) However, the challenge may be scaling this project to large systems and how it can be replicated to other systems. 3) Also, it seems that the project budget seems to be uncertain at this time.

**Reviewer 2:** SETO should ask the team to outline the budget, tasks and timelines to accomplish the project goals.

**Reviewer 3:** SETO should continue to support micro-grid systems that are going to be the essential part of the ecosystems. This project involves the cross-communication and safety dependencies across sub-sections that can be scalable. SETO should recommend more research in this topic with more collaborators from Utilities, ISO's and IEEE.

## Secure Monitoring and Control of Solar Photovoltaic Systems through Dynamic Watermarking – $4,400,000

*Texas A&M Engineering Experiment Station | College Station, TX | Principal Investigator: Le Xie*

This project is working to develop and demonstrate an active defense mechanism of cyber-resilient photovoltaic distribution system operation using a dynamic watermarking technique to monitor cybersecurity. The technique involves injecting a probe signal onto the grid to authenticate grid actions. The approach includes real-time deployment of online computational algorithms in real-world critical locations. The team will test and validate the integrated communication, control, and computational framework using an existing system.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This Project proposes to design a comprehensive strategy to detect and attack with more than 95% accuracy and a control strategy that will ensure system operation during the attack. The team is likely to use a signal injection technique, supported by algorithms that will ensure operation even under noisy measurements and cyberattacks. The approach seems novel for a distribution network which is dominated by PV inverters. if this successful this could help other inverter-based systems on the distribution systems as well. Project start date is missing in the material presented.

**Reviewer 2:** The project is aligned with resiliency objectives through investigation into means to detect cyber threats in the distribution systems. The challenges and differences presented by distribution systems versus transmission are well articulated. The report focuses on discussion of the cyber intrusion detection. The report also references development of control strategies but the specifics were not provided.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project duration is anticipated to be 3 years and has not started yet and the team has not presented a started date as well.

**Reviewer 2:** The project provides some novel approach to detection of cyber intrusion and some measures of stabilization that would apparently apply to the control algorithm. The project has a utility partner, the role is not described but presumed to be in the provision of data for modeling of a real world based distribution system. The periodicity and mechanisms by which the results would be disseminated to the industry were not included in the report.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The tasks are well aligned to meet to design, develop and test the watermarking technique. The team plans to demonstrate this technology on real world test bed. Based on the description provided it seems like the validation would happen on a simulation test bed. Suggestion: The efficacy of this technology may be better supported by a field validation as well.

**Reviewer 2:** Score: 5. Comments: The broad task descriptions are reasonable but details lacking in some areas.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The team could benefit if they plan for a field validation. What kind of distribution systems could benefit from this method? Rural, vs. Urban distribution systems; Roof top inverters vs. MW scale inverters etc. Does the signal injection need to be tailored for every system?

**Reviewer 2:** The project description doesn't supply details on the goals of the controls scheme, Detection based on watermarking may erroneously flag valid conditions as cyber intrusion. It would be important to report on false detections in addition to proper detections.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Add inverter manufacturers to the Advisory board or as partner may provide the necessary support on the inverter modeling aspect.

**Reviewer 2:** The role of the industry partner might be critical in proofing the concept with real-time data to ensure conditions are not erroneously flagged as potential intrusion; and objectives of the control algorithm. The project may benefit from inverter manufacturer or DER system provider as well.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** SETO should consider this as a high-risk approach. The validation of this technology needs to be very robust and applicability of this technology needs to be assessed, because each distribution system is somewhat unique, defined by the load, generation and multiple voltage levels. At this point the project seems less defined in terms of timelines and scope. The $4.3MM budget needs to be justified as well.

**Reviewer 2:** 1) The approach to cyber intrusion detection appears interesting. 2) The report could benefit from some additional level of detail. 3) The role of the industry partner might be critical in proofing the concept with real-time data to ensure conditions are not erroneously flagged as potential intrusion.

## Multi-Level Cybersecurity for Photovoltaic Systems – $3,500,000

*University of Arkansas | Fayetteville, AR | Principal Investigator: Alan Mantooth*

This project addresses cybersecurity at both the inverter and system levels for photovoltaic energy systems. First, the team is developing an inverter to address supply-chain security, real-time intrusion detection methods, vulnerability mitigation, control system security, safety protocols, and other concerns. Then, at the system level, the team will use machine-learning algorithms, a multilayered blockchain platform, and model-based intrusion detection.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 3 |
| Set critical challenges to overcome | 5 | 4 | 3 |
| Implement a high-risk, high-impact approach | 6 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 2 |
| Advance the U.S. solar industry substantially | 6 | 4 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Very well thought out project and commend all the supporting groups working on this project. At this point of time, I do not see any weakness in the approach laid out. Testing models and algorithms on simulation and validating on hardware is the right approach. The innovation here is bringing together the cyber security protocols that are typical and novel together with the modernization of the PV systems deployment.

**Reviewer 2:** Strength: A two level cyber security scheme is proposed by the team to enable a full proof security of the PV Plant. This probably a robust solution. Weakness: Based on the material presented there is no novelty in the idea itself. Also, the cost benefits of a two-level security vs. a single plant/farm level cyber-security need to be traded off.

**Reviewer 3:** The project somewhat aligns with the SETO mission but only in a limited way—it enhances the cyber security of solar inverters that could help expand their usefulness. Therefore, the contribution to the US solar industry advancement is not so high. The technology, while developed for solar inverters, could potentially be applied to other inverter technologies that may reach out beyond the field of DOE's research. The project duration (36 months from April 2020 through March 2023) is commensurate with other projects. The budget ($3.6 million DOE and $1.1 million cost share), with adequate cost share, is on the higher end—this makes other projects look more attractive if SETO is focused on solar itself, rather than peripheral technologies that enhances the ability of solar. The project just started in April 2020 and while the report discusses milestones for the initial period, the longer-term schedule and milestones are unclear.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 0 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 0 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 0 |
| Collaborates with sufficient stakeholders | 6 | 5 | 0 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project scope and laid out plan very well meet all the requirements needed sufficiently. Multiple universities, National labs, Co-operative utility and bigger company collaboration is great.

**Reviewer 2:** This project started on April 1st, so there is not much to evaluate at this point. Based on the tasks proposed it is not clear to me if the team plans to compare and contrast the benefits of 2 level (inverter and farm) cyber-security) vs. farm level cyber security and how does this compare with the state of the art cyber-security strategies where the entire farm is behind a firewall at the POI and various stakeholders who need access to the plant have their own firewalls to get access to the plant SCADA network.

**Reviewer 3:** The project starts in April 2020 so all questions are not applicable.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes. The tasks and milestones are described well in the report. The plan seem justified.

**Reviewer 2:** Score: 5. Comments: The tasks proposed at each level seem appropriate to accomplish the proposed goal but I strongly suggest the team to provide a trade-off analysis as per my comments above.

**Reviewer 3:** Score: 3. Comments: The report does not articulate any tasks. It does discuss milestones but only for the immediate period (first budget year). Combined with the fact that the project is just starting, assessing whether each task adds unique and important value to achieving the overall goals of the project, with the current report, is not feasible without speculation and perhaps meaningless.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Don't see any blind spots at the moment.

**Reviewer 2:** Cyber-Security for critical/sensitive points on the Distribution grid need to be evaluated. Every device on the edge of an electrical network does not need to have a highest level of security. The Team should consider defining a level of security that is needed and assign a cost function to it.

**Reviewer 3:** The report is focused on the technical side and does not discuss much about field testing, or commercialization. While the team does list a utility member, the role is not discussed at all. Given the larger weight of academia members, the project does risk the potential of ending up as another research that is technically valid but practically not useful and therefore not deployed.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project involves all necessary stakeholders appropriately.

**Reviewer 2:** This team probably needs to have a couple of utilities on their project Advisory board to provide them guidance on the requirements. Jay Johnson's team from SNL and/or a cyber-security expert from NREL.

**Reviewer 3:** The team's focus as of now appears to be in the technical details, likely because the project is just being started and also coincides with the team members' areas of expertise. However, the team should think and plan for the field testing and commercialization or deployment following for the project to succeed. A role specifically in charge of the project after the proto-type technology is developed appears to be missing. The utility and the PV system operator could play an expanded role. On the other hand, the team has many members with similar skillsets (largely academia and labs). The coordination of tasks among these team members with overlapping expertise may become a challenge in maintaining a collaborative and yet efficient team.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** SETO to continue encouraging this content, collaboration and fund.

**Reviewer 2:** SETO should look at all the Cyber-security projects and trade them of based on the merits. Use the work done by Sandia National Labs (Jay Johnson) to set the basic requirements for the projects to be evaluated against. Some of these projects that are just starting they could potentially add the above recommendation as a task in BP1.

**Reviewer 3:** The project team should look beyond developing the technology and think about how the technology developed could be used in the real world. The role of the utility partner should be defined to help identify the potential flaws or road blocks, and potential areas for improvement. This should also be reflected into the team's future plans. Otherwise the project faces a risk of becoming another study that is technically valid but practically not useful.

## Optimal Reconfiguration and Resilient Control Framework for Real-Time Photovoltaic Dispatch to Manage Critical Infrastructure – $3,699,984

*University of North Carolina at Charlotte | Charlotte, NC | Principal Investigator: Sukumar Kamalaasdan*

This project is devising a grid management tool that detects cyber and physical threats and can form dynamic clusters to optimally manage photovoltaics and energy storage to improve grid resiliency and support critical infrastructure. This tool has two-level control with reconfigurable grid networks, which allows operators to isolate damaged sections while still powering the rest of the grid.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 6 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Firstly, I would like to thank and congratulate the project supporting groups focusing on this topic. With many types of DER's such as PV, energy storage and other increasing penetration on to the grid, it is very important to understand the strengths of optimal usage of these DER's when the abnormal situations arise. This project aptly focuses on the micro-grid clusters and ability to operate flexible loads in a sectional region by the controller. All the study is performed on modeling and no experimental study is realized here. It is not clear on how much of the modeling blocks are already developed for use in this project. The assumptions made and accuracy of the models in real-time analysis is questionable. However, this is an important part of the puzzle that needs in-depth analysis and provide scope for experimental evaluation and proof of concept.

**Reviewer 2:** The main goal of this project is to develop a tool that can identify potential PV farm energy storage cluster and manage the cluster for improving grid resiliency during natural and man-made attacks, and at the same time improve grid reliability during normal operation. The tool consists of: a) a situational awareness module b) proactive resiliency diagnosis and predictive adaptation module c) a hierarchical control with dynamic clustering and organizational module, d) optimal power flow module, and e) a network reconfiguration and cyber security threat detection module. The proposed approach is scalable, platform-neutral and requiring minimal communication between active PV stations, storage nodes, and distribution control center (DCC). The project set critical challenges to overcome, that include the technical tasks and distribution of the project tasks in a modular approach among project participants. Synchronized and timely co-ordinations among the project partners to deliver the main goal of this project is critical. The budget seems a little high, and project duration seem reasonable, considering many tasks and participants. The weakness of the project may be that it is rather academic and for now how it will be validated on a real system is not specified. It is also unclear how many entities will use it.

**Reviewer 3:** From the report, it was difficult for this reviewer to understand the specific milestones. While it was clear that a control algorithm was to be developed to enable clustering and grouped control of distributed resources, the specific criteria defining optimal and resilient performance was not clear. The objectives of the grouping compared to centralized control was not clear. Is the intent to form separated autonomous systems? Details on the protective schemes were also not clear.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 3 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 3 |
| Collaborates with sufficient stakeholders | 4 | 4 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** A 3yr schedule for the simulation models in definitely reasonable within the given budgets. The end results or the analysis is properly quantified. The team distribution and assignment is done very well to achieve the goal in a timely fashion. However, the project is missing stakeholders like Utilities, and ISO (independent system operators) but has great support from national labs and university organizations.

**Reviewer 2:** The project duration is three years, and it was started 3 months ago. The project includes seven objectives. The first milestone is scheduled for April 2020, and since none of the milestones is reached yet, it is hard to evaluate if they will be met on time. The project will focus on the following specific performance metrics that include net capacity factor improvement, increase in PV penetration, both reliability and resilience improvement and PV dispatchability with optimal energy storage size. All metrics are defined quantitatively. In addition to the University of North Carolina there are seven partners involved in the project, each doing their own part of the project. The tasks are currently distributed for the first budget period. The results are shared between the project participants, although it is not clear how frequently. The project participants include universities, national labs and a software development company. For now, the project doesn't collaborate with other stakeholders that could benefit from it, such as electric utilities.

**Reviewer 3:** The report does not explain the measured criteria of the outcomes. The premise appears to be enhancing resiliency; but the means to characterize the improvement is not articulated. The specific milestones were not listed. There is not a utility partner for field demonstrations. Is the proposal that these cluster form microgrids? What is the interrelationship between the overall power system, its operation, and this autonomous controller?

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The task breakdown and the milestones described to achieve the desired goal is very well laid out.

**Reviewer 2:** Score: 5. Comments: The project includes seven tasks that add important values to the project goals. They are the following: 1) Development of dynamic integrated T&D model with situational awareness module that updates the operation of the grid in the presence of DER cluster that participates in improving reliability and resiliency during normal or abnormal conditions. 2) Cluster organization and hierarchical area control module that organizes the DER cluster and develops an area controller. 3) Grid level optimization module that helps optimally manage active and reactive power in DER clusters considering grid conditions. 4) Dynamic cluster control architecture and risk/threat resiliency module that organizes all the cluster level controllers dynamically based on the risk and also measures the level of risk. 5) Network reconfiguration module that reconfigures the network and provides protection schemes to harden the cluster. 6) Grid-aware communication and cyber security threat detection module that provides a communication infrastructure for implementing the control and protection schemes and detects and analyzes cyber security related threats. 7) Overall integration, real-time lab scale and field validation. The final objective is to develop a software platform that is tested in the lab and partly in the field and can be integrated with hardware. The results are validated and verified in the hardware and in the field. The tasks are organized and distributed among the project partners. Currently, the breakdown of the tasks for the first budget year is developed.

**Reviewer 3:** Score: 4. Comments: The tasks seemed reasonable; but the overall goal or premise was unclear: how are the clusters to improve resiliency?

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Only simulation analysis is performed here and show weakness due to missing validation on experiment. The assumptions in the PV, ESS and load forecast is not clear and may end up being inaccurate.

**Reviewer** 2: I think that the project authors need to collaborate with more stakeholders that could benefit from the project, such as electric utilities with high solar PV penetration where the project may be applied. The requested funding is completely from DOE, maybe it would make sense to look for other sources of funding also.

**Reviewer 3:** If the objective of the project is in fact to have identified clusters separate and operate as autonomous systems using naturally imbedded storage/PV, the project must consider the fact that storage is a finite energy resource and PV energy only available during certain hours of a day. Unless specifically designed to accommodate a native load it is unlikely storage would be installed of the size required to serve distributed loads without supplemental energy sources (the power system as a whole, or other conventional generation).

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The project is missing stakeholders like Utilities, and ISO (independent system operators) but has great support from national labs and university organizations.

**Reviewer 2:** I think that electric utilities with high solar PV penetration where the project may be applied need to be involved in the project.

**Reviewer 3:** The project does not appear to have participation from DER providers or utility. It may benefit the project to involve utility operators to understand power system resiliency needs and frame the objectives. Use of native solar and storage to supplement resiliency or form islands requires consideration of the finite energy availability.

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** SETO should encourage these studies of flexible asset control by utilities and ISO's for grid resilience in needed times, encourage more cost down for energy storage systems deployment to better commend PV adoption, and help gather support from the stakeholders missing in the project.

**Reviewer 2:** 1) The purpose of the project is to advance solar energy's role in strengthening the resilience of the U.S. electricity grid. The project will develop a grid management tool that detects cyber and physical threats, and forms dynamic clusters to optimally manage photovoltaics and energy storage in distribution systems. The project is related to strengthening the grid resiliency and reliability. 2) In my opinion, the project is mostly academic, so far it is not clear how it will be validated and how many industry entities will use it. It is also not clear how it will perform in the real-time conditions. 3) The budget for the project is rather high, and the funding is requested only from DOE with no other cost share.

**Reviewer 3:** 1) The project needs to include the specific manner in which the proposed cluster controller will enable enhanced resilience. 2) The project report did not specify the milestones and dates. 3) The project could benefit from interaction with utility operators to define system resiliency needs.

## Protection and Restoration Solutions to Reliable and Resilient Integration of Grid-Connected Photovoltaic Installations and Distributed Energy Resources: Design, Testbed, Proof of Work and Impact Studies – $4,298,146

*University of Oklahoma | Norman, OK | Principal Investigator: John Jiang*

This project team is working to build an intelligent sensor network that communicates with the distribution system. The network will autonomously detect and isolate problems while using solar energy to help restore power to the distribution grid after an outage.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 6 | 6 |
| Set critical challenges to overcome | 3 | 6 | 5 |
| Implement a high-risk, high-impact approach | 3 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 6 | 5 |
| Advance the U.S. solar industry substantially | 3 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aims at using solar and other inverter technology resources to help solve dynamic stability faults and other potential issues on the distribution network. It generally aligns with the SETO mission, although it may not help lower the LCOE of solar, which is a larger SETO goal. The product developed can likely be used for other inverter-controlled resources and therefore can have a wider application. However, the application may be limited to the power industry and not provide much benefits to research activities beyond DOE. The project duration (41 months from March 2020 through July 2023), while still comparable to other projects, is longer. With the project just started, the future schedule is not articulated. The budget ($4.5 million DOE and $1.9 million cost share), with adequate cost share, is among the highest, indicating a comparative disadvantage if one were to look at the performance/cost ratio. In addition, while the project team indicates field tests will be performed in the third year, putting the product developed to be used in practice may be a challenge for this team, which is largely from academia and no one from the industry.

**Reviewer 2:** This project is addressing transient instabilities that could caused by IBRs on the distribution systems and proposes to provide a fault detection and restoration solution. this has a broad applicability to solar, wind and battery resources on the Distribution. There are other kinds of transients disturbances that occur on the grid caused by weather, cyber-attacks etc. that would need fault detection and restoration. Some of that is addressed by the teams working on Situational awareness and cyber-security teams. However, this team could get an external input into this solution and respond to such inputs.

**Reviewer 3:** The objective of this "protection and restoration of power distribution grid" research project is to develop, prototype and field demonstrate a novel "system restoration" concept and critical technology for distribution grid protection during the stressed grid operating condition, aiming at supporting high penetration of grid-connected solar PV and inverter-based energy resources (IBRs). This project offers adaptive protection and restoration solutions to support switching operations of solar PVs and IBRs, particularly during the fault transient period, so that these unconventional energy systems are able to correctly respond to dynamic disturbances. This presents a significant challenge. The risk is high because it is a completely new approach and because the first two years of the project the work is mostly academic. Integration of the new technology in the power grids for field testing and the tests themselves will be performed in the third and fourth years of the project. Although the budget is large, but it is appropriate for such long project duration (3.5 years). The project will add significant value to research because it is a new approach to the existing power system protection and restoration schemes. The weakness of the project may be that it is largely academic, especially in the first two years, and it is not certain how it will work in the real grids.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 0 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 0 | 5 | 4 |
| Collaborates with sufficient stakeholders | 0 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project started in March 2020. Given that there has been less than a month since project start, these questions are not applicable.

**Reviewer 2:** This project is delayed by almost a quarter and hence scores a bit low on the performance and delivery but the scores can improve once the project gets into a high gear.

**Reviewer 3:** The project has set ambitious goals and milestones, however it just started. In the first year, it will build two testbeds – one for a cyber-physical power distribution grid and the other one for a Hardware-in-loop transmission grid. It will also investigate the nature of fast switching transients of grid-connected solar PV systems and IBRs and their impact on the protection schemes of the power grid. Then, both testbeds will be commissioned for research and advanced concepts from a physics perspective will be developed, which will take another 18 months. In the last part of the project development, a prototype novel technology for distribution grid protection and restoration will be built and the validation tests and studies will be carried out in realistic power grids. The nature of the project doesn't allow to quantitatively measure its impact. The impact will be in enhancement of the grid reliability and resiliency if the new technology will be widely implemented. The project has a strong research team of experts from several universities. The future users of the new technology that this project brings, such as electric utilities, and also inverter manufacturers are not included in collaboration on this project at this time.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: The report does not articulate any tasks. It also does not discuss milestones. This may be because the project was just kicked off last month. The report does provide an overview of the scope. However, assessing whether each task adds unique and important value to achieving the overall goals of the project, with the current report, is not feasible without speculation.

**Reviewer 2:** Score: 5. Comments: The tasks are well outlined and structured to accomplish the end goal. The team could add an additional external input: There are other kinds of transients disturbances that occur on the grid caused by weather, cyber-attacks etc. that would need fault detection and restoration. Some of that is addressed by the teams working on Situational awareness and cyber-security teams. However, this team could get an external input into this solution and respond to such inputs.

**Reviewer 3:** Score: 6. Comments: The project consists of seven tasks and will take 3.5 years to complete. The tasks include: 1) Complete the design and construction of the physical testbed at the University of Oklahoma. 2) Complete the design and construction of the hardware-in-loop testbed at North Dakota State University. 3) Provide an improved understanding of complex and ultra-fast transients in power grids via research. 4) Commission two testbeds and demonstration of their functionalities. 5) Develop and prototype the new protection/restoration technologies. 6) Integrate the new technology in the power grids for field testing. 7) Carry out field tests and validation These tasks are distributed among three budget periods. Each task brings unique and important value to the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The budget, with adequate cost share, is among the highest, indicating a comparative disadvantage if one were to look at the performance/cost ratio. In addition, while the project team indicates field tests will be performed in the third year, putting the product developed to be used in practice may be a challenge for this team, which is largely from academia and no one from the industry.

**Reviewer 2:** Not much at this point because of the delayed start. The team should plan to include a couple of utilities and may be NREL on the Advisory board to get better guidance.

**Reviewer 3:** The project participants include only universities at this time. I think that it is important to include more stakeholders, such as electric utilities who will benefit from this project. The project is largely academic, especially in the first years, and it may be challenging to apply it to a real power system.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team with all members from academia appears to be very focused on the technicality, and largely in the research arena, rather than having actual field experience. A utility partner to help with the field test and identify the potential flaws or road blocks, and potential areas for improvement would certainly benefit the team. Another potential weakness of the team is that it lacks a commercialization expert and a leader who can balance the technical side and commercial side. This may lead the project to struggle later when the field test and commercialization become the main tasks. A neutral leader (who is not from academia) to balance the team that is composed of members with similar academic expertise may also help.

**Reviewer 2:** Not much at this point because of the delayed start. The team should plan to include a couple of utilities and may be NREL on the Advisory board to get better guidance.

**Reviewer 3:** I think that the project will benefit if electric utilities and National Labs are also included in it.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project team is currently focused on the technical aspects of their product. They should look beyond developing the technology and think about how the technology developed could be used in the real world. A utility partner to help identify the potential flaws or road blocks, and potential areas for improvement would greatly benefit the team. A neutral leader to balance the team that is composed of members with similar academic expertise may also help. Views beyond simply developing the technology should also be reflected into the team's future plans. Otherwise the project faces a risk of becoming another study that is technically valid but practically not useful.

**Reviewer 2:** SETO can make sure that the PI can make this solution is complete if they could get an external input into this solution and respond to such inputs. There are other kinds of transients disturbances that occur on the grid caused by weather, cyber-attacks etc. that would need fault detection and restoration. Some of that is addressed by the teams working on Situational awareness and cyber-security teams.

**Reviewer 3:** 1) This project is to improve the fundamental understanding about the complex and ultra-fast transients in power grids, creating new protection/restoration technical solutions to steer a fleet of solar PV systems and IBRs actions within an ultra-short time frame. 2) The solutions will safely allow multiple grid-connected PV systems and IBRs to take correct protection/restoration actions and to reduce the impact of their incorrect actions on the grid reliability, so that the likelihood of unnecessary activation of protection schemes or system-wide failure is minimized. Thus, it will significantly advance the solar power industry. 3) The project is largely academic in its first years, and there is a risk that it may not perform as intended in a real power grid.

## Modeling and Control of Solar Photovoltaics for Large Grid Disturbances and Weak Grids – $898,060

*University of South Florida | Tampa, FL | Principal Investigator: Lingling Fan*

This project is designing dynamic models of utility-scale solar plants and their interactions on grids with large penetrations of generation through distributed energy resources like solar-plus-storage systems and wind power. These models will be used to construct a coordination strategy and a stability enhancement module for photovoltaic and storage systems so they can respond to rapidly changing grid conditions.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 | 3 |
| Set critical challenges to overcome | 4 | 3 | 3 |
| Implement a high-risk, high-impact approach | 3 | 3 | 2 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 3 | 3 |
| Advance the U.S. solar industry substantially | 3 | 4 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project tries to enable solar to respond to solve dynamic stability issues, and aligns with the SETO mission, although it may not help lower the LCOE of solar, which is a larger SETO goal. The analytical model developed can potentially be used for other inverter controlled assets and therefore can have a wider application, however, it may be limited to the power industry and perhaps not provide significant benefits to research of other fields (i.e., beyond DOE). The project duration (36 months from August 2019 through July 2022) is commensurate with other projects. The budget ($1.2 million DOE and $0.3 million cost share), however, is at the lower end. The project started in August 2019 and the team seems to have cleared their milestones to date. However, the forward schedule and milestones are not articulated in the document. The project team should also think about practical implementation—for example, if the approach only works during daytime when the sun is out, that would necessarily lead the operator to have at least two operating procedures, one for daytime when the solar assets are available, and one for night when they are not. This complication may not be welcomed by the operators.

**Reviewer 2:** The purpose of this project is to understand dynamic phenomena by designing dynamic models of utility-sale solar plants and their interactions with grids. These models will be used to construct a coordination strategy and a stability enhancement module for PV inverters. The project provides grid industry adequate models for solar PVs to capture essential dynamics and help grid industry design PV integration requirements and guidelines. The project also provides inverter industry stability enhancement technology for PVs to export more power in weak grids. While the topic of PV and its grid interaction modelling is an issue that the industry needs to improve on, the way this project is proposed and planned, doesn't seem to align the efforts with other ongoing initiatives across different organizations as well as manufacturers of solar PV plants. Such project should involve organizations such as NERC and WECC along with manufacturers and utilities that have significant PV installations. Having a university and a national lab addressing such a broad topic, may not be the most effective approach. The cost for the project considering its duration seems to be very reasonable, but the 80% share of DOE funding seems to be high.

**Reviewer 3:** Firstly, I would like to thank and congratulate the supporting teams working on this project. The motive of the project to improve the stability of the PV and storage inverters operation when grid-tied is crucial as that is the case for 99% of the time. The modeling study and analysis that the university taking here is commendable. However, the project scope seems more academic than commercialization and provable on large scale. Over the last 5 years, the national labs (like NREL and Sandia labs), inverter manufacturing companies, industry organized SIWG(smart inverter working groups) and IEEE 1547/UL1741 standard technical panel have worked together to develop the smart inverter functions that can be utilized to achieve the same goal for small-scale and large-scale PV systems. This has proven to be very effective and various PUC (public utility commissions) and ISO (independent system operators) already deploy these mechanisms at scale to prove the stability improvement.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 3 |
| Collaborates with sufficient stakeholders | 4 | 5 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The report clearly identifies the dates and milestones. Despite only starting in August 2019, the project already achieved three milestones as planned and the report indicates they are aware of the progress and reflecting the findings to date to future work. They have published interim findings into a number of papers as well. Their report also discusses stakeholder engagement as an important task, however, no concrete examples or evidence was provided. Overall the report suggests that the team is on track as planned.

**Reviewer 2:** The budget and schedule seem reasonable. The first goal of design adequate model for scalable computing and small-signal analysis was already accomplished. The tools for black-box model identification using measurement data and modular small-signal analysis that can accommodate PV inverter in large-scale grids were designed. Some other project goals were also achieved. The 11 tasks shown in the project report and their schedules seem realistic and within the reasonable budget. The main measure of the impact is how close the model output matches the time-domain simulation results and real-world inverter performance under grid disturbances. The impact of the project is measured appropriately. The project authors will use webinars to disseminate research results and seek feedback from the industry stakeholders. Another project partner in addition to the University of Southern Florida, is NREL who is actively engaged. How often the results will be disseminated, is not clear at this time. The three budget periods of the project include stakeholder involvement. The technology will be disseminated to the industry not only through stakeholder meetings but also IEEE conferences and WECC working group meetings.

**Reviewer 3:** The fundamental blocks of the PV system and grid system are commonly available at researchers or national labs to utilize. So the time of research spent on this development is redundant. Based on the report, most of the simulation development seem already proved and tested to the most extent as part of the academia goals. In addition to experimental verification, the topic presented is more suitable for IEEE conference and journal for wide audience view. The scope of this being commercialized is extremely low. The appropriate parties to be involved would be Sandia National Labs, NREL and the SIWG along with inverter manufacturers that already spent several years in this area with thousands of participation. The novelty of this control strategy or use-case seem weak and narrow. If the control strategy is proven strongly and wide accepted by the technical experts of the field, this can be part of the standards to be commonized.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The milestones and associated schedules (corresponding to budget year) are identified in the report and easy to follow. Two flowcharts—one showing the tasks and budget year, another showing the models being developed—allow the reader to follow how each task respectively adds unique and important value to achieving the overall goals of the project. However, the forward schedule and milestones are not articulated in the report. Overall the report suggests that the team, to date, is on track as planned.

**Reviewer 2:** Score: 4. Comments: There are three budget periods each with 3-4 tasks to be achieved by the project team. They include: 1) development of accurate dynamic models for utility-scale PV systems and their interactions with grids, 2) construction of coordination strategy for multiple PV systems, and 3) design and hardware prototyping of stability enhancement module for PV inverters. The expected outcomes from this project include: analytical models of utility-scale PV systems and their interactions with grids suitable for small-signal analysis; coordination strategy for multiple PV inverters and battery inverters to avoid device interactions; and a stability enhancement module for PV inverters. Even if the project cannot be completed without all these tasks and each has value, these tasks seem to be more typical rather than unique and important.

**Reviewer 3:** Score: 3. Comments: The fundamental blocks of the PV system and grid system are commonly available at researchers or national labs to utilize. So the time of research spent on this development is redundant. Based on the report, most of the simulation development seem already proved and tested to the most extent as part of the academia goals. In addition to experimental verification, the topic presented is more suitable for IEEE conference and journal for wide audience view. The scope of this being commercialized is extremely low. The appropriate parties to be involved would be Sandia National Labs, NREL and the SIWG along with inverter manufacturers that already spent several years in this area with thousands of participation. The novelty of this control strategy or use-case seem weak and narrow. If the control strategy is proven strongly and wide accepted by the technical experts of the field, this can be part of the standards to be commonized.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The project team should think about practical implementation of the technology being developed—for example, if the approach only works during daytime when the sun is out, that would necessarily lead the operator to have at least two operating procedures, one for daytime when the solar assets are available, and one for night or cloudy days when they are not. This may also require seasonal adjustments. Such complications may not be welcomed by the operators.

**Reviewer 2:** The team that the project authors put together are reputable organizations with great track record in achieving their objectives. However, I think a consortium of broader group of entities is required to tackle the modelling issues, including inverter manufacturers and electric utilities with high PV penetration.

**Reviewer 3:** The project leaders need to establish strong justification on why the already existing and proven smart inverter functions that Sandia labs, SIWG and IEEE has developed are not sufficient to resolve this problem. Even so, how can the use case narrowed down to a specific example is applicable or useful to the wide adoption of the PV adoption.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** A utility who could become the sounding board for the technology being developed would greatly help. Otherwise, it could end up being another study that is technically valid but practically not useful and therefore not deployed.

**Reviewer 2:** The project would have benefited significantly from participation of organizations such as NERC, PV manufacturers, and utilities with high solar installments such as the ones in California.

**Reviewer 3:** More national labs like Sandia Labs. More panels like IEEE SIWG and UL1741 standard technical panel. More inverter manufacturers and IEEE experts who may have already proven concepts like these.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project team should look beyond developing the technology and think about how the technology developed could be used in the real world. A utility partner would greatly help identify the potential flaws or roadblocks, and potential areas for improvement. This should also be reflected into the team's future plans. Otherwise the project faces a risk of becoming another study that is technically valid but practically not useful.

**Reviewer 2:** 1) This project is designing EMT dynamic models of utility-scale solar plants and researching their interactions with grids with large penetrations of solar PV generation. These models will be used to construct a coordination strategy and a stability enhancement module for photovoltaic and storage systems so they can respond to rapidly changing grid conditions. 2) The project objective is too broad and the research and the modes are not unique or innovative. 3) The project doesn't involve inverter manufacturers and doesn't involve utilities with high solar penetration which could benefit from the project.

**Reviewer 3:** The scope of the project is narrow/ limited. The amount of SETO resources needed to consider this project is not justifiable. Irrespective of SETO, universities and organizations like IEEE and NREL can separately fund these small projects as part of academia research and development.

## SolarSTARTS: Solar-Assisted State-Aware and Resilient infrastructure System – $4,411,297

*University of Utah | Salt Lake City, UT | Principal Investigator: Masood Parvania*

This project is inventing an automated resilience management system that will use distributed solar photovoltaics, distributed energy resources, sensors, and distribution monitoring and switching equipment to improve the resilience of critical infrastructure and emergency centers. The system includes a cyber detection and outage management tool. PacificCorp is partnering with the University of Utah to validate the system.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goal of this project is the development and demonstration of the ARMS solution. The team plans to develop the outage data management system, cyber state awareness engines, cyber secure resilience control system utilizing distributed solar PV systems, flexible loads, energy storage and visualization engines. The goal seems to be development of high-fidelity visualization of the Distribution network that has high PV penetration and use that information to build cyber secure controls. Strengths and weakness are not clear based on the description provided.

**Reviewer 2:** This project is developing the automated resilience management system (ARMS) solution to enhance the resilience of the power distribution grid in case of power outages. The ARMS solution aims to improve the situational awareness of the electric grid and to enhance the opportunities that solar PV systems could provide as flexible sources. Successful deployment of the ARMS solution will be reflected on the advancement in the solar energy's role in strengthening the resilience of the U.S. power grid. The project objectives are very relevant to the solar industry and how it could be utilized for the purpose of enhancing the situational awareness of solar systems. The weakness may be that the project is at very early stage and it is not clear how the work will be coordinated between different parties. However since each of the team members have significant experience moving such projects forward, they will find a way to efficiently cooperate and coordinate their work.

**Reviewer 3:** The project definition, laid out plan and schedule seem fairly appropriate. No weakness observed at this time.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The team was delayed by a quarter in 2019 and in 2020 is still gearing up to speed on the project. Not much to report at this point.

**Reviewer 2:** The project has reasonable goals with manageable budget and schedule. Expected impact of the project is significant, as it provides automated resilience management systems which in certain areas such as California and other places could be extremely critical, especially during the fire season. It will allow to achieve a more resilient distribution system. Based on the reasonable milestones and schedule of deliverables provided by the project proponents, it is clear that the project is well planned and very likely to be well executed and produce the anticipated results. Having universities, National lab and industry partners makes for a solid team to take on such projects.

**Reviewer 3:** The context mentions 3 years but the calendar dates only show Jan 2020 to Jan 2022. is this a typo?
I recommend to include any ISO (independent service operators) or IOU's (investor owned utilities) as part of the project supporting groups.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Project tasks and milestones talk about assembling and building the ARMS system however key figure of merits /KPIs are not clear. If this solution was developed who would use this and how much benefit would they get?

**Reviewer 2:** Score: 6. Comments: Each of the project's tasks (development of the Visualization Engine (VizEng), the situational Awareness for Resilience (StAR), the development of the cyber physical outage data management (CP-ODM) system, developing cyber-physical distribution testbed for testing ARMS solution, the development of the real-time communication, control and outage data collection system, the cyber-physical outage data management system, the state-awareness for resilience System, and the cyber-secure resilient control system) fit the description of adding unique and important value to achieve overall project goal.

**Reviewer 3:** Score: 5. Comments: Agree with the appropriate explanation provided on the report.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** There are several blind spots: 1) The targets to achieved are not clear. 2) The distribution grid would receive this solution but has utility shown any interest? 3) Who are the industry and utility partners?

**Reviewer 2:** In my opinion, the project may include more electric utilities other than PacifiCorp where the project could be tested and validated.

**Reviewer 3:** Time to time resources evaluation.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This program needs industry and utility partners on the Advisory board and needs the goals defined quantitatively.

**Reviewer 2:** The project includes as participants two universities, one national lab, and a utility with transmission and distribution knowledge, which all are contributing to the success of the project. In my opinion, engaging a utility that has high penetration of solar PV generation, such as in California would have added value to the project

**Reviewer 3:** I recommend to include any ISO (independent service operators) or IOU's (investor owned utilities) as part of the project supporting groups.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This program needs industry and utility partners on the Advisory board and needs the goals defined quantitatively. This program lacks clarity and direction in my opinion.

**Reviewer 2:** 1) This is an innovative project that will develop and demonstrate the integrated, scalable, and cost-effective solution for enhancing the resilience of the U.S. power grid and critical infrastructure against outages. 2) The project involves a strong team from universities, national lab and electric utility. 3) The project fits perfectly with the objective of the funding.

**Reviewer 3:** SETO to continue supporting projects of this focus. SETO supporting collaboration of these project organizations is commendable. SETO is encouraging advantage of already proven technologies and bringing them together to enhance the technology faster.

# System Operation Reliability

## Advanced Solar and Load Forecasting Incorporating High Definition Sky Imaging: Phase 2 – $850,000

*Brookhaven National Laboratory | Upton, NY | Principal Investigator: Paul Kalb*

This project is developing a platform for short-term (0-30 minute) solar forecasting. The team is deploying a network of high-definition total sky imagers and related equipment and developing software to allow for improved cloud and irradiance forecasting at several sites across New York State. That network can stitch together multiple images provided by individual imaging systems, which can expand forecasting capabilities over larger regions and longer time horizons.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 1 |
| Set critical challenges to overcome | 5 | 1 |
| Implement a high-risk, high-impact approach | 4 | 1 |
| Match well with the level of DOE funding and planned project duration | 4 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 1 |
| Advance the U.S. solar industry substantially | 4 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Improved forecasting will benefit grid operators when integrating solar facilities and will enable higher penetrations.

**Reviewer 2:** Reviewer has no expertise in this area.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 1 |
| Measures impact appropriately (e.g. quantitative) | 5 | 1 |
| Disseminates results frequently and actively engages partners | 5 | 1 |
| Collaborates with sufficient stakeholders | 5 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Milestone achievement is on schedule.

**Reviewer 2:** Reviewer has no expertise in this area.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: No grid operator would deny better more timely forecasting. That says it all.

**Reviewer 2:** Score: 1. Comments: Reviewer has no expertise in this area.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None identified.

**Reviewer 2:** Reviewer has no expertise in this area.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No missing stakeholders identified.

**Reviewer 2:** Reviewer has no expertise in this area.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The ability to mitigate large steep ramps is a great benefit.

**Reviewer 2:** Reviewer has no expertise in this area.

## Microgrid-Integrated Solar-Storage Technology – $4,000,000

*Commonwealth Edison Company | Chicago, IL | Principal Investigator: Shay Bahramirad*

This project addresses availability and variability issues inherent in the solar photovoltaic technology by utilizing smart inverters for solar photovoltaics combined with battery storage and working synergistically with other components within a microgrid community. This project leverages on the Energy Department-funded microgrid cluster controller and is connected to the existing 12 megawatt Illinois Institute of Technology microgrid.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project objective is to address availability and variability issues inherent in solar photovoltaic (PV) technology by utilizing smart inverters for solar PV/battery storage and working synergistically with other components within a community microgrid. The project also enables widespread sustainable deployment of low-cost, flexible, and reliable PV generation. The MISST algorithm built into commercial microgrid management system (MGMS) and is being tested using HIL test setup at ComEd lab; comprehensive test setup has been built to emulate the actual Bronzeville Community Microgrid. The team has plans to demonstrate islanding capabilities with a controllable Diesel Generator scheduled for April 2020.

**Reviewer 2:** This project developed and demonstrated cost-effective technologies for solar generation that incorporates energy storage and works to meet both consumer needs and the needs of the electric grid. The preliminary results obtained from both in a laboratory HIL setup and by conducting selected tests in the field are promising as it can enable widespread sustainable deployment of low-cost, flexible, and reliable PV generation. This project used smart inverters to address availability and variability issues inherent in solar PV and developed a synergistic strategy with other components within a community microgrid. The field testing is done by testing solar PV and BESS systems, as well as microgrid islanding operation for a scaled-up utility-level 7.5 MW Bronzeville Community Microgrid (BCM). The controller can monitor and control a range of various DER assets along with other grid forming resources and other protection and distribution automation assets.

**Reviewer 3:** For microgrid advancement, this project is adequate.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Submit technical paper describing performance requirements of the proposed MISST solution for operation under high PV penetration levels (≤30%) for both interconnected and islanded operation modes. Validated Smart inverter for medium-power PV application and medium-power BESS applications Evaluated and select a suitable customized solar forecasting solution. Detailed data collection plan and performance metrics targets are established. Implemented control requirements of the MISST solution on BESS and controllable loads in response to changing conditions of solar PV output Proposed sites for construction of the PV systems and respective detailed civil/structural and electrical engineering design packages. The process of securing site approvals and permits for the PV systems is started. Proposed sites for construction of BESS and respective detailed civil/structural and electrical engineering design packages. The process of securing site approvals and permits for BESS installation is started

**Reviewer 2:** The project has met the important milestones within reasonable timeframe and budget. The project has established a well-qualified team with multiple stakeholders involved.

**Reviewer 3:** It doesn't appear that there is much communication about this project beyond the project members. Communication is key for these projects for industry awareness.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: This project would develop and demonstrate cost-effective technologies for solar generation that incorporates energy storage and works to meet both consumer needs and the needs of the electric grid. The learnings from this project will enable widespread sustainable deployment of low-cost, flexible, and reliable PV generation, and provide for successful integration of PV with the electric grid. The intended outcome is to test the developed technology both in a laboratory HIL setup and by conducting selected tests in the field. The field testing is done by testing of solar PV and BESS systems, as well testing of microgrid islanding operation that involves the installed PV, BESS and mobile generator.

**Reviewer 2:** Score: 5. Comments: The project team has tested the proof-of-concept to coordinate and control solar and storage system to maintain constant output and successfully tested controller using integrated power and control hardware in the loop (HIL) setup. The tasks developed for each phase are related and dependent, and each task brings an unique value to achieving the overall goals of the project.

**Reviewer 3:** Score: 5. Comments: I think the project is organized properly according to its goals.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I do not see any blind spots at this time.

**Reviewer 2:** No blind spots have been found for this project.

**Reviewer 3:** I do not identify any blinds spots for the PI.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I believe the team is well represented.

**Reviewer 2:** This project team collaborated with a diverse range of organization and stakeholders in order to deliver the project results.

**Reviewer 3:** It doesn't appear that there are any communications with respect to this project outside of the project team.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project would develop and demonstrate cost-effective technologies for solar generation that incorporates energy storage and works to meet both consumer needs and the needs of the electric grid. The learnings from this project will enable widespread sustainable deployment of low-cost, flexible, and reliable PV generation, and provide for successful integration of PV with the electric grid. The intended outcome is to test the developed technology both in a laboratory HIL setup and by conducting selected tests in the field. The field testing is done by testing of solar PV and BESS systems, as well testing of microgrid islanding operation that involves the installed PV, BESS and mobile generator.

Reviewer 2: The microgrid test bed can be used in the future for other projects since it provides a unique opportunity to explore other aspects of monitoring and controlling PV solar resources.

**Reviewer 3:** I would recommend gauging the value and interest of further microgrid research by the industry.

## Risk-Informed Hierarchical Control of Behind-the-Meter Distributed Energy Resources with AMI Data Integration – $3,000,000

*Eaton Corporation | Beachwood, OH | Principal Investigator: Chaitanya Baone*

This project is developing a real-time controller of behind-the-meter distributed energy resources, such as solar and battery storage, and loads to ensure that bulk power system operators or distribution utilities get enough power. Integrating data from smart meters and advanced metering infrastructure (AMI) enables optimal provision of grid services to improve grid reliability in distribution systems with high solar penetration. To enable scaling and minimize adoption risk, the team—along with the National Renewable Energy Laboratory, Electric Power Research Institute, Pecan Street, Provo City Power, and Commonwealth Edison—are working with existing utility infrastructure.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** To study how to coordinate the operations of BTM solar is one of great challenges for a future grid, especially without investing on expensive communication networks. It has a potential to fundamentally change how the future grid is operated. If successful, this project will enable optimal provision of high-value grid services from behind-the-meter (BTM) solar PV and other synergistic DER such as battery storage, electric vehicles, and flexible loads. This will not only add more value proposition to BTM solar, but also allow these resources to enhance the reliability and resilience of the grid, being part of solutions to address the issues related to a high penetration of BTM solar PV resources. The innovative part of this project is To redesign an enhanced smart meter that will interact with diverse DERs, extract load disaggregation information, and execute optimal coordination control commands.

**Reviewer 2:** Utilizing DER to provide grid services, such as voltage control/reactive power is an industry identified need to achieve very high penetrations of DER. Utilizing existing infrastructure, such as AMI, is a very good method to minimize costs.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has not started so that the project performance cannot be observed. The project team has laid out a solid project plan with identified resources to execute the project and also identified potential risks and corresponding mitigation plans.

**Reviewer 2:** As this project has just been initiated, there is no data to review.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The whole project is divided into 3 phases, and a targeted milestone is set up for each phase. Overall, the path forward to achieving the project goal is feasible and the dependency between different phases is clearly understood.

**Reviewer 2:** Score: 5. Comments: The different budget periods are logical.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** No blind sport has been found for this project.

**Reviewer 2:** Have not identified a blind spot.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** This project team consists of manufacturer, research institute, national laboratory and utility. Since EPRI is part of the project team, this project can leverage this advantage for dissemination of the project results.

**Reviewer 2:** I think the stakeholders are appropriate for this project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The end goal of the project is to arrive at a field-demonstrated solution. The field demonstration should prove that the proposed AMI infrastructure is scalable and effective in managing a large number of distributed resources. The project team is encouraged to develop a plan towards faster industry-wide adoption after the completion of this project. A hierarchical control solution that leverages smart meters will be developed to enable aggregation of DER and Demand Response (DR) assets to provide the grid services. The project team should consider different requirements for the control solution when applied in deregulated and regulated environments.

**Reviewer 2:** This is a good project to continue and support for all the reasons mentioned above.

## Adaptive Protection and Validated Models to Enable Deployment of High Penetrations of Solar Photovoltaics – $4,100,000

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Jens Boemer*

This project is developing and testing trustworthy models of solar photovoltaic facilities to enable power system engineers to plan, operate, and protect transmission and distribution systems. The models aim to inform system designs so that they can leverage smart inverter capabilities for microgrids and islanded systems, which operate independently of the national grid, to ensure the resilience of critical infrastructure and maintain grid safety and reliability. The team also plans to demonstrate adaptive protection systems that use advanced photovoltaic capabilities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 4 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project has not yet started. The overall objectives for the project are to develop and validate high-fidelity models of solar PV facilities at all levels of the power system across all operational reliability time frames for stability; protection; EMT; co-sim; and QSTS analyses, and integrate these models into the commercial software tools used by power system engineers to plan, operate, and protect transmission and distribution (T&D) systems. Also, the project would use newly developed models for advanced adaptive protection schemes Although not seen as weaknesses, three challenges identified are (1) limited adoption of developed models, (2) ability to represent control capabilities across all inverter vendors, and (3) limited ability to field test adaptive protection settings across a range of operating conditions.

**Reviewer 2:** Accurate modeling is a necessity to moving forward with higher penetrations of inverter based resources.

**Reviewer 3:** Weaknesses: Although I recognize the advantages of leveraging existing modeling industry groups, leaving out the specific vendors from direct contributions risks the project running at a slower pace and falling behind the state of the art. Also, there is a strong industry push toward real-code models, and associated standards, which are not considered in this work. Strengths: good team members, who probably can appreciate and mitigate these weaknesses.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 1 | 1 |
| Measures impact appropriately (e.g. quantitative) | 4 | 1 | 1 |
| Disseminates results frequently and actively engages partners | 4 | 1 | 1 |
| Collaborates with sufficient stakeholders | 4 | 1 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has not yet started.

**Reviewer 2:** Since this project has not yet started, this section cannot be scored.

**Reviewer 3:** This project is generally acceptable. Note that all "6" values are entered where either I have insufficient knowledge on the topic, or insufficient information was provided to correctly evaluate.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The project has not yet started.

**Reviewer 2:** Score: 6. Comments: The modeling aspect is critical to the next step of adaptive protection.

**Reviewer 3:** Score: 1. Comments: Note that all "6" values are entered where either I have insufficient knowledge on the topic, or insufficient information was provided to correctly evaluate.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1**: No blind spots were evident in this project.

**Reviewer 2:** I do not see any of the "usual" blind spots with respect to modeling in this project.

**Reviewer 3:** Note that all "6" values are entered where either I have insufficient knowledge on the topic, or insufficient information was provided to correctly evaluate.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project seems to be well represented. Participants include the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), PEACE LLC, US Army Core of Engineers (USACE), PPL Electric and Consolidated Edison (ConEd).

**Reviewer 2:** They have identified all appropriate stakeholders and how they will interact with them.

**Reviewer 3:** Note that all "6" values are entered where either I have insufficient knowledge on the topic, or insufficient information was provided to correctly evaluate.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project provides the innovation needed by developing, validating, and implementing models to represent the dynamic behavior of PV at all system levels in commercial T&D system planning and protection analysis tools thereby enabling the assessment of the reliability of systems with higher PV penetrations and the ability of those PV resources to support system reliability through advanced inverter functions. This project provides the further innovation of applying the models to develop and demonstrate adaptive protective relay settings to support high PV penetration and leverage smart inverter capabilities in microgrids/islanded systems to increase system resiliency. The project will also enable application of the models for demonstrating the use of adaptive protective relay settings to leverage smart inverter capabilities in microgrids/islanded systems to increase system resiliency. Solidifying the ability of PV to support system resiliency will further enable higher penetration.

**Reviewer 2:** Accurate modeling is essential and needed quickly in the industry. The deliverables this project is proposing are essential tools for the transmission planners. This project would be in the top 3 of my list.

**Reviewer 3:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

## Advanced Grid-Forming Inverter Controls, Modeling and System Impact Study for Inverter Dominated Grids – $4,200,000

*GE Global Research | Niskayuna, NY | Principal Investigator: Maozhong Gong*

This project is developing a modeling method and automation tool to analyze the stability of a large energy system with mixed resources, such as inverter-based generation and traditional generators, and see how they interact with each other. The team is also developing controls for individual and clusters of grid-forming photovoltaic inverters to improve grid stability under various conditions. The technology will be implemented in GE's commercial photovoltaic inverter, thereby facilitating its commercialization.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 6 |
| Set critical challenges to overcome | 6 |
| Implement a high-risk, high-impact approach | 6 |
| Match well with the level of DOE funding and planned project duration | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 |
| Advance the U.S. solar industry substantially | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Grid forming inverters may be a key to the "new" grid. This research is much needed in the industry to achieve high levels of penetration of inverter based resources.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 |
| Measures impact appropriately (e.g. quantitative) | 0 |
| Disseminates results frequently and actively engages partners | 0 |
| Collaborates with sufficient stakeholders | 0 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Since this project has not started, I cannot score these items.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each of the tasks is appropriate to achieve the project goal.

### 4. What 'blind spots' the principal investigator has, in this project, that are important to consider?

**Reviewer 1:** I cannot identify blind spots at this time.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No missing stakeholders at this time for this type of project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is critical research for grid operators and planners to ensure the reliable integration of inverter based resources at high penetration levels.

## Robust Distributed Energy Resource Management System Control Verification – $2,500,000

*Lawrence Livermore National Laboratory | Livermore, CA | Principal Investigator: Jovana Helms*

Implicit trust in the control commands issued by distributed energy resource management systems to solar inverters presents a cybersecurity vulnerability to the power grid. This project addresses this risk by using advanced analytics to verify the commands sent by the management system control center. The team is developing techniques to approximate the state of the grid and distributed energy resource management system control algorithms—independently of the management system—so local controllers can verify that a distributed energy resource management system command is valid based on current conditions. Distributed energy resource components can then operate independently, even if a communication link between the management system and local controllers is down, increasing the resilience of the system.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 1 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 5 |
| Advance the U.S. solar industry substantially | 3 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project objectives align with cyber security SETO goals. The objectives of this project do not seem related to the system Operation reliability objectives. The reason for this observation is that the project looks for a criteria to use the commands sent to a plurality of PV inverters to identify "malicious command execution attacks." There is no optimization or coordination of PV inverters associated to the project. There is also no protective relaying aspect to this project. With that objective in mind, the project goal is based on a novel idea of using the plausibility that a collection of PV inverter commands are realistic or possible as a criteria that there is no cyberattacks. This initial year of execution seems to have led to useful thinking and verification of the proposed approach. This exercise resulted in significant modification to the scope of work.

Part of the scope may have become less demanding from the point of view of analytics. The machine learning that would ultimately need to be performed at the DER level may have some practical limitations, given that at the PV inverter would normally not have feeder voltage and other infeed quantities to facilitate the machine learning for the particular topology of the feeder. Not all PV inverters would have same configurations to detect the "malicious command execution attacks."

**Reviewer 2:** Good concept, good project communication, seemingly achievable goals.

**Reviewer 3:** The objective of the project is to: 1) Remove implicit trust between central control and DERs via data driven algorithms that enable DERs to collaboratively verify that a command is not malicious. 2) Build coupled simulation environment utilizing LLNL's HPC capability for empirically evaluating effects of real and spoofed control commands on grid stability. 3) With industry partners, work towards in situ testing. DER-based sensor measurement seemed insufficient to support state estimation. Another challenge is how best to develop a general solution that will be applicable to growing catalog of remote control capabilities planned for next generation PV inverters. Also, how do you establish the correct working model for stakeholders.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 1 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 3 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Milestones and deliverable have been affected by the justified change in direction of the project execution. Dissemination seems to be delayed as the past efforts resulted in good learning and limited analytical efforts of the type that can facilitate paper publication.

**Reviewer 2:** Acceptable based on submitted material.

**Reviewer 3:** The project team demonstrated an initial proof-of-concept for solar curtailment command verification in which solar inverters jointly evaluated a linear regression model to predict voltage at the point of common coupling: when this predicted value was outside nominal range the curtailment command was allowed, otherwise it would be rejected as unnecessary. These results were promising insofar as predictive regressions (rather than traditional state estimation) provide an attractive basis for collaborative command verification: the underlying models can be trained in distributed fashion on devices, their algorithmic scalability properties have been well studied and demonstrated, and they benefit from increased data collection, meaning the protection afforded by this kind of approach strictly increases with additional DER penetration.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: There is no significant explanation of each task. Likely because the form proposed does not necessarily requests that. This reviewer has the same comments in most reviewed projects.

**Reviewer 2:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** Score: 5. Comments: It was not easy to link task with goals.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Blind spots could be that some of the command rejection criteria that is derived in this effort may be relatively close to typical technics in other generation assets to reject commands that seem to be off due to comm failures (as opposed to attacks).

**Reviewer 2**: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** DER-based sensor measurement seemed insufficient to support state estimation. Another challenge is how best to develop a general solution that will be applicable to growing catalog of remote control capabilities planned for next generation PV inverters. Also, how do you establish the correct working model for stakeholders.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project has good partners. Based on the description provided the PI is working to increase participation of those entities in this later stage of the project.

**Reviewer 2:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** Other participants are Revolutionary Security, Schweitzer Engineering Laboratories and Southern California Edison, which seems adequate for this project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is more a cyber security project than a Systems Operation and reliability project, if evaluated based on the objectives and deliverables. There is risk that the outcome is similar to existing practices is generators to reject false/ inaccurate commands due to comm failures. The original idea and the learning that took place in the project are useful.

**Reviewer 2:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** The project is intended to remove implicit trust between central control and DERs via data driven algorithms that enable DERs to collaboratively verify that a command is not malicious.; build coupled simulation environment utilizing LLNL's HPC capability for empirically evaluating effects of real and spoofed control commands on grid stability, and validate algorithm with industry testing. The intended of the project is the demonstration of novel analytics and inter-device communication algorithms that can be readily incorporated into DER and DERMS device firmware, and that harness the constellation of those devices to provide collaborative command verification as a defense against malicious command execution attacks. Research into resilience-conferring technologies such as those pursued in this project will play a fundamental role in allowing the incorporation of high percentages of solar generation. In an era of advanced persistent threats by heavily resourced adversaries, it is simply a nonstarter that any solution to increasing dependence on renewables rely on increased network control of DERs without at least as much attention given to the security properties of those new control systems.

## Accelerating Systems Integration Standards II – $2,400,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andy Hoke*

This project updates standards in interconnection and interoperability of solar photovoltaic and other distributed energy resources at the distribution level. The team is leading an update of conformance testing standards to reflect the industry standard from the Institute of Electrical and Electronics Engineers. To tackle emerging system integration challenges, the team is also developing guidance such as operational best practices for bulk power systems with high levels of photovoltaics and integration of distributed energy storage. Improved practice recommendations and certification standards for end-to-end interoperability of distributed energy resources is also under development.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 3 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 1 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: These particular standards are very important, and having consistent strong leadership is very valuable. Weaknesses: I have been contributing to IEEE 2800 extensively, and I feel that the accelerated schedules of these standards drive the control of the standards to the paid full-time staff such as EPRI or very motivated stakeholders. Key technical contributors and experts are mainly unpaid or sponsored by their companies alongside other duties. Accelerated schedules leave these key experts with insufficient time, and result in a weaker standard.

**Reviewer 2:** This effort will not generate new technology or analytical approaches associated to the goals from SETO. The project does however facilitate relevant dialog and standard definition directly impacting the goals from SETO. The standards supported are very relevant.

**Reviewer 3:** This project helps to fill current gaps in standards to overcome barriers for interconnection and interoperability of DERs and IBRs in general, and photovoltaic (PV) systems in particular, which will lead to more technically sound PV installations that can be used in new ways to enhance the reliability and resilience of the electric grid. Specifically, the project focuses on technical leadership of IEEE 1547.1 (verification of DER interconnection requirements) and IEEE P2800 (bulk-connected inverter-based resource interconnection requirements). The leadership supported by this project has greatly driven the agenda of IEEE 1547.1 and IEEE P2800 to move forward.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 1 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 1 | 6 | 6 |
| Collaborates with sufficient stakeholders | 1 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Acceptable.

**Reviewer 2:** Milestone schedules are defined based on progress of standards approvals. that is reasonable and has some risk captured in the project description. The amount of funding is significant, but this type of activity can be time consuming. Dissemination and stakeholders is inherent to the forums where these standards are discussed.

**Reviewer 3:** 1547.1-2020 has been published and IEEE P2800 draft is close to the completion.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 2:** Score: 5. Comments: Standards supported are very relevant specific WGs were not described.

**Reviewer 3:** Score: 6. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** Given that the participation in these forums is typically not funded, I am wondering if the project team or SETO could be required or may prefer to state to the participants of these forums that participation of some members is funded by SETO. This reviewer does not know that this is required, just sharing this reaction to the approach of this project.

**Reviewer 3:** No blind spots were found in this project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** No comment.

**Reviewer 2:** None.

**Reviewer 3:** The project has collaboration with stakeholders to reach consensus for the standard developed.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** Not a research project. Very relevant effort for SETO objectives.

**Reviewer 3:** The DOE funds enable subject matter experts to provide unbiased strategic and technical leadership to targeted standards. This leadership will accelerate the development of the standards and help drive consensus among diverse industry stakeholder groups, resulting in more effective standards that remove barriers to extremely high PV, DER, and IBR adoption. Thus, it is highly recommended to continuously support this efforts.

## Distribution Function in Time Series Simulation – $300,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andy Walker*

This project with HOMER Energy Inc. intends to commercialize a distribution function that replaces the current steady-state assumption in an hourly simulation, to expose phenomenon for grid integration and net-metering, such as balancing, ramp-rates, inverter clipping, sell-back to the utility, and management of all assets on a power distribution system. The goal is to make computer modeling of variable power supply patterns much more accurate and expose new information required for reliability and efficiency of the overall distribution system.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 5 | 4 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project developed and commercialized a distribution function that replaces the steady-state assumption of time-series simulation for PV. The benefit is to reduce the error and better-represent phenomena of interest to grid integration of variable resources. This improved accuracy is not only helpful to economic predictions but also essential for resilient grid operations and control. The project team has evaluated the performance of the proposed distribution function by comparison to detailed data and also piloted on an actual project to demonstrate its application, indicating its technology maturity.

**Reviewer 2:** This effort is targeted to a particular improvement in HOMER. The impact of this effort important and limited to the improvement of PV generation estimations based on proposed methods. The size and funding of the effort seems in line with the effort. The impact of this effort outside DOES is related to the use of HOMER outside of DOE. This reviewer is not a user of HOMER. My understanding is that HOMER is frequently used.

**Reviewer 3:** The increased accuracy of annual production will be a great benefit to homeowners who are making economic decisions on whether to install. It will also benefit resource planners, who rely on forecasts when planning to serve load in the most economic fashion. It will also be a great benefit to developers when determining the feasibility of development in less than optimal locations.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has met important milestones within reasonable timeframes and budgets.

**Reviewer 2:** The deliverable of this effort is fairly concrete, in the sense that a new feature is added to HOMER. Regarding how the project success is measured, seems that timely release of the feature is a good indication of success. Showing the difference in the accuracy of the PV energy production with this the proposed approach with respect to the prior approach for few example applications would also help quantify project success and impact. An aspect not elaborated in the information provided is the documentation of this feature for HOMER users. This may be implied and would constitute an important part of the deliverable.

**Reviewer 3:** Milestones have been met and appear to be ahead of schedule for remaining work. The Design Charrette as well as the draft article for Nature Energy are good examples of industry outreach.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**Reviewer 2:** Score: 4. Comments: Tasks described in information seem aligned with objective. There is no significant explanation of each task. Likely because the form proposed does not necessarily requests that. This reviewer has the same comments in all reviewed projects.

**Reviewer 3:** Score: 5. Comments: The tasks, as described, are really the logical sequence that must be taken to develop the new distribution function for a software release.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No blind spots have been found in this project.

**Reviewer 2:** This reviewer is not a HOMER user to identify detailed feedback.

**Reviewer 3:** The only potential "blind spot" may be if other software programs, other than HOMER, do not adopt it.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project has collaborated with one business partner selling commercial software product. The feedback for this improvement can be solicited from end-users to maximize its values to users.

**Reviewer 2:** Seems useful to understand the interest of HOMER users on this feature, that was likely a consideration already.

**Reviewer 3:** None identified.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project has created strong partnership between NREL and HOMER Energy LLC so that this improvement will be available in at least one commercial software product. Other efforts should be encouraged to reach out to other vendors so that the technology developed can be be widely used in industry.

**Reviewer 2:** This is a good concrete project. This project in isolation may be of modest impact. If this is part of a larger objective of facilitating the availability of simulation tools to assess PV applicability, the benefit of activities like this have an overall larger impact. In that sense, it would be important to consider a general assessment of features of interest in HOMER, rather than single feature addition. (This reviewer is not a HOMER user, for that reason this comment is not specific.)

**Reviewer 3:** Better forecasting should always be pursued. Ensure that this "new" distribution function is deployed across many software forecasting applications. Better forecasting is a great value to both the economic and reliable planning aspects of integrating PV Solar into the system.

## Enhanced Control, Optimization, and Integration of Distributed Energy Applications – $3,920,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Murali Baggu*

This project develops, validates, and deploys a unique and innovative data enhanced hierarchical control architecture that enables the efficient, reliable, resilient, and secure operation of future distribution systems with a high penetration of distributed energy resources like solar energy. This architecture enables a hybrid control approach where a centralized control layer will be complemented by distributed control algorithms for solar inverters and autonomous control of grid edge devices. The architecture aims to be fully interoperable and include all the cybersecurity aspects that are necessary for reliable and secure system operation.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The operational challenges were centered on reverse power flows, transients from variability of PV systems, feeder load balancing, and voltage stability. A unique and innovative Data Enhanced Hierarchical Control architecture will be developed, tested and deployed to systematically enable a transition towards new operational processes of system with high DER penetration and allow backward compatibility of emerging control strategies with legacy assets. The project will pave the way for distribution systems to transition from the present control methodologies to new control paradigms that are effective, reliable, resilient, secure and enables high penetration of solar resources. This project is the first of its kind to deploy and demonstrate the proposed DEHC platform. This platform would provide ample evidence that the proposed technology would propagate benefits to the broader utility, industry and power engineering sector.

**Reviewer 2:** The project is a success since through simulations, the project team has demonstrated the effectiveness of a hybrid control approach where multiple voltage-regulation technologies, both at central and grid edge levels, are seamlessly integrated to achieve reliable and efficient system operation in the face of volatile ambient conditions. The field demonstration is under way and will further validate the performance of the proposed DEHC architecture. The proposed DEHC architecture will be validated through power and controller hardware-in-the-loop simulations with at least 10,000 virtual nodes at NREL's ESIF and further deployed at the demonstration sites at Xcel Energy. The validation at this large scale will fully test scalability of the DEHC architecture. The proposed architecture ensures backward compatibility of emerging control strategies with legacy assets so that it can be fully inter-operable. It also include all the cyber security aspects that are necessary for reliable and secure system operation.

**Reviewer 3:** This is a very good project for utilities to use as a reference moving forward to enable high penetrations of DER. Voltage regulation is a difficult thing to manage on the feeder. A simple way to accomplish it is to avoid any voltage regulation action by the DER. However, this is wasting a fast acting resource as well as a resource that has built in capability. The potential for this project to develop the architecture, as well as an example of how to implement this new architecture, is very valuable to utility distribution engineers.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 0 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team developed and demonstrated DEHC architecture in simulation using utility feeders to meet the ENERGISE goals of enabling a solar energy penetration level beyond 50% relative to the peak load and beyond 125% relative to daytime minimum load. The developed architecture managed the system voltages within the ANSI limits under high PV penetration levels in both the simulations and hardware-in-the-loop experiments. The team also successfully developed an integrated model that includes both ADMS control modules and grid-edge device operation to demonstrate the hybrid controls. In the integrated model, the ADMS controls the legacy assets and grid-edge devices while the RTOPF DERMS controls the PV inverters, thus demonstrates the hierarchical controls. The team also executed the HIL test plan successfully through co-simulations using the integrated model involving representative feeder models and field measurement data to evaluate DEHC functionality. It also successfully developed and executed the cybersecurity and interoperability plans for the evaluation of DEHC architecture.

**Reviewer 2:** The project has made impressive progresses as planned and met the project milestones for both the first and second phases for the project.

**Reviewer 3:** Overall, I think they are making good progress. The one drawback that I see is in the field demonstration. It would be very beneficial if they could have deployed the field test on a high penetration feeder.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project will pave the way for distribution systems to transition from the present control methodologies to Net control paradigm that are effective, reliable, resilient, and secure and will enable higher levels of DER penetration.

**Reviewer 2:** Score: 5. Comments: In Budget Period 1 the team developed and designed a systematic approach of the coordination between multiple features to realize the proposed DEHC architecture. In Budget Period 2 the team executed the test plans to validate the proposed DEHC architecture in HIL environment at NREL's Energy System Integration Facility (ESIF) laboratory. In Budget Period 3 the team will perform field deployment and demonstration. The result obtained from phase 1 and 2 has laid out a foundation for the field demonstration, which helps to achieve the overall project goal.

**Reviewer 3:** Score: 5. Comments: This is a very good project for utilities to use as a reference moving forward to enable high penetrations of DER. Voltage regulation is a difficult thing to manage on the feeder. A simple way to accomplish it is to avoid any voltage regulation action by the DER. However, this is wasting a fast acting resource as well as a resource that has built in capability. The potential for this project to develop the architecture, as well as an example of how to implement this new architecture, is very valuable to utility distribution engineers.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I do not see any blind spots at this time.

**Reviewer 2:** No blind spots have been found for this project.

**Reviewer 3:** Cannot identify a blind spot.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I believe the project is well represented by industry experts.

**Reviewer 2:** This project has involved a broad range of stakeholders, and built a strong partnership with a utility.

**Reviewer 3:** I think that a plan for disseminating this information more widely is warranted. The only things I can see now are a presentation at IEEE PES GM and a published NREL document. A strategy to introduce this to utilities would be very beneficial.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project would pave the way for distribution systems to transition from the present control methodologies to new control paradigms that are effective, reliable, resilient and secure, and enable very high penetrations of solar energy sources. The project is the first-of-its-kind deployment and demonstration of the proposed DEHC platform will provide ample evidence of the effectiveness of the proposed technology and will propagate benefits to the broader utility, industrial, and power engineering sectors. The proposed method will also be scalable and enable full observability of the distribution systems, as well as being fully interoperable.

**Reviewer 2:** The next phase field deployment is more critical as it will provide ample evidence of the effectiveness of the proposed technology. After the completion of the project, the field test data and results can be shared with research community and accelerate the adoption of the proposed architecture.

**Reviewer 3:** Try and field demonstrate on a high penetration feeder. Develop a strategy to widely disseminate this to utility personnel. Maybe a T&D article.

## Grid Optimization with Solar – $1,591,603

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Yingchen Zhang*

This project develops a novel control scheme that provides system-wide monitoring and control using a small fraction of the active devices on the grid. The key innovation of this project's approach is to proactively manage very large distributed energy resource populations using only a few measurement points for input through predictive state estimation and a few carefully selected control nodes identified and dispatched through online multi-objective optimization. The platform gives utilities the capability to seamlessly dispatch legacy devices and distributed energy resources to achieve system-wide performance and reliability targets.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 1 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 5 |
| Advance the U.S. solar industry substantially | 5 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Important goal to use minimal data entry. Weaknesses: Normal ML weaknesses... not much discussion of fail-safes or protection against bad predictions. Seems to be very hard to implement in a practical system, outside the simulation testbeds, but the project does not go this far. HIL testbed may not represent real system uncertainty very well.

**Reviewer 2:** Well aligned with topic area goals of "control and coordination of solar generation at both bulk power and distribution levels, in accordance with the desired state of grid operation." The problem stated is a significant challenge for grid integration, particularly for commercial and residential solar. There is risk associated to with the technology being developed. There are also important risks that if these tools have high level of complexity or require significant tuning/application engineering for it to be applied to a system, the adoption of these tools and methods by distribution or subtransmission operators may be limited. The use of machine learning may have some challenges for the system proposed to instruct commands during unusual operating conditions (like severe outages). This particular aspect was not elaborated in the available information. The deliverable of this work seems to be tailored to distribution or sub transmission operators or vendors of software solutions for control centers in those companies. The benefit to the solar industry is relevant and indirect.

**Reviewer 3:** The GO-Solar project aims to develop a transformative real-time operational platform to monitor and control a coupled subtransmission and distribution system with greater than 100% PV penetration on distribution circuits and enables extremely high-penetration solar generation in a cost-effective, secure, and reliable manner. The key innovation of the GO-Solar approach is to proactively manage very large distributed energy resource (DER) populations using only a few measurement points. GO-Solar will revolutionize utility approaches to integrating extreme penetrations of distributed PV by introducing a highly scalable set-point dispatch method for DERs to achieve system-wide targets. This allows for a highly adaptive framework that can be dropped into existing utility operations as a highly flexible, cost-effective, and secure utility-owned system to manage voltage under current and future grid architectures.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 1 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 1 | 6 | 6 |
| Collaborates with sufficient stakeholders | 1 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Key stakeholders at HECO are required to ensure the work is implementable. However, stakeholder input doesn't seem to go beyond provision of data.

**Reviewer 2:** Dissemination described seems appropriate and in venues of relevance to the scope of the effort. NREL and HECO are important lab and industry stakeholder. It would be relevant for this effort that HECO participates in providing data and also at a later stage of the project in evaluating or providing feedback regarding the balance between expected complexity of the system proposed and the benefits of its implementations. This project would benefit from participation of DMS or network automation partner to provide feedback regarding integration of provided solutions to pre-existing systems or control rooms.

**Reviewer 3:** The project has met important milestones within reasonable timeframes and budgets. A high-precision, machine-learning-based PSE is developed to accurately estimate the current system states and forecast the system states in the short-term future using only sparse measurement data that are available in distribution systems. The PSE will support OMOO algorithms to allow for the fast dispatch of only a small number of DERs, such as PV, through smart inverters while asynchronously dispatching legacy devices, such as voltage regulators and capacitor banks, to avoid the need to control millions of devices in real time. New advanced validation frameworks will be developed to demonstrate the GO-Solar solution, including 1) a full-scale integrated transmission-distribution simulation of the entire Oahu Island energy system (HECO's largest island power system) using the HECLIS co-simulation engine running on NREL's Eagle high-performance computer; and 2) hybrid power hardware-in-loop (HIL) and controller HIL testing platform with at least 100 actual hardware devices.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 2:** Score: 4. Comments: There is no significant explanation of each task. Likely because the form proposed does not necessarily requests that. This reviewer has the same comments in all reviewed projects. Tasks or milestones described seem aligned with the goals.

**Reviewer 3:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** ML carries a risk of bad predictions, with potential reliability implications. Also, hardware interface with legacy DER and future DER is unclear.

**Reviewer 2:** The following aspects not mentioned in the projects description may be relevant aspects to consider in this project, as risk or as future efforts: The value of the proposed method is associated to increased visibility and ease of operation from the distribution or subtransmission control center. The integration of these algorithms to pre-existing control centers already equipped with SCADA and a particular software solution is relevant for utilities to adopt it. Part of the research could be related to the recommended approach for DMS, EMS or similar to integrate this solution. Also, what is the minimum level (if any) of visibility and data required from measurement point and the specification of the DER interfaces to be able to take the instructions from this system. The use of machine learning may have some challenges for the system proposed to instruct commands during unusual operating conditions (like severe outages). This particular aspect was not elaborated in the available information.

**Reviewer 3:** No blind spots have been found in this project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 2:** NREL and HECO cover many critical aspects. It would be beneficial to include EMS, DMS or similar software solution vendor that would eventually incorporate this as a feature. The project team may already have done that through HECO contacts.

**Reviewer 3:** This project team includes HECO, and it brings significant value to the project, from the proof of the concept to the field demonstration.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** No comment.

**Reviewer 2:** Goal of this effort is well aligned with topic area and project goal is ambitious.

Risk could lay in research not being easily adopted as part of existing control center control solutions. The use of machine learning may be incompatible with the need for appropriate response during outage conditions that are less frequent. While this project is aligned with SETO goals, other goals related to technical feasibility of even higher PV penetration (as opposed to optimization) may be related to SETO goals with higher urgency.

**Reviewer 3:** The GO-Solar solution will develop much-needed real-time operation tools for utility companies to operate large numbers of distribution circuits at greater than 100% distributed PV penetration with minimum need to expand communications and controller investments. Future funding can be provided to support a continuity of this research work.

## Multi-Time-Scale Integrated Dynamics and Scheduling for Solar – $2,900,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jin Tan*

This project is creating and validating advanced grid models by developing simulation models that seamlessly and cost-effectively combine dispatching and dynamic response analysis, where dispatching ranges from a day ahead to minutes, and dynamic response from seconds to sub-seconds. To study the impacts of photovoltaic variability on system reliability at different times, the team is developing a multi-time-scale grid model and an integrated photovoltaic model. These models give operators a more complete understanding of how short-term photovoltaic variability affects transmission-system operations like reserve scheduling and energy deployment. They also help operators accurately assess system reliability when deploying energy and reserve-scheduling under transient instability events, such as the failure of a major generator, and allow them to see how quickly standby generators can ramp up. The team is also studying interactions among all types of essential reliability services provided by photovoltaic power plants.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project proposes a first-of–its-kind MIDAS framework to study the impact of multi-timescale variability of PV on grid and the performance of using PV to provide frequency-related ancillary services. The EMTP models are utilized, and it is especially valuable when studying the grid dynamics whena high penetration of PV solar resources is present. It can reveal the instability and phenomena which positive sequence model is not able to capture. This project has made built a testbed in PSCAD and PSLF for the model validation and comparison. In the next phase, the EMTP model for Maui will be created. Maui EMPTP model can be validated against the event disturbance data and used as a test bed to study the impact of solar PV over the system stability in a realistic grid representation. Other works in the simulations and modeling of multiple-timescale variability of PV resources are a continuity of the previous work funded by DOE. One option for the future work is to incorporate emerging technologies, like a hybrid structure of PV + battery into this framework as the grid resources are continuously evolving.

**Reviewer 2:** Strengths: Good project organization and leadership, with clear allocation of responsibility. Clear communications. Practical approach to each stage.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 1 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has met the milestones set for different project stages. The project team is collaborating with multiple stakeholders and has delivered measurable progresses for the project.

**Reviewer 2:** Acceptable based on information provided.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project consists of multiple tasks, and each task is focused on studying the variability of PV resources at a different time scale.

**Reviewer 2:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No blind spots have been found for this project.

**Reviewer 2:** No comment.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project team is collaborating with stakeholders ranging from utilities to ISOs.

**Reviewer 2:** No comment.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The primary focus of this project is to investigate the impact of multiple variations of PV resources on the grid operations, especially the frequency response. It is a reasonable assumption that the control of voltage and frequency could be decoupled in a synchronous machine dominant grid. However, this will not be the case when the penetration of PV is extremely high. In such a case, the voltage issues could also be examined using the EMTP model developed. The EMTP model, once it is validated, can be used for multiple purposes and other studies in the future. In this regard, it is very valuable.

**Reviewer 2:** No comment.

## Robust Distributed State Estimator for Interconnected Transmission and Distribution Networks – $633,792

*Northeastern University | Boston, MA | Principal Investigator: Ali Abur*

This project develops, implements, tests, and validates a comprehensive state estimation algorithm for combined monitoring of transmission and distribution systems. Using this technology allows the computational complexity and solution time to be bounded regardless of the system size and number of measurements. By using a mixed set of measurements under different network configurations, utilities will be able to handle any number of available solar photovoltaic units connected to the distribution system.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goal of the project was to develop a monitoring tool to track behind the meter solar PV units' impact on transmission system via a combined Trans/Distr state estimator. This is shown to be possible for test systems of modest size. The project team is in the process of validating the developed code for large utility scale systems under different bad data and unbalanced operation scenarios. The project team were faced with several challenges which should not be viewed as weaknesses. One of these challenges is the acquisition of network and measurement data to be used for validation and testing of the developed software tools. While the transmission systems are well monitored by redundant measurements, the opposite is true for most distribution feeders. Another challenge is coordinating the development of two different estimators and then combining them with minimum or no user intervention. Other technical challenges relate to issues of three-phase initialization which is problematic for feeders with negligible line charging and unbalanced loads. It is also observed that the multi-area estimation framework is sensitive to the way the networks are partitioned.

**Reviewer 2:** This project developed a hierarchical communication and computation framework to facilitate development of a monitoring system for transmission and distribution systems. This is done by a robust state estimator, which can solve positive sequence multi-area transmission systems simultaneously with 3-phase distribution systems. In particular, this state estimator addresses several challenges: very large system size, model complexity (by way of distributing the computations) and large number of solar PV units connected to the distribution system on multiple feeders. The test and validation with small systems shows superior performance and it is currently being tested using large utility transmission and mixed phase and large test feeder with solar PV units.

**Reviewer 3:** The project is well defined with a concrete objective of extending state estimation that includes transmission and distribution. This goal is aligned with the goals of the track associated to coordination and optimization of PV operation, particularly for distributions PV. Some other projects are more directly aligned. This project contributes to the coordination and real-time operation support with high penetration PV by developing a state estimation approach that SCADA/DMS/EMS systems could use in addition to other features to optimize PV operation. This reviewer has limited expertise in the area of this project to assess if the idea proposed is novel or how much this adds to state of the art tools.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** A robust state estimator which can solve positive sequence multi-area transmission systems simultaneously with 3-phase distribution systems is formulated, developed and implemented. It is tested with small systems for validation and it is currently being tested using large utility transmission and mixed phase and large test feeder with solar PV units.

**Reviewer 2:** This project has met important milestones within reasonable timeframes and budgets. The first set of milestones were successfully completed. These were related to validation of the two state estimators for the transmission and distribution systems. The second year's milestones were related to implementation of bad data processing capability to both estimators and they were both successfully reached and validated by Monte Carlo simulations. The remaining milestones of the project which are expected to be achieved at the end of the project are related to the performance of the overall combined estimator.

**Reviewer 3:** Level of dissemination seems in line with project funding and size. PJM and Northeastern are great team. The level of engagement of PJM beyond providing data is not completely clear. It is recommended that PJM personnel have the opportunity to provide feedback regarding metrics to assess effectiveness of the state estimation approach of the project.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The first set of tasks of the project were successfully completed. These were related to validation of the two state estimators for the transmission and distribution systems. A second task was related to implementation of bad data processing capability to both estimators and they were both successfully reached and validated by Monte Carlo simulations. Other tasks of the project are expected to be achieved at the end of the project.

**Reviewer 2:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**Reviewer 3:** Score: 6. Comments: There is a nice and short description of each tasks. each task seems to build upon prior tasks consistently towards the end objective.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It was not clear how this project would promote the integration of higher levels of DER.

**Reviewer 2:** No blind spots have been found for this project.

**Reviewer 3:** This reviewer has limited expertise in the area of this project to assess blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project does not have a broad spectrum of advisors.

**Reviewer 2:** This project team collaborates with various stakeholders. The project team has held a one-day workshop at Northeastern University with good attendance by participants from the utility/power industry, academia and national research laboratories. A second workshop is planned for September 2020 at the end of the project.

**Reviewer 3:** EMS/SCADA/DMS OEM could be a good addition to this project. That would however require additional project cost associated to the effort to incorporate the findings in a format that can be used, adopted or tested in commercial product.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project is scalable to large number of feeders. It can handle large multi-area power grids, and it remains robust against errors even when they occur at transmission and distribution system boundaries while incorporating solar PV units connected in distribution systems. One of the programs developed in this project is the Multi-Area Transmission System State Estimation program which is a hierarchical state estimator with two levels: the first level solves the independent state estimation problems posed by each individual area separately (serially or in parallel), and the second level solves the state estimation problem posed by a boundary system defined from the area definitions used in the first level.

**Reviewer 2:** The developed software will have potential for commercialization and can be used at control centers to complement the existing EMS network applications. The future efforts to explore this should be encouraged and supported.

**Reviewer 3:** While the goal of this project is valuable and in line with some of the objectives from the topic, the impact is a bit indirect. Project is well formulated and has realistic and clear objectives with reasonable metric objectives for the DOE cost.

## Optimization of Excess Solar and Storage Capacity for Grid Services – $3,000,000

*NV Energy | Las Vegas, NV | Principal Investigator: Michael Brown*

This project evaluates using behind-the-meter storage, demand response, and utility “electric storage as a service” to extend the benefits and adoption of behind-the-meter solar through grid services. These services will be enabled by artificial intelligence and blockchain-powered smart contracts that can track and settle transactions leveraging information from smart meters and smart inverters. The team is working to develop artificial intelligence to use excess storage capacity for grid operations and to pay customers for their extra capacity.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project targets at more efficient use of DER assets, providing more grid services to the grid and offering more economic values to BTM solar resources. If successful, the project could remove barriers to adoption and increase the accessibility and affordability of storage while increasing the economic value of BTM PV systems via the larger suite of grid services. This project plans to use a hardware-in-loop test and field demonstration to demonstrate and validate its performance. In doing so, the project can study thoroughly key technical risks, which include access to data; the bandwidth and latency of associated telemetry to obtain required data; and the risk of insufficient data quality for financial settlement under current utility regulation. This project is very ambitious, covering a variety of emerging techniques, the distributed control architecture, DER learning agents, and blockchain based financial settlement will be demonstrated. To integrate them in this context could be a challenge. More justifications need to be provided regarding the use of blockchain in this project.

**Reviewer 2:** The project is intended to benefit customers and ratepayers via more efficient use of DERs. The team would develop and demonstrate a distributed control architecture (DCA) to supports new dynamic DER aggregation and service with co-optimization algorithms across a hierarchical control scheme. Also, learning algorithms at the grid edge will enable the GSS and a new Energy Storage-as-a-Service product offering financial transactions will be leveraging Blockchain technology for settlement. Although not a weakness, regulatory risks exist with respect to the development of new customer services in a regulated utility environment. Also, DER asset integration risks exist related to device interfaces and communication pathways. And project management risk exists related to multiple workstreams that must converge into an operational system of systems demonstration with customers.

**Reviewer 3:** This reviewer has limited experience in some areas of this project, like the use of blockchain for financial settlements. Will not comment on those aspects. The algorithm implementation in the PV and PV plus storage, etc. for grid services is not expected to be a novelty, as indicated in the report. The novelty seems to be related to the aggregation of DER and coordination of the grid services. The risk of the project, on the other hand, are of a less analytical nature (data availability, requirements for financial settlement, etc.), as described in the report. Another risk is the benefit of this system potentially not justifying the investments. It would seem that the main contribution of this project to the advancement of the industry is more in figuring out how to abate the several risk items and demonstrate a working system. The process of building this system will also position the project team to potentially uncover risks or considerations that are not yet understood in the industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Well-organized project plan with reasonable time frame and budgets.

**Reviewer 2:** The project is scheduled to begin in April 2020. However, the project team is proposing to advance utility demand response (DR) operations through coordination and integration of behind-the-meter (BTM) photovoltaic systems (PV) and energy storage (ES) via novel machine learning software applications embedded in a distributed control architecture. The project team expects to increase the customer value provided by a BTM PV system by enabling grid service payments and virtual storage via ESaaS whereby customers can access affordable storage capacity to increase and optimize the value streams associated with their PV systems, hence reducing costs for themselves and fellow ratepayers. Utility optimization of excess storage capacity across the ESaaS unit and aggregated BTM DERs will drive further economic value.

**Reviewer 3:** The project did not start, not much information was available to the reviewer in details of this aspects. The general plan provided seems to include consideration to these aspects and details may be defined at a later stage.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: All of three tasks are developed under an unified theme, and the path forward to achieving the overall goals of the project is clear.

**Reviewer 2:** Score: 5. Comments: This is difficult to ascertain from the data provided however, the project team stated that a minimum target of 15% reduction in the NPV of rooftop solar for participating customers. The team also claimed to demonstrate advanced non-wires solution leading to 1MW/4MWh of distribution feeder peak load reduction. The team also stated that smart contracts for multiple grid services are financially settled with customers monthly in a transparent fashion.

**Reviewer 3:** Score: 4. Comments: General description provided indicates so.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No blind spots have been found for this project.

**Reviewer 2:** The major hurdle is overcoming the transmission/distribution challenges such as communications, control and Latency in responding to grid instructions.

**Reviewer 3:** Was elaborated in prior questions.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project team consists of a various range of stakeholders, including utilities, vendors and universities.

**Reviewer 2:** I did not see any utility representation.

**Reviewer 3:** This project has a great project team with representation of key stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project is very ambitious in the project goals which it attempts to achieve. As a variety of emerging techniques will be explored in this project, the risks of implementing these in a field demonstration should be clearly understood. A cost-benefit analysis may be considered to quantify and measure the value of the grid services provided by distributed energy resource.

**Reviewer 2:** The project team plan on utilizing PV and ES smart inverter (SI) control for use in a defined set of grid services that will be developed as a suite of software applications aggregating distributed DER learning agents. The team also plan on developing and demonstrating a grid-edge energy storage-as-a-service (ESaaS) solution that increases the adoption of BTM PV by increasing the affordability of storage The project team also plan on co-optimizing aggregated grid services provided by BTM PV, BTM PV plus ES, ESaaS, and DR assets. Lastly, the project team believes it can lower the transaction costs of customer financial settlement for use of their DER assets by deploying a blockchain and smart contract enabled settlement system.

**Reviewer 3:** This project is quite practical in terms of the implementation of a system/process. The novel analytics is a moderate fraction of the effort. The findings of this project advance the industry in the directions of SETO goals if the system and processes associated to this effort prove important benefits. It is not clear to this reviewer that that will be the case. This reviewer has no experience related to “connection of the distributed agents to blockchain for financial settlement” to comment on its impact or novelty.

## Suite of Advanced Models for Photovoltaic Systems – $2,000,000

*Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Suman Debnath*

This project delivers three kinds of models—dynamic, high-fidelity, and advanced—of utility-scale photovoltaic generators, as well as power systems with high penetrations of distributed energy resources in distribution feeders. These models aim to capture the system dynamics under different conditions to better understand how the grid responds to various events. Advanced control functionalities aim to reduce momentary power cessation, increase system stability, and improve grid reliability.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 5 |
| Set critical challenges to overcome | 6 | 4 | 3 |
| Implement a high-risk, high-impact approach | 6 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 0 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 3 |
| Advance the U.S. solar industry substantially | 6 | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is in an area of great need for research. The dynamic behavior of inverters to faults and contingencies on the electrical grid is not known at this time. Simulation is practically non-existent due to the lack of models. I think this aligns with SETO's goal of enabling deployment of solar.

**Reviewer 2:** The project is expected to start in April 2020. A suite of EMT models of PV systems will be developed in this project that simulate faster than existing high-fidelity models of PV systems. The models developed will be validated against available data and baseline models. They will be evaluated in present grid scenario and tested with advanced control functionalities in future grid scenarios. Although not considered weaknesses of the project there are several challenges identified. One foreseeable challenge is the availability of data on smart inverter's response to extreme events. Another challenge is the availability of grid models in EMT domain simulators (like PSCAD).

**Reviewer 3:** The mentioned goal of fast dynamic models of PV systems is relevant and aligned with the goals of the track. The method proposed to achieve that was not clear to this reviewer. The input data (block diagrams, code from models in other tools, etc.) to be used for the creation of the models was also not clearly describe and can significantly affect the impact of this effort. The process to get these models incorporated to the planning tools normally used by ISOs was also not described. Without description of some of these aspects, this reviewer sees a considerable risk of an effort that is not using the current state-of-art as a solid reference point for comparison for simulation tool accuracy and computational speed.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Since the project has not been undertaken yet, I cannot score most of the elements, so I just indicated a 4. The one strong point though is the industry collaboration. The project team has all of the right participants to make this project a success.

**Reviewer 2:** Although the project has not yet stared, the models of PV systems developed will be able to accurately represent the dynamics during defined contingencies with greater than 95% accuracy. They will also simulate up to 25x faster than baseline models. The models developed will be evaluated in present and future scenarios, with advanced control functionalities incorporated into the PV system models in future scenarios. The advanced control functionalities based on model predictive methods will help mitigate some of the present generation problems like momentary cessation, and future problems with high-penetration PV systems like low inertia. The evaluation of these systems will be performed through EMT-TS co-simulations to study large-scale systems with high-fidelity models of PV systems.

**Reviewer 3:** Metrics to assess impact could include comparison with similar simulation assessment (i.e. TS or EMT) to assess computational speed. Also metric for accuracy would also be appropriate. The project description mentions: a) simulation models, b) integration methods and c) equipment features (i.e. PV inverter control features). These three different aspects requiring different type of input data and metrics could be further explained in the documentation or potentially reviewed, given that the project did not yet start

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project has highlighted the challenges that the industry is facing and their sequence is sound.

**Reviewer 2:** Score: 5. Comments: The dissemination of results in this project is expected through conference publications, journal publications, and conference presentations. Additionally, these results will be provided through industry advisory board meetings to stakeholders (including utilities and independent system operators – ISOs). There is an increasing trend amongst utilities and ISOs to perform EMT simulation of larger grids with the PV systems. The future and present scenarios simulations will showcase the utilization potential of the models, especially with this requirement becoming an increasing need for utilities and ISOs. The scalability of the developed models in large grids will be evaluated in this project through co-simulations in EMT and TS domains.

**Reviewer 3:** Score: 4. Comments: There is no significant explanation of each task. Likely because the form proposed does not necessarily request that. This reviewer has the same comments in all reviewed projects.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Have not identified any blind spots.

**Reviewer 2**: There were no blind spots identified at this time.

**Reviewer 3:** Potential blind spots are: 1) reference of current tool performance to measure improvements; 2) clear differentiation between integration method ideas and simulation model developments; 3) for inverter simulation model development, clearly establishing the PV inverter or simulation model to be used. In order to advance the industry, the selection of the input data could affect the usefulness of the associated project deliverable; 4) models or methods, even if novel and with good advantages could be of limited value if the ISO cannot incorporate to their planning processes. A path to implementation or use of the outcome of this project by ISO could benefit the impact

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** All stakeholders are included.

**Reviewer 2:** The project team is well balanced and is comprised of a broad spectrum of expertise.

**Reviewer 3:** Simulation software vendor participation could improve the impact of this project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** We need more projects like this that are researching the dynamic characteristics of inverters and developing the ability for transmission engineers to simulate the system with higher penetrations of inverter-based resources.

**Reviewer 2:** There is great interest in simulation of high-fidelity PV dynamic models (through EMT/EMT-TS cosimulation) from utilities with high-penetration of PV to understand the response of the grid during contingencies, but with limited capabilities to perform such analysis. DOE funding will enable addressing these gaps that are critical to be addressed for reliable, secure, and resilient operation of existing and future grids. The developed models will be of great interest to NERC Inverter-based Resource Performance Task Force (IRPTF), NERC System Planning Impacts from Distributed Energy Resources (SPIDER) working groups, and IEEE P2800 to understand problems faced with high penetration of PV. They will be able to study following in future grids: (i) Loss of PV generation (including partial loss) during extreme events and the corresponding reasons; and, (ii) Impact of advanced control functionalities on future grids during extreme events (including reduced momentary cessation, providing inertia capabilities to improve grid reliability). The EMT-TS co-simulation requirements and boundaries for each type of simulation would be of interest to CIGRE working group C4.56. The working group is investigating the EMT simulation requirements for systems with high penetration of inverter-based generation.

**Reviewer 3**: The problem statement and overall objective of this project is aligned with the SETO goals in this topic. The approach described to advance the industry towards this goal was not well articulated in the information received.

## Security Constrained Economic Optimization of Photovoltaics and Other Distributed Assets – $3,221,649

*Opus One Solutions | Somerville, MA | Principal Investigator: Vivek Somasundaram*

This project takes a holistic approach to address critical challenges that prevent high levels of distributed solar penetration in power system networks. The team is coordinating interaction of solar generation units, electric cars, energy storage devices, and demand-side management programs to provide multiple grid services in real-time. This project aims to deploy a general-purpose software platform that will create an optimal dispatch of distributed resources while ensuring secure and normal operations of electric power distribution networks. The project will ultimately enable large scale deployment of the solution to other cooperatives and municipal- and investor-owned utilities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Firstly, I would like to thank and congratulate the research and development groups supporting on this project. With the high level of PV penetration, more than the smart inverter functionality of PV inverters, the storage system (ESS) are a great resource in increasing grid stability and managing load over utilities. This project is a great example of system integration and end to end functionality testing. While the goal/motive of the project is clear, the report does not explain how this is achieved in milestones such as details around what is already realized and what needs to be done, what level of simulations performed before heading into experimental phase. How does the collaboration and testing happen with the utilities and example customer sites? The detailed planning and path to achieve the goal is missing in this report and not mentioned other than the high-level objective.

**Reviewer 2:** The project concept is interesting and the objectives are highly aligned with the SETO objectives for this research area. The initial stages of defining requirements to develop specifications, definitions, operational base plans, test plan, etc. would be broadly useful to industry. However, the actual product development, and results, seem to benefit specifically customers of this particular product line, rather than industry at large. This would limit the benefits to that subset of industry that is utilizing this product line.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 |
| Disseminates results frequently and actively engages partners | 2 | 4 |
| Collaborates with sufficient stakeholders | 2 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The report mentions 3 budget periods but only show time period from Jan 2020 to Jan 2022, is there a typo? Being the sole research stakeholder, the project is missing supporting groups like a specific local utility co-op or customer sites and deployment phase. Mostly focuses on achieving a demonstratable product but not a path on how to commercialize. Need to provide clear picture on what is off-the-shelf and what is the proprietary built for this project. The goals are mentioned subjectively but no quantitative targets specified in the report.

**Reviewer 2:** The project is in the initiation phase and thus no evaluation of past performance is possible. The list of tasks looks reasonable. It appears that stakeholder involvement and information exchange may be limited to customers utilizing a specific commercially available platform. The project would provide more value to industry if findings could be shared with industry at large.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The report is missing the detailed tasks and the milestones associated with the budget periods to properly estimate the review.

**Reviewer 2:** Score: 5. Comments: The tasks described appeared reasonable.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Need to clarify what is already realized and what needs to be done. 2 year timeline is very aggressive for the scope defined. Without other stakeholders to support like NREL or utilities or such, it is hard to verify the experimental outreach.

**Reviewer 2:** The funded work should provide benefits to industry outside of the particular customer base of this developer. The use case may be limited to very specific micro-grid needs due to the complexities needed in closed loop OPF controls; which are utilized rarely even in the transmission control due to the challenges.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Missing support from organizations like NREL, co-op utilities etc.

**Reviewer 2:** It could be useful to collaborate with an industry entity to ensure knowledge gained is shared across the industry i.e.; EPRI, national lab, etc.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** SETO should continue to encourage projects that quantify the PV penetration and stability with other DERs like energy storage. SETO should help organizations like these to get support from organizations like NREL to realize the goals. SETO should help this organization in laying out more detailed path on this can be achieved.

**Reviewer 2:** 1) The project scope is interesting and aligned with resiliency with high DER penetration. 2) The project scope appears intended to further development of capabilities of a particular supplier product. 3) The project may primarily benefit the developer and customers of the product line, unless learnings are expanded and shared to industry as a whole.

## Protection of High-Penetration Distributed Photovoltaics – $1,000,000

*Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Thomas McDermott*

This project is working to define best practices for power system protection—independent controls that isolate faults on the grid—for radial distribution circuits with high photovoltaic penetration. A radial system is a common type of power distribution system. Because high photovoltaic penetration creates bidirectional power flow, and inverters respond differently to faults, traditional protection methods need to be revised. Photovoltaics and battery energy storage inverters produce low-fault currents that don't function properly under traditional overcurrent and distance protection. And with new requirements in new industry standards, like IEEE 1547, devices known as undervoltage relays can't detect faults. This project evaluates potential local solutions—such as high-energy traveling waves, incremental quantities, relays without settings, and focused directional methods on distribution networks—and conducts field tests at two sites. These alternative protections have the potential to overcome costly special protection studies and other grid integration requirements.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 0 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Protection of U.S. distribution circuits is one of the grand challenges to overcome in order to increase penetration of BTM PV resources. Most U.S. distribution circuits have been radial, with fault current supplied only from the substation source. Protection zones are bounded by simple time-overcurrent devices like relays (plus circuit breakers to interrupt), reclosers (relay plus interrupter in a single package), and fuses. Each of these operates autonomously with none of the communication links or cooperative schemes that are common on transmission systems. Conventional distributed energy resources (DERs) may provide enough fault current to compromise the time-current coordination of these devices, but with photovoltaic (PV) DERs, the opposite problem arises. PV inverters don't provide enough fault current to operate overcurrent devices. Therefore, undervoltage trip settings required by IEEE 1547 have served as the de facto fault detection method for many PV installations. Recent changes to IEEE 1547 introduced voltage regulation and ride-through functions to distributed PV, which means that undervoltage trip can't be relied on to detect faults, especially at high penetration levels. Some utilities have required direct transfer trip (DTT) for larger PV, but this is an expensive barrier to PV integration. The project has solved these protection issues in the near term by employing commercial relays in new ways. This project also recommends a new set of best practices for system protection with high-penetration PV on radial circuits, compatible with IEEE 1547-2018 and CA Rule 21.

**Reviewer 2:** Detection and isolation of faults in system conditions with high PV penetration is a relevant problem and aligned with the track goals. Resolution to these problems without demanding increased fault contributions from PV inverters facilitates connection of more PV generation in a given system or feeder.

**Reviewer 3:** The project team has already identified setting-less relays, focused directional, single-point traveling wave and incremental distance relays for more detailed evaluation. The goal of this project is to verify one or more of these schemes as being suitable for immediate industry application using commercially available relays. The process began with simulation of each scheme with settings, on feeder models provided by partner utilities and publicly available test feeders. Successful schemes then proceed to lab validation on relay hardware, then field trials at the partner utilities. During field trials, the new relays will collect data and attempt to detect faults, but not actually trip feeders or PV. Although not a weakness, the project team found that single-point traveling wave methods are unsuitable for distribution feeders with tapped loads and laterals, especially when considering the multi-grounded neutral. One of the relays, uses proprietary filtering and other logic, but the team was able to implement reference models based on available literature, and then validate our understanding using open-loop tests in the lab. Some schemes trip on dynamic behaviors of the PLL during faults, which means that the tripping quantity does not persist.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has met important milestones within reasonable timeframes and budgets. The project's objective is to increase the allowable PV penetration, up to 100% of feeder peak load, while maintaining three Critical protection system qualities defined in the table below. Within those constraints, the two Numerical metrics are also to be optimized. The project considers cost, by developing best practice guidelines to reduce engineering labor, and technology maturity, by using commercially available hardware to implement new schemes.

**Reviewer 2:** Project objectives are impactful and realistic. Measuring impact of approach using OpenDSS and ATP simulations is reasonable. A potential limitation is that PV inverter response is highly dependent on, for example, manufacturer controls and inverter control configuration. That is, PV inverters from two manufacturers may have noticeably different response to a particular fault with same grid conditions. Also, a PV inverter product configured to meet different grid code requirements may have noticeably different response to a particular fault with same grid conditions. Understanding the sensitivity of the protective relaying approach proposed to variations in PV inverter response is likely relevant to measure effectiveness.

**Reviewer 3:** Overall, dynamic and transient models of PV inverters with phase-locked loop (PLL) effects have been developed for OpenDSS and the Alternative Transients Program (ATP) in a form suitable for protection system studies. These models have been published. Three partner utility feeder models have been converted to OpenDSS using scripts that have been published, without proprietary data.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project began with model-based design and proceeded through open-loop hardware testing to validate the settings, before field trials in a detect-but-not-trip mode.

**Reviewer 2:** Score: 4. Comments: The tasks described are relevant to achieve the overall goals. There is however no complete list of tasks in the forms provided. The list of protective relaying methods described add value to the effort.

**Reviewer 3:** Score: 5. Comments: Overall, dynamic and transient models of PV inverters with phase-locked loop (PLL) effects have been developed for OpenDSS and the Alternative Transients Program (ATP) in a form suitable for protection system studies. These models have been published. Three partner utility feeder models have been converted to OpenDSS using scripts that have been published, without proprietary data.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No blind spots have been found in this project.

**Reviewer 2:** Potential blind spots are the variation in inverter response to faults based on manufaturer or configuration. Another consideration is the speed. There is a potential gain in simplicity of relay tuning if the speed of response is slower than 3 cycles (inverter responses are less different after the initial transient of 2-3 cycles). Consideration of slower response (if system stability and equipment damage allow) could add value to the conclusion of this effort.

**Reviewer 3:** No blind spots were evident from the write-up.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project team collaborated with a variety of stakeholders and organizations.

**Reviewer 2:** Project participants include utility entities, academia and national labs. Participation of inverter manufacturer could have benefited the effort.

**Reviewer 3:** The project team is well represented.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project team is suggested to work with IEEE Standard Development Committee, NERC and other regulatory bodies to make a broad impact in this area.

**Reviewer 2:** Relevant and concrete project goals aligned with track objectives. Relevant exploration of existing and novel relaying approaches to resolve the problem stated. Potential risk of the simulation environment used to test the methods being specific to a particular PV inverter or inverter configuration.

**Reviewer 3:** The Project team has their focus on (1) detecting all faults within the protected zone of operation, (2) preventing false tripping for faults outside the zone of protection, and (3) trip the minimum number of devices to isolate a fault. Overall, the project : Solves protection issues with commercial relays, or combinations of relays, used in new ways; Keeps relay dependability, security and selectivity at higher levels of distributed photovoltaics; Reduces cost and complexity of communication-based protection schemes. Field trial is scheduled to start by the Sumer of 2020.

## Keystone Solar Energy Future Project – $3,141,920

*PPL Corporation | Allentown, PA | Principal Investigator: Yi Li*

This project leverages several different grid technologies to deploy a distributed system platform that bridges the gap between existing and future technologies by monitoring, controlling, and optimizing a high penetration of solar generation. The team is also developing a multi-layer device and communications architecture and a 500-customer pilot on at least ten distribution circuits. An extensive one-year, real-world testing will be performed, proving all of the target parameters before deploying it system-wide.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 1 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is an excellent project! It is a project that utilities can immediately incorporate into their operation. It addresses multiple issues faced by utilities in connecting and managing high levels of DER.

**Reviewer 2:** Strengths: Led by utility is a major strength, and is on track to deliver concrete results.

**Reviewer 3:** Project objective is aligned with track goals. Based on the available description the project has an ambitious but yet well-defined goal. The progress described is very encouraging. The focus on demonstration on PPL system drove a very practical and rigorous approach in the decision making during the project this far. The part of this project dedicated to automating the DER application review process through a customer-facing web portal facilitates integration of PV from a process perspective. The part of the project related to designed, built and is piloting a Distributed Energy Resource Management System (DERMS) is aligned with topic goals associated with coordination of DER. This project benefits all DER, not only PV.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 1 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 1 | 1 | 4 |
| Collaborates with sufficient stakeholders | 1 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project does not appear to be disseminating the results of the project to the industry. This is very useful information that the industry could benefit greatly from. We need to develop a strategy to disseminate this project information.

**Reviewer 2:** Acceptable based on information provided.

**Reviewer 3:** This project leadership by a utility seems to have benefited the focus on practical implementation. There is good participation from academia and manufacturers of related equipment. The metrics of success and impact based on web portal approval in current processes seems appropriate. The metrics proposed for the other aspects of the project are good (development of scrypt for protocol conversion). Additional quantification of the benefits to PPL of the optimized operation of DER with respect to the operation before DERMS may benefit the understanding of the impact of this phase of the project. Something along those lines is referenced in the project overview, but elaborated in other sections of the provided information.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: This project has real world issues and solutions for utilities to manage high penetrations of DER in both managing the application process and managing the operation of them after installation.

**Reviewer 2:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** Score: 4. Comments: There is no significant explanation of each task. Likely because the form proposed does not necessarily requests that. This reviewer has the same comments in all reviewed projects. The list of milestones provided seems well targeted towards the two main objectives of this project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None seen.

**Reviewer 2:** Scalability beyond service area will be a challenge due to the same obstacles already overcome, including protocol compatibility, etc.

**Reviewer 3:** Potential blind spots could be related to the applicability of these tools and approaches to other utilities. The stakeholders may be more focused on getting these systems to work in PPL. At the same time this was a significant advantage to drive completion and concrete contributions. May be not a blind spot, but interesting opportunities for future work are teh details and possible improvements of DMS functions once the PV systems can be properly modelled, monitored and accounted for.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Need to develop a communication strategy to industry for this project.

**Reviewer 2:** No comment.

**Reviewer 3:** Stakeholders in this project seem to cover the critical aspects.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Excellent project. Need to develop communication strategy to inform industry of this project.

**Reviewer 2:** No comment.

**Reviewer 3:** This industry led project seem to have more focused and lead to more concrete contributions than other projects reviewed. On the other hand, it would make sense that SETO has a combination of projects like this and other projects with efforts that may be even more disruptive if successful. Dissemination of this effort to other utilities, to the extent of facilitating adoption of solutions or approach, could be of interest for SETO. Also, this project attempts to simplify the evaluation of DER connections and optimization of DER operation. This reviewer considers important to manage the balance between this type of objectives (optimizing DER) and other objectives that may be more related to technical feasibility of even wider deployment of PV that could be of higher urgency.

## Adaptive Protection and Control for High Penetration Photovoltaics and Grid Resilience – $4,900,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Matthew Reno*

This project team is designing a scalable adaptive protection platform for distribution systems and microgrids with high penetrations of distributed energy resources, like solar photovoltaics, that improves the selectivity and sensitivity of the protection system. The team is creating communication-free modular units that attach to intelligent protection devices to guarantee the protection system's operation during extreme weather, equipment failures, and other events. This project will transform power system protection from static settings that are not sufficiently reliable for high penetrations of solar to a platform that can adapt to real-time grid conditions.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 5 |
| Set critical challenges to overcome | 6 | 4 | 3 |
| Implement a high-risk, high-impact approach | 6 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 0 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 3 |
| Advance the U.S. solar industry substantially | 6 | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is in an area of great need for research. The dynamic behavior of inverters to faults and contingencies on the electrical grid is not known at this time. Simulation is practically non-existent due to the lack of models. I think this aligns with SETO's goal of enabling deployment of solar.

**Reviewer 2:** The project is expected to start in April 2020. A suite of EMT models of PV systems will be developed in this project that simulate faster than existing high-fidelity models of PV systems. The models developed will be validated against available data and baseline models. They will be evaluated in present grid scenario and tested with advanced control functionalities in future grid scenarios. Although not considered weaknesses of the project there are several challenges identified. One foreseeable challenge is the availability of data on smart inverter's response to extreme events. Another challenge is the availability of grid models in EMT domain simulators (like PSCAD).

**Reviewer 3:** The mentioned goal of fast dynamic models of PV systems is relevant and aligned with the goals of the track. The method proposed to achieved that was not clear to this reviewer. The input data (block diagrams, code from models in other tools, etc.) to be used for the creation of the models was also not clearly describe and can significantly affect the impact of this effort. The process to get these models incorporated to the planning tools normally used by ISOs was also not described. Without description of some of these aspects, this reviewers sees a considerable risk of an effort that is not using the current state-of-art as a solid reference point for comparison for simulation tool accuracy and computational speed.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Since the project has not been undertaken yet, I cannot score most of the elements, so I just indicated a 4. The one strong point though is the industry collaboration. The project team has all of the right participants to make this project a success.

**Reviewer 2:** Although the project has not yet stared, the models of PV systems developed will be able to accurately represent the dynamics during defined contingencies with greater than 95% accuracy. They will also simulate up to 25x faster than baseline models. The models developed will be evaluated in present and future scenarios, with advanced control functionalities incorporated into the PV system models in future scenarios. The advanced control functionalities based on model predictive methods will help mitigate some of the present generation problems like momentary cessation, and future problems with high-penetration PV systems like low inertia. The evaluation of these systems will be performed through EMT-TS co-simulations to study large-scale systems with high-fidelity models of PV systems.

**Reviewer 3:** Metrics to assess impact could include comparison with similar simulation assessment (i.e. TS or EMT) to assess computational speed. Also metric for accuracy would also be appropriate. The project description mentions: a) simulation models, b) integration methods, and c) equipment features (i.e. PV inverter control features). These three different aspects requiring different type of input data and metrics could be further explained in the documentation or potentially reviewed, given that the project did not yet start.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project has highlighted the challenges that the industry is facing and their sequence is sound.

**Reviewer 2:** Score: 5. Comments: The dissemination of results in this project is expected through conference publications, journal publications, and conference presentations. Additionally, these results will be provided through industry advisory board meetings to stakeholders (including utilities and independent system operators – ISOs). There is an increasing trend amongst utilities and ISOs to perform EMT simulation of larger grids with the PV systems. The future and present scenarios simulations will showcase the utilization potential of the models, especially with this requirement becoming an increasing need for utilities and ISOs. The scalability of the developed models in large grids will be evaluated in this project through co-simulations in EMT and TS domains.

**Reviewer 3:** Score: 4. Comments: There is no significant explanation of each task. Likely because the form proposed does not necessarily requests that. This reviewer has the same comments in all reviewed projects.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Have not identified any blind spots.

**Reviewer 2:** There were no blind spots identified at this time.

**Reviewer 3:** Potential blind spots are: 1) Reference of current tool performance to measure improvements. 2) Clear differentiation between integration method ideas and simulation model developments. 3) For inverter simulation model development, clearly establishing the PV inverter or simulation model to be used. In order to advance the industry, the selection of the input data could affect the usefulness of the associated project deliverable. 4) Models or methods, even if novel and with good advantages could be of limited value if the ISO cannot incorporate to their planning processes. A path to implementation or use of the outcome of this project by ISO could benefit the impact.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** All stakeholders are included.

Reviewer 2: The project team is well balanced and is comprised of a broad spectrum of expertise.

**Reviewer 3:** Simulation software vendor participation could improve the impact of this project.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** We need more projects like this that are researching the dynamic characteristics of inverters and developing the ability for transmission engineers to simulate the system with higher penetrations of inverter-based resources.

**Reviewer 2:** There is great interest in simulation of high-fidelity PV dynamic models (through EMT/EMT-TS co-simulation) from utilities with high-penetration of PV to understand the response of the grid during contingencies, but with limited capabilities to perform such analysis. DOE funding will enable addressing these gaps that are critical to be addressed for reliable, secure, and resilient operation of existing and future grids. The developed models will be of great interest to NERC Inverter-based Resource Performance Task Force (IRPTF), NERC System Planning Impacts from Distributed Energy Resources (SPIDER) working groups, and IEEE P2800 to understand problems faced with high penetration of PV. They will be able to study following in future grids: (i) Loss of PV generation (including partial loss) during extreme events and the corresponding reasons; and, (ii) Impact of advanced control functionalities on future grids during extreme events (including reduced momentary cessation, providing inertia capabilities to improve grid reliability). The EMT-TS co-simulation requirements and boundaries for each type of simulation would be of interest to CIGRE working group C4.56. The working group is investigating the EMT simulation requirements for systems with high penetration of inverter-based generation.

**Reviewer 3:** The problem statement and overall objective of this project align with the SETO goals in this topic. The approach described to advance the industry towards this goal was not well articulated in the information received.

## Electric Access System Enhancement – $3,962,113

*Southern California Edison | Rosemead, CA | Principal Investigator: Juan Castaneda*

This project leverages existing information systems and processes to increase efficient communication exchange between the utility and the customer or resource provider interconnection process by optimizing control of the resource. This complete lifecycle approach defines the necessary data to be exchanged, the grid and device characteristics, and the operating constraints and protocols to enable effective controls and operations. This structured and automated exchange of characteristics and parameters accelerates the interconnection process, establishes common information requirements, and enables effective operational connection of distributed energy resources to the grid.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 3 |
| Advance the U.S. solar industry substantially | 4 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project has a goal of testing and demonstrating a seamless interconnection portal to enable services to support the utility, ISO and co-optimization services. The team also had to overcome complexities such as cyber security, large number of stakeholders and legacy issues. The strengths of this project are (1) demonstrating a streamlined interconnection process between the utility and a city, (2) ability to communicate with DER in large scale via approved communication protocol, (3) demonstrate DER value to customers, the bulk electric system and (4) assess cyber security for DER communication. The team still has to overcome the risk of field demonstration to over 100 customers to show that DERs with smart inverters can comply with Rule 21 Phase 3 requirements.

**Reviewer 2:** This project developed and demonstrated a Distributed Control Architecture (DCA) platform that enables interoperability, communication and control in the presence of high DER penetration. This project is part of efforts at SCE to modernize its power grid. This project has achieved a great success since it demonstrated the seamless integration of high penetration levels of PV and energy storage systems which can provide reliability services into the distribution system and to the wholesale market. This project demonstrated that it can effectively manage voltage and thermal constraints for multiple simulated distribution circuits. Up to 20% increase in circuit hosting capacity can be achievable without significant curtailment of PV generation. By optimally scheduling energy storage system with >50% solar penetration, the proposed approach can lead to 50% flatter net load profile while reducing ramp rates.

**Reviewer 3:** Strengths: This working at addressing practical challenges with commercial implementation, contracts, cyber security, and others. These may not have been the focus initially, but the lessons learned are among the most valuable aspects of these projects, as many of the projects track along similar goals. The lessons learned should be clearly identified and published (General comment for all projects).

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 1 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 1 |
| Collaborates with sufficient stakeholders | 0 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team has already claimed it showed up to 20% increase in circuit capacity is achievable without significant curtailment of solar PV. The team also claimed that optimum scheduling of energy storage system with over 50% of solar penetration can lead to 50% flatter net load profiles.

**Reviewer 2:** The project has met important milestones within reasonable timeframes and budgets. The project team also performed very well to disseminate the project results.

**Reviewer 3:** Acceptable from the information available.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: It appears that each of the following tasks of the project adds important value in achieving the overall goal of the project. The project team: Validated the interoperability if the proposed architecture; Demonstrated a streamlined process between SCE and the city of Santa Ana solar PV interconnection processing portal; Demonstrated functionality to manage voltage and thermal constraints for multiple simulated distribution circuits; The project team also plan on demonstrating provisions of DER services to multiple entities.

**Reviewer 2:** Score: 5. Comments: The project consists of several tasks, which include 1) to test and demonstrate a streamlined interconnection portal (and process) between the utility and the local jurisdiction to enable reduced interconnection times. 2) to test and demonstrate the DER self-provisioning process to interconnect and establish communications with DERs in the lab environment. 3) to establish communication protocols (DNP3 and IEEE 2030.5) and test systems integration of battery energy storage system (BESS) and solar PV system. 4) to determine value of services provided by DERs, resulted from optimum scheduling and operation. Together, these tasks achieve the overall goals of the project. These tasks also were very well established to explore different aspects, ranging from communications, performance and value chain.

**Reviewer 3:** Score: 6. Comments: No comment.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The team has identified the risk of field demonstration requiring the participation of up to 100 customer to show that DERs with smart inverters complied with Rule 21 Phase 3 requirements.

**Reviewer 2:** No blind spots are found for this project.

**Reviewer 3:** No comment.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I believe the project team is well represented.

**Reviewer 2:** The project has collaborated with a variety of organizations and have defined the clear role for each stakeholder.

**Reviewer 3:** No comment.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project is in alignment with SETO's mission in that the strengths of this project are to: (1) demonstrate a streamlined interconnection process between the utility and actual customers, (2) show the ability to communicate with DER in large scale via approved communication protocol, (3) demonstrate DER value to customers, BES and utility.

**Reviewer 2:** SCE is one of the leaders deploying advanced technologies to modernize the power grid. The future work as a continuity of this project or to expand the scope of the work should be encouraged. Other works like cybersecurity or microgrid can be conducted using the test bed developed by this project.

**Reviewer 3:** No comment.

## Phasor-Based Control Scalable Solar Photovoltaic Integration – $1,458,356

*University of California, Berkeley | Berkeley, CA | Principal Investigator: Sascha von Meier*

This project designs, implements, and validates an innovative framework to enable a distribution grid with solar photovoltaic generation greater than 100 percent. By explicitly controlling voltage phasors at specific network nodes, this framework simultaneously addresses multiple operational challenges, including high resource variability, reverse power flow, grid visibility, and coordination between transmission and distribution systems. The framework solves the problem of complex interdependencies in large networks by creating options for partitioning the grid both physically and computationally.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 0 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is developing a radically new, layered control framework termed as Phasor-Based Control (PBC) to manage solar generation and other variable energy resources on the grid. PBC will provide a framework and mechanism to optimally recruit distributed resources for the grid services while preventing the local impacts in the distribution system. The approach proposed in this project is innovative. It consists of controllers at two layers. A supervisory (S-PBC) controller sets targets for voltage magnitude and phase angle (V, ?) at different nodes in the transmission or distribution network. A local (L-PBC) controllers recruit real and reactive power (P, Q) from solar inverters to track phasor targets. The approach is enabled by using Micro phasor measurement units (ÂµPMUs). ÂµPMUs have been proposed to monitor the grid statuses, and this project is the first of kind to extend the applications of ÂµPMUs for power grid control.

**Reviewer 2:** This project is developing a radically new layered control framework termed Phasor-Based Control (PBC) for managing solar generation and other variable energy resources on the electric grid. If successful, PBC will provide a unified framework and mechanism to optimally recruit variable and distributed resources for grid services while preventing adverse local impacts (such as voltage constraint violations) in the distribution system that would limit permissible solar penetration levels. Because the PBC framework is grid-centric rather than resource-centric, it enables PV and other resources (including loads) to consistently act as good citizens on the grid, responding directly to physical measurements and the needs of the network, without the need for locational pricing. I did not see any blatant weakness however there were a few challenges such as performing PBC in a time step as fast as 1 second. Communication with hardware has proven to be another challenge, as this involves latencies outside the purview of the PBC controller. Also, commercial inverter APIs are typically limited in allowing execution of explicit external P-Q commands with smooth increments in all four quadrants; this issue is being addressed in the FLEXLAB, but will impact commercialization of PBC.

**Reviewer 3:** The project's weakness appears to be the need for precise accuracies of impedance between nodes. Since it is stated that there is a lack of "reliable" models of the distribution system, it appears this is a major obstacle.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has met important milestones within reasonable timeframes and budgets. The project team also published a few publications to disseminate the project results.

**Reviewer 2:** The project team has showed it is possible for a supervisory controller to express a desired power flow solution in terms of voltage phasor profiles, to communicate nodal phasor targets to local controllers, and to actuate local resources to track phasor targets in the presence of time-varying loads and solar generation. The team also illustrated use cases matching an external phasor target to enable switch closure, three-phase balancing on an unbalanced distribution circuit, and controlling net power flow (import/export) at the feeder head. The team also showed voltage magnitudes have been regulated to within 0.01 per-unit of target in simulation for a 300+ node feeder; where local PBC achieves 90% of the steady state value with a settling time of 5 seconds under transient disturbances >0.1 p.u. The team also showed for the HIL testing, the project created a flexible and secure data and communication infrastructure for PBC based on the open-source eXtensible Building Operating System (XBOS) developed at UC Berkeley.

**Reviewer 3:** Communication via papers appears to be above average.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in this project adds unique and important value to achieving the overall goals of the project.

**Reviewer 2:** Score: 5. Comments: From the milestones achieved so far, the project seems to be aligned with the overall goals of the project.

**Reviewer 3:** Score: 5. Comments: The tasks are aligned with the desired outcome.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No blind spots have been found in this project.

**Reviewer 2**: No blatant blind spots was evident from the write-up. The project team comprises academic experts in power systems and control engineering, industry partners with experience in power system modeling, simulation and distributed resource control, and electric utility advisors.

**Reviewer 3:** Performing state estimation at a distribution level is very difficult and, as observed by the project, very difficult to achieve the high fidelity needed to dispatch based on state estimation.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team has collaborated with multiple stakeholders.

Reviewer 2: I believe the project is well represented.

**Reviewer 3:** None identified.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** ÂµPMUs have been applied previously for monitoring the grid statuses and this project can have some linkage with other applications utilizing ÂµPMUs. In doing so, ÂµPMUs can be viewed as a fundamental feature for smart distribution systems and bring more values to the visibility and control of future power grid.

**Reviewer 2:** Phasor-Based Control will present a completely novel approach for coordinating variable and distributed resources. The framework is agnostic to the type of resource being controlled – generation, storage, or controllable load. It is unique as a control paradigm that makes network constraints explicit and is able to prioritize grid stability and resilience first. The project work plan systematically built and scaled up the PBC capability through four task groups: Case Design, Control Algorithm Development, Controller Implementation, and HIL Simulation. In Year 1, the team validated the basic validity of the PBC paradigm, and a simulation infrastructure for PBC was built. In Year 2, the team tested the stability behavior for three alternative local control algorithms under different scenarios, expanded the library of circuit models for simulation, and implemented the communication and control architecture for PBC in the HIL setting. Year 3 ties these efforts together, with HIL demonstration of selected cases, in silico simulations of PBC on larger networks, and a value analysis focusing specifically on security benefits of controlling entire distribution feeders by PBC.

**Reviewer 3:** This would be a very complex method to dispatch resources and would result in complete dependence on state estimation of distribution circuits.

## Integrated Distributed Energy Management System at Riverside Public Utility – $2,613,764

*University of California, Riverside | Riverside, CA | Principal Investigator: Hamed Mohsenian-Rad*

This project is working to design, deploy, and validate at scale a novel distributed energy resource management system. Its main component will be a sophisticated numerical analysis platform that will enable a network management solution for real-time control. The solution provides secure and optimal dispatch of distributed energy resources for power system networks (both transmission and distribution) on feeders with over 50 percent photovoltaic penetration.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project develops and validates a distributed energy resource management system (DERMS) to automate integration, monitoring, and control of DERs with advanced sensor data and novel hierarchical control algorithms. This would increase the penetration of DERs, enhance their visibility and controllability, and accelerate reliable integration. The technical challenges include: (1) the development of several phases of testing to set up a suitable automated interface to host a wide variety of DER-related algorithms, and different hardware devices, (2) testing of the algorithms on actual inverters, and (3) monitoring algorithms utilize a heterogeneous set of legacy and advanced sensor measurements in innovative ways to mimic practical network conditions.

**Reviewer 2:** This project directly supports the SETO mission as it enables individual and clustered PV and DERs to act as visible and controllable resources to solve grand challenges associated with renewable integration. A distributed energy resource management system has been tested and validated to automate integration, monitoring and control of DERs with advanced sensor data and novel control algorithms. The success of this project will increase penetration of DERs, enhance their visibility and controllability when they are integrated into power systems. A modular hierarchical platform was developed and its features are 1) the system is scalable and 2) the objective functions can be tuned and customized. As the algorithms developed by this project will be opensource, it will produce more broad impacts beyond this project and bring significant values to the DER research community.

**Reviewer 3:** The need to manage DER at high penetration levels is critical for grid operators. In order to achieve these high levels, management must be developed.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Major milestones have already been completed. First, the overall platforms and algorithms were developed. Second, the platform and selected algorithms were validated in PG&E's HIL testing facility. Third, the demonstration plan was developed and the performance objectives were identified and approved by DOE. Fourth, several key hardware of the DERMS platform were commissioned at the test site.

**Reviewer 2:** The project has met important milestones within reasonable timeframes and budgets. Also, the performance of the proposed framework is satisfactory and measured against the target performance metrics.

**Reviewer 3:** The project appears to be moving forward at a reasonable pace and is meeting its milestones.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project has finished algorithms development, HIL testing, and several field installations. The most recent accomplishments are about preliminary testing of the selected algorithms at the project site.

**Reviewer 2:** Score: 5. Comments: The project plan is well organized and unified under the project theme. Each task contributed a value to achieving the overall goals of the project.

**Reviewer 3:** Score: 6. Comments: The tasks are aligned with the project's goals.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** I do not see any blind spots at this time.

**Reviewer 2:** No blind spots have been found for this project.

**Reviewer 3:** None identified.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Other Participating Organizations: Riverside Public Utilities, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Smarter Grid Solutions, Pacific Gas & Electric, GridBright

**Reviewer 2:** This project team already collaborated with a broad range of stakeholders.

**Reviewer 3:** Once again, it is critical that this technology is disseminated to utilities/grid operators. A vehicle to ensure that is needed.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** The project will develop a modular and hierarchical platform that engages DERs to regulate network constraints and optimize distribution-level objectives such as losses and nodal voltage magnitudes, as well as to enable aggregated services to increase the grid operation flexibility. The project will quantify and report the benefits of advanced sensor networks and multi-objective control strategies for PVs inverters and batteries. The project will also deliver the developed algorithms as open-source to the wider DER grid community.

**Reviewer 2:** As the project will share their developed algorithm as open source with the research society, a user group community can be established to accelerate the adoption of the algorithms and continuously improve its effectiveness. The proposed framework to increase the visibility and controllability of DERs can also help to develop other business cases to unlock the values of DERs. This kind of efforts could be encouraged to push the performance envelope of DERs under various operation conditions.

**Reviewer 3:** This is a good project and critical to allowing higher penetrations of DER in the future.

## Scalable/Secure Cooperative Algorithms and Framework for Extremely High-Penetration Solar Integration – $1,275,000

*University of Central Florida | Orlando, FL | Principal Investigator: Zhihua Qu*

This project designs and develops a scalable architecture and a set of algorithms for distributed control and optimization. The platform encompasses automatic fault location isolation and service restoration and Volt/VAR optimization; distribution system state estimation algorithms for both the conventional non-convex task and the convex state estimation task; a three-phase unbalanced power flow model that captures the non-linear behavior of system components and enables rapid computation of sub-transmission network and unbalanced distribution network; a two-stage stochastic security-constrained algorithm for real-time operational planning; and a distribution energy market framework that utilizes both model-based and data-based techniques to provide market-based signals for real and reactive power control of photovoltaic systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 1 | 5 |
| Set critical challenges to overcome | 5 | 1 | 5 |
| Implement a high-risk, high-impact approach | 4 | 1 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 1 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 1 | 4 |
| Advance the U.S. solar industry substantially | 4 | 1 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aligns with SETO's goal of enabling solar DER.

**Reviewer 2:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** This reviewer has limited experience in this area. Project objectives align with SETO and track objectives related to coordination and optimization of distribution connected PV. The project makes use of state-of-the-art tools and seems to further develop these tools to apply them to larger systems (more nodes). The approach towards development and demonstrations seems realistic and innovative. The focus on commercialization potential seems in line with SETO objectives of advancing the industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 1 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 1 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 1 | 6 |
| Collaborates with sufficient stakeholders | 5 | 1 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project appears to be on schedule and meeting milestone dates. Communication via papers and publications appears to be good.

**Reviewer 2:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** This project spent significant effort in dissemination in the form of books and papers. If all these publications were done within the budget of the project, the feedback is that less dissemination activities will allow for use of a larger amount of funding for core project execution. MA-OpenDSS also seems like a relevant dissemination activity. The impact assessment is thorough in terms of covering several aspects (IP, market receptivity, const-benefit and research impacts)

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks are logically aligned with the project goal.

**Reviewer 2:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**Reviewer 3:** Score: 5. Comments: There is no significant explanation of each task. Likely because the form proposed does not necessarily requests that. This reviewer has the same comments in all reviewed projects. The milestones describe do seem aligned with the goals

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None identified.

**Reviewer 2:** No comment.

**Reviewer 3:** None.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None identified.

**Reviewer 2:** No comment.

**Reviewer 3:** The projects has solid collaborators and partners.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** While this is another DERMS project, it has value in that it is producing a product that industry can use.

**Reviewer 2:** No comment.

**Reviewer 3:** This project description includes a clear plan and past milestones to clearly facilitate the improvement of commercial products based on the research. The work described seems significant compared to the DOE cost. Also, this project advances optimization of DER operation. This reviewer considers important to manage the balance between this type of objectives (optimizing DER) and other objectives that may be more related to technical feasibility of even wider deployment of PV that could be of higher urgency.

## Robust and Resilient Coordination of Feeders with Uncertain Distributed Energy Resources: From Real-Time Control to Long-Term Planning – $1,424,285

*University of Vermont | Burlington, VT | Principal Investigator: Mads Almassalkhi*

This project develops a layered predictive optimization and coordination framework to coordinate the flexible resources available in the distribution grid, as well as the legacy control devices, to ease the fluctuations and variability in solar generation. Solar forecast data is leveraged to schedule the dispatchable flexible resources in a look-ahead fashion, while any mismatch due to solar forecast errors will be solved through real-time coordination of the controllable resources. New estimation methods are leveraging data from smart meters and sensors to estimate the available flexibility in the distribution system, as well as identify the real-time operating conditions, to aid in the informed decision making process. Aggregated models of the flexible resources will be leveraged in a hierarchical fashion to implement autonomous response to contingencies.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 1 |
| Set critical challenges to overcome | 5 | 5 | 1 |
| Implement a high-risk, high-impact approach | 5 | 4 | 1 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 1 |
| Advance the U.S. solar industry substantially | 5 | 4 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project will deliver a similar multi-time-scale approach to overcome challenges associated with extreme renewable integration and highly distributed resource coordination in low voltage distribution systems. The project develops fast optimization methods for distribution feeders and networks with DERMS capability for integrating locally aggregated DERs (i.e., active nodes) into small, dispatchable energy storage elements distributed throughout each feeder. The feeder's energy resources are then aggregated up to the substation where it represents a dispatchable, feeder-level equivalent battery, which is subject to economic optimization to determine optimal feeder dispatch schedules.

**Reviewer 2:** This project aligns with the SETO goal of advancing solar DER. Managing high levels of BTM solar will be critical for high penetrations.

**Reviewer 3:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 1 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 1 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 1 |
| Collaborates with sufficient stakeholders | 5 | 5 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team has completed the coupled GML-FOL-STL simulation on a 1-second resolution, which Showed the full hierarchy's ability to respond to changing market opportunities in wholesale markets by managing virtual batteries (and grid-enabled inverters) while considering constraints of the underlying 3-phase, AC feeders. The team also tested the real-time coordination hierarchy within the context IEC 68150 DER communication protocols (GOOSE, MMS) for 100 devices within the timescales necessary for effective coordination (faster than 1 sec).

**Reviewer 2:** Good coordination across disciplines. Met deliverables.

**Reviewer 3:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: This project uniquely and importantly focuses on developing commercially viable advanced distribution system operator (DSO) capabilities under future scenarios of extremely high penetrations of solar PV generation and flexible DERs. Funding the comprehensive and innovative DSO technology proposed herein will enable utilities to transition from being passive volt/VAr/loss optimizers to become empowered energy coordinators.

**Reviewer 2:** Score: 5. Comments: The tasks are aligned with the project goal.

**Reviewer 3:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project has overcome a number of technical barriers such as: â€¢ For the system-wide GML economic optimization, the project team had to developed a stochastic optimization framework for flexible demand that considers the variability in both solar PV and NYISO real-time (5-min) prices. â€¢ For the feeder-specific FOL optimization, the project team had to achieve a fast (1- minute) optimization of virtual batteries and inverters in a multi-period, 3-phase, AC feeder circuit model. â€¢ For real-time corrections and resilience, the project team had to develop a cheap sensing and stabilizing PID control scheme that senses substation currents and voltages to compute power and broadcast real-time set-point corrections for VBs to reduce the effect of unmodeled components, real-time contingencies at the VB layer, and unexpected solar PV injections. â€¢ For the STL, the project team had to characterize 100-200 active nodes (or DERs) as a so-called "virtual battery." The project team still has to solve the combined, large-scale GMLFOL-STL simulation in less than 60 seconds.

**Reviewer 2:** None identified.

**Reviewer 3:** No comment.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team is well represented.

**Reviewer 2:** I believe they have good representation from all stakeholders.

**Reviewer 3:** No comment.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The proposed technology unleashes the flexibility of flexible grid assets and, in the process, reinvents the traditional utility from a volt/VAR-focused loss-minimizer into a full-service empowered energy coordinator (i.e., a distribution system operator or DSO). This is achieved by adapting wide-area control concepts to hierarchical, multi-timescale distribution system operations that integrate > 50% energy from solar PV. This framework is broken into three layers 1) system-wide, 5-15 minute grid market layer (GML); 2) regional, 1-minute feeder operational layer (FOL); and 3) local, 1-second service transformer layer (STL), which are coordinated to enables the utility or DSO to: â€¢ Operate the entire system economically (GML); â€¢ Manage networks optimally and within limits (FOL); and â€¢ coordinate active nodes dynamically and locally (STL).

**Reviewer 2:** There are many proposals for DERMS architecture and methodology.

**Reviewer 3:** No comment.

## A Scalable Control Architecture for 100 Percent Photovoltaic Penetration with Grid Forming Inverters – $4,900,000

*University of Washington | Seattle, WA | Principal Investigator: Brian Johnson*

This project is developing two kinds of grid-forming controls: fast communication-free controls for inverters for solar-plus-storage systems, and slower controls that use a distributed communication architecture for system-wide energy management. These controls aim to be immune to communication outages and be compatible with small solar energy systems as well as the bulk power grid.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 6 | 6 | 4 |
| Implement a high-risk, high-impact approach | 6 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project will overcome the impediments to massive adoption of grid-connected PV and ensure system reliability during any PV penetration level. A power grid with a 100% penetration of PV resources requires a revolutionary redesign of the controllers while maintaining a satisfactory reliability. This project is innovative and valuable as it attempts to overcome these issues. One unique feature of this project is to use experiments to validate performance of proposed controllers on commercial inverter hardware. The experimental results can help to gain more insights on the technology proposed. The planned experiment can act as a key test bed to study complex phenomena seen in real-world systems The project will perform simulations on the realistic systems with both grid-forming and grid-following inverters so that their interactions can be better understood.

**Reviewer 2:** This project is critical to the ability to achieve a 100% inverter system. This type of research is necessary for the industry.

**Reviewer 3:** Strengths: Important topic for hitting high penetrations. Weaknesses: Documentation on approach is very sparse.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 1 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 1 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 1 |
| Collaborates with sufficient stakeholders | 5 | 4 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Since the project has not been started, the project performance is not observed.

**Reviewer 2:** Since this project is not started yet, I cannot score it in this area. I just gave a 4 for everything, since I cannot score based on performance.

**Reviewer 3:** Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project plan is composed of three phases: theoretic research, analytical model and experimental test. An execution of this project plan ensures that the project progressively reaches the ultimate project goal, i.e., to develop and validate the next generation power grid control.

**Reviewer 2:** Score: 6. Comments: The order of the tasks is logical to achieve the outcome.

**Reviewer 3:** Score: 1. Comments: Note that a score of "1" indicates that either insufficient information was provided, or that I have insufficient knowledge to provide a score on this question.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** No blind spots have been found for this project.

**Reviewer 2:** Do not rely on the myriad of definitions for grid-forming inverter that are present today. Develop a definition of what grid-forming inverter is for this project.

**Reviewer 3:** No comment.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project plans to collaborate with multiple stakeholders. To some extent, the project team can work with NERC or other regulatory bodies to seek input and feedback for the reliability requirement of future bulk power systems.

**Reviewer 2:** Be sure to engage industry widely to disseminate the knowledge that this project will bring.

**Reviewer 3:** No comment.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is a high-profile project since maintaining the stability of a PV dominant grid is a grand challenge. The project team is suggested to validate the performance of their proposed design using multiple realistic and representative grid models. To test this on a large scale, realistic test bed model or hardware experimental platform is a big plus. The reliability requirement of future bulk power systems could differ from what we have today. This can be taken into account when designing the controllers for the future power grid with a high penetration of PV resources.

**Reviewer 2:** This is a mission critical project to enable the highest penetrations of inverter resources.

**Reviewer 3:** No comment.

## A Data-Driven Multi-Timescale Predictive, Proactive, and Recovery Optimization Framework for Solar Energy Integrated Resilient Distribution Grid – $900,000

*Argonne National Laboratory | Lemont, IL | Principal Investigator: Bo Chen*

This project team is developing resiliency planning for microgrids supported by solar photovoltaics. The team is creating a pre-event, proactive energy management optimization model and solution that enables flexible load, storage resources, and distributed solar energy to be strategically prepared for dispatch in the event of a grid disturbance, like extreme weather. They will also develop a post-event, real-time operation optimization model and solution. These microgrid and solar solutions have the potential to improve grid operations and provide microgrid islanding, without power from the electric grid, for up to five days.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 3 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project report clearly addressed the methodology and main result of utilizing distributed energy resources for resilience enhancement. The project goal is defined in a logical manner. The topic closely fits SETO mission. The proposed data-driven approach is a critical challenge to overcome because it most of the traditional approaches for enhancing the grid resilience is model-based. The impacts on electric utilities, vendors and regulation agencies are clearly described. The reviewer believes that there is room for improvement: What is the advantage of the data-driven optimization method over the model-driven one for improving the grid resilience? The report is expected to clearly address this issue.

**Reviewer 2:** Goals and approach look good. It's unclear to me how much value this brings to the industry as a whole, though (this is more a comment on the concept of solar improving resiliency in general, not on this specific project).

**Reviewer 3:** The target of this project is twofold: (i) to prepare a power distribution system "to be ready" for a major natural disaster and (ii) to operate such system after such disaster, relying mostly on solar resources. This target clearly aligns with SETO mission. The potential challenges (not critical in my view) are clearly described and they make sense to me. This is a high-risk, high-impact project. Not many serious attempts to address similar problems are available in the literature. To identify a truly useful methodology to tackle this problem is a risky endeavor, but if identified, such methodology would be most useful for the power industry. I think the required DoE funding is modest for the relevance of this project. I think this project adds very significant value to existing research outside DOE-funded efforts since it is rather unique. If successful, this project will help to advance the US solar industry, and the US power industry as well.

## 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 6 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The milestone of this project is designed in a reasonable manner and achieved on time. The whole project is mainly divided to: 1) Pre-event preparation optimization mode, 2) Post-event operation and restoration optimization, and 3) Develop data interface for implementing the proposed outage management strategy. In particular, the optimization method for resilience enhancement is tested by both small-scale (123 node) and large-scale (10,000+ node) systems. The results show a satisfying resilience improvement. The lead organization, Argonne National Laboratory, closely collaborates with the project partners, such as Iowa State University, Bloomfield Utility. Each organization fully completes the share of task. The actual budget exceeds the expected budget by a small amount ($3000+). This is acceptable.

**Reviewer 2:** Performance looks good. It's good that they have multiple utilities on the team.

**Reviewer 3:** The project objectives/milestones are being achieved as expected. The benefits of the methodology proposed are being assessed in a quantitate manner (to the extent this is possible in power systems). The dissemination of the ideas via IEEE journal publications is excellent in my view. All relevant parties are represented: government (this is a National Lab project), universities (more than one) and power utilities (two municipal ones).

## 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks of this project can be summarized as: 1) Pre-event preparation optimization mode, 2) Post-event operation and restoration optimization, 3) Coordination between solar power resources and other flexible resources, and 4) Develop data interface for implementing the proposed outage management strategy. These tasks are closely aligned with the overall goal of the project which is to improve the distribution system resilience by using multiple distributed energy resources.

**Reviewer 2:** Score: 5. Comments: Yes, each task in the project adds unique and important value.

**Reviewer 3:** Score: 6. Comments: I think that all tasks of the project are properly coordinated and make sense.

## 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The reviewer thinks there are mainly two blind spots in the report. 1) There have been many successful model-based research works for enhancing the grid resilience. Thus, the PI is supposed to explain in more detail about the advantage of data-driven method over model-based method in resilience improvement. 2) The proposed data-driven method requires a large amount of measurement data. Since the measurement data may have some error, it is quite important to evaluate the robustness of the proposed method.

**Reviewer 2:** I don't know of any blind spots.

**Reviewer 3:** I don't identify significant blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project involves a national laboratory, two universities, and an electric utility company. Each organization is responsible for a share of the whole project. Therefore, no stakeholders, organizations or collaborators are missing in this project.

**Reviewer 2:** I can't think of any critical stakeholders, etc., that are missing.

**Reviewer 3:** The view of the ISO might be relevant as the coordinator of many distribution systems, and eventual helper in the post-disaster situation.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The following are three most important pieces of the reviewer's feedback. 1) The project goal and milestones are defined in a logical manner. The topic closely fits SETO mission. 2) The proposed data-driven approach to resilience improvement is a critical challenge. It has considerable impacts on multiple organizations, such as electric utility, vendors and software companies. 3) The proposed model-based method requires a large amount of measurement data. Since the measurement data may have some error, it is quite important to evaluate the robustness of the proposed method.

**Reviewer 2:** It isn't clear to me how much overall value work related to solar for distribution resiliency brings to utility customers and the solar/energy industry (this is less a comment about this particular project, and more about the concept in general).

**Reviewer 3:** 1) Please consider incorporating the coordinating view of the ISO. 2) Are the optimization algorithms developed sufficiently efficient for large-scale distribution systems? Please look carefully into this. 3) Do the actions to get ready for a natural disaster make economic sense? Which is the trade-off readiness vs. cost?

## Alternating Current and Direct Current Hybrid Distribution Grids with Solar Integration: Architecture, Stabilization, and Cost Assessment – $826,000

*Argonne National Laboratory | Lemont, IL | Principal Investigator: Dongbo Zhao*

This project analyzes the potential of hybrid alternating current and direct current distribution grids. This is a change from the alternating current-only grids currently used that require photovoltaics to be converted to direct current, although direct current could also benefit electric vehicle charging, batteries, light-emitting diode lighting, and other technologies. The concept of direct current nanogrids, microgrids, and medium-voltage distribution grids has drawn increasing attention in both academia and industry. In an effort to maximize the benefits of direct grids in terms of system cost, efficiency, and operation performance amid the challenge of reliable control under high penetration of intermittent solar energy, the team is develop controls for a hybrid grid. They are using a universal impedance-based stabilization approach, with a decentralized and adaptive impedance loop to provide direct current section and alternating current section stabilization, and add interface inverters that interlink the two subgrids.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This seems to be a relevant and valuable project.

**Reviewer 2:** This project pertains to hybrid AC/DC grids and encompasses technical and economic analyses. This is aligned with SETO mission. In my view, the critical challenge is the economic viability of such hybrid grids. The work carried out in this project might help address such major challenge. Yes, this is a high-risk high-return project. Hybrid grids are (almost) nowhere to be seen in the real world. The work of this project might help make these grids economically feasible, and thus viable in practice. The funding seems reasonable considering the objectives of the project. I think this project adds some value to existing research outside DOE-funded efforts. This is so because not many research efforts have been / are being carried out in this area. The project may help the US solar industry if the economic feasibility of hybrid AC/DC grids become clearer.

**Reviewer 3:** The project develops architecture, stabilization strategy, cost and efficiency analysis of a hybrid AC and DC distribution grid. In particular multi-port converter is developed that integrate solar and other distributed generation sources in the DC grid and also facilitates connection of other DC sub grids and conventional AC distribution grid. While the project can potentially contribute to SETO's goal of integrating solar in reliable cost-effective manner. The project only shows cost savings and increased efficiency in the presence of DC loads and at high levels of PV penetration. The project report doesn't mention any research on this subject outside of the project itself so it's hard to judge if it adds value to existing research in this area. On the other hand, there should be similar research in microgrids area as well as multi-port converters for offshore wind application that could have been leveraged here. I scored 4 in Advance the US solar industry substantially because I don't see that this project is readily applicable or scalable, I think it is certainly moves the research in this area forward but more in a longer horizon which will not have substantial short term impact on US solar industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 2 | 5 |
| Collaborates with sufficient stakeholders | 4 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** More engagement with utilities and/or inverter manufacturers would be good.

**Reviewer 2:** The project is achieving its targets as expected. I don't identify any issue on this front. Dissemination is not good: just a conference paper and the project is finishing up. Authors should disseminate their work widely, preferably via journal articles (IEEE and the like) and relevant conferences. The power industry is missing. The contribution/view of ISO would have been most beneficial to the project.

**Reviewer 3:** The milestones are clearly set, measured and all the original milestones have been achieved in time. One additional milestone was added, and with that project timeline was extended, and that milestone is being worked on right now. The project report states how the tasks are distributed between the project partners some of the tasks are worked on by several project partners but there are no details about frequency of meetings. There seems to be no external stakeholders involved and, in my opinion, this is what is missing from the project. Distribution network owners/operators or a small utility could have been excellent external stakeholder for this project. The project could have benefited from external technical advisory committee consisting of distribution grid operators and research organizations working on similar subjects.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, each task in the project adds unique and important value.

**Reviewer 2:** Score: 5. Comments: I would have paid less attention to power electronic devices and much more to AC/DC system-wide integration issues. However, I think all the tasks of the project make sense to attain the objectives pursued.

**Reviewer 3:** Score: 6. Comments: Each task in this project is unique and important to achieve the overall goal. The multi-port converter needed to be developed, then universal stabilization approach for the hybrid grid was developed and tested on several models of the hybrid distribution grid using IEEE 34 bus test system, to study costs and economic efficiency of such hybrid systems the tool that allows to evaluate costs and efficiency advantages was developed as well. All these tasks are integral part of this project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Are all DC loads the same? It seems that some of the cost and efficiency analysis results would be sensitive to the type of DC loads. Additional inverter OEM and utility input might reveal other blind spots.

**Reviewer 2:** In my view, the critical point is to show economic viability. Technical viability is (or will be) clear.

**Reviewer 3:** There is no discussion of how this concept could have been applied in the realistic distribution network, no feedback from distribution network operators/owners or utilities. I am not sure collaboration with research organizations working on similar area or research is taking place. From the project report is hard to say how the proposed technology/hybrid grid compares to other alternatives.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Utilities and additional inverter OEMs.

**Reviewer 2:** The power industry (the major user of the outcomes of the project) view is not represented in the project. The perspective of one or several ISO would have been invaluable. Such perspective is quite different than that of a software vendor, such as ABB.

**Reviewer 3:** As I mentioned above distribution network operators/owners, utilities and other research organizations working on similar issues (e.g. EPRI, NREL etc.)

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Looks like an exciting project. Additional utility and inverter OEM input would be good to make sure that things are relevant.

Reviewer 2: 1) Incorporate the view of the power industry (not just that of a software vendor), e.g., the view of utilities (they would be major users of hybrid AC/DC grids), or that of ISOs. 2) Disseminate the outcomes of the project using journal articles (IEEE and the like) and presentations in relevant conferences (e.g. those pertaining to IEEE). 3) Make sure that the outcome of the project makes economic sense, and is economically viable.

**Reviewer 3:** 1) I am not sure how scalable or readily applicable this project is. 2) It could have greatly benefited by a group of external stakeholders, mentioned above, providing feedback throughout the course or the project. 3) There is no comparison in the project with other available options.

## An Energy Internet Platform for Transactive Energy and Demand Response Applications – $1,199,687

*BEM Controls | McLean, VA | Principal Investigator: Jason Lin*

This project is developing a blockchain-enabled open architecture platform that allows commercial and industrial buildings to buy and sell excess rooftop photovoltaic energy generation and energy consumption reduction, known as negative watts or negawatts, in a secure and reliable way.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 4 |
| Set critical challenges to overcome | 6 | 6 | 4 |
| Implement a high-risk, high-impact approach | 6 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The major strength of this project is that it provides energy internet platform at multiple levels (e.g. individual building level, microgrid level, and transactional level) to seamlessly manage, optimize, and transact energy. Also, a new blockchain-like database platform (QLDB), which is developed by AWS, is applied to record the cleared transactions. Two possible weaknesses: 1) the project team may need to better explain the energy trading algorithm and how the algorithm is used to determine the market clearing prices, 2) The difference between WiseGrid and WiseMrkt is not very clear in the proposal. It seems WiseMrkt and WiseGrid have some very close functions and can be integrate as one. The project team may need to describe more details of such two things.

**Reviewer 2:** This project pursues the development of integrated Demand Side Management (DSM) tools at the user (WiseMrkt), building (WiseBldg) and distribution levels (WiseGrid). This is a relevant endeavor that aligns well with SETO mission. The critical challenges to overcome (system complexity and user adoption) are well established. I think this is a high-risk high-impact endeavor since quite a few similar attempts have failed. DOE funding seems appropriate to me (on the modest side). If successful (many similar attempts have failed), this project will add significant value to existing research outside DOE-funded efforts. If successful, the project may advance the US solar industry moderately.

**Reviewer 3:** Strengths - seems to be building on existing systems. Weaknesses - unclear how much total value this can/will bring to the industry.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 2 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** A concrete project schedule is provided in the report, with milestones given for evaluating the performance of the proposed energy Internet platform. The project goal and the methods applied are clearly explained. Also, the project partners involve experts from a variety of areas (e.g. university and utility companies), whose expertise will certainly contribute to the successful implementation of the project. Each activity has its corresponding professionals to conduct which ensures the effectiveness and efficiency of process.

**Reviewer 2:** The project seems to be progressing as planned. Milestones as being achieved as expected. No dissemination effort is reported, which is surprising. All relevant stockholders seem present: software developer and leader, university and power utility.

**Reviewer 3:** It's still early in the project, but looks like they are off to a good start.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: There are four main tasks in this project. Each task aims to either extend the previous work or develop algorithms/functionalities that are previously not available. The project partners are working actively on solving these challenges. Therefore, the tasks added some unique and important values to the project, and together will contribute to achieving the goal of the project.

**Reviewer 2:** Score: 6. Comments: All tasks being/to be carried out seem relevant. They are carefully coordinated to achieve the objectives targeted.

**Reviewer 3:** Score: 5. Comments: Yes, each task in the project adds unique and important value.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** One possible blind spot in the project is that the project team does not mention what the impact of communication delay on the performance of the proposed energy internet platform.

**Reviewer 2:** Dissemination is missing.

**Reviewer 3:** This seems like a very broad project and it could be hard to make meaningful progress in so many directions.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team has involved experts from a variety of fields. It could be even better to include researchers or industry partners with communication engineering background to enable the feasibility of the proposed platform for real-world applications.

**Reviewer 2:** I think most relevant stakeholders are present: software developer, university and power utility. Incorporating the view of a Distribution System Operator (DSO) would be valuable.

**Reviewer 3:** Engagement with national lab(s) would be good to see.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The idea of integrating energy internet platform at multiple levels (e.g. individual building level, microgrid level, and transactional level) to seamlessly manage, optimize, and transact energy; 2) Using a blockchain-like database platform (QLDB) to record the cleared transactions; 3) The performance test on Bronzeville microgrid with more than 1100 participants remains a significant challenge in Phase II of the work, but the results would provide guidance for future studies.

**Reviewer 2:** 1) The cost of electricity per day and person in a medium-class household of four is about $1 to $2. That is, less than the cost of a cup of coffee. Which are the incentives (economic or otherwise) for consumers to engage in DSM activities using your software? 2) Disseminate your outcomes within the power industry and within the relevant power system research community. 3) Regarding the actual implementation of the software begin developed, engage the view of the regulator (Public Utility Commission).

**Reviewer 3:** Good to see they are building on existing systems.

## Advancing the Weather Research and Forecasting Solar Model to Improve Solar Irradiance Forecast in Cloudy Environments – $1,620,000

*Brookhaven National Laboratory | Upton, NY | Principal Investigator: Yangang Liu*

This project is developing solar-specific improvements to the weather research and forecasting model for improving prediction of solar irradiance in cloudy environments. Specific areas of improvements are cloud microphysics, radiative transfer, and innovative analysis packages.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The major strength of the project is that it focuses on studying the important cloud properties that are closely related to solar irradiance. A novel DNI calculation method has been proposed in the project and cloud microphysics parameterization is being studied for contributing to a more accurate solar irradiance forecast. One possible weakness of the project is that the project mainly focuses on applying physics-based methods. Some data-driven methods can also be applied as a supplement to the physics-based methods.

**Reviewer 2:** The project aims at improving solar irradiation forecasting under cloudy conditions. This is an important endeavor aligned with the interest of the research community. The project team seems well integrated and working in a careful and coordinated manner. Challenges encountered are clearly identified, and the way they have been overcome is clearly explained. I don't see here a high-risk high-return endeavor, but an incremental improvement of important tools. The budget seems appropriate to the effort required. It is surprising the fact that the power industry is not represented in the project team.

**Reviewer 3:** The project aims to improve the state of the art WRF-Solar model for solar irradiance forecasting in cloudy conditions on the day ahead time and intra-day horizon. Improving solar forecast removes uncertainty associated with solar power production, meaning less reserves will be procured to cover for this uncertainty and less costs are associated with solar integration. With that the project aligns well with SETO mission and goals. One of the strong sides of this project in my opinion compared to others reviewed is that in this project the team conducted simulations with other commonly used cloud microphysics schemes and quantified the model differences. I think this approach benefits both this project and informs the existing research outside DOE funded efforts. I scored 5 on Andvances the US solar industry substantially because this is project focuses on the cloud microphysics model which in turn improves solar irradiance forecasting which then in turn needs to be converted into solar power forecast with that this just a step towards improving solar industry and other steps need to be mat to make further advances.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 2 | 5 |
| Collaborates with sufficient stakeholders | 5 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has demonstrated trackable achievements till the current stage. Several novel physics-based models for studying the cloud property have been applied and publishable records are shown in the report. It is suggested that a clearer distribution of tasks among the project partners be provided, so that each partner can contribute based on their expertise. In addition, it is also suggested some quantitative metric measurements should be defined for evaluating the accuracy of the physics-based model.

**Reviewer 2:** No dissemination efforts are reported. It would be most appropriate that the findings of the project are reported in worldwide relevant journals. These findings should also be reported in conferences and workshops. Incorporating the view an input of the power industry is most needed. The power industry is the primary user of the tool being improved.

**Reviewer 3:** The project is reaching its milestones within reasonable time frames and budget. Each project partner has its role in the project clearly defined however from the project description it is not clear how frequently project partners meet/ interact. The project has tests other cloud micro physics schemes and quantified the model differences. The results of the project have been presented at a number of conferences and in peer reviewed publications. It is not clear if these interactions resulted in any feedback or collaboration with research organizations working on similar projects.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: There are four tasks listed in this report, including improving cloud microphysics parameterization, improving radiative transfer, model analysis and model evaluation. Each task is an essential step in completing the goal of improving the WRF solar irradiance forecast accuracy under the cloudy conditions. The successful completion of the tasks will provide a more accurate modeling of the cloud properties and an in-depth understanding of the radiation-cloud relations.

**Reviewer 2:** Score: 6. Comments: Tasks are clearly described. Their interrelations are carefully described as well. I believe that all tasks make sense to achieve the goals of the project.

**Reviewer 3:** Score: 6. Comments: The tasks in this project are well defined and each task adds unique and important value to achieving overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** One possible blind spot in the project is that it mainly relies on physics-based model for improving the solar irradiance forecast. It is suggested that some data-driven methods can also be leveraged to make up for the deficiencies of the model-based methods. Since some physical phenomena such as cloud microphysics can be difficult to parameterize due to uncertainties or other hidden information. The data-driven methods can play a role under such circumstances.

**Reviewer 2:** The team should widely disseminate their findings, using relevant well-known journal publications.

**Reviewer 3:** This is not my area of expertise so I couldn't come up with any.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The main project participants are from research institutes and universities. It could be better to include research institutes from atmospheric area or meteorological area to provide more insights into the weather and climate impact on the solar irradiance forecast.

**Reviewer 2:** The power industry is clearly missing, particularly ISOs, which are major users of the tool being improved.

**Reviewer 3:** The project team seems to have tested other available models and documented the findings however as per project report there's no feedback or collaboration with developers of those models to, possibly, achieve any further improvements. Other research organizations working on such models would be recommended stakeholders/collaborators in this case.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The project focuses on the detailed modeling of the cloud properties related to the solar irradiance, which could provide a better understanding of the radiance-cloud relationship and to further contribute to improving the solar irradiance forecast accuracy; 2) The computational complexity remains a significant challenge for both physics-based and data-driven model. Model optimization should be an interesting future direction; 3) Standard baseline cases as well as concrete quantitative metrics should be provided as a forecast performance evaluation criterion.

Reviewer 2: 1) Incorporate the view of the power industry 2) Focus of validating the improvement of the tool. Quantify error improvements contrasting the tool with and without improvements. Clearly report this. 3) Disseminating your findings in relevant fora.

**Reviewer 3:** 1) I think this project is well defined and on track. The project team set very detailed milestones and metrics. 2) It is hard to understand from the project report of how much improvement is expected and possibly some quantification of if this improvement is significant or now, may be how it translates into solar power forecast improvement (as something more tangible) 3) The project could probably benefit from collaboration with other research organizations working on these types of models.

## Advanced Peer to Peer Transactive Energy Platform with Predictive Optimization – $1,199,026

*ecoLong | Albany, NY | Principal Investigator: Nancy Min*

The rise in distributed energy resources requires the development of new technologies that enable prosumers—consumers that produce their own energy—to transact directly with other energy users to help meet their energy needs. This project uses new technology to allow consumers, solar owners, and utilities to directly transact with each other in order to maximize economic and technological benefits.

### 1. The project’s goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic’s goals and support SETO’s mission | 5 | 3 | 4 |
| Set critical challenges to overcome | 5 | 3 | 4 |
| Implement a high-risk, high-impact approach | 5 | 3 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 1 | 4 |
| Advance the U.S. solar industry substantially | 5 | 1 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The major strength of the project is to develop a Volttron-Fabric platform to increase the reliability of the communication when there is limited network resource. The project also focuses on using blockchain-based technology to turn energy participants from passive to proactive prosumers. The weakness of this project is that there is no discussion on how cooperative game theory can be used to determine the electricity pricing. Also, the project team may need to better explain what machine learning/artificial intelligence methods would be used for solar forecasting and intrusion detection. It would be better to show the feasibility of the P2P electricity transaction. In addition, in the poster, the project team may need to consider whether the electricity market transformation from ‘Today’ to ’Tomorrow’ without transmission network makes sense or not.

**Reviewer 2:** The description in the summary sheet and the poster are very general and vague and provides no indication or justification as to how the block chain base approach contributes to enhancing the resilience and reliability of the distribution system. Both the summary report and the poster are primarily full of popular technical jargon without clearly stating how the proposed approach aid in achieving the stated goals.

**Reviewer 3:** Strengths - looks like the project has strong goals. Weaknesses - unclear how much total value this can/will bring to the industry.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 2 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 1 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 1 | 5 |
| Collaborates with sufficient stakeholders | 6 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team brought together multiple stakeholders to collect suggestions on the potentials of blockchain and transactive energy for power system applications. Also, the tasks are fairly distributed among the multiple partners such that each partner can contribute based on their expertise. However, it is suggested that the quantitative metric measurement should be better defined. Otherwise, it would be difficult to evaluate the performance of the proposed peer-to-peer transactive energy platform.

**Reviewer 2:** The project started in September of 2019 and is in its second quarter of performance. One does not however see quarterly milestones. There is a Go/No-Go test in September of 2020 however, no metrics that are supposed to be met are provided in the material supplied to the peer review team.

**Reviewer 3:** It's still early in the project, but looks like they are off to a good start.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: There are five main tasks in this project. Each task considers some specific issues and is closely related to other tasks. Some of them are challenging, such as developing a scalable and interoperable platform of coupled Fabric and Volttron with optimized performance. However, the reviewer believes that the successful completion of the tasks will increase the reliability and flexibility of future power grids.

**Reviewer 2:** Score: 1. Comments: There is not enough information available to determine this.

**Reviewer 3:** Score: 5. Comments: Yes, each task in the project adds unique and important value.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** In the project report, significant effort has been devoted on explaining the importance of developing a Volttron-Fabric platform to enable transactive communication and controls. However, it is recommended that an effective energy management and pricing strategy is also important to realize the goal of delivering reliable and affordable electricity to customers.

**Reviewer 2:** Need to specifically identify how grid resiliency and reliability will be improved using the proposed methods. This has to be clearly outlined. What is involved in terms of tools and analytical basis in the interoperable and scalable platform? Without some specifics this provides no meaningful information. In the picture of the platform shown nothing is legible. What function does the block chain perform?

**Reviewer 3:** This seems like a very broad project and it could be hard to make meaningful progress in so many directions.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** It is suggested that the experts on blockchain and electric vehicles could be involved to provide insights and evaluate the performance/feasibility of the proposed peer-to-peer platform.

**Reviewer 2:** There are no utility partners involved in this project who can provide specific system related guidance to this project.

**Reviewer 3:** It would be good to see a utility or other grid operator on the project team, but it is good that utilities and ISOs were included in the February workshop.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The idea of using Fabric-Volttron platform to improve the communication reliability and ensure the integrity of transactive information and controls. 2) Using blockchain technology to improve the energy efficiency and promote the integration of DERs to the grid. 3) A quantitative metric should be provided to evaluate the performance of the proposed platform.

**Reviewer 2:** This project has been supported for about 2 quarters. One does not see any quarterly milestones and any mention of specific development of the proposed tool. Without knowing this it is not possible to make a judgement. The preparation for a peer review is quite incomplete, either in terms of the summary report or the poster. Providing some technical details of what is contained in the tool being development is important in order to make a knowledgeable review.

**Reviewer 3:** Good to see that they are building on/interacting with existing platforms like VOLTTRON.

## Probabilistic Forecasts and Operational Tools to Improve Solar Integration – $1,799,826

*Electric Power Research Institute | Knoxville, TN | Principal Investigator: Aidan Tuohy*

This project is developing improved probabilistic solar and net load forecasts for three separate utility case studies, each with different operating procedures. The team is using advanced tools to research and develop methods for each utility to manage uncertainty in a reliable and economic manner in daily operations. In addition, they hope to validate these methods by integrating forecasts and decision making functions into a scheduling management platform to verify the use of probabilistic forecasts to reduce integration costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: a probability-based forecast improvement strategy is developed and integrated into a platform, improving operating strategies, and thus reducing the costs of solar uncertainty management in power systems. Weakness: it would be more convincing to compare the proposed method to existing forecast methods and quantify the improvement. Also, how the improved prediction enables better decisions should be justified, and the cost reduction needs to be calculated.

**Reviewer 2:** This is an important component for power system operation for determining reserve requirement based on a probabilistic solar forecast. The project, however, lacks one serious component. When PV is integrated in the grid and when the reserve requirement is determined purely based on the forecast there is no guarantee that the grid will not have any grid constraints which will prevent the reserve from being delivered where needed. The team has appeared to make sufficient progress.

**Reviewer 3:** The project develops probabilistic solar power forecasts, which capture uncertainty of solar power output and explores use of these forecasts in utility operations. Additionally, the project will develop a platform that enables new power system operating strategies using probabilistic power forecasts. Potential impacts from these project that align well with SETO goals are to reduce costs of managing solar power production uncertainty and improve solar power integration into power system. Additional reduction in costs can be achieved by reducing amount of reserves that utility carries if reserve requirement is based on probabilistic forecasts rather than some worst-case scenario that tries to cover all possible outcomes. Critical challenges to overcome in this project are well defined such as obtaining necessary data from the utilities and building production cost models that are detailed and representative enough. The project is high impact not necessarily high risk as EPRI is pulling together some methods and tools they've previously used on other projects to help achieve the objectives of this one. Probabilistic solar forecasts are not currently being widely used in industry and reserve requirements to cover forecast uncertainty are often time deterministic, so this project progresses research in this area even outside of DOE funding. The strength of the project is in improving probabilistic solar forecasting, looking for use cases of such forecasts as well as collaboration with operators in understanding of how these forecasts can be used. One potential area to focus on is transferability of the obtained results to other utilities and ISO areas, but EPRI seems to be exploring these avenues collaborating with other utilities/ISOs outside of this project team (SPP, California ISO). Probabilistic solar forecasts are only part of the solar integration puzzle that's why I graded a 5 not 6.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 3 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Multiple stakeholders work together to develop operational tools. The project is well-organized, and essential data have been collected. In milestone status, it would be more clear to summarize the milestone in a table attached with metric definition, progress, and due/complete date.

Reviewer 2: The project does not appear to have specific quantitative metric to judge the efficacy of the probabilistic forecast and some evaluation of how well the reserve requirement is sufficient. This needs to be included.

**Reviewer 3:** The spending on project to date seems relatively low. However, according to the project report with models built and forecast improvements identified, spending in budget period 2 is picking up significantly, and expected to be close or at plan by end of BP2. Project focuses on ensuring that the developed methods can be transferred to other regions and while it has 3 utility partners already (Hawaii Electric, Southern Company and Duke Carolinas region) EPRI team has collaborated with other utilities and ISOs discussing primarily discussing dynamic reserve determination methods using probabilistic solar forecasts developed in this project. They have disseminated the results of the project to wider EPRI membership and presented at ESIG and IEEE events. However, I think collaboration with a very similar DOE project Coordinated Ramping Product and Regulation Reserve Procurements In Caiso And Miso Using Multi-Scale Probabilistic Solar Power Forecasts (DE-EE0008215) is missing. Both projects are developing probabilistic solar forecasts to be used by utilities and system operators, both are identifying reserve requirement as a primary use for probabilistic the forecasts, apart from visualization tools being developed in the other project there are no differences between the scopes for these two projects, so I think both could benefit from better collaboration and identification of differences and similarities and maybe utilizing each other experiences?

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project is divided into three main tasks. First, to improve probabilistic solar forecasting. Next, to test the potential use of probabilistic information. Finally, to develop a scheduling management platform. All three tasks are closely related to the final platform.

**Reviewer 2:** Score: 5. Comments: The tasks in the project are well thought out and align with the goals and objectives of the project. One aspect which is important and missing is the determination of the deliverability of the determined reserve. If a reserve is available and cannot be delivered due to grid constraints, then it is of no use.

**Reviewer 3:** Score: 6. Comments: The main value of this project is in development of improved probabilistic solar forecasts. However probabilistic forecasts are not widely used in operations and it's important to supply those along with the "manual" of how those should be used to gauge the highest benefit these is where two other tasks of the project have an important value, because first task 2 is used to investigate and test potential use cases for probabilistic information and then task 3 demonstrates the benefits of these approaches compared to business as usual during actual operation. During this period operators also have an opportunity to familiarize themselves with probabilistic forecasts.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Data preprocessing needs to be emphasized to improve the forecast accuracy. The machine learning algorithms needs to be more specific for the type of forecasting and scheduling problem. How the trained models can be migrated to various operating conditions or systems needs investigation.

**Reviewer 2:** Just determining reserve requirements and the bounds of them may be insufficient. It is also important to determine if there are no grid constraints and that the reserve can be delivered where required. Some quantitative measure of the accuracy of the reserve determined needs to be included.

**Reviewer 3:** It's not necessarily a "blind" spot but rather a weakness of this project that to show the benefit of probabilistic forecasting a detailed model of actual utility operation needs to be modeled, and benchmarked. This is hard, time consuming task. Since there are 3 utility partners in the project, I wonder if any overarching conclusions can be made from the project results that hold for all three utilities regardless of their differences in characteristics, it could also be useful to point out results that are not constant between 3 utilities and explain why. This could help future users of probabilistic solar forecasts to potentially skip time consuming and completed testing stage and start using probabilistic solar forecasting right away based on the generic findings from this project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** More involvement of data scientist and machine learning scientists are encouraged.

**Reviewer 2:** The team is well balanced.

**Reviewer 3:** I think this project has well covered set of relevant stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) There are lots of existing projects on probabilistic forecasting. A white paper on reviewing existing methods are helpful. The effectiveness of the proposed method needs to be compared with the state-of-the-art probabilistic methods. 2) The technology pathway is solid for the project to be successful. The data processing and machine learning approaches need to be more specific. 3) The final deliverable (the platform) has the potential to improve the grid operation in utilities with high renewables. Part of the project is recommended to be released opensource for broader impact if possible.

**Reviewer 2:** A quantitative measure for the accuracy of the reserve requirement should be developed. The reserve requirement determination should include evaluation of the grid constraints in delivering the determined reserve to where it is needed. The proposed method should be compared with other methods of determining reserve requirements. There are other ARPA-E projects which have used stochastic wind and PV production forecast scenarios together with look ahead SSCED and SSCUC together with grid constraints which have been shown to work well in large systems. Need to follow other work in this area.

**Reviewer 3:** 1) The project improves probabilistic solar forecasting and explores it use cases and with that, while being innovative, is very practical and directly applicable in utility operation. 2) The project is building upon other relevant experiences and tools that project team already have developed in previous projects this brings additional value to this project. 3) I would recommend the project team tries to draw broader conclusions (assuming that it's possible), that could be used someone universally and let the future users skip testing/benefit analysis phase before start using probabilistic forecast in operations. Again, assuming that such broader conclusions are possible.

## Enable Behind-the-Meter Distributed Energy Resource Provided Grid Services that Maximize Customer and Grid Benefits – $3,000,000

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Aminul Huque*

This project team is researching, developing, and demonstrating collected data and controls to enable behind-the-meter solar photovoltaics and other distributed energy resources. The goal is to cost-effectively provide grid services in both distribution and bulk power systems while enhancing system reliability. The team is conducting advanced transmission, distribution, and distributed energy resource simulations to validate the merit and performance of distributed energy resource-provided services, and better estimate the potential need for network upgrades. The team will lead an industry collaboration to develop behind-the-meter distributed energy resource grid services guidelines to expand the provision of grid services and address existing regulatory barriers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project utilizes the BTM PV systems for grid services in both bulk power systems and distribution systems. The project goal is clearly defined, including the device-level control algorithm, the coordination between TSO and DSO, and techno-economic metrics. The goal aligns with the SETO mission and the requirement of U.S. industrial application. The project is split into several 10 reasonable milestones, such as algorithm development, hardware-in-loop test and field demonstration. Besides the strengths of this project, the reviewer has some concerns. First, the "grid service" is a broad concept and not clearly defined in this report. Second, it is not practical to achieve the best performance in both technical and economic aspect. The report should focus on one aspect.

**Reviewer 2:** The project will only start on April 1, 2020. At the time of this review what one see is the brief peer review summary and the poster. The goals and objectives of the project are well aligned with the needs of the industry and community. The project will examine the impact of behind the meter DERs on both the distribution and bulk transmission systems. The objectives of the project are mentioned in broad general terms without providing any specifics, e.g. it is stated that NYPA would perform the HIL. What does this involve? What aspect of the problem will be examined through this HIL analysis? Two major electric utilities are involved in the project and do represent the stakeholders well. In terms of technical content it would have helped if a brief description of the co-simulation between the T&D systems was provided since this is a critical component of the project in achieving the set goals.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 1 |
| Disseminates results frequently and actively engages partners | 4 | 2 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project is split into several 10 reasonable milestones, such as algorithm development, hardware-in-loop test and field demonstration. The report also mentioned collaborating with sufficient partners in the project study to better demonstrate the industrial implementation. The reviewer's concern is that the measures of the impact is not clearly discussed. For example, how to evaluate the performance of the grid service performance by using BTM PV?

**Reviewer 2:** At the time of the review conducted by the peer reviewer this project had not started. It only starts on April 1, 2020. The project does tackle and interesting problem. The team is well balanced and also two entities associated with the grid at the edge. Given the brief description in the peer review document, making any significant judgement about the project other than saying that team is well balanced and that the technical objectives are well thought out, it is unrealistic to make any other inference about the project in terms of a peer review. Additionally, the summary does not make any mention of the qualitative metrics that will be used to judge the success of the project tasks.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The subtasks are closely related to the overall goal of the project.

**Reviewer 2:** Score: 5. Comments: Yes the tasks are well aligned with the overall goals of the project. They include both the distribution and transmission systems. One aspect that would need to be clarified is that the BTM DERS, are located in secondary distribution circuit. How will the team obtain information regarding the physical layout and electrical properties of this portion of the system and will only the AMI be used to obtain measurements and is this information sufficient to perform the control envisioned? This needed to be clarified in at least the poster.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The PI of this project has several issues to clarify once the project starts: 1) The scope of "grid service" is not clearly defined. Since "grid service" includes a wide variety of grid-level control and optimization methods, it is impossible to implement all grid service functions equally. Instead, this project should focus on part of PV-based grid services that have not been fully studied. 2) The title of this project includes "maximizing customer and grid benefits". However, the PI did not provide an idea on how to coordinate the benefits of power grid and customers. In practice, achieving better stability and reliability might degrade the customers' economic benefits or comfort level. This problem should be fully considered in a comprehensive project.

**Reviewer 2:** The fact that BTM DERs exist in the secondary distribution circuit and the sampling rate of the AMIs associated with these DERs is limited, the team needs to carefully examine what kind of measurements would be utilized to trigger the controls being envisioned.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The electric utility company and ISO are missing in the project. The report claims doing field demonstration of the BTM PV control algorithms. Hence, the great support of utility company is highly needed. Additionally, the project team may need ISO's data when studying the coordinated control between TSO and DSO.

**Reviewer 2:** The project could add a DMS vendor to provide more input about the distribution level controls.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The three most important pieces of feedback are: 1) The goal aligns with the SETO mission and the requirement of U.S. industrial application. The project is split into several 10 reasonable milestones. 2) The "grid service" is a broad concept and not clearly defined in this report. This project should clarify which grid services by BTM PV have not been fully studied year. Then, the impact and contribution of this project will be highlighted. 3) The title of this project includes "maximizing customer and grid benefits." However, the PI did not provide an idea on how to coordinate the benefits of power grid and customers.

**Reviewer 2:** At this stage in the review, the project has not yet started so answering this question is not possible.

## Coordinated Ramping Product and Regulation Reserve Procurements in California Independent System Operator and Midcontinent Independent System Operator Using Multi-Scale Probabilistic Solar Power Forecasts – $1,108,203

*Johns Hopkins University | Baltimore, MD | Principal Investigator: Ben Hobbs*

This project advances the state-of-the-art in solar forecasting technologies by developing short-term and day-ahead probabilistic solar power prediction capabilities. The proposed technology will be based on the big-data-driven, transformative IBM Watt-Sun platform, which will be driven by parallel computation-based scalable and fast data curation technology and multi-expert machine learning based model blending. The integration of validated probabilistic solar forecasts into the scheduling operations of both the Midcontinent and California Independent System Operators will be tested, via efficient and dynamic procurement of ramp product and regulation. Integration of advanced visualization of ramping events and associated alerts into their energy management systems and control room operations will also be researched and validated.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This seems to be a relevant and valuable project.

**Reviewer 2:** This work will help advance SETO goals of integrating hundreds of gigawatts (GW) of solar economically and reliably into the power system. Critical challenges are well defined in the project for each of the four "work packages" (forecasting, reserve requirements, economic benefits and visualization) report and possible solutions going forward identified. Probabilistic solar forecasts are not currently being widely used in industry and reserve requirements to cover forecast uncertainty are often time deterministic, so this project progresses research in this area even outside of DOE funding. The strength of the project is in improving probabilistic solar forecasting, proposing use cases of such forecasts such as determination of reserve requirements and visualization for system operators, as well as collaboration with two large system operators (CAL-ISO and MISO) in understanding of how these forecasts and tools can be used and further improved. Probabilistic solar forecasts are only part of the solar integration puzzle that's why I graded the last criteria as a 5 not 6. Project report also underlines that to benefit from the developed probabilistic forecasts fully similar level forecasts need to be developed for wind and solar.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 |
| Collaborates with sufficient stakeholders | 3 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Performance looks good. The fact that an NDA was only recently signed with CAISO to get data, and has not been put in place with MISO, is a little concerning.

**Reviewer 2:** The project report presents a detailed table of milestones and measures of impact, the project is on budget and on time according to the project report. I was particularly impressed with tight collaboration with system operators and frequent visits and discussions to gain understanding and feedback on operator needs and possible use of probabilistic forecasts and visualization tool. Based on the project report the results are being disseminated at the conferences and through scientific papers. However, I think collaboration with a very similar DOE project Probabilistic Forecasts and Operational Tools To Improve Solar Integration (DE-EE0008601) is missing. Both projects are developing probabilistic solar forecasts to be used by utilities ans system operators, both are identifying reserve requirement as a primary use for probabilistic the forecasts, apart from visualization tools being developed in this project there are no differences between the scopes for these two projects, so I think both could benefit from better collaboration and identification of differences and similarities and maybe utilizing each other experiences?

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Yes, each task in the project adds unique and important value.

**Reviewer 2:** Score: 5. Comments: The project has three parallel flows rather than tasks that follow one another: development of probabilistic solar forecasts, evaluation of economic benefits of these forecasts and development of the visualization tool for a system operator that is based on the probabilistic forecasts. Each of the tasks is unique and important for this project and leads to the achievement of the overall project goal. One flow/task that I think is missing, at least based on the project report, is evaluation of sufficiency of the procured reserves based on the probabilistic forecasts, i.e. for an extensive period of time test if the reserves procured as proposed in this project are sufficient or excessive or insufficient, and what are the underlying reasons, can anything be improved? This task is there in DE-EE0008601 but I couldn't see it here, maybe it's just not in the project report.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It seems possible that some of the improvement seen over CAISO's calendar-based ramp requirements methods are just due to factoring in general solar conditions (e.g., is it a "high solar day" or a "low solar day"), not necessarily probabilistic components.

**Reviewer 2:** As I mentioned above one blind spot, at least based on the project report, is evaluation of sufficiency of the procured reserves based on the probabilistic forecasts, i.e. for an extensive period of time test if the reserves procured as proposed in this project are sufficient or excessive or insufficient, and what are the underlying reasons, can anything be improved? This task is there in DE-EE0008601 but I couldn't see it here, maybe it's just not in the project report. Related issue is the project takes existing reserve products that the system operator has today as an input. These products were developed based on the knowledge and tools that the system operators (in this case CASIO and MISO) had at the time. What if with the tools that are being developed in this project these products are actually not the right ones and need to be redesigned and additional savings can be made that way?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I can't think of any critical stakeholders, etc., that are missing.

**Reviewer 2:** Collaboration with other researchers working on the same subject I think is missing. DE-EE0008601 is only one of the examples, I am sure there are other research organizations working on the probabilistic wind and solar forecasts and this project could benefit from e.g. comparison in terms of forecast accuracy, use cases for the forecasts etc.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This looks like valuable work.

**Reviewer 2:** 1) Testing reserve requirements based on probabilistic solar forecasts for sufficiency based on real time operation and possibly recommending improvement to existing products could be included as a part of this project.
2) Collaboration with other similar DOE projects and other research organization could be beneficial. 3) This project involves close collaboration with ISOs, the project team is also looking for ways to make the outcomes of the project configurable for other entities that are not currently participating in the project, these way the project will continue to provide benefit when it's over. I was hard to understand from the project report how is the project team is going to make the results available to other potential users and what are the ways for them to start using these tools?

## A Machine Learning Approach to Predicting Missing Cloud Properties in the National Solar Radiation Database – $250,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Grant Buster*

This project is building a data pipeline to facilitate the development of machine learning models. These models will then be used to improve the identification of cloud type and density as part of the input to the National Solar Radiation Database. The team is training, testing, and validating different machine learning approaches to determine which performs best and then integrating a finally selected model into the database workflow.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 6 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The major strength of the project is that it focuses on a very fundamental yet critical problem, improving the quality of the input data for solar irradiance forecast, more specifically, making up for the missing cloud property data. The data preprocessing is a very important step in the implementation of almost all machine learning methods, and this project will be working on this very specific aspect. For weakness of the project, a clear definition of missing cloud properties that are mostly related to solar irradiance forecast should be provided. Since not all cloud properties are related to solar irradiance, the project can focus more on the related aspects to save efforts in data preprocessing.

**Reviewer 2:** This is a newly awarded project which when the review report was submitted had not yet started. The project is an interesting project to include information regarding cloud cover in the National Solar Radiation Database using machine learning. Machine learning is a vast topic and this aspect is addressed in a very cursory manner and issues related to machine learning techniques and inputs for training are addressed in very broad generalities without any specifics. This would have helped to better understand the specifics of the approaches will be considered since this is the key component in improving the National Solar Resource Database. Some details of how the project would be adjusted if some of the machine learning techniques do not perform well enough to meet the set 70% improvement target.

**Reviewer 3:** The project has just started with the goal to improve accuracy of cloud property inputs that are used for solar surface irradiance in National Solar Radiation Database. The data base is widely used by developers, research organizations etc. and improving irradiance accuracy will benefit the entire user community. More accurate data will allow better evaluation of future project performance and financing and with that will promote further development of cost-effective solar power. Critical challenges of this project are the ones that are characteristic to any big data related project is data quality and volume of data. Another challenge that is also higher risk is ability to find machine learning model that make best use of available data and that are suitable and effective to model cloud cover property with desired accuracy.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 5 | 1 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** A concrete project schedule is provided in the report, with quantitative measurements given for evaluating the performance of the applied method. The project partners involve research scientists from a variety of areas including machine learning, data engineering, atmospheric remote sensing, etc., whose expertise will certainly contribute to the successful implementation of the project.

**Reviewer 2:** The project has not yet started so not possible to make this assessment.

**Reviewer 3:** Project milestones are set and metrics to measure them defined. The project is conducted solely by NREL so no collaboration with other partners is exacted however there could be more collaboration potentially with other researchers working with the similar model outlined in the project report. Apart from publishing the resulting model as an open source there seem to be no collaboration with external stakeholders. May be the project could benefit from more interaction with internal stakeholders such as other research organizations working in a similar field of research as well as broader dissemination of the intermediate findings in peer reviewed paper publications and conferences.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: There are five main tasks listed in the report. Each task is closely related to the project objective and is an essential step in the conventional machine learning implementation process. The tasks focus on solving the critical challenges related to the project, such as data management at a large scale, machine learning model design and validation. All tasks are closely related to each other and together will contribute to achieving the goal of the project.

**Reviewer 2:** Score: 4. Comments: The proposed tasks are well laid out except for the machine learning task which is key to the project. No specific details are provide and not alternate approaches are provided if a considered approach does not pan out.

**Reviewer 3:** Score: 6. Comments: Each task outlined in this project is unique and necessary for project completion: the project consists of 3 main phases: data preparation and planning, model experimentation and model finalization and integration.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** In the project schedule, it is mentioned that one measurement of the project performance is to improve GHI MAE. Another important feature of solar irradiance is DNI (direct normal irradiance). There should also be some measurements on the forecast accuracy of DNI.

**Reviewer 2:** The point made earlier about alternate machine learning approaches should be carefully considered.

**Reviewer 3:** Apart from lack of collaborating/discussion with other research organizations applying machine learning methods in cloud property modelling I don't see any other blind spots for this project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the success?**

**Reviewer 1:** The project has already involved experts from a variety of fields including machine learning, data science and atmospheric studies. It is suggested that industry partners who work directly with big data or forecast could be involved to provide some standard commercial references for evaluating the forecast performance.

**Reviewer 2:** There are no other participating organizations.

**Reviewer 3:** Research organizations that are conducting similar type of research or developing similar models.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) More fundamental aspects of applying machine learning methods, such as data collection and data analysis, should be given more attention, in order to build a solid foundation for the successful implementation of machine learning; 2) Comprehensive quantitative metrics for measuring the performance of the forecast model should be provided; 3) Although this project focuses on a simple aspect in solar irradiance forecast by predicting the missing cloud data, the impact can be substantial since a complete solar source data can contribute to many other researches for fully developing the value of solar energy.

**Reviewer 2:** Some amount of alternate risk measures should be built into the project.

**Reviewer 3:** 1) I think this is very useful how impact low cost project. 2) The goals of the project, milestones and metrics are clearly defined. 3) I think, the project could benefit from wider dissemination of intermediate results inviting feedback from research organizations working on similar problems.

## Foundational Open Source Solar System Modeling – $1,800,00

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Janine Freeman*

This project strives to improve the accuracy and usability of the System Advisor Model as a reliable tool for techno-economic modeling of photovoltaic systems. It also aims to generate a well-documented source code that is available through open-source licensing to the general public and to create an active developer community that can contribute to the evolution of this application.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 5 | 3 | 5 |
| Implement a high-risk, high-impact approach | 4 | 2 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: Built on a mature solution (SAM), this project adds the Python wrapper for modeling the performance and financing of PV models. This project is unique in this category that combines modeling and financial analysis. Weakness: This limited number of examples (3 in total, as of the review time) included in the project is a major weakness. The documentation is also limited. Without examples, tutorials and good documentation, it's difficult to expect the user base to grow. The pysam project also included all source code instead of linking the compiled library dynamically. Having multiple copies of SAM source code makes maintenance difficult.

**Reviewer 2:** The project enhances and maintains an useful tool used by many utilities to examine both the performance and financing of solar systems. The project pursues four avenues in parallel: software maintenance and technical support of the SAM and PVWatts platforms; platform and PV model improvements and stakeholder engagement activities, and open source activities to foster the continued creation of a vibrant open-source community around the SAM and PVWatts tools. In retrospective, this is more of a tools development, maintenance and user support activity to promote solar deployment.

**Reviewer 3:** Based on my understanding from project report the project develops further already existing models for performance and financing of solar systems adding new features and capabilities to the models, making the models open source and facilitating community participation in further models use and development. The project also improves the models adding capabilities based on the latest technology developments and changes in financing of solar as well as solar + storage projects. With that the models are extremely useful and important for supporting SETO's mission in furthering PV integration and reducing costs of the projects. The project is building upon models that were previously developed using earlier DOE and non-DOE funding as well as interfaces with users of these models to obtain additional funding for further enhancements of the models based on the interests of those users. I am not an SME in this field and therefore am not familiar with other research/efforts in this area apart from what is covered in the project report.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project meets the milestones. The goal for stakeholder engagement ("by year 3, we are targeting greater contribution to the open-source codebase by the user community, measured by at least 10 large (>10 lines of code) contributions from that community ") is insufficient. Ten lines of Python code is nowhere close to a large contribution. Large contributions need to be a feature, model, examples, or documentation. It is recommended to reduce the number of the expected number of contributions to a few and make them real contributions.

**Reviewer 2:** Given the nature of the project and its end goal of providing a tool to evaluate solar projects and their financial feasibility, this project has met all its stated goals. The project provides a tool of value to many stakeholders. However, this is more of a software development and maintenance project than a project which is innovative and cutting edge.

**Reviewer 3:** The project has a clear list of milestones and timelines and seems to be meeting those based on the project report. I really liked the quantitative metrics that the project team came up with to measure the impact on the industry (including download statistics, start instances of the models, number of registered users and publications citing the models). I think (possibly in the future reports) one of the metrics could also short description of select use cases/success stories where use of the models made significant impact/difference for a PV (or PV+battery) project and informed project design. The project team has an excellent track record of disseminating the results of the projects and collaborating with stakeholders though a number of workshops and conferences, webinars and interactions with online community of model users. I think one stakeholder group that possibly is missing from this are utilities and system operators to provide inputs of possible uses of PV (and hybrid) projects and how those are changing overtime. I seems from the project description that the main use of PV (and hybrids) that is being evaluated by the models is producing energy, however with more and more of those resources integrating into power systems and resources that traditionally provided system services retiring, as well as with federal incentives phasing out there are potentially other revenue streams than just energy production that need to be considered in the performance and financing models.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks in this project added values to the project. The Python wrapper allows end users to integrate SAM into their workflow.

**Reviewer 2:** Score: 6. Comments: This project provides a tool of significant value to its stakeholders and also enhances and promotes the integration of solar energy.

**Reviewer 3:** Score: 6. Comments: The project has a number of parallel workflows rather that subsequent tasks: software maintenance and technical support, platform and PV model improvements and stakeholder engagement activities, open source activities. Each of these workflows is furthering model improvement and dissemination, widening stakeholder base and engagement, and establishing that feedback loop with the stakeholders that leads to further model improvement. All of these activities are unique and important and contribute towards achieving overall project goals.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The project does not seem to have fully utilized modern software engineering tools (WSGI, Binder) for automating the wrapper generation.

**Reviewer 2:** None at the moment.

**Reviewer 3:** As I mentioned above, and at least based on the project report, I think the main part that is missing is engagement with utilities and system operators for understanding how potential revenue streams for solar and hybrid projects are changing already now and going forward, there is a need to include a suit of existing and emerging Ancillary Services products that solar and hybrid project can potentially participate that will affect the outcomes of PV (or hybrid) performance and financing models. There can also be interconnection requirements that result in PVs (or hybrids) operating outside of their MPPT, which in term will affect project performance. These aspects need to be included in the models developed in this project. However, stakeholders developing/introducing these Ancillary Services and interconnection requirements are usually not the same stakeholders that are developing PV (and hybrid) projects.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The project has been engaging with impactful industry players including Sunrun, Enphase, AEP, Southern Company, EPRI, and First Solar. The engagement with partner national laboratories is encouraged as some labs have on site small scale renewable systems.

**Reviewer 2:** All the right stakeholders are the users of this tool and the open source features provides enough external input.

**Reviewer 3:** I've mentioned it above in the 'blind spot' section. Collaboration with ISOs and vertically integrated utilities is missing. Additionally, are there other similar models that other researchers or commercial organizations are developing, can this project benefit from collaborating with those? The project report suggest that these model is fairly unique but there must be others out there, what are the differences, advantages/disadvantages of those?

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Opensource tools are developed to enable problem solving. This project needs to provide more application problem examples in addition to just developing a Python interface. 2) Milestones need to be adjusted. Instead of having 10 users to contribute 10 lines of code per contribution, substantial contributions are needed. 3) Examples and documentation for pysam needs to be improved to attract more external users.

**Reviewer 2:** 1) Use by stakeholders. 2) Relevance of the tool as solar integration progresses and accelerates. 3) Ability of the tool to innovate, incorporate new models and new features.

**Reviewer 3:** 1) This seems to be great ongoing effort with massive stakeholder community participation and ongoing improvements, certainly that points towards high importance of this project and necessitates continued funding. 2) It would be great to see a select brief description of actual use cases, showing importance and benefit of these models to the PV (or hybrid) developers in the next project report as one of the project success metrics. 3) Collaboration with ISOs and utilities that can provide information on potential revenue streams for PV (and hybrid) models that are currently not considered in the models would be highly beneficial.

## Probabilistic Cloud Optimized Day-Ahead Forecasting System Based on Weather Research and Forecasting Solar – $1,720,806

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta*

This project develops a publicly available ensemble-based solar capability for the weather research and forecasting model that will serve as a baseline operational solar irradiance forecasting model. The team is using an adjoint analysis technique to adjust the most important variables and calibrate the weather research and forecasting solar system ensemble to provide accurate estimates of forecast uncertainties. This resulting system will increase the accuracies of intra-day and day-ahead probabilistic solar forecasts that can be used in grid operations.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 3 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: This is a relevant project for the industry and seems to have a high likelihood of at least moderate success. Weaknesses: Unclear how the resulting model will be adopted by industry.

**Reviewer 2:** This project aims at improving solar forecasting under cloudy conditions using assembles. The underlying forecasting tool is NCAR's WRF-SOLAR. The objective is deriving accurate probabilistic solar forecasts (under cloudy conditions) in the ranges 24–48 hours and 6–24 hours. This is relevant for the power industry. This objective clearly aligns with SETO mission. The critical components (that do not look like that critical) of the project to achieve success are clearly described. In my view, this is a moderate-risk moderate-gain endeavor. The project will most likely be successful, which will translate into moderately improved forecasts. I don't identify groundbreaking transformative elements in this project, but relevant forecasting work. The funding level seems appropriate and in line with similar projects. The project will add some value to existing research outside DOE-funded efforts since probabilistic forecasts based on ensembles are not that common. The project may help advance the US solar industry.

**Reviewer 3:** The project addresses the important topic of day ahead solar irradiance forecast. The topic is of importance in supporting PV integration and improved system operational efficiency, economy, and reliability. If the project meets the stated quantitative metric of a 50% reduction in error, it would be a significant step forward.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Additional ground observations could be leveraged, beyond just what is available from First Solar.

**Reviewer 2:** The project is progressing as planned and tasks and milestones are being completed/reached as expected. Improvement criteria are being achieved. Dissemination via conference presentations is good, but not via journal articles. The PV power manufacturing sector is represented in the project, but power utilities/ISOs are not. However, they are major users of the outcomes of this project.

**Reviewer 3:** The project seems to have some initial forecast results as displayed on the poster. Judging by the results shown some of the predicted ensembles do have an error of more than 50%. Not clear how this meets the metric established for accuracy in the project. The summary and the poster needed some explanation of how the ensembles are generated. From a grid integration perspective, just predicting irradiance is not sufficient. It is important to also provide a electric power output of a specific PV system or installation. Without this it would not be very useful from a grid integration perspective.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Yes, each task in the project adds unique and important value.

**Reviewer 2:** Score: 6. Comments: The tasks of the project make sense to achieve the objectives targeted. They are adequately scheduled and coordinated. No issue on this front.

**Reviewer 3:** Score: 5. Comments: The project if successful would be an important component of promoting solar PV integration into the grid and would benefit power system operation by more accurately predicting solar output in the day ahead operating horizon.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It is unclear how well the ground measurements from First Solar will be able to correct any inaccuracies in the NSRDB.

**Reviewer 2:** Disseminate your outcomes via journals visible to the power industry (ISO and utilities) and the power system research community. They are the major users of the results of this project.

**Reviewer 3:** Need to meet the error criterion metric. Need to predict PV electric output to provide benefit to system integration. Need to improve summary report development.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1**: Is NOAA going to run WRF-Solar? If not, entities that may end up running it should be engaged in some way.

**Reviewer 2:** Please incorporate the view of both power utilities and power ISOs. They will be major users of the outcomes of this project.

**Reviewer 3:** The team is well composed and does have stakeholders from various organizations.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Publicly available probabilistic solar forecasts are going to be very useful to the industry, so I think this is very valuable work from a capable team.

**Reviewer 2:** 1) Make sure that the tool interface is easy to use for the power industry and for the power system research community. This will guarantee the widespread use of the tool. 2) Disseminate your outcomes via journal articles visible to the power system community (IEEE and the like). 3) Incorporate the view of ISOs and power utilities, the major users of the outcomes of this project.

**Reviewer 3:** Need to predict PV electric output just not irradiance. Need to improve reporting. Meeting quantitative error metric is important.

## Solar Radiation Research Laboratory – $1,200,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta*

This project funds the Solar Radiation Research Laboratory to maintain and test solar measurement devices and ensure they are certified for accuracy and precision. The team operates the Baseline Measurement System to provide high-quality, long-term solar and atmospheric measurements. These measurements can be used for instrument comparison and development, standards development, the development of radiative transfer and solar variability models, and validation studies. This project also maintains the national standard for solar measurements and disseminate accurate solar measurement and modeling methods and best practices.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: The previous measurement researches from solar radiation research laboratory (SRRL) lays a solid foundation for developing new methods and practices for efficient measurements in the PV industry; Further, the high-quality database, calibrations, and measurement tractability provided from SRRL are crucial to both academic researches and industrial developments. Weaknesses: The project seems involves too many objectives, and the major tasks could be further discussed. Also, it would be more convincing if the superiority of the developed standards is discussed.

**Reviewer 2:** This is a useful project to provide high quality solar measurements to solar project developers. The project provides important functions of the ability to calibrate solar radiometers and advances instrumentation for solar measurements. The project has made good progress.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project is well advanced. Fruitful achievements are presented in the milestone status. The development of calibration methods and traceable measurements aligns with the project plan. A few journal and conference papers are published. The project team has sufficient expertise to execute and complete the proposed project plan successfully.

**Reviewer 2:** The project has effectively provided a very important function of calibrating radiometers and developing new instrumentation to make accurate measurements to solar project developers. The project has produced effective results and has met all the milestones. It has collaborated well with various entities and provides an important service. The project has also effectively published their work and effectively disseminated their work.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The listed three tasks add unique and important value to achieving the overall goals of the project. However, the connection of each task could be further clarified.

**Reviewer 2:** Score: 6. Comments: The project tasks are well coordinated and contribute significantly to the overall success of the project. The project team has made good progress and has effectively provided a service which was not available due to a key manufacturer of instrumentation no longer producing the needed instrumentation.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** A possible blind spot could be that the project involves a lot of sub-tasks, such as updating the standards, improving the best practice hand-book, improving calibration method, delivering a low-cost measurement system, and developing radiation models. The PI could consider to focus more on a few major tasks.

**Reviewer 2:** None so far.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The reviewer suggests that an industry partner who has experiences in manufacturing and deploying solar cells could be included to provides field experiences.

**Reviewer 2:** The team has collaborated well and has included the necessary stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The SRRL is maintaining a high-quality solar radiation calibration and measurement which is essential to other studies. 2) The development of a low-cost measurement aligns with the SETO's objective on cost reduction. 3) The objectives of this project might be too broad.

**Reviewer 2:** This project has been meeting all objectives and milestones. It provides a key service to solar project developers and by providing the instrumentation needed for measurements covers a large gap left by a former manufacturer not producing the needed equipment.

## Solar Uncertainty Management and Mitigation for Exceptional Reliability in Grid Operations – $1,698,933

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Bri-Mathias Hodge*

The project is designing novel algorithms to create probabilistic solar power forecasts and automate their integration into power system operations. Adaptive reserves will dynamically adjust reserve levels conditional on meteorological and power system states. Risk-parity dispatch will be developed to produce optimal dispatch strategies by cost-weighting solar generation scenarios on forecast uncertainty. This project will test the integration of probabilistic solar forecasts into the Electric Reliability Council of Texas' real-time operation environment through automated reserve and dispatch tools that can increase economic efficiency and improve system reliability.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 5 | 6 | 3 |
| Implement a high-risk, high-impact approach | 5 | 4 | 2 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 3 |
| Advance the U.S. solar industry substantially | 4 | 6 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This seems to be a relevant and valuable project.

**Reviewer 2:** The project serves an important need of advancing probabilistic approaches in renewable forecasting to be included in power system operational tool to enhance power system operation. Working with a large ISO is an attractive aspect of this project. One question that arises is that ERCOT is largely dominated by wind resources and has limited solar penetration with potential for increasing. It is not clear from the description if the wind data was included in addition to the solar data in the analysis which was conducted. This needs to be clarified. One other aspect which needs more exploration is that the solar forecast is probabilistic, but the economic dispatch is still a risk parity based deterministic dispatch which does not seem to include any security constraints. If reserves are calculated using this approach, there is no guarantee that the determined dispatch can be delivered when needed because of transmission constraints. This aspect needs to be carefully examined.

**Reviewer 3:** The project goal is threefold: a) to develop a probabilistic forecasting tool, b) to develop a risk-aware economic dispatch and c) to derive operating reserves based on these tools. This aligns well with SETO mission. I don't see critical challenges in this endeavor. It inserts itself in the current stream of research work pertaining to power system operations under significant renewable integration. In my view, this is not a high-risk, high-impact project. If successful, it will provide an additional tool to operate a power system under significant renewable penetration. Funding seems reasonable, but on the high side. This project is similar to other projects carried out elsewhere.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Performance looks good.

**Reviewer 2:** The team is well balanced and has stakeholders from all the relevant areas of development and application. The investigators have published their work on a regular basis and in the right fora. The impact of the results could be improved by just not determining the amount of reserves scheduled compared to the deterministic methods but to also examine if the determined reserves can be delivered when needed. If the reserves are located at locations where then cannot be delivered due to transmission constraints then that is as good as not having sufficient reserves. Important to address this issue.

**Reviewer 3:** The project is progressing according to planning. In my view, it is important to focus on the economic savings (at equal reliability level) from using the tool for many operating conditions and in systems other than ERCOT. The project team is disseminating outcomes adequately via IEEE journals and conferences. An applause on this front. In my view, all relevant stakeholders are represented.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Yes. It isn't clear how valuable the SolarView tool is, but as it appears to be already complete, that isn't a major concern either way.

**Reviewer 2:** Score: 5. Comments: The various tasks in the project have been carefully thought out and do add significantly to completing the overall objectives of the problem. With renewable resources many ISOs solve look ahead dispatch up to 3 hours ahead at 5 minute intervals. Some clarification is needed whether the look ahead dispatch was only done for a 5 minute ahead horizon. The longer period is need to ascertain that sufficient reserves can be procured for a longer horizon.

**Reviewer 3:** Score: 4. Comments: In my view, the initial task is not needed. Why not using forecasting tools available via National Labs? Some of these tools are currently being improved with SETO funding. Other tasks make sense to me.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** While they note that the results would be easily transferable to other grid operators, it seems that some of it is very specific to ERCOT's operations. This is not necessarily a problem, but could limit how well the results could be transferred.

**Reviewer 2:** 1) Why is the look ahead horizon only 5 minutes? 2) What guarantee are provided that the reserve determined can be delivered where needed? 3) Why is the economic dispatch not security constrained?

**Reviewer 3:** Why developing a forecasting tool? Why not using a currently available forecasting tool (at National Labs)?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I can't think of any critical stakeholders, etc., that are missing.

**Reviewer 2:** The team is well balanced and has the right mix of stakeholders participating in it.

**Reviewer 3:** I think all relevant stakeholders are included in the project. Good job on this front.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This looks like valuable work.

**Reviewer 2:** 1) Need to address the points raised earlier. 2) Just determining reserve requirement is not sufficient. Also need to determine that the reserve determined can be delivered where needed. 3) Once reserve is determined then in the 5 minute look-ahead dispatch it is important to proceed further and include this in the next period and include generation contingencies and network constraints in proceeding with the look ahead dispatch. 4) There are ARPA-E ongoing projects which have done this and use a full blow stochastic SCED and stochastic SCUC where the wind and solar forecasts are used to generate scenarios for the SSCED and SSCUC and do this at 5 minute intervals for a 3 hour horizon.

**Reviewer 3:** 1) Use a well-proven forecasting tool available via National Labs. Compare it with the one that has been developed. Which one is better? 2) Do quantify the economic gains from reduced reserve requirement using many operation scenarios, and if possible, in systems other than ERCOT. 3) Which is novel, unique, highly relevant… in the risk-aware economic dispatch tool to be developed?

## The National Solar Radiation Database – $1,200,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta*

This project develops and provides public access to high-quality, long-term solar resource data sets through the National Solar Radiation Database. These data sets encompass studies from the U.S. Department of Energy and solar industry in grid integration, capacity expansion, resource planning and deployment, national energy modeling, production cost modeling, and regional solar deployment. The team is updating the database to provide timely data, incorporate new information from the Geostationary Operational Environmental Satellite system, and improve data set quality through regular research on identified weaknesses.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: The solar radiation database maintained by this project provides a high-quality platform for various solar-related research, such as PV array sizing and siting. The proposed work is highly aligned with SETO cost reduction targets. An accurate and easy-to-access solar radiation database could significantly improve the forecast accuracy. Also, the objectives and deliverables are clearly articulated and presented with a reasonable timeline and delineation of tasks, milestones, and responsibilities. Weakness: It would be more convincing if the advantages of NSRDB over other solar radiation database, such as NASA or solcast, could be discussed.

**Reviewer 2:** This is an important project and provides invaluable data to a wide category of users from project developers to researchers who work in a range of topics. This type of data can be used in many applications and studies. It would be good to advertise the availability of such data to. This type of data will also significantly aid project developers in planning and locating new projects. The team has provided great service to the nation in making this data available.

**Reviewer 3:** National Solar Radiation Database (NSRDB) is a leading public source of high-resolution solar resource. The data base has been in existence for over 20 year and has 55 000 unique users. The goal of this project is to provide users with satellite-based, high resolution solar radiation database, starting from 1998 that reflects the latest advancements in satellite remote sensing and solar radiation modelling. The project thus updates and improves NSRDB. Additionally, the project will provide updated typical meteorological year every year and provide on demand data to the user, it additionally explores ways to conveniently deliver data to the users. Data from the databases are used as input into other tools for solar project performance and financing assessment, among other applications. With that it aligns very well with SETO mission to facilitate cost effective PV integration, advances solar industry in the US as well as adds significant value to the existing research as research organizations are also among the user community of NSRDB. One of the challenges highlighted in the project report is obtaining accurate irradiance data in places with changes in terrain elevation. The project team recognized the challenge however admitted that additional funding would be required to improve evaluation methods.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 6 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The tasks of this project are well deployed. The milestone status shows that NSRDB-2018 meteorological data with high resolution. Is released to the public. The database website has attracted a huge number of visitors and users. However, the progress of releasing NSRDB-2019 meteorological data is not discussed in the milestone status. Also, the responsibilities and achievements of other participating organizations could be further clarified.

**Reviewer 2:** The team has published widely on this topic and in a number of different types of journals and conferences. This is important to make information about the data known to diverse communities of interested individuals who could use this data.

**Reviewer 3:** The project meets all important milestones on time, and has fairly straight forward ways to measure the impact such as for example using Google analytics on the data base user statistics etc. The interactions between project team members are not detailed in project report apart from showing the distribution of tasks. The project resulted in a large number of peer-reviewed publications, a technical report and conference participation (presentation and posters) with that the results seem to be well disseminated. The project team is also planning a webinar to inform the stakeholders about availability of new data and seek feedback from the users about their requirements from the NSRDB.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks listed by the PI is clear and straightforward. The data set collection, validation and dissemination are well dealt by the proposed tasks. Each task is an essential step to release an accurate solar radiation data sets.

**Reviewer 2:** Score: 6. Comments: This project in one of the more successful projects in this round of peer review. It provides immense value and the nature of the data provided by the project could be used a diverse community of individuals and groups who could derive great benefit from this data and develop solar projects and tools based on this data.

**Reviewer 3:** Score: 6. Comments: There are four distinct tasks in the project. Each task of the project is well defined and is unique and important in achieving overall project goal.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The reviewer recommends that the project team may consider adding a layer of bad data filtering for the purpose of removing random errors and noises. Also, the further improvement of data viewer could be another task.

**Reviewer 2:** There is not much one can complain about what this project has achieved.

**Reviewer 3:** I think the project has clearly defined goals and milestones and is on track, has wide dissemination of results and plans on additional involvement through the webinar for NSRDB users, with that I couldn't see any other blind spots for this project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** An industry partner could be included to provide advises on what type of meteorological data is more crucial in the field.

**Reviewer 2:** The team and stakeholders are well balanced.

**Reviewer 3:** I think the project has a wide range of stakeholder involvement through publications and dissemination of the results at the conferences. The planned webinar will hopefully provide additional feedback from the NSRDB user community.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The NSRDB is a well-known public solar radiation database which is crucial to other studies. 2) The project aims to update the database and further improve the accuracy, which highly matches with SETO's mission. 3) From the milestone status, it seem that the NSRDB-2019 data have not been released yet.

**Reviewer 2:** This is a project of immense value and both NREL and SETO should publicize the availability of such data to the greatest extent possible to make as a large a community of interested users aware of this data.

**Reviewer 3:** 1) This is a high-impact project, this database is widely used and it's very important to keep improving its accuracy as it feeds into many other projects that are shaping solar industry. 2) The project goals are well defined and on track. 3) I found the validation and improvement of user interface tasks especially important and necessary for this project.

## Deploying Intra-Hour Uncertainty Analysis Tools to GridView – $500,000

*Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Nader Samaan*

This project is focused on the integration of intra-hour uncertainty analysis tools to GridView, a widely used tool to help transmission planners, electricity market modelers, and regulators perform production cost modeling studies. This project aims to add capabilities to GridView that enable users to perform high-fidelity simulations of five-minute markets while considering real-world uncertainties and constraints.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 4 |
| Set critical challenges to overcome | 5 | 5 | 3 |
| Implement a high-risk, high-impact approach | 6 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 3 |
| Advance the U.S. solar industry substantially | 6 | 3 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: The GridView is an advanced and mature market analysis platform for both generation and planning studies, which lays a solid foundation for the proposed integration work. The enhanced GridView helps ISOs or utilities conduct the behavior analysis under high solar energy penetrations, which enables a reliable integration in industrial practice. Weakness: No major weakness. Only a minor comment: the reviewer believes that there are multiple simulation tools for renewable generation market analysis. It would be more convincing if the superiority and uniqueness of this project are further clarified.

**Reviewer 2:** The project addresses an important topic in the area of power system operations planning with high penetration of renewable resources. The peer review document states that the tool developed will be used in the WECC and CAISO. However, there is no direct involvement with any of these entities in the project tasks as they evolve, even in an advisory role. The project team has made two presentations for WECC stakeholders but no mentions of their response to the presentations and steps to be taken based on these responses has been presented. The project was awarded in Jan 2020 and the first major deliverable is due only in August 2020 which is white paper identifying gaps in the intra-hour modeling. The first major analytical development deliverable is due in Feb 2021. The project is yet at a nascent stage and it is difficult to make a technical judgement of the progress. One aspect which probably deserves close attention is the tool to generate forecast errors in generation - solar and wind, and in load. This will be the critical tool and the ability of this tool to provide accurate forecast errors is critical. Based on the poster it appears that a truncated normal distribution is used to model solar and wind generation and load. It is not clear and no supporting justification is provided as to why this choice of distribution would necessarily be a good fit for all three aspects. Having some experience with commercial day ahead wind forecasts at a major ISO, I have seen significant errors in these forecasts and the errors by no stretch of imagination necessarily have this truncated normal distribution. As a matter of caution it would be important to look at a combination of historical data at the sites in terms of power output, actual past output in the time intervals before the error forecast for both wind and solar, and actual weather conditions in terms of the clear sky index for the solar forecast. Additionally the load forecast is well known to have a strong correlation with the temperature in the operating horizon. Care should be taken to ascertain that the truncated normal distribution is the best approach to forecast errors.

**Reviewer 3:** The objective of this project is to improve a commercial power system simulation tool. I am not sure that this aligns with SETO mission. I don't see significant challenges to overcome: similar tools have been developed by the power system research community. In my view, this is a low-risk low-return endeavor. It the project is successful, the commercial tool in question would be better. Funding level seems reasonable (on the high side) as compared to similar projects. I don't think this project will add significant value to existing research outside DOE-funded efforts. I think similar ideas have been developed by the power system research community. For the reasons above, I don't think this project will advance the US solar industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 3 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 3 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 3 | 6 |
| Collaborates with sufficient stakeholders | 6 | 4 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The initiation date of this project is 06/01/2020, which means this project has not started officially. However, the project schedule is clear and reasonable. The report includes details on team members, industrial partners, resources, and allocation of efforts to tasks that are appropriate. Also, milestones and deliverables are indicated clearly.

**Reviewer 2:** It has been only three months since the project was awarded. Based on the material in the poster and the project, one can only judge that the project is underway and PNNL the prime contractor is working with the sub ABB to develop this tool. A cursory view of the underlying analytical development is provided in the poster. The critical tool is the development of the solar, wind and load forecast error tool. This is the tool the project hinges on. Judging by the very brief explanation provided by the means of a figure in the poster, care should be taken in developing this tool. All three aspects, wind and solar generation and load forecasts have a high degree of uncertainty and it may be not be possible to model all three aspects with a truncated normal distribution to determine forecast errors. To a certain extent this project is in the very early stages of its inception and this reviewer is of the opinion that it is unfair to the project participants to make these judgments when the project is just getting started. Overall one can judge that the project is underway the principal players are collaborating and have made attempts to appraise the stakeholders of the project and its components. The material provided does not however, provide any indication that the stakeholders have committed to participate in the project and play an active advisory role. This would have been important to do so.

**Reviewer 3:** The project has not started yet. Milestones and impact measurements seem to be correctly defined. Intended dissemination actions are not specified in the report. Although WECC systems will be used for testing, the power industry (power utilities, ISOs) is not directly involved.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: All listed tasks are crucial to the enhancement of GridView. The integration of forecast error model, reserve calculation, and sub-hour optimization capability are indeed essential steps toward a reliable platform for market studies under high solar energy penetrations.

**Reviewer 2:** Score: 5. Comments: The tasks outlined in this project are important. These tasks are outlined in the poster and all of the individual tasks will play an important role is achieving the stated goals of the project. These tasks include a) forecast error generation for solar and wind generation and load, b) determining the balancing reserve requirements, c) determining the load following and regulation requirements and d) the balancing reserve calculation. The project team envisions development of the initial source code for each element to ABB which will probably ( because this is not mentioned in the document) evaluate and test the code and make necessary enhancements to meet the specifications of an operations planning tools and integrate the various modules into Gridview. Hence, each of the tasks outlined is critical for the overall success of the project.

**Reviewer 3:** Score: 6. Comments: The project has not started yet. The tasks seem to be properly designed and coordinated.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The reviewer would suggest a comparison with other algorithms with the swinging door algorithm. The ramping requirements calculation is a vital part when solar energy penetration is high. A more reliable solution could be obtained through the comparison of different algorithms.

**Reviewer 2:** This reviewer has provided detailed comments about the error forecast tool dealing with solar and wind power generation and the load. In the very brief description provided in the poster, the authors intend to use a truncated-normal distribution to characterize the uncertainty in the forecast error. This has to be carefully examined and evaluated and pre-judging a specific type of distribution for all three aspects under consideration may not provide the correct characterization of the uncertainty. This task is critical to the success of the project and great care should be developed in formulating this task. It is here that the stakeholders can provide actual data to test the concepts. The summary document does mention an Anchor Data Set but provides no indication of what this data set includes.

**Reviewer 3:** Regarding improvements to be implemented, scan the power system literature for effective solutions. Produce a non-commercial version of the tool being improved, and make it freely available to the power system research community.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project has included experts from both research institutes and industries, with clear task allocations. The reviewer would recommend the team to incorporate a partner from academia or utilities who could offer suggestions from the users' viewpoint.

**Reviewer 2:** The direct collaboration with WECC and CAISO participants in a technical advisory role is not apparent. This reviewer is of the opinion that such a role is critical to the success of this project. Such a role will also facilitate the use of actual data from these stakeholders to test and validate the tools developed. Without such interaction the acceptance of the tool by the stakeholders may not be forthcoming.

**Reviewer 3:** It would be most appropriate to directly involve a university research group and the power industry (power utility or ISO).

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The enhanced GridView has the potential to provide a better simulation platform for solar energy integration analysis, which could benefit ISOs to make operation decisions when solar penetration is high. 2) The final outcomes and deliverables of this project are promising because both the GridView and PNNL's uncertainty analysis tools are mature software products. 3) The collaboration between PNNL and ABB on this project should be close enough since the integration of source codes always encounter unexpected issues.

**Reviewer 2:** 1) Keep an open mind on the characterization of the uncertainty. Use past historical data to verify that the truncated-normal distribution is a good characterization of all the aspects which are uncertain. 2) Involve stakeholders actively in the project as technical advisers and keep them abreast of the technical progress and actively seek feedback during the development of the tool. 3) It would have helped to provide more information about the anchor data set and the nature of the data contained in it to judge if this data set had the necessary information to evaluate the efficacy of the tool developed from a viewpoint of the stakeholders.

**Reviewer 3:** 1) Make available a free version of the tool to university researchers and public institutions. Make sure the user interface is simple and clear. 2) Disseminate widely the outcomes of the project via journal papers and conference presentations. 3) Involve the power system research community. Incorporate a university as a partner.

## Development of the Next Weather Research and Forecasting Model – $1,214,872

*Pacific Northwest National Laboratory | Richlands, WA | Principal Investigator: Larry Berg*

This project is developing the next generation of solar resource capabilities integrated into the weather research and forecasting model to include enhancements for intra-day and day-ahead forecasts of solar irradiance. The new or improved treatments include absorptive aerosol, cloud microphysics, subgrid variability in irradiance, and application of uncertainty quantification techniques.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 4 |
| Set critical challenges to overcome | 6 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The target of this project is forecasting error improvement (over a previous forecasting tool). This is the "everlasting target" of forecasters. The particular items targeted to achieve error improvements are clearly discussed. The team seems to include the appropriate experts for this endeavor. I don't think that the work being carried out is high-risk high-reward, but most important for the research community and for the industry. The budged seems commensurate to the objective pursued. So far, dissemination of outcomes (via presentations and workshops) seems adequate, but journal publications would be most desirable.

**Reviewer 2:** The major strength of the project is to innovatively consider the impact from cloud entrainment and cloud microphysics on the solar irradiance forecast, especially GHI and DNI. The project also focused on analyzing the subgrid variability of solar irradiance using a machine learning method for the development of parameterization, which will improve the forecast performance. Regarding weakness, it's suggested that some explanations of what machine learning methods are being used for parameterizing the subgrid variability should be better explained in the report, or some validations of the machine learning method should be provided.

**Reviewer 3:** This project was initiated in early July of 2018. The primary objective of this project is to reduce forecast errors in certain key variables associated with solar forecast by 25%. The project has been in place for 20 months. In terms of progress, the project has fallen behind in meeting quite a few milestones. One reason for the delay was associated with one member of the team leaving to join another organization but is still a key member of the project. The project has faced many technical challenges. During the early part of the project the team observed that the proposed approach did not provide the specific forecast improvement goals and had to reorient the approach taken. Additionally, during the early part of the project a key element the WRF Physics package had an update with a new parameterization and this required adjustments to model physics. Another approach considered by the team for the parameterization of the subgrid variability was envisioned to be a simple look-up table which would be a function of just two variables. This premise however did not correlate well with the observed data in Oklahoma and the team had to resort to a machine learning technique to develop the parameterization. Given the complexity of weather modeling in solar forecasts this appears to be a significant misread on part of the project team to have oversimplified the problem. The project has 11 more months left and would require a significantly enhanced effort on part of the project team to meet the goals and objectives of the proposed projects and achieve the last three milestones that are remaining.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 | 2 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 2 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 4 |
| Collaborates with sufficient stakeholders | 6 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project started on 7/1/18. So far, I think the work is progressing as expected. Hurdles found have been carefully identified and remedial actions have been taken. The coordination within the team seems to be working effectively.

**Reviewer 2:** The project is well organized and the multiple tasks are reasonably distributed among the multiple partners. However, it is suggested that in the milestone status, more quantitative measurements should be provided to demonstrate the project progress, such as what are the current RMSE and MAE using the proposed WRF model. It can be hard to evaluate the performance of the proposed forecasting methods without some quantitative measurements.

**Reviewer 3:** The team's goal was to tackle of problem of great importance and the team has some worthy goals. However, either due to some unforeseen circumstances and a certain level of oversimplification of the assumptions have led to the team having to alter their proposed approaches and reorient their efforts. This has also led to the team having a delay in meeting the milestones. Given these setbacks the team has made significant efforts to make changes and have presented their results at the AMS annual meeting, the AGU and a meeting of ESIG. These are all relevant fora for the presentation of the work being pursued. Given the setbacks the team has had, the quantitative measure of the quality of the forecasts should have been more carefully thought out and the parameterization carefully examined.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: I believe so. Tasks are designed to reduce forecasting errors by improving a number of modeling components that are well-identified and explained in the report. Improving the targeted modeling components makes sense to me.

**Reviewer 2:** Score: 5. Comments: There are four main tasks in this project. Each task considers some specific issues, which have not been fully addressed in the previous WRF model, related to improving the forecast accuracy of the solar irradiance. Some tasks are challenging, such as modeling the cloud microphysics and parameterizing the sub-grid temporal variability of solar irradiance. The project partners are working actively on solving these challenges. Therefore, the tasks added some unique and important values to the project.

**Reviewer 3:** Score: 4. Comments: The tasks envisioned in the project are well thought out. However, it appears the metrics to measure the success of each task and the complexity of approach required were not carefully thought out. It appears the project also had an unanticipated delay due to a key project member moving to a new job. I have addressed other issues above in detail.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Please do disseminate project findings through widely visible journal publications, not just specialized conferences and workshops. The community that needs good solar data is diverse and does not necessarily attend the conferences/workshops that the project team has used for dissemination.

**Reviewer 2:** It is recommended that applied forecast method in the project should be compared with some existing forecast methods to prove the novelty and the superiority of the former. Also, a correlation analysis is recommended to clearly demonstrate the relationship between some factors, such as cloud entrainment, cloud microphysics, and the solar irradiance, in order to extract the most important features for solar irradiance forecast.

**Reviewer 3:** The PI appears to have misjudged the complexity of the atmospheric modeling problem related to solar forecasts. The project has faced two serious technical setbacks, one related to the cloud entrainment assumptions because of which a significant accuracy metric was not met and the second related to the parameterization of the variability in which the problem was oversimplified to a look-up table consider two variables and the team then having to resort to a machine learning based approach to perform the parameterization.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The power industry, a major user of the data generated by the tool being developed, is not represented in the project. Incorporating the power industry view (via ISOs or TSOs) would be most appropriate.

**Reviewer 2:** The project includes partners from both research institutes and industries, with a clear division of tasks among the partners. It's recommended that some data scientists or machine learning scientists could be included to provide a better data analysis of multifarious weather and climate factors and to further improve the performance of the forecasting model.

**Reviewer 3:** The project team primarily consists of atmospheric and weather modelers and one person from a company closely associated with instrumentation and environmental measurements. One component in terms of stakeholder which is missing in the team is representation from organizations which would use the improved solar forecast. This would be important to judge what accuracy of improvement would greatly help the user of the forecast. This for e.g., could be a utility scale solar farm or an operations planning manager at a large electric ISO. Since this project comes under the grid integration category there appears to be no input from an entity associated with grid integration who would significantly benefit from an improved solar forecast.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Make sure that the tool includes a friendly interface to easily generate forecasts at different locations within a region and for different hour-ahead periods (e.g. day ahead, 2-hour ahead). 2) Disseminate your findings effectively and widely via journal publications. 3) Incorporate the power industry view, e.g. the view of an ISO.

**Reviewer 2:** 1) The project discusses some critical challenges for improving the forecast of solar irradiance, such as the modeling of cloud microphysics, which should be an interesting direction for future research. 2) Concrete quantitative measurements should be provided in order to evaluate the performance of the proposed project. 3) More detailed explanation of the applied methods in the project should be provided in order to evaluate the feasibility and practicability of the project.

**Reviewer 3:** 1) It has been 19 months since the project was funded. The project faced two technical setbacks and one unforeseen change in employment of team member. The project has also experienced a delay in delivering the milestones. 2) For a seasoned team that has worked in this arena for some time the two technical setbacks do reflect on the proposed approaches and the ability of the team to anticipate the complexity of the problem. 3) For a grid integration project, the project team does not appear to have any input from a grid integration entity that would benefit from an improved solar forecast.

## P2P Transactions with Demand Flexibility for Increasing Solar Utilization – $1,144,221

*QCoefficient | Chicago, IL | Principal Investigator: Vincent Cushing*

As more renewable energy is added to the electric grid, ensuring a reliable and efficient grid becomes more challenging. This project is working to automate smart energy transactions and improve grid operations when more solar energy is connected to the grid.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 3 |
| Set critical challenges to overcome | 3 | 5 | 4 |
| Implement a high-risk, high-impact approach | 3 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 2 | 2 |
| Advance the U.S. solar industry substantially | 3 | 3 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The report is written using a bombastic marketing-type language, alien to the R&D community, and is difficult to follow. It seems to describe a number of ways to improve a Demand Side Management (DSM) tool pertaining to buildings with the aim of PV integration. DSM and PV integration align with SETO mission. I don't see challenges in this project. It my view, it is a moderate-risk moderate-gain endeavor. If successful, it might help improving DSM and PV integration in buildings. The budget seems reasonable, but on the high side (with respect to similar projects). It may add some value to existing research outside DOE-funded efforts, but DSM research for building is a crowded research activity. The project may help advance the US solar industry marginally.

**Reviewer 2:** The project was initiated in July of 2018 and deals with the use of thermal energy storage in buildings to support the grid. This could prove to be an important distributed resource if successful. It appears the project has completed Phase I. However, it is not clear what was accomplished in Phase I either from the summary report or the poster. The summary talks about the tool EMeister and what is involved in it but does not specifically say whether EMeister has been developed and tested. Some clarity should be provided as to how the thermal energy stored in concrete and drywall is recovered and utilized. What are the peer to peer transactions envisioned? None of this is clearly described in the summary.

**Reviewer 3:** Strengths: Using buildings/load to better operate the grid is a good strategy. Weakness: It isn't clear how successful this project will be, or that it will bring a lot of value.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 2 | 3 |
| Measures impact appropriately (e.g. quantitative) | 6 | 2 | 3 |
| Disseminates results frequently and actively engages partners | 3 | 3 | 3 |
| Collaborates with sufficient stakeholders | 6 | 5 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project seems to be progressing as planned and achieving the objective targeted. Dissemination to the relevant R&D community seems in its initial state. The university partners may want to disseminate outcomes via relevant conferences and prestigious journals, e.g. conferences and journals pertaining to IEEE. All relevant stakeholders seem adequately represented. What is, specifically, the support enlisted from NYSERDA, NYISO, and ConEd?

**Reviewer 2:** The project summary and the poster do not provide a clear picture of what has been accomplished in Phase I and how it would be extended in Phase II of the project. There is very little technical description of how the thermal storage mechanism works. It is clear that during off-peak hours and when electric energy from PVs is available this could be stored as thermal energy in concrete and drywall. What is not clear and not stated anywhere in the summary or the poster is how is this stored thermal energy recovered and how long will the thermal energy stored before it is used, and if there is any loss during the storage. This information should have been clearly provided otherwise for a reviewer seeing this work for the first time there is no opportunity to glean this information from what is provided.

**Reviewer 3:** It seems that the project is lacking critical partners, and may not have time to get them in place for demonstration. Project results seem lacking.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: It seems that the tasks being/to be carried out make sense to achieve the objectives targeted.

**Reviewer 2:** Score: 2. Comments: This is really not clear because very little is said about the tasks in the project.

**Reviewer 3:** Score: 3. Comments: Some of the tasks are unclear.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** I don't identify any specific blind spot.

**Reviewer 2:** Has not any technical background the energy storage and retrieval process. No metrics established to show how well this process works. This should have been clearly described in the project summary and the poster.

**Reviewer 3:** The sample data in the poster may not be adjusting for weather and building use differences between the sample days in 2018 and 2019.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Disseminate widely the outcomes of the project among the power engineering industry/research community.

**Reviewer 2:** The project has a well-structured team and utility partners.

**Reviewer 3:** It seems they are lacking participation from more than just one building owner/operator. They also are seeking a "PV partner," which makes it sound like they are behind on another collaborator.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Produce a non-commercial version of the tool being improved and make it available to researchers. 2) Widely disseminate the outcomes of the project using IEEE fora (and the like). 3) Seek the input of the power industry. What is, specifically, the support enlisted from NYSERDA, NYISO, and ConEd?

**Reviewer 2:** 1) Technical concepts on which the project is based not well characterized. 2) Energy cycle efficiency of storage and retrieval not measure - critical to evaluate efficacy of the proposed idea. 3) Description of what was accomplished in Phase I not provided.

**Reviewer 3:** Reduction in energy shown in poster does not seem feasible or is not well explained. 75 MWh "charged" and 350 MWh "discharged" is not possible without significant energy efficiency measures, which are not explained. It seems more likely that they are comparing two very dissimilar days, which may mean that apparent energy reshaping/demand reduction is not there.

## Enabling Extended-Term Simulation of Power Systems with High Photovoltaic Penetration – $350,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: David Schoenwald*

This project seeks to address the need for more accurate grid simulations that require less computation, time, and costs to produce. The team is developing dynamic grid simulation tools to support analysis of a grid with high levels of solar photovoltaic generation, advancing the power industry's understanding of grid behavior as more renewable energy is added. The project focuses on advancements in the numerical methods used to solve the system of differential and algebraic equations that represent power systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 4 | 4 |
| Implement a high-risk, high-impact approach | 4 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 3 |
| Advance the U.S. solar industry substantially | 4 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Seems like a quick and useful addition to industry capabilities.

**Reviewer 2:** The project objective is to develop an integration algorithm to be embedded in a power system dynamic simulation took considering PV sources. And then, to implement the algorithm developed in a commercial tool, PowerWorld. This requires some modifications of currently used power system simulation algorithms. This is a relevant endeavor that entails limited risk. The expected advances are important, but, in my view, not ground-breaking. It aligns well with current research endeavors within the power system community. The team seems to be well-integrated and able to efficiently cooperate. The funding level seems appropriate to me.

**Reviewer 3:** I think this project aligns well with topic's goals and SETO mission. It's hard to understand applicability of the solar model that's being developed, looking only at the project report. I am also not sure how much value this research adds outside of DOE funded efforts. PV variability is handled in a number of different ways, PV dynamic models are well developed by this stage, probably EMT type models need additional work or models that would enhance positive sequence simulations by capturing some of the controls that are currently not being modeled such as plant level controller and PLL, EPRI is doing some work in that direction. There is also similar project funded by DOE called MIDAS that, I think, covers all of the scope of this project but also loops with production cost simulations to get other generation dispatch correctly. With time frames of the models being 15 minutes, one need to do that stage and represent how other unit dispatch changes over time as solar output changes (as well as load varies and wind varies).

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 5 | 6 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project just started. Seems like they have a good plan, but there is no “performance to date” to evaluate.

**Reviewer 2:** The project started 3/1/2020. No time yet to accomplish anything. The plan seems good.

**Reviewer 3:** The project just has started so my scoring is based on the project plan rather than actual progress. I think the plan that the project team laid out is achievable. There is a range of stakeholders that the project team is going to collaborate with, however I would additionally suggest EPRI and MIDAS project team (NREL, EPRI, UTK, etc.) that are already working on similar models to see the gaps an add value. Also for the next review round may be more solid plans should be made about where and how the results of the project will be disseminated and discussed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, each task in the project adds unique and important value.

**Reviewer 2:** Score: 6. Comments: I think so. The work is an algorithm modification that entails limited risk and moderate gain. In this context, the tasks are properly organized: algorithm development, checking, adjustments, and implementation in a commercial software.

**Reviewer 3:** Score: 6. Comments: I think each of the tasks listed within the project are important and unique and there’s no overlap, however as I suggested above I think the project can benefit from reaching out to research organizations that are already working on similar tasks, to save time/add value/find gaps.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I don't know of any blind spots.

**Reviewer 2:** Significant research work has been reported on the subject matter. For instance: [1] H. N. V. Pico and B. B. Johnson, "Transient Stability Assessment of Multi-Machine Multi-Converter Power Systems," in IEEE Transactions on Power Systems, vol. 34, no. 5, pp. 3504-3514, Sept. 2019. [2] K. Kawabe, Y. Ota, A. Yokoyama and K. Tanaka, "Novel Dynamic Voltage Support Capability of Photovoltaic Systems for Improvement of Short-Term Voltage Stability in Power Systems," in IEEE Transactions on Power Systems, vol. 32, no. 3, pp. 1796-1804, May 2017. [3] K. Kawabe and K. Tanaka, "Impact of Dynamic Behavior of Photovoltaic Power Generation Systems on Short-Term Voltage Stability," in IEEE Transactions on Power Systems, vol. 30, no. 6, pp. 3416-3424, Nov. 2015. [4] S. Eftekharnejad, V. Vittal, G. T. Heydt, B. Keel and J. Loehr, "Impact of increased penetration of photovoltaic generation on power systems," in IEEE Transactions on Power Systems, vol. 28, no. 2, pp. 893-901, May 2013. Carry out a detailed literature review.

**Reviewer 3:** Again my thoughts are mainly based on the project report, I think significant blind spots are not making use of existing research on the subject and not including other important stages such as security constrained economic dispatch of generation, AGC, load and wind models of similar accuracy. Without these pieces this is just a one part of the puzzle which on its own is not very useful. Also in the project report inertia is mentioned several times and I think these models will help with studying inertia in any way, I think such models would be more useful to evaluate total performance of frequency response of which inertial response is just a starting piece (first few seconds) and could be studied with models already available without going into 15 minute long simulation.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I can't think of any critical stakeholders, etc., that are missing.

**Reviewer 2:** I think an ISO, e.g., ERCOT, is missing. Nevertheless, I think the project team is appropriate to carry out the project, and I believe they are in contact with ISOs.

**Reviewer 3:** I've already mentioned before, I think it's MIDAS project team (NREL, EPRI, UTK) and EPRI on their own as I think they've done some of the similar work as well.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Looks like a good project.

**Reviewer 2:** 1) Make available a free version of the tool to the research community. 2) The project will greatly benefit from incorporating the view/contribution of an ISO. 3) It would be most appropriate that the proposed algorithm enhancement is tested in a realistic power system. Detailed characterization of the three "test cases" to be used is not provided in the report.

**Reviewer 3:** 1) Solar model that extends from milliseconds to minutes is just one model, other processes and models need to be represented to obtain usable results for such simulation. 2) I think the project team needs to build a stronger case with regards to intended application of this model, and why "looping through a number of existing models and applications (the approach somewhat along the lines of MIDAS) wouldn't work? 3) I think other research organizations such as EPRI and NREL need to be included for collaboration/discussion/use of already existing experience. If there are difference between the proposed approach and others those should be better highlighter in the future project reports.

## Physics-Based Data-Driven Grid Modeling to Accelerate Accurate Photovoltaic Integration – $2,970,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Matthew Reno*

Uncertainty in distribution grid modeling can lead to inaccuracy in decisions regarding photovoltaic integration, limiting the number of photovoltaic systems that can connect to the electric grid. This project is working to increase the precision and accuracy of distribution system models by more efficiently processing grid measurements. The team is developing several physics-based, data-driven, machine-learning algorithms that enables distribution grid models to dynamically adapt to changing grid conditions. This enables usability for all distribution feeders with monitoring. The team will validate the algorithms to improve modeling accuracy and decrease uncertainties in photovoltaic hosting capacity by at least 90 percent.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 2 | 6 |
| Implement a high-risk, high-impact approach | 2 | 6 |
| Match well with the level of DOE funding and planned project duration | 2 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 6 |
| Advance the U.S. solar industry substantially | 2 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this pro;;ject in 100-200 words.**

**Reviewer 1:** I must say that I fully disagree with the starting point of this research work: "Uncertainty in distribution grid modeling leads to overly conservative or inaccurate decisions regarding PV integration and limits acceptance of higher levels of PV. Simulation tools are often severely limited in their effectiveness by the model accuracy." Accurate uncertainty modeling pertaining to control, operations and planning of distribution network is well addressed in the technical literature. I invite the authors to carefully check IEEE Xplore. Moreover, many simulation tools available in the literature do embody a detailed uncertainty representation which allows an accurate representation of stochastic sources, such as PV solar units. I invite the authors to carefully check IEEE Xplore. The project objectives align with SETO mission. I don't see critical challenges to overcome. Authors address a well-known problem using an unusual approach. Eventually, they will derive similar conclusions to those derived by other research groups using less unusual approaches. In my view, this is a high-risk low-return endeavor. The risk pertains to the unusual approach; returns would be similar to those reported in the technical literature by using more conventional techniques. Funding seems high to me. In my view, this project adds a new approach to a "classical" problem. I am skeptical regarding the capability of this project to advance the US solar industry substantially.

**Reviewer 2:** The projects develops methods to lift uncertainty in distribution grid modelling, which may help lift conservative assumptions regarding PV integration while on the other hand ensuring reliability while integrating distributed PVs with that it aligns very well with SETO mission and goals. The project develops physics-based data-driven Machine Learning algorithms that allow distribution grid models to dynamically adapt to the continuously changing grid. The project leverages available data from Advanced Metering Infrastructure, PV systems and distribution PMUs to calibrate the models.

According to the project report. There is a need for tools to conduct reliable assessment of PV hosting capacity on the feeders and with that the project advances US solar industry substantially. The project also recognizes the challenges of data quality (data errors, data unavailability and data not being synchronized) and works on addressing those in their methodology.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 4 |
| Collaborates with sufficient stakeholders | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project seems to be attained its objectives as expected. Dissemination is good. I would encourage the authors to focus on journal publications that generally have higher visibility. The view/contribution of the power industry is missing (which is different from the consulting view/contribution of EPRI): no power utilities, no ISOs.

**Reviewer 2:** The project meets all important milestones and measures the impacts appropriately in a number of milestones even higher accuracy has been achieved than anticipated. Project report doesn't provide sufficient information on collaboration of project partners. Additionally, in my opinion, the project could substantially benefit from a Technical Review committee formed by distribution utilities. This are the end-users of the product that the project is working on and I am surprised not to see any involvement from distribution utilities one way or the other. This would also inform project partners in terms of usability of their models and data availability at a given distribution network to intput into the model.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks described and their coordination seem adequate to achieve the objectives.

**Reviewer 2:** Score: 5. Comments: The project is split into 4 objectives: developing improved modelling tools for planning with high PV penetration, provide visibility into real time solar generation on the distribution system, create accurate high resolution (spatial and temporal) models based on data measurements and enhance understanding of PV advanced inverter settings. All of these objectives add unique and important value towards achievement of the overall project goals. I think the project is mainly geared towards development of the models however some attention I think needs to be dedicated to implementation and usability by actual distribution network operators, both in terms of data availability to inform the models and ease of use.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Please, do review the literature (e.g. IEEE Xplore) on “Uncertainty in distribution grid modeling…” and on “Simulation tools…” You may find very relevant developments.

**Reviewer 2:** I think one of the main blind spots as I already mentioned above is feedback from distribution utilities. Will distribution system planners and operators be able to implement this model? Do they have data available to attain accuracy that these models seem to be offering? Do operators have skill set to set up, train and maintain this model. There is not much said about objective 4 in the project report that is enhancement of understanding for PV advanced inverter settings. I think this is another very important task, and is it possible to built in inverter settings into this models with high accuracy it will be possible to evaluate how many of them will trip in case of distribution or transmission fault or system-wide frequency events.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The power system view is missing: the project does include contributions from power utilities/ISOs (which are different from the consulting view/contribution of EPRI).

**Reviewer 2:** As I mentioned above I think distribution network operators and planners are missing in this project. Also the project report stays silent on if there other similar projects/research, and if there is I think this project could benefit from either collaboration or at least comparison of benefits and simplifications of each.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Carry out a detailed literature review. Many “traditional” approaches do accurately represent uncertainty for decision making regarding control, operations and planning of power distribution systems. Which is the novel contribution of your approach? 2) Incorporate the view of the power industry: both power utilities and ISOs. 3) Do emphasize disseminating results via journal publications.

**Reviewer 2:** 1) Collaboration with distribution companies to showcase usability and usefulness of proposed methods would be very useful. 2) Are other research organizations outside of the project team that the project could benefit from collaboration with? 3) The project is timely and important and has an ambition of developing high accuracy distribution feeder models that have capability to dynamically adapt to changing grid conditions.

## Advanced Distributed Grid Infrastructure – $1,000,000

*Span.IO, Inc. | San Francisco, CA | Principal Investigator: Chadwick Conway*

This project is developing hardware for solar-plus-storage systems that will integrate a hybrid inverter into a novel breaker panel. This aims to reduce the cost and complexity of adopting distributed energy resources like solar by reducing installation time and material costs. This system will be used in newly built homes and retrofitted ones. It will give homeowners the ability to monitor and control both their loads and generation and also improve the interface between homes and grid operators.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 6 |
| Set critical challenges to overcome | 3 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Appears that the intent of this project is to integrate a hybrid inverter into an existing electrical panel and energy management system product, to reduce the labor associated with installing a separate inverter. From this perspective it will provide a cost reduction and perhaps increase market adoption through more "appliance-like" product aesthetic and less space required. It is high risk and changes the industry a bit in that it changes the typical supply chain and availability of a standard electrical panel from well-established and dominant manufacturers. Moving the inverter, energy management, and protections into the main electrical distribution panel brings value, but perhaps this same value can be achieved as an "add-on" to an existing MDP as well to expand the available market?

**Reviewer 2:** This is an exciting project, has the potential of reducing balance-of-system cost and installation labor soft cost of a residential solar PV system. The targeted 15-20% overall cost savings has the potential for rapid commercialization and to strengthen the U.S. solar manufacturing for renewable energy hardware. Weakness: The project team should include more stakeholders with diverse background. Entities like utility/ISO DER department, EPCs with experience of installation of residential solar PV system would be a plus to the project success.

**Reviewer 3:** Strengths: This is a very focused project. The PI is from an industrial company very interested in commercializing the output of the project. The technical risk is relatively low. The output of the project will ease the adoption of PV + storage in residential applications. Weaknesses: It is possible that other US and non-US manufacturers are already working on this or similar concept.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 3 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 6 |
| Collaborates with sufficient stakeholders | 3 | 3 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Participation with other stakeholders would benefit this project for increased visibility into the benefits it brings to the PV industry as a whole. Perhaps a utility representative for adoption of functions for grid stability and future program engagement.

**Reviewer 2:** As stated in the project report, the project has not yet initiated. As a result I gave a score of 3.

**Reviewer 3:** The project start date was 3/1/2020. The project had not started as of the date of the project report. The project team members are part of a single organization and should have good internal communications and data-sharing.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Overall goals of the project are well supported with detailed steps toward inverter integration and testing.

**Reviewer 2:** Score: 4. Comments: The 24-month project has two budget periods (BP) centering on product design. BP 1 aims to de-risk and inform the form, fit and function of the hybrid inverter, with the approach of a combination of customer engagement and a series of iterative prototype. BP 2 aims to refine- confirm and validate the product-intent design. The approach of BP2 is to iterate on the prototype and then send the product to third-party labs for testing and validation. The milestones and metrics listed in two budget periods are reasonable, clear, and adding value to achieve the overall goals of the projects.

**Reviewer 3:** Score: 6. Comments: Individual tasks have not been listed in the project report. However, the milestones have been broken down in detail and show a logical sequence within a budget period and from budget period to budget period. Hence, it can be concluded from this sequence that each task in this project adds unique and important value to achieving the overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** This project demonstrates a creative way to package a new set of functions into an easy to install system, but not clear on how this type of overall house energy management can be easily implemented in existing home markets. Is there value beyond the integrated "smart" distribution panel to investigate?

**Reviewer 2:** Given the experience of this project team, I have not seen any "blind spots" the PI has.

**Reviewer 3:** Being from an industrial company, the PI is less likely to have market blind spots, but there is always the likelihood of a US or non-US competitor releasing a similar product sooner than by the completion of this project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Participation with other stakeholders would benefit this project for increased visibility into the benefits it brings to the PV industry as a whole. Perhaps a utility representative for adoption of functions for grid stability and future program engagement.

**Reviewer 2:** The project should include more stakeholders with diverse background. Entities like utility/ISO DER department and grid operators should be involved to guide the grid service functional design. In addition to the cost saving of hardware and instillation, the proposed technology could potentially benefit the grid by providing grid services such as demand response, aggregation and dispatch of solar, battery energy storage and EV, grid black-start, and even voltage and frequency response. The utilities and ISOs are in the best position to inform and prompt the benefits of these additional services.

**Reviewer 3:** Additional stakeholders are not necessary at this stage of the project. The project report states that Span.io is targeting obtaining partner pilot agreements by the end of Budget Period 2.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Integration of components and functions is a primary way to reduce labor costs and space requirements, but can also be self-limiting. Integrating proprietary devices and equipment with what may be readily available components may limit market adoption. 2) Stakeholders from outside the primary applicant is always beneficial for industry advancement and adoption. 3) This project demonstrates that there is an aesthetic component to PV adoption, and that even small cost savings in labor can be meaningful.

**Reviewer 2**: 1) Cost saving. Need to clarify the definition of targeted overall 15-20% target saving. Does "overall" means solar PV panel and battery are included? 2) Can the project team add a case study to demonstrate how and when the proposed technology may generate greater benefits to residential solar industry. 3) Feedback from Utilities and EPCs.

**Reviewer 3:** 1) This is a very targeted project. 2) The project team is invested in making this a commercial success and has laid out a detailed milestone plan. 3) US and non-US suppliers may be working independently on similar projects.

## Open Source Evaluation Framework for Solar Forecasting – $794,364

*University of Arizona | Tucson, AZ | Principal Investigator: William Holmgren*

This project develops an open-source framework that enables evaluations of irradiance, solar power, and net-load forecasts. Team members have previously collaborated on forecasting trials for utilities, developed operational solar and wind forecasts, and led projects using the open-source PVLib simulation and performance tool. The goal is to make the open-source evaluation framework more easily available for forecast providers, utilities, balancing authorities and fleet operators for non-biased forecast model assessment.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 5 | 3 |
| Implement a high-risk, high-impact approach | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 3 |
| Advance the U.S. solar industry substantially | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is well positioned to advance the power industry through an open-source solar data and forecasting platform. Strength: the project-related materials are well organized in the repositories and on the dashboard website. Documentation is in the top tier amongst open-source tools in the power industry. The engagement with shareholders is sufficient for the current phase. Weakness: No major weakness. Here is a minor one for the project team to further improve: while there have been inquiries about anonymous data sharing, the project needs to come with a plan for even more stakeholder engagement. This is not a specific one but a general comment for all data related projects.

**Reviewer 2:** The project employs an open source solar forecasting software developed by PI and aims to support electric utilities. The tools provide solar forecasts, PV power output forecasts and net load forecasts. Somewhere in the summary the PI mentions deterministic forecasts and probabilistic forecasts. However no indication is given as to how probabilistic forecasts will be obtained. The project is still waiting to develop appropriate metrics to determine the accuracy of the forecast. This is important to develop and also critical for determining the accuracy of the forecast tool.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 3 |
| Measures impact appropriately (e.g. quantitative) | 6 | 3 |
| Disseminates results frequently and actively engages partners | 6 | 2 |
| Collaborates with sufficient stakeholders | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This reviewer considers the project as outstanding (top tier) in terms of performance. Open-source repositories are well organized, documentations are clear and sufficient, website contains most necessary information for getting involved, and the dashboard platform is up and running as of the review date. This project is exemplary in open-source practices (version control, issues, and reviews). The API was not working as of the review date. Possibly due to a JavaScript issue.

**Reviewer 2:** For a project that started in July 2018, there seem to be significant gaps in what the project has achieved in nearly 21 months of effort. In terms of forecasts as deliverables, there is very little to show in what has been presented in the summary or the poster. Not having metrics to measure the accuracy of the forecasts is a significant drawback. The team needs to put significant effort in overcoming these key hurdles and develop these elements.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: This project is important as it provides an open source platform for sharing solar data for enabling better forecasting. While solar data is available sparsely, the platform developed in this project has the potential to aggregate data from various sources and lead to forecasting advancements. Tasks in this project including the python library and platform aligns well with the project vision.

**Reviewer 2:** Score: 3. Comments: The tasks are well laid out and make sense but the research output to support the measure of success and efficacy of the developed approaches is not clear. Neither the summary nor the poster provide any indication of what the forecasts look like and how they compare to the actual measurements. With Arizona being a rich solar state, it is surprising that the team has not made connections with local solar farm to test their approach.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It is recommended to engage users in the early stage. As the volume of data grow, cloud computing/bucket storage might be needed for scalability.

**Reviewer 2:** Need to metrics to measure accuracy of forecasts. Where will probabilistic forecasts be used and how will they be used? With TEPCO being involved as a partner why is it not possible to get local solar data from a large farm in or community project or roof tops in Arizona?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Solar owners of all sizes: owners, aggregators, small utility, and large utility. Solar inverter vendors: their firmware may have the capability of connecting to the platform. State-level Public Utility Commissions: they may be interested in adopting a platform for open source data, or seeking to house such a platform within its infrastructure.

**Reviewer 2:** The PI should make serious attempts to involve the local solar industry to support this project in terms of measurements to aid the project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) This project is well done in the current phase: good open source practice, high activity, and great documentation. The continuation of funding is recommended. 2) It is encouraged to engage more stakeholders early as laid out in Question 6. 3) The platform and software aspect have built solid foundation for project success. Publicity could be a high priority for next phases.

**Reviewer 2:** 1) For a project that has been ongoing for 21 months there is limited progress in this project. 2) Not having a metric to measure accuracy of the forecast is a serious drawback and it appears the partner in the project has not provided enough support. 3) SETO should encourage the PI to leverage the help of TEPCO (a partner in the project) to identify large solar projects in Arizona to provide data for the project.

## HAIMOS Ensemble Forecasts for Intra-Day and Day-Ahead GHI, DNI, and Ramps – $1,316,203

*University of California, San Diego | San Diego, CA | Principal Investigator: Carlos Coimbra*

This project is developing the Hybrid Adaptive Input Model Objective Selection (HAIMOS) ensemble model for solar irradiance forecasting. HAIMOS is a physics-based and data-driven model that forecasts both direct normal irradiance (DNI) and global horizontal irradiance (GHI) for horizons up to 72 hours in advance. One of the key gaps in these technologies is the lack of accurate solar forecasts for DNI and inaccurate forecasting of large, sudden changes in irradiance, known as irradiance ramps. This project aims to develop a forecast accuracy that is considerably higher than that of the persistence or baseline forecast, across a wide range of time horizons for both GHI and DNI.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 4 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The main strength of the project is that an ensemble method is proposed for increasing the forecast accuracy of DNI and GHI. An integration of three methods, the Numerical Weather Prediction, deterministic physics-based algorithms, and new-generation cloud cover products is applied, which combines the advantages from both physics-based method and the data-driven method. One weakness of the project is that there could be more discussions on how an accurate day-ahead/intra-day solar irradiance forecast can be applied to serve the electricity market, such as providing ancillary services. Maybe this can be done in the 3rd year of the project.

**Reviewer 2:** The project advances the topic of physics-based/data-driven forecast model to improve direct normal and global horizontal irradiance to aid in determining more accurate solar forecasts. The PIs in the summary document that the developed method improves the RMSE measure of the DNI and GHI forecast by 30% compared to the persistence forecast of these quantities, however, what is not clear is how it improves the solar electrical output forecast. For power system operations this is more important than the measure of irradiance. The project has published important publications on the work done. The project has also met most of the milestones in a timely manner.

**Reviewer 3:** The project is developing physics-based/data-driven forecast to improve direct normal and global horizontal irradiance prediction in the time horizon of 1-72 hours. The goal is to produce more accurate probabilistic solar forecasts and forecast large irradiance ramps. The project has an ambitious goal to to increase the state-of-the-art forecast skill by 10-35% and even by 50% by the end of the project. The project team admits that setting 50% target is risky, but they are confident that we the data they have at their disposal this goal is achievable still. As with some other projects, I think the main weakness of this one is that it seems to be done by the project team in isolation, there are not mentioning of other probabilistic solar forecasts that this project outcomes could be compared to, while in fact there are two other SETO funded projects developing probabilistic solar forecasts as part of their work DE-EE0008601 and DE-EE0008215.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project goal and the methods are clearly explained. A forecast performance metric is defined to measure the performance of the proposed ensemble method. Numerical results are demonstrated to prove that the proposed ensemble method has better accuracy over the reference method. In general, the project is being implemented according to the proposed schedule.

**Reviewer 2:** The project has met most of its milestones in a timely manner. The project has successfully met its first Go/No-Go criteria and is due for its next Go/No-Go evaluation in June of 2020. The PIs do show significant improvement in their DNI and GHI forecasts over persistence, however, it is also important to show how this improves solar electric output forecasting. Without this analysis it is difficult to judge the efficacy of the proposed approach in terms of aid grid integration of solar resources. The PIs have been active in disseminating their work. One aspect of the collaboration which could be improved is to include an industry advisor from an electric utility say SDG&E who could take advantage of the improvement in irradiance forecast to obtain more accurate solar electric output forecast to improve power system operation.

**Reviewer 3:** The project meets all of its milestones so far, there have been some slight delays with certain tasks, but the project team has caught up shortly after the deadlines set. The project measures accuracy of the developed forecast with a reference forecast, but at least based on the project report it seems to me that accuracy comparison is not wide enough the project report only mentions one of the industry standards in forecasting which is also from their project partner which I don't think provides fair comparison to other existing solar forecasters (two other ones are participating in DE-EE0008601 and DE-EE008215 for example). Each partner in the project seems to have their own task it's not quite clear from the project report how closely they collaborate. Apart from publishing the results in a number of scientific papers and sharing the data set with the wider community/reporting on a number of downloads of the data set, there seem to be no collaboration or wider stockholder involvement in this project.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1**: Score: 5. Comments: There are five tasks listed in the report, including data collection, data preprocessing, cloud optical estimation, setting up of the ensemble forecast framework, validation of the forecast method based on a pre-defined metric. The tasks are all related to achieving the goal of the project and are clearly explained. The current results demonstrate the value of the proposed ensemble forecast method.

**Reviewer 2:** Score: 6. Comments: The PIs have carefully laid out the important tasks in their project and described how they are interrelated. Each of these tasks is critical to the success of the project and adds an important value to achieving the overall objectives of the project.

**Reviewer 3:** Score: 6. Comments: The project is split into 9 tasks which are divided between two project partners. Since the project is half way through only half of the tasks (the ones that are complete) is listed in the project report (data collection, obtaining historical irradiance forecasts for 6 locations with distinct climate, development of cloud properties estimation method, developing and testing adaptive training techniques to obtain point forecasts for DNI and GHI 1-72 hours ahead with accuracy improvement over smart persistence model of 30%, demonstration of achieved forecast skill as set out in the project goals). All of these steps are unique and important in achieving overall project objective and according to the project report seem to be well on track.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The current forecast is implemented on a time horizon from 1 to 5 hours. For electricity market, there is day-ahead market, and also real-time balancing market. The latter has a shorter time horizon from 5 to 15 minutes. To improve the short-term solar irradiance forecast accuracy at minute-level should be an interesting topic to look into.

**Reviewer 2:** The PIs should consider using the improved irradiance forecast in obtaining appropriate PV electric output forecast and demonstrate if there is considerable improvement in this forecast compared to actual measurements.

**Reviewer 3:** I think the main blind spot that I can see based on the project report is lack of comparison with other available methods and forecasts and lack of wider stakeholder involvement.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** It could be better to include research institutes from atmospheric area or meteorological area to provide more insights into the weather and climate impact on the solar irradiance forecast.

**Reviewer 2:** As suggested earlier, the team should consider bringing in a technical advisor from a local electric utility like SDG&E who could provide guidance on using the forecasts of irradiance to estimate PV electric output and examine how this is capable of improving power system operations in the inter hour and intra hour periods.

**Reviewer 3:** Collaboration with other forecasters of probabilistic solar irradiance and/or power production, collaboration with potential users of the forecasts to better understand their needs and capabilities. Collaboration with project teams of DE-EE0008601 and DE-EE0008215 projects.

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) The idea of utilizing solar energy to support the more efficient energy market is an interesting research direction. 2) The combination of physics-based method and the data-driven method for improving the solar irradiance forecast accuracy is novel, since many forecast models merely based on the data-driven method. The physic model can add more relevant features to the data-driven method to formulate more meaningful forecast models. 3) A standard quantitative metric should be provided to fairly evaluate different forecast models.

**Reviewer 2:** 1) Extend forecast to PV electric output. 2) Include a technical advisor form an electric utility. 3) Demonstrate how improved PV electric output can improve power system operation.

**Reviewer 3:** 1) I think this project is being done in isolation, at least judging by the project report, the collaborations seems to be happening only between two project partners. 2) The project is focused on irradiance forecast development while conversion to power production forecasts and possible use cases by utilities/ISOs are being left out. 3) I think the accuracy of the resulting forecasts needs wider validation with other industry standard forecasts available from other research organizations and vendors.

## Autonomous Inverter Controls for Resilient and Secure Grid Operation – $3,000,000

*University of Central Florida | Orlando, FL | Principal Investigator: Zhihua Qu*

This project aims to provide a unified control design framework to enhance photovoltaic inverter controls and address the technical challenges of keeping the grid secure. It will coordinate grid-forming and grid-following inverters and black-start capability, which enables systems to restart independently after a power outage; ensure scalability and system stability; and protect against cyberattacks. The team will validate the technology using software simulations and lab field tests.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 4 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Valuable type of work that will be needed for future high-renewable grid. Weaknesses: A standardized control scheme will be difficult to get industry adoption of.

**Reviewer 2:** Improving the controllers commanding the inverters of PV installations is certainly aligned with SETO mission. I think the authors describe carefully the challenges to overcome and provide adequate mechanisms to address them. In my view, designing a better controller for inverters is not a high-risk high-outcome endeavor. If the project is successful, an improved inverter controller will be available to the power industry. The funding seems high for a project focused on designing a controller of an inverter, not an inverter. Designing better controllers is consistent with current research efforts of the interested research community. The power industry will benefit from improved controllers to command the inverters of their solar installations.

**Reviewer 3:** By proposing unified control design framework for grid-forming and grid-following inverters the project aligns really well with SETOs goals of increasing the penetration of PV resources (along with other inverter-based technologies such as wind and battery storage) while enhancing system performance, reliability, and resilience. The project will develop and test novel control designs and with that has potential to substantially advance US solar industry. The project will lean on previous experiences from other DOE funded efforts that PI and project members are/were involved in, however the project report doesn't seem to regard other research available in this area. Most notably significant amount of research done within EU-funded MIGRATE project, also NREL, EPRI, University of Washington and University of Texas has done some work in GFM controls. There is a lot of ongoing work currently, developing GFM control strategies, I think it would be beneficial if this project could show benefits and drawbacks of their proposed control strategies in comparison to other proposed ones.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project just started. Seems like they have a good plan, but there is no "performance to date" to evaluate.

**Reviewer 2:** The project started 03/01/2020. No outcome to evaluate yet. The dissemination plan seems adequate. It would be great to have a power industry representative (e.g., Duke Energy) within the project, not just as a member of the Industry Advisory Board.

**Reviewer 3:** The project is just starting but the timelines outlined in the project report looks reasonable and achievable. T he project team plans to assemble Industry Advisory Board (IAB) that includes Duke Energy, Florida Power & Light, OUC, and representatives from other utility companies and hardware vendors to provide technical review and evaluations on a biannual basis to ensure that the project technical specifications meet grid operational needs and the developed solutions are directly transferable to vendors and utilities. The project steering committee, consisting of the PIs from the four project member entities (as far as I understood), will work to incorporate IAB inputs into the project work. The IAB is only going to meet twice a year, it may not be sufficient, and I suggest more frequent meetings based on the project milestones could be more advantageous. Furthermore, I think broader stakeholder collaboration and interaction would be advantageous, such as participation in NERC IRPTF, IEEE P2800 drafting team. Energy Systems Integration Group (ESIG) has High Inverter Based Resource Task Force under reliability working group where GFM is one of the discussion topics, ESIG holds technical workshops twice a year where the results of this project could be disseminated.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1**: Score: 5. Comments: Yes, each task in the project adds unique and important value.

**Reviewer 2:** Score: 6. Comments: I believe the tasks to be carried out, which are clearly explained, make sense and are properly coordinated/integrated. They are needed to achieve the overall goals of the project.

**Reviewer 3:** Score: 6. Comments: The project plan is outlined in the report is detailed and the tasks are unique, subsequent and important to achieving the goals of the project.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1**: None that I know of.

**Reviewer 2:** The project is well envisioned, described and structured. No additional comment at this stage.

**Reviewer 3:** It seemed to me the assumption in the project is that all inverters on the system will have same unified GFM/GFL controls which I think it's impossible, I would suggest that in the later stage of the project the project team investigated inter-operability of their proposed control strategies with GFM controls developed by other organizations. For example EU MIGRATE project had tested inter-operability of 3 different GFM control philosophies and found though the simulations on real size grid that all three approaches can seamlessly work in parallel. Also in the real world by the time GFM inverters with proposed control strategy are available there'll be 1000s of IBRs already installed that do not have these features. I would be important to investigate how inverters with proposed GFM control can co-exist with existing GFL inverters, what is the percentage of GFM inverters with proposed strategy is needed on to operate 100% inverter-based system. Is this system specific, what characteristics matter in this case? Does this mean that some of the existing GFL resources need to be decommissioned or retrofitted? Is it possible to retrofit existing GFL resources to apply the proposed GFM control? Another blind spot I think is scalability and practicality of the proposed study methods, for example how practical it is to conduct EMT study for a large interconnected system with 1000s of buses?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Engagement in some form with additional inverter OEMs would be good to see.

**Reviewer 2:** In my view the power industry is missing. Authors plan to organize an Industry Advisory Board with power industry representatives, which might be helpful to some extent. However, I believe it would be much more effective to have power industry representatives within the project.

**Reviewer 3:** I've already named above, I think research organizations (NREL, EPRI, University of Washington, University of Texas) already working on the same topic as well as system operators already dealing with very high penetration of IBR resources are missing from this project. I think the latter stakeholders could provide that "reality check" that I've mentioned in the blind spots section above, while the former group could help brainstorm and coordinate GFM control strategies.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Good work plan. Good to see both utility and inverter OEM involvement.

**Reviewer 2:** 1) Quantify the impact of the controller to be developed within the overall context of a power utility. Improving controllers, improving inverter designs or improving the overall management of the distribution system? Which is better? 2) Incorporate the view of the power industry into the project (in a more effective manner that through Industry Advisory Board). 3) Emphasize dissemination via relevant journals.

**Reviewer 3:** 1) This project is yet another one working on GFM control strategy in isolation from industry and other research organization working on the same topic. 2) There is a need for more collaboration with system operators from areas already experiencing very high penetration of IBRs to get that practical feedback that's missing from this project. 3) There's a need to disseminate the results of this project to a wider audience than just trough IEEE publications. There is a number of forums currently discussing high penetration of inverter-based resources and project team should take active participation in those forums disseminating the results of their research.

# Power Electronic Devices and Control

## Solar Power Electronics Modular Integrated Node Platform – $2,296,150

*Flex Power Control | Los Angeles, CA | Principal Investigator: Robert Dawsey*

This innovative power electronics platform combines solar power with stationary energy storage and electric vehicles to minimize installation costs and to optimize the use of solar energy. The project is developing advanced controls built on system awareness and communications, coupled with cloud-based analytics for optimized energy utilization. The platform leverages silicon carbide-based power electronics to provide high efficiency inverters, in addition to having controllable power flow between the distributed energy resources and the load.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project appears to support SETO objectives in terms of combining function and equipment for cost reduction in both technology installation, in a "smart home energy management" environment. The attention to increased power electronics reliability is noted. It seems that the advanced topology (well known in academia, but not production) is the novel and high risk/high impact component of this project. If the complexity and controls coordination is successful and proven in a real-world environment, there will be industry advancement. The ancillary components of this project are interesting, but differentiation with currently available products/services would be helpful to understand. Showing/demonstrating the impact on the grid (grid interaction, support, robustness, communications) and advantages of this technology and approach would add a lot of value to this project and overview.

**Reviewer 2:** This project aims to develop a solar power electrics modular integrated node platform consisting of advanced power electronics and an energy management system platform. This technology will enhance the use of solar energy through the integration and synchronization with other technologies such as stationary energy storage, EV charging and site load management. The top down approach defining the system requirement and the simulation comparison between once upon a time Emma Shao was here.

**Reviewer 3:** Strengths: New technology, in both hardware and software, for a single integrated system for the home. Good plan and a well-rounded team consisting of a university, national lab and industry partners. Potential weakness: There may be other (US or non-US) manufacturers developing a similar system.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 6 |
| Collaborates with sufficient stakeholders | 4 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Reasonable time frame and budget, but at critical integration and pivotal point. Not clear on the role of ORNL, but good simulation/validation work with the university. Stakeholders from or collaboration with utilities or relevant regulatory bodies for compliance/interoperability with emerging trends and programs. Not clear on dissemination of information based on the information shown.

**Reviewer 2:** The milestones in budget period 1 has been accomplished, including hardware and software development; Univ. of Kentucky simulation and Analytical development.

**Reviewer 3:** The project report states that there were some delays in the initiation of the project due to contractual issues and the testing task was delayed due to requiring thermal enhancements for the DAB unit. Different tasks are being done by different partners on schedule demonstrating proper collaboration.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: It seems that most of the pieces are in place or close to completion, pending the final integration and real-world testing. In this respect the tasks are informative to the next step. The risks associated with the final integration and how this will be validated and measured would be helpful for assessing the value of the next phase.

**Reviewer 2:** Score: 5. Comments: Each task in this project adds value to achieving the overall goal of the project.

**Reviewer 3:** Score: 6. Comments: While tasks have not been explicitly identified by task number, they are listed as part of the Budget Period actions. These tasks add unique and important value to the overall goals of the project. They include hardware and software design, simulation and testing of the prototype product.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It seems that the power electronics and controls present a significant integration challenge, but also the primary opportunity here. The advanced analytics and cloud-based integration in interesting, but not clear on the immediate objective or value of the project. It may be useful to demonstrate how the cloud-based analytics and communication in integral to the performance of the SPIN unit, and which portions are critical to the success of this technology. While there is increased reliability projected through component selection, integration of functions perhaps increases the risk of a single failure point. Is there some level of modularity or redundancy to this design that can be discussed to offset this perceived risk?

**Reviewer 2:** A path to industry advancement is necessary. Otherwise no significant blind spot is noted.

**Reviewer 3:** Potential acceptance/non-acceptance by utilities.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Representation from a utility, system operator, or related regulatory body may be useful in demonstrating how this addresses grid interaction, stability, etc. with respect to emerging national standards and programs.

**Reviewer 2:** Engagement of industry, regulatory, utility, system operators, as well as research and development stakeholders.

**Reviewer 3:** Consider having utilities, either as project partners/consultants or as part of an Industry Advisory Board.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Integration of functions can bring cost reductions that allow the use of more costly robust components, but brings operational risk through increased complexity. Complexity brings more risk when implemented in the field, and it would be valuable to understand how this will be assessed as a path towards the actual field test. 2) The impact of this technology integration has benefits that can improve grid interaction, support, and resiliency. The project description and tasks could benefit from addressing these functions in the context of emerging standards and programs. 3) It would be beneficial to highlight how the analytics and cloud-based communications impact the development of the advanced and integrated topology and controls.

**Reviewer 2:** 1) Quantifying the strengths and weaknesses in overall value to both the market and public interest. 2) Industry involvement.

**Reviewer 3:** 1) Potentially disruptive technology. 2) There may be other US and non-US competitors working on similar concepts. 3) Collaboration/consultation with utilities/distribution entities may be beneficial.

## Modular High Frequency Isolated Medium-Voltage String Inverters Enable a New Paradigm for Large Photovoltaic Farms – $1,752,973

*Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Deepak Divan*

This project is developing and validating a new inverter to significantly reduce the balance-of-system costs in larger commercial and utility-scale photovoltaic farms. The inverter realizes higher-value propositions such as dispatchability and dynamic grid support. The project uses a medium-voltage string inverter topology and a soft-switching solid-state transformer, which can interconnect direct current from solar panel strings at 600 to 1000 volts to a standard utility distribution voltage of 4.16 kilovolts. The medium-voltage line will be fed from a standard utility substation that derives power from a 69-500 kilovolt transmission source, eliminating a 60 hertz transformer in the power path and resulting in both cost and efficiency savings.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project addresses SETO objectives for cost reduction through decreased balance of system cost and grid support, and is a high risk, high impact project. Additional focus on the impact on reliability and security could be further described, as these are important aspects of new disruptive technology when compared to existing technology. Demonstration of multi-function string inverters with medium voltage output with equivalent or better performance, reliability, and resiliency with respect to current technology and plant design will provide an opportunity advance the US solar industry in the utility sector. Reliability and "robustness" of this type of technology for this application could be addressed more effectively as this is critical when applying to a utility scale inverter-based generation facility. While efficiency goals do not appear to be primary objective, the impact on reduced plant wide losses and overall plant efficiency could also be highlighted to a greater extent.

**Reviewer 2:** This project aims to develop a medium-voltage string inverters that allow direct connecting the string inverter to 4kV distribution grid. This technology enables large commercial and utility scale PV farms to reduce the balance of system cost and provide grid ancillary services. The 3-port design enable energy storage integration without additional converter. The project in line with SETO's mission of reducing the cost to make solar energy affordable.

**Reviewer 3:** Strengths: 1) The project has a good plan and a strong project team. 2) The project is proposing innovative technology. 3) The project will use string inverters for PV and battery storage, converting low-voltage dc to medium voltage ac at the 4 kV level, with an eventual aim of 13 kV, after completion of the SETO project. The 300 kW inverters should be able to eliminate PV string combiner boxes and save on the dc or ac low-voltage cabling. 4 kV and 13 kV levels are suitable for direct connection to the distribution grid via a utility-owned transformer or for a single-stage transformer connection to 33 kV or 69 kV distribution systems. Potential Weaknesses: 1) Costs of conventional central inverters and string inverters are coming down rapidly and the proposed solution may be commercially attractive over a narrow range of PV and storage plants. 2) This particular comment applies only for plants connected directly to the transmission system/bulk power system - AC distribution at 4 kV (or even 13 kV) may require specialized transformers or two stages of transformation to get to 230 kV transmission levels, perhaps reducing the overall cost benefit of this solution. Getting a viable single stage transformation solution may require additional work outside the scope of this project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 3 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project consists of an appropriate set of stakeholders with specific applicable skill sets and addresses the need to engage a commercialization partner at a later stage. It is well organized into discreet milestones with measurable components.

**Reviewer 2:** The report shows the project had passed the first Go/No-Go point on July 31, 2019. The accomplished tasks include S4T MVSI converter simulation, 300 KVA S4T MVSI bronze prototype design, 20 MW solar farm design, financial analysis. Excellent project team including First Solar, Southern Company, EPRI, ORNL, etc. Results dissemination was not addressed in the report.

**Reviewer 3:** The project report does not flag any deviations from the schedule. Different tasks are being done by different partners on schedule demonstrating proper collaboration.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each step demonstrates an incremental and informative step prior to engaging the next stage in proof of concept. I might suggest to perhaps emphasize and accelerate the regulatory and commercial aspects and supporting details on how this might affect new regulatory models and grid/farm interaction (as these are stated primary goals of the project). As previously stated, the reliability and robustness of this type of technology compared to current technology/approach could be discussed or demonstrated more effectively.

**Reviewer 2:** Score: 6. Comments: The PI did not explicitly describe the tasks in the report. However, the milestone status provides information that can be used for evaluating the tasks. Project tasks include converter simulation, design of a smaller prototype, design of a 20 MW solar farm testing system, financial analysis, design and HIL simulation of a bigger 300 kVA inverter, simulation of a 300 kVA inverter, design and testing of the 300 kVA inverter, MVSI system testing.

**Reviewer 3:** Score: 6. Comments: The task list is comprehensive for the scope of this project and each of the 14 tasks is unique. The tasks include simulation, hardware and controls design, commercial analysis of the solution and study of the possible changes in regulations enabled by the technical solution developed in the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** As noted above, this project addresses the technical and performance aspects of this new approach, but does not address any advantages or disadvantages relative to reliability or robustness of this solution in a utility scale environment.

**Reviewer 2:** No 'blind spot' has been found.

**Reviewer 3:** 1) The costs of all PV and storage inverters, including central and conventional string, are decreasing; and, the efficiencies are increasing. 2) When demonstrated on a complete 20MW or larger size real plant, the solution may not be competitive.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Comprehensive team and stakeholders on this project. Commercialization partner may be useful at a later stage.

**Reviewer 2:** I think the project has a good mix of diverse technical background.

**Reviewer 3:** The project has a good mix of partners - universities, national labs and industry. The project team should start communicating with solar and storage developers to interest them in the viability of the solution and to partner on full-scale site demonstrations in the future.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) MV output string inverters with integrated energy storage and dispatch capabilities has the potential to reduce PV plant cost and enhance performance and grid interaction, and this is a well-defined and supported project to evaluate at least one approach. 2) New potential regulatory models to enable more utility interaction could be substantiated a bit further as both a goal and a risk. 3) Reliability and robustness of technology or topology (possible advantages or disadvantages) for utility scale applications could perhaps be highlighted as an aspect of LCOE if there is any perceived differentiation with current technology and approach.

**Reviewer 2:** 1) Disseminating research findings. 2) Performance and reliability of the MVSI at 4KV and 300 KVA. 3) Grid functionalities.

**Reviewer 3:** 1) This project has a good, well-rounded team. 2) Component costs are constantly decreasing, component efficiencies are constantly increasing. 3) A full scale plant deployment of this solution may be a new follow-up project.

## Advanced Silicon Carbide Wafer Manufacturing for Low Cost, High Efficiency Power Electronics in Solar Applications – $1,000,000

*Halo Industries, Inc. | Palo Alto, CA | Principal Investigator: Andrei Iancu*

This project is developing a technology that mechanically fractures wafers off blocks of silicon carbide without wasting material. These wafers can be processed into power electronics devices that can be used in solar applications. Conventionally, the wafers are sawed off the blocks, which is a slow process in which the sawing wastes some material. This new technology could be faster and, if so, could reduce the cost of wafers due to higher throughput and reduced material loss.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goal of this project to reduce waste in SiC wafer manufacturing aligns well with SETO goals through reduction in cost of high efficiency material that currently poses a barrier to widespread market adoption of higher efficiency inverters.

**Reviewer 2:** This project aims to improve silicon carbine wafering to reduce cost by at least 50% whole improving throughput by >2x, and demonstrate commercial viability of wafering technology. The proposed technology, if succeed, will likely reduce the cost of solar inverter and therefore make solar energy affordable.

**Reviewer 3:** 1) The wafer slicing technique for SiC investigated in this project has the potential to reduce cost, waste, slicing time, and produce wafers which are more uniform and have better surface qualities.2) The project team is ideally suited for this project as they have previously developed a similar technique for wafering Si ingots. Weaknesses: 1) None identified, except as in all projects, there is uncertainty of the final outcome.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 3 | 6 |
| Collaborates with sufficient stakeholders | 4 | 3 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This seems to be a project with a high degree of upfront activity and possibly costs as it is truly an approach that has not been developed previously. Perhaps additional stakeholders in the laser and material processing could inform and shorten the upfront activity.

**Reviewer 2:** This project is at its inception so no milestone status updates are available. As a result a score of 3 was given to all metrics in this category.

**Reviewer 3:** 1) The project starts on 3/1/2020. There is no specific progress expected at this time, and none is noted in the progress report. 2) While there are no other partners in the SETO grant, the PI is getting SiC ingots cost-free from a supplier. Also, the PI will seek support from at least two customers during the course of the project.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

Reviewer 1: Score: 4. Comments: Not very well outlined, as it seems to be inherently dependent on incremental success of hypothesized solutions.

**Reviewer 2:** Score: 3. Comments: The planned milestones were briefly addressed in the project report, including 1) process throughput, process yield and material loss metrics, 2) validation, 3) development of cost of ownership model and 4) customer engagement and 3rd party product evaluation.

**Reviewer 3:** Score: 5. Comments: While project tasks have not been explicitly noted, the 4 top level milestones identified in Section 12 Milestone Status show that milestones and actions listed add unique and important value to achieving the overall goals of the project.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Nothing significant to note.

**Reviewer 2:** Significant blind spots are not noted.

**Reviewer 3:** While no blind spots have been identified by this reviewer, it is noted that that a non-US supplier may be working on developing a similar technique or another technique which has similar benefits.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Industrial laser stakeholders perhaps.

**Reviewer 2:** Halo Industries is the prime recipient and there are no other participating organizations.

**Reviewer 3:** The PI has a pilot customer/partner agreement with a SiC ingot supplier and will be working with downstream wafer users to do a third-party validation of devices during the course of the project. In addition, they will be seeking customer support. At this point, no additional stakeholders are suggested.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) SiC cost reduction is important. With reduction in waste during processing, it is even better. 2) Approach appears to be high cost and high risk, with challenges to bring to fruition. Are there alternate means to investigate as well in parallel for low waste low cost SiC processing for PV inverter use? 3) Recognizing the sensitivity of IP, a milestone, reporting, and sharing mechanism should be outlined with some information and process disseminated.

**Reviewer 2:** 1) Disseminates result. 2) Involve more stakeholders. 3) No/no-go Point is important.

**Reviewer 3:** 1) This project has the potential for reducing SiC wafer slicing costs, waste and manufacturing time. 2) The resulting technique would be beneficial to other applications in addition to solar. 3) There is a possibility that a non-US (or other US) manufacturer may be working on a similar technique.

## Enabling Interoperability for Photovoltaic Inverter Controllers – $149,995

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kumaraguru Prabakar*

Protection systems in the power grid are necessary to ensure that there are minimal disruptions to customers when a fault occurs. Protection schemes are designed to identify faults as quickly as possible and isolate those parts of the system while maintaining electrical service to as many customers as possible. As the grid continues to incorporate higher levels of inverter-based photovoltaics, existing protection systems need to change due to the much lower levels of fault current produced by inverters. This project is developing Travelling Wave based protection schemes as an innovative method to overcome these challenges and allow for wide-spread deployment of inverter-based photovoltaics. These protection schemes can be implemented at both the transmission and distribution system to simultaneously ensure stability of the distribution system and reliability of the bulk system, while enabling significant penetration of distributed PV and other distributed energy resources.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 6 |
| Set critical challenges to overcome | 4 | 5 | 4 |
| Implement a high-risk, high-impact approach | 3 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 5 |
| Advance the U.S. solar industry substantially | 3 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** While it is generally understood that improving interoperability and standardizing controls/protocols typically results in cost saving and value, the information available (poster and report) does not clearly state how this project aligns with SETO's goals in terms of value and cost impact on the industry. It may be beneficial to express its impact on existing initiatives like SunSpec, for example, or challenges in market adoption if specifically applied to residential and commercial scale (as noted in the abstract).

**Reviewer 2:** This project aims to develop standard software code in DNP3 and IEC 61850 for inverters' embedded controllers that will enable interoperability with other components in the system. The goal is clear, the approach is feasible and impact is potentially profound. Noticeably this is a one year, $150,000 project, which is "small," "quick," but highly focused project. I would like to see more such quick turnaround but highly focused projects from DOE.

**Reviewer 3:** Strengths - Well defined; appropriate topic area, duration and cost; this is a follow-up to a previous project; potential for being adopted by commercial manufacturers. Possible weakness - Overall success will depend on the adoption of the developed code in commercial products. While the strategy for this is outside the scope of this project, the DOE should keep track of industry adoption as a feedback mechanism on funding efficacy. While the project impact could be high, the approach should not be considered risky.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 3 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Appears to be a narrow scope activity under this project in collaboration with a single commercial stakeholder. May be beneficial to include other device manufacturers or regulatory stakeholders engaged.

**Reviewer 2:** The project team just completed the 1st quarter, the accomplishment include: development of initial code to test basic inverter function using Manufacturing Message Specification (MMS) protocol and data exchange capability using the Generic Object Oriented Substation Event (GOOSE) protocol. The team is currently working on implementing inverter grid functions such as volt/var, volt/watt, frequency/watt and voltage ride through.

**Reviewer 3:** The lead team has one partner who will be involved in the final stage of the project. While there are no other stakeholders identified, the team discussed the project at an IEC 61850 WG meeting and received positive feedback. While it is not a stated aim of the project, the commercial partner could consider polling inverter manufacturers to check on openness to adoption.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Please expand on how this particular protocol translation device will impact the PV industry as noted and not just as another protocol translation product for the commercial partner. Will this complement, compete, or differentiate from current industry initiatives, for example?

**Reviewer 2:** Score: 5. Comments: This project consists of four task: 1) Acquire DNP3 and IEC 61850 library, 2) Embedded controller code development, 3) Code deployment and testing, 4) Demo.

**Reviewer 3:** Score: 6. Comments: The tasks are necessary and in the correct order for this team. Perhaps another team, who is already knowledgeable may not require the training identified as Task 1.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Based on the documents provided, it seems that identification of the current issues with today's technology and protocols, and the associated complications with the interoperability with other components, is not clear. In addition, while IEC61850 and DNP3 are predominant larger system level protocols, why are they appropriate for residential and commercial inverter/component level control and communication as noted in the abstract. Is this also applicable to utility scale inverters and plant level components?

**Reviewer 2:** No "blind spots" have been identified for the PI.

**Reviewer 3:** I don't see any blind spots in the planning for the project. Of course, given the current COVID-19 situation and the short duration of this project, there may not be slack to make up for any delays incurred because of lack of access to simulation and in-person testing.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** As this is being proposed for embedding in smart inverters, or as an add-on protocol converter for legacy inverters, an inverter manufacturer partner may be valuable. As this may be well aligned with current, and perhaps intermediary steps, collaborating with PV industry regulatory group member(s) (SunSpec, CARule21 gateway/aggregation) may also be valuable for understanding future market commercialization and implementation.

**Reviewer 2:** Stakeholders should include utility distribution department who knows the state-of-art and challenges of communication in distribution grid.

**Reviewer 3:** Future technology commercialization projects for inverter related projects should consider having additional stakeholders like inverter and plant controller manufacturers, who would be interested in using the outputs of this project or the product offering of the commercialization partner. It is possible that the commercialization partner has already done a lot of market research with a range of inverter sizes and applications and sees the commercial potential and benefits. This has not been explicitly mentioned in the documents supplied for the review.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Standardization of PV inverter controls/protocols with other components and existing systems is an important topic for overall PV adoption and grid penetration. 2) It is unclear, based on the poster and report, how this project specifically addresses the mission of SETO. It would benefit the PI and industry partner to perhaps expand on this as there very well could be some beneficial outcomes. 3) Partnership or collaboration with an inverter manufacturer, utility, or appropriate regulatory entity may help guide this project in this respect - for example, is it feasible or necessary to use these protocols at the inverter level, does this possibly address shortcomings in currently emerging programs like CA Rule 21 or compliment them, etc.

**Reviewer 2:** 1) Disseminates results. 2) Utility involvement.

**Reviewer 3:** The feedback below applies to future technology commercialization projects. If possible, SETO can consider some of these suggestions (items 2 and 3) for the current project: 1) Before funding a technology commercialization project, consider asking for the market estimate. 2) If possible, include a small portion of funding in the project for the commercialization partner to continue market research during the course of the project and provide feedback to SETO. 3) If not already there (and, if it is possible in a DOE SETO project), consider including a mechanism for the commercialization partner to have to report the commercialization results back to SETO within a certain period of time (e.g., 2 or 3 years after the end of the project).

## Photovoltaic Inverter Systems Enabled By Monolithically Integrated Silicon Carbide-Based Four Quadrant Power Switch – $1,517,146

*North Carolina State University | Raleigh, NC | Principal Investigator: Subhashish Battacharya*

This project creates an ultra-high-density, low-cost power conversion device using a newly developed single die silicon carbide-based power semiconductor switch that can block voltage and carry current in all polarities or quadrants of the power switch. The proposed scalable power conversion device can enable single-stage power conversion and then be used as a building block for photovoltaic inverters to meet and exceed efficiency, reliability, and power density targets when compared to conventional two-stage cascaded solutions.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 3 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project meets the intent of SETOs mission by developing technology to simplify inverter design and eliminate less reliable components, resulting in lower cost and longer life. The report itself and poster would benefit from addressing specific SETO mission support functions - critical challenges to the industry and how this is intended to help, not just challenges to the development of the technology.

**Reviewer 2:** This project aims to develop grid interfaced PV converter-based hardware prototypes. Advanced packaging of SiC BiDFET based on high thermal conductivity ERCD laminates will be used. The technology allows the elimination of bulk DC capacitor.

**Reviewer 3:** The main aims of the project are: 1) Develop a new semiconductor device which will enable cost effective employment of novel topologies to solar applications. 2) Demonstrate the use of the new device in the novel topologies. Strengths: The project has a good plan. The project is proposing innovative technology. Potential Weakness: The project team consists of members from a single organization.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 6 |
| Collaborates with sufficient stakeholders | 3 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** There are no stakeholders listed on the report. Otherwise, the project is organized well and results are disseminated well.

**Reviewer 2:** Milestones are clear and achievable. Cannot see diverse stakeholders from the 2020 peer review project report. Five publications.

**Reviewer 3:** The project report states that the original schedule is being met. Different tasks are being done by different members of the team on schedule demonstrating proper collaboration.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task informs the next and checks at critical intervals before proceeding.

**Reviewer 2:** Score: 3. Comments: The project report does not have enough material based on which I can make meaningful judgement. Therefore a score of 3 was given.

**Reviewer 3:** Score: 6. Comments: The project is divided into 5 tasks, including device development and testing and converter development and testing. Each task is unique and important for achieving the overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** A fundamental description of how this technology will advance the PV industry, address current issues, and support SETO's mission would be beneficial in general.

**Reviewer 2:** No 'blind spot" was noted.

**Reviewer 3:** 1) Cost competitiveness of the new device will require sufficient demand/volume.2) Using a different topology compared to existing ones may bring up new system level issues.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It seems that inverter manufacturer or other industry design stakeholders may be useful in the application/commercialization side of this project.

**Reviewer 2:** The project report did not include the stakeholder information.

**Reviewer 3:** A national labs and/or industry partner would make a valuable addition.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Project technology has potential high impact on industry, but this could be demonstrated more clearly in the information available. System level benefits noted in the overview and goals are not well described, developed, or established in the project tasks and report. 2) Project is well organized and supported with key milestones clearly determined. 3) Advantages or disadvantages in terms of reliability and grid support/resiliency specific to this technology could be more clearly highlighted.

**Reviewer 2:** This project is out of my expertise and I really can't give any meaningful technical feedback.

**Reviewer 3:** 1) This project is developing new technology and is in the early stage research stage. 2) Conventional component and inverter costs are constantly decreasing. 3) Learnings from this project can be leveraged into exploration of the BiDFET device on different converter topologies and applications for future SETO and other DOE projects.

## Multiport Autonomous Reconfigurable Solar Power Plant – $2,500,000

*Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Suman Debnath*

This project is developing an integrated system of modular power electronics devices that connect utility-scale solar power plants and energy storage with the high voltage direct current and alternating current distribution and transmission grid. This system, referred to as a multiport autonomous reconfigurable solar power plant, introduces greater grid stability and enable continued operation under grid disturbances through advanced controls. It also includes a cyber-physical security layer for the controller that uses a combination of data-based and physics-based integrity checks to determine intrusions.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 |
| Set critical challenges to overcome | 5 | 6 |
| Implement a high-risk, high-impact approach | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aims to develop integrated power electrics to interface utility-scale solar PV, energy storage system, dc, and AC systems with advanced gird services. The goal of this project aligns well with the goal of targeted topic area which is to innovate and discover new hardware solutions to improve equipment efficiency and reliability, reduce PV plant lifetime costs, enhance capabilities for advanced power flow control, and enable increased amounts of solar energy on the nation's grid. The expected benefit is ambitious - achieve 50% reduced costs and losses than the discrete development.

**Reviewer 2:** Strength: This project suggests a multi-terminal, multi-energy source Power Electronics and controls, which is innovative concept and there are several technologies that need to come together to demonstrate the technically feasibility of this approach. The team does have the right kind of technical expertise to accomplish the goals. Weakness: The practical applicability of this approach at transmission or sub transmission level is low. There are several challenges in terms of cost, supply chain of new SiC based components etc need to be established. Also, connection of energy sources to utilities and transmission system decisions are made on LCoE, which possess additional challenges.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Milestone status meets expectation. Excellent results disseminating including submitting one journal paper, three conference paper accepted, and two conference presentations. Stakeholders include OEM, utilities, ISOs etc. Quantitative impacts include 20% and 58% performance increase in frequency response and voltage response, respectively. 63% improvement in the electrical cost of MARS with respect to the state-of-the-art.

**Reviewer 2:** The project seems to delayed by a quarter, on budget. The team is running into some modelling challenges due to lack of availability of grid EMT models. This project will provide a lot of understanding on various technical aspects and I myself have been part of such projects at GE and First Solar. So it is a good but difficult project and less like to provide any commercial impact in the short term.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The project report does not include the tasks but the milestones description can be converted into tasks.

**Reviewer 2:** Score: 6. Comments: The team has developed high-fidelity power electronics model. Trying to overcome the challenge lack of EMT grid models by using existing transient stability (TS) models. Significant progress on controls to meet grid frequency and voltage requirements and cost and efficiency modelling to show the cost reduction and improvement on efficiency of power electronics.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Technology-to-Market or commercialization need to be considered.

**Reviewer 2:** There could be several blind spots given the enormity of the technical and commercial challenges for an actual adaption. But these blind spots are not relevant for this project scope. At this point this a modelling effort.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** A diverse team consisting of national labs (ORNL), equipment OEMs (ABB), simulation equipment OEMs (Opal-RT), universities (Georgia Institute of Technology and Missouri Science & Technology), ISO (MISO) and Utilities (SCE).

**Reviewer 2:** This team needs to engage solar and battery EPCs and Transmission system cost modelers to get a true cost benefit analysis done. The component level cost, efficiency and performance numbers can be provided to the EPCs and Transmission system cost modelers and they could then provide a site specific estimate of LCoE.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The benefit to the grid - improvement of 12% on frequency response and 60% on voltage support - is significant. What the trade-off of this significant improvement? 2) More components usually means the degradation of overall system reliability. Have the project team considered this issue? If yes what the mitigation methods have been used. 3) Commercialization.

**Reviewer 2:** SETO could ask the team to provide a more accurate overall system cost/performance model for a couple of locations/site in the US where this technology if success could be viable. SETO should ask this team needs to engage solar and battery EPCs and Transmission system cost modelers to get a true cost benefit analysis done. The component level cost, efficiency and performance numbers can be provided to the EPCs and Transmission system cost modelers and they could then provide a site specific estimate of LCoE.

## Power Electronics Reliability Standards – $1,200,000

*Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Jack Flicker*

This project assesses photovoltaic converter and inverter reliability, since reliability and failure mechanisms of photovoltaic power electronics are key cost drivers. The team is conducting tests to quantify the difference in reliability attributed to nonstandard operating conditions, compare the effects of potting and component layout to reliability temperature gradients, and evaluate the equivalency of different reliability tests. This data will directly impact the standards-making process for photovoltaic power electronics devices and will conclude with the publication of a testing and qualification standard for photovoltaic power electronics.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Reliability is key to the adoption of PV technology or any emerging market, and impacts the lifetime cost of energy of the system. Reliability and resilience are important factors overtime, but must be assessed int he context of cost and standardization. This project is performing activity to inform industry wide reliability standard development process. This project and report would benefit from a review of the challenges in developing a reliability standard in this industry in particular rather than just the challenges in developing and releasing a standard, and how this project will help address these challenges.

**Reviewer 2:** This project aims to assess PV converter and inverter reliability by conducting tests to quantify the difference in reliability attributed to non-standard operating conditions, comparing the effects of potting and component layout to reliability temperature gradients, and evaluate the equivalency of different reliability tests. This this is a pioneer work as currently there exist no reliability standards related to PV power electronics products. The results of this project will provide guidance to achieve long-term reliability in the PV industry that can bring costs down to DOE SETO 2030 goals.

**Reviewer 3:** The project's objectives are to be the principal developer of the IEC 621093 inverter reliability standard based on extensive testing and test data. The two partners in this project are national labs who are experts in this field. The project period is 3 years and the budget is commensurate with this duration. Ensuring long term reliability of inverters by having inverters meet the recognized reliability standard being developed by this project will help meet DOE SETO's 2030 LCOE goals. However, this project, while potentially having a high impact, cannot be classified as high-risk. Also, the development of an IEC reliability standard, while helping the US solar industry design more reliable products, will also help the solar industry world-wide.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** As this project is driven in coordination with the working group and individuals generating the IEEE standard milestones and collaboration are inherent.

**Reviewer 2:** Project milestone accomplishment to date include: 1) First draft of IEC21093 committee draft. 2) Second draft of IEC621093 committee draft. 3) Two separate long-term reliability tests were instituted. 4) A high-fidelity thermal mode was created and validated. 5) The means to automatically test component stress in the inverter during operation were added. Only one paper has been published but considering the nature of the work (reliability standard) it's reasonable.

**Reviewer 3:** During the first year the project has submitted the 2nd draft of the standard to the IEC committee, initiated two long term reliability tests and created and validated a long-term thermal model. IEC standards are consensus standards, so the very nature of the standard making process requires sharing information with partners and collaborating with many stakeholders, as has been done by the project team.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each tasks activity informs committee decisions and actions.

**Reviewer 2:** Score: 4. Comments: I can't find the tasks in the 2020 peer review project report. However the project objectives were described in detail and can serve the purpose of tasks.

**Reviewer 3:** Score: 5. Comments: While project tasks have not been explicitly listed in the project report, Section 7 of the report lists three objectives and gives the actions under each objective. Each of these actions adds unique and important value to achieving the overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Just describing some of the specific challenges to developing reliability standards in particular and how this project addresses these.

**Reviewer 2:** How about the wind industry? Do they have any reliability standards already exist or currently being working on?

**Reviewer 3:** Tests done on residential inverters may not scale easily to larger commercial and utility-scale inverters.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** IEEE working groups usually provides sufficient feedback and direction.

**Reviewer 2:** Solar PV equipment OEMs and solar plant operators/owner need to be involved in the project. Their inputs are vital to the success of the project.

**Reviewer 3:** As the IEC standards development process has many stakeholders, and the project team comprises two national labs with expertise in the subject of component reliability, the reviewer does not see the need for any additional stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Reliability is key to the PV Industry and SETO overall goals. 2) Reliability needs to be assessed and implemented in a manner that does not unreasonably increase costs. 3) Reliability standards need to be applied in a fair and balanced manner that does not artificially favor or misrepresent one technology over another.

**Reviewer 2:** Involve solar PV equipment OEMs.

**Reviewer 3:** 1) Rigorous data collection is essential for standards development. There is a lot of value in DOE SETO funding data-driven projects which provide the basis for setting industry standards. As an example, future funding could be allocated to fund extensive data collection of actual system faults and analysis of the data to develop voltage boundaries and ride-through requirements for inverter-based resources that would inform and be incorporated into IEEE 1547, P2800 and other industry standards. 2) The IEC 621093 standard developed by this project will be very useful in meeting the DOE SETO 2030 LCOE goals. 3) Scaling of data gathered from residential inverters for application to commercial and utility-scale inverters may not be trivial.

## Autonomous Grid-Forming Inverters Enabled by Always-On Universal Droop Control without External Communication or Phase-Locked Loops – $600,000

*Syndem LLC | Chicago, IL | Principal Investigator: Qingchang Zhong*

This project is developing a hacker-proof, grid-forming inverter that doesn't rely on a communication network, can avoid cascading blackouts even when there are grid faults, and can start up the grid without the help of a traditional generator in what's known as black start. The inverter will be able to autonomously resynchronize with the grid while supplying local loads, including during a black start. The project addresses a major challenge of high penetration of solar and other distributed energy resources and offer guidelines for distributed energy resource integration to improve grid stability, resiliency, security, and reliability.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 6 |
| Advance the U.S. solar industry substantially | 4 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project addresses SETO goals of grid resiliency and security, but unclear on the mission of achieving lower cost opportunities and accessibility. It is not real clear on the differentiating technology here, but the overall project serves to inform the industry well on challenges facing increasing grid penetration and management of distributed resources.

**Reviewer 2:** This project aims to leverage Syndem's patented grid-forming technologies to develop autonomous grid-forming PV inverters with advanced functions; and thoroughly study the scalability of the proposed technology. The approaches include further R&D, Formation of stakeholder advisory committee, Lab scale test bed, Scalability study, field testing preparation, and Field testing with a utility-scale microgrid.

**Reviewer 3:** In general, this project has just begun, so it is hard to perform a complete evaluation. That noted, this project is extremely interesting and necessary to push the state of technology forward and increase overall solar penetration in the US. Its advantages are several fold, looking at a broad, large test of a new inverter design that addresses several of the shortcomings of current inverter technology. Adherence to new cybersecurity standards and the ability to synchronize and black start from a solar resource are two very worthy and important goals. The disadvantage is that this is a scale test of a new technology, a lot could go wrong during the course of the investigation.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Fairly aggressive schedule with field studies involved, but achievable. Would feel more attainable with a more discreet task driven schedule and key milestones identified. Stakeholders are well rounded, but not sure why a utility, regulatory, or system operator stakeholder is not included and engaged. Inform and guide on other impacts than FERC perhaps.

**Reviewer 2:** The project just got started on Feb. 1st 2020. Therefore, a score of 3 was given. The project has a diverse team - startup, university, small company and utility (CO-OP). A score of 5 was given to 2.4 Collaborates with sufficient stakeholders.

**Reviewer 3:** The project just began, so it is difficult to evaluate or measure success. This is the reason for the low scores, that I can at this point only assume from the evidence given that the project team has set appropriate tasks and organized the team comprehensively. They appear to be thorough and cover the components needed to test a new technology at scale.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks are well developed and inform each next step.

**Reviewer 2:** Score: 5. Comments: The proposed 8 tasks seems reasonable and practical.

**Reviewer 3:** Score: 6. Comments: Yes. The tasks indicate a progression from scientific idea to a technology that is at a late enough stage to consider for pilot projects.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** A more clear differentiation of this inverter technology relative to market available inverter technology to demonstrate the value of the incremental R&D on the inverter prior to the field testing.

**Reviewer 2:** Extensive research has been proposed and some have been conducted to achieve grid forming technology. What are unique innovations in this work?

**Reviewer 3:** An evaluation of other competing designs in the marketplace -- what are other approaches to this problem, how is this technology superior (or not) to other designs coming through technology development organizations?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Utility, system operator, or other relevant regulatory representative to provide guidance on this FERC and other applications from a grid operator perspective.

**Reviewer 2:** Need to involve solar PV equipment OEMs.

**Reviewer 3**: They are listed -- for the start a collaboration between university and national laboratories. As the study progresses the work incorporates the input of potential customers. To this end, tech to market work cannot start early enough. While getting the technology right is the first task of the project, getting the technology right in a market context is extremely important.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Research and field testing to investigate impacts and solutions for increased grid penetration and, resiliency, microgrid operation, and overall security are valuable projects to pursue. 2) The specific advantage and differentiation of this inverter technology is not clear as to addressing these topics or for field testing in order to inform and transform the industry. 3) The value and details on how a micro-grid and central inverter technology can operate fully autonomously and control the point of interconnection or other node without network communication - SCADA cyber-security is another topic. Many currently available inverters can operate with autonomous functions based on the inverter terminals but require other communications for POI control.

**Reviewer 2:** 1) Technology to market. 2) Detailed field testing plan to demonstrate the benefit of proposed technology to the grid. 3) Control coordination between multiple inverters.

**Reviewer 3:** 1) This is an interesting technology -- the inverter market is due for disruption. 2) There is a substantial amount of technical risk -- but mitigating those factors is the point of the work! 3) The project is getting off to the right foot, but it is important to have the tech-to-market conversation earlier rather than later to avoid developing a project that does not meet industry.

## A Reliable, Cost-Effective Transformerless Medium-Voltage Inverter for Grid Integration of Combined Solar and Energy Storage – $2,735,138

*University of Arkansas | Fayetteville, AR | Principal Investigator: Yue Zhao*

This project aims to enhance photovoltaic plant reliability with significantly reduced lifetime costs for a high-density 300 kilowatt central inverter. It converts 1.5 kilovolt direct current output of the photovoltaic systems to 4.16 kilovolt alternating current without the use of bulky 60 hertz transformers. The proposed technology lowers the lifetime costs of silicon carbide inverters through the simultaneous electro-thermal design of the subsystem and the components of the inverter. This project establishes a basis for new innovations by addressing the challenge of multi-objective optimization while accounting for inverter cost and reliability constraints.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The use of SiC and a transformerless MV inverter improves the cost, efficiency and perhaps reliability of a large PV plant, mostly by removing the conventional transformer. This is a presented as a "single function" technology which enhances the probability of success but does not discuss some of the emerging integration of other functions like storage in the utility space. Well-developed project with a strong path to market outlined. This project would benefit from a discussion on reliability and resiliency specific to this technology for grid interaction and support.

**Reviewer 2:** This project aims to develop and demonstrate a high-density 300 kW central inverter using all Sic power modules. The ambitious goal of achieving more than 50% system cost and LCOE reduction is inline with SETO goal of cost reduction to make solar energy affordableand accessible for all Americans. The two-step approach - Holistic 3-level integrated multi-objective optimization and co-designed electro-thermal management, control and reliability - seems practical and implementable. There appears to be a gap in terms of commercialization.

**Reviewer 3:** Strengths: The project has a good plan and a strong project team, including an inverter manufacturer. The project is proposing innovative technology. The project is targeting 300 kW, 4 kV inverters without a bulky LV to MV transformer for commercial solar applications. The project is emphasizing metrics-based reliability testing. By targeting commercial solar applications, the project team does not have to contend with the LV to 34.5 kV transformer used in utility-scale transmission-connected applications. Potential Weaknesses: Costs of conventional central inverters and string inverters are constantly coming down and, even with the elimination of a LV to 4 kV transformer the proposed solution may be commercially attractive only over a narrow range of PV and storage applications.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** String stakeholder engagement. From the information provided, more details on measuring reliability within typical utility grid faults and transients would be helpful.

**Reviewer 2:** The project has completed 1) 1st pass power converter, high frequency transformer and control algorithm design and implementation, 2) cabinet level assembly and testing of triple active bridge converter, and 3) medium voltage side inverter design and assembly. This project has led to several publications in the power electrics and energy conversion area. The project participants/stakeholders include university, research arm of big manufactures, small companies.

**Reviewer 3:** The team had contract delays with Eaton and project role issues with Wolfspeed. These have been resolved, but have resulted in some delays and spending moves to the project. Working is progressing well among the different partners and the project is expected to complete all planned tasks in Budget Period 2.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task is well developed and informs the next step of the progress. Shows incremental activity with critical milestones that must be achieved before proceeding.

**Reviewer 2:** Score: 6. Comments: This project consists 6 tasks. These tasks are mutually supportive and add unique and important value to achieving the overall goals of the project.

**Reviewer 3:** Score: 5. Comments: The project report has not listed all the tasks in the project. Section 8 Project Objectives of the project report lists the top-level actions in each budget period. These actions are done in stages and provide unique and important value to achieving the overall goal of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Reliability and resiliency among grid transients and other faults without a conventional transformer, and specific to this technology, could be explained in more detail.

**Reviewer 2:** No 'blind spot' has been identified.

**Reviewer 3:** The cost of central and string inverters is constantly coming down and efficiencies are going up. The solution at the end of the project may be attractive in only a limited range of commercial applications.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** In this case, the team may benefit from a utility and/or regulatory body to address grid protections, fault simulation and grid support risks/benefits of this specific technology.

**Reviewer 2:** Engagement of industry and research and development stakeholders is fundamental to achieving SETOs mission.

**Reviewer 3:** The project has a good mix of stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Higher efficiency technology and transformerless medium voltage inverter output are important to reducing the overall cost and increasing performance of utility. This project shows promise in this respect. 2) Grid support and resiliency are key and need to be discussed further relative to strengths and weaknesses of this specific technology. 3) SiC is showing promise in current technology and inverter applications. With the additional efficiencies in this approach, does it offset some of the time/cost barriers to market associated with SiC?

**Reviewer 2:** 1) Commercialization. 2) Trade-off between cost reduction and system reliability degradation. 3) Stakeholders with diverse background.

**Reviewer 3:** 1) The project has the potential of developing technology which will reduce LCOE. 2) The project is focused on the commercial solar market, which is most appropriate for the 4 kV output. 3) A follow-up project could be to extend the output to higher ac voltages.

## Compact and Low-Cost Microinverter for Residential Systems – $1,872,818

*University of Maryland | College Park, MD | Principal Investigator: Alireza Khaligh*

This project aims to create a holistic design of microinverters using the emerging gallium nitride semiconductors combined with a novel circuit with reduced components and filters. The project models thermal stresses and their effect on reliability by using a multi-physics-based approach resulting in an improved assembly design. It is anticipated that the microinverter will yield more than 250,000 hours of operation with no failures under consumer rooftop and commercial installation use conditions, while simultaneously achieving lower costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 4 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** It seems that the project meets the SETO objective of cost reduction and potentially reliability of micro-inverters with the use of new materials and reliability.

**Reviewer 2:** This project aims to design a commercially viable microinverter that will help to significantly lower the LCOE cost of residential solar. The approach to design, including four major components - electrical, thermal, reliability and design for manufacturing, allows each group to use and develop its specific expertise for the success of entire project. The project impacts include reduction of residential microinverter LCOE cost (microinverter BOM, balance of system, and O&M costs) and enhanced converter- and system-level reliability.

**Reviewer 3:** Strengths: The project has a good plan. The project is proposing innovative technology. The project is designing and validating a microinverter using GaN devices. Potential Weaknesses: Costs of solar inverters are coming down steadily and the proposed solution may not remain commercially attractive by the anticipated date of commercialization.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 4 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Description of the reliability concerns and pricing considerations, and how/when they could be overcome, and how this project addresses this would be helpful. Are there any risks or advantages of this type of technology in a true grid environment?

**Reviewer 2:** The project has been broken down into several milestones with associated evaluation metrics. These milestones are covered in 3 budget periods. All the milestones to date are on track to be completed. Encourage the project team to disseminate the study results to journal such as IEEE Transaction on Power Electronics and international conference.

**Reviewer 3:** The project report states that the project is on track to meet Budget Period 1 milestones. Difficulties encountered during the course of the project so far have been solved. The project report states that all project aspects will be overseen by industry partner(s).

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, each task informs the next the next and removes risk.

**Reviewer 2:** Score: 4. Comments: Tasks were not explicitly discussed in the report.

**Reviewer 3:** Score: 6. Comments: While tasks are not explicitly listed, the project is broken down into milestones within each of the three budget periods. The milestones add unique and important value to achieving the overall goals of the project.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Not really, just a better description of the benefits and risks associated with GaN and how this project addresses them.

**Reviewer 2:** No "blind spot" has been identified.

**Reviewer 3:** The project report states that final commercialization may be pursued by a university spin-off company. Unless the project team has had success with previous commercial ventures in a similar mass-produced product, this may not be as easy as anticipated. It may also take longer to go to market and could lead to non-competitiveness of the technology developed during the project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It seems that the industry partnership has been a challenge but worth pursuing. Regulatory and PV manufacturer stakeholders may provide insight into performance requirements and integration challenges relevant to commercialization as well.

**Reviewer 2:** Would like to see more project participants and stakeholders other than University of Maryland.

**Reviewer 3:** The project team should evaluate the right go-to-market strategy. Regardless of whether it is done through a university spin-off or through licensing to an existing inverter manufacturer or some other means, the micro-inverter will need experienced production and marketing personnel. These personnel should be brought into high-level discussions as early in the project as appropriate.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Further reduction in micro-inverter cost will help bring more adoption of simple to install PV systems, and a focus on reliability will bring value to the industry. 2) While cost implications are unknown, further research into the commercialization of GaN semiconductor material is beneficial. 3) Industry stakeholders are important for bringing novel technology to commercialization with respect to regulatory, manufacturing, and installation aspects.

**Reviewer 2:** 1) More diverse project participant. 2) Disseminates results frequently.

**Reviewer 3:** 1) The project has the potential to reduce residential PV LCOE. 2) The project will need to start preparing the go-to-market strategy as soon as appropriate. 3) Other US and non-US manufacturers may start producing inverters which are more commercially competitive.

## Modular, Multifunction, Multiport, And Medium-Voltage Utility Scale Silicon Carbide Photovoltaic Inverter – $2,887,025

*University of Texas at Austin | Austin, TX | Principal Investigator: Alex Huang*

This project is developing the next-generation utility-scale photovoltaic inverter referred to as a modular, multi-function, multiport, and medium-voltage utility-scale silicon carbide solar inverter. Called the M4 Inverter, it directly converts the direct current output of solar panels to medium-voltage alternating current, eliminating the bulky and costly low-frequency transformer. The inverter also has a direct current port to interface with an additional energy storage device. The device has multiple functionalities and can be used for reactive power support, fast frequency regulation, and peak power reduction, and enables synthetic inertia to be integrated into the inverter for grid support. Taken together, these advances will enable the inverter to drastically reduce the levelized cost of energy.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Combining separate functions into a single device, and transitioning away from conventional medium voltage transformers with MV string inverters provides a cost benefit in terms of equipment and operation, provided they can provide the same, if not better, grid functions and robustness. The goals and milestones achieved show promise, but it would be helpful to discuss potential strengths and weaknesses of this specific technology/topology applied in utility grid environments when connected directly at medium voltage.

**Reviewer 2:** This project aims to develop a 1 MVA/4160V inverter system with integrated battery storage. In addition to research and development on inverter design, this project also includes a comprehensive cost and benefit analysis for evaluating the LCOE improvement. The project in line with SETO's goal of cost reduction to make solar energy affordable and accessible for all Americans.

**Reviewer 3:** Strengths: 1) The project has a good plan and a strong project team. 2) The project is proposing innovative technology. 3) The project includes a partner who is looking at commercialization of the technology developed in the project. Potential Weaknesses: 1) Costs of conventional Si central inverters and string inverters are coming down and the proposed solution may be commercially attractive only over a narrow range of PV and storage plants. 2) This comment applies only to transmission-connected/bulk power system connected plants - For transmission-connected plants, to get to 230 kV or higher transmission connections an in-plant ac distribution system at 4 kV may require specialized transformers or two stages of transformation, perhaps reducing the overall cost benefit of this solution. Getting a viable single stage transformation solution (4kV to 230 kV) or a higher voltage M4 inverter may require additional work outside the scope of this project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Well defined work plan and adherence to plan and good milestone results. The stakeholders represent appropriate sectors for the phases outlined.

**Reviewer 2:** Accomplished milestones were presented. Detailed descriptions were given. Three conference papers have been accepted.

**Reviewer 3:** The project report states that one of the original partners, Wolfspeed, had to drop out of the project, but that work was picked up by another partner within the project team. The project is on track with the original schedule. Different tasks are being done by different partners on schedule demonstrating proper collaboration.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each stage of the work plan is well defined and provides incremental value to the overall goal and objective of concept demonstration. Only minor comment is that serial development of separate aspects of a proposed integrated solution may be risky with final step being the actual integration. Perhaps a step that evaluates the strengths and weakness with respect to the grid management capabilities and inherent robustness of this type of solution in a utility scale environment.

**Reviewer 2:** Score: 4. Comments: The project was not discussed in the report, however it appears they are covered in six WPs. No detailed information was released for each WP, but from high level they appear to be reasonable.

**Reviewer 3:** Score: 6. Comments: The project has been divided into 6 work packages (WPs). The WP list is comprehensive for the scope of this project and each of the 6 WPs is unique. The WPs are subdivided into milestones.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Cost efficiency and combined function appears to be the driver of this project activity meeting those specific objectives of SETO, but a discussion, or addressing the reliability and resiliency aspects of medium voltage inverters with the removal of line frequency transformers.

**Reviewer 2:** 'Blind spot' was not noted.

**Reviewer 3:** The PI should be aware that the cost of conventional Si central and string inverters is constantly decreasing and efficiencies are increasing.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Team is well represented. Perhaps a PV manufacturer would complement the team.

**Reviewer 2:** The project team consists of two universities, one national lab, two industry companies and one ISO. Recruiting stakeholders such as solar plant operators with operational experience will add value to the project.

**Reviewer 3:** The project has a good mix of partners - universities, one national lab, an RTO and industry. The project team should consider starting to communicate with solar and storage developers to interest them in the viability of the solution and to partner on full-scale site demonstrations in the future.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Reducing the amount of equipment on a PV plant while combining functions and controls is critical in reducing the overall cost of generating electricity and meeting SETOs goals in this respect. This project is demonstrating. 2) Projected reliability, resiliency, and support in a utility scale environment are important factors that could be highlighted in the context of this technology more. Molecularity does not always mean reliability, for example. 3) Background on LCOE assumptions, or a comparative table, may be useful in evaluating this (and other) project's progress and projected success.

**Reviewer 2:** 1) Technology-to-Market piece. 2) Performance metrics for grid service. 3) Cost and benefit analysis.

**Reviewer 3:** 1) This project has a good, well-rounded team. 2) Cost of components used in solar plants, e.g., inverters, are constantly decreasing and component efficiencies are constantly increasing. 3) A full scale plant deployment of this solution may be a new follow-up project.

## Modular Wide-Bandgap String Inverters for Low-Cost Medium-Voltage Transformerless Photovoltaic Systems – $2,253,060

*University of Washington | Seattle, WA | Principal Investigator: Brian Johnson*

This project is developing a string inverter that uses integrated circuit control blocks, each comprised of a wide-bandgap-based power converter and local controller that can be assembled in a modular fashion to produce ultra-low-cost medium-voltage transformerless photovoltaic inverters. Each circuit control block will be fabricated on high-voltage printed circuit boards with planar magnetics, such that automated manufacturing processes can be leveraged for maximum cost savings and throughput. This eliminates costly passive components and low-frequency transformers, substantially reducing electrical balance-of-system costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 4 | 6 | 6 |
| Implement a high-risk, high-impact approach | 5 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project addresses SETO objectives for cost reduction through decreased balance of system cost and power electronics, and is a high risk, high impact project. Elimination of the conventional medium voltage/low frequency transformer in utility scale systems can improve cost, reliability, project delivery time, etc., provided the advanced solution is comparable in both performance and reliability, as well as cost. Scalability of the technology could be discussed further in addition commercial scalability and application (strengths and weaknesses) - perhaps in the context of MV isolation and limits, handling of grid-like transients, etc. Additional focus on how this technology/topology will address reliability, robustness, and grid stability/interaction - perhaps projected strengths or weaknesses inherent to this technology.

**Reviewer 2:** The ultra-low-cost medium-voltage transformer-less design, coupled with distributed and decentralized control schemes has the potential to reduce the cost. Modular structure design minimizes single point of failure. Among all reviewed projects the goal of this one - 3-5% LCOE reduction - appears to be most achievable. The approach, from framework design by NREL and UW, to distributed control design by UW and CU and C^2 design by CU, CW and NREL is practical and reducing the risk of project failure. The 10+ block testing at the NREL's controlled grid interface facility adds the value of advancing the proposed technology in grid space.

**Reviewer 3:** Strengths: 1) The project has a good plan and a strong project team. 2) The project is proposing innovative technology. 3) The project will use string inverters for PV and battery storage, converting low-voltage dc to medium voltage ac at up to 35 kV. This has the potential of resulting in a substantial reduction in dc collector system and ac collector system cabling and other costs. 4) While getting to 35 kV will be a significant challenge, this will allow a single stage voltage transformation to transmission level 230 kV without using a medium voltage transformer. Potential Weaknesses: 1) Costs of conventional central inverters and string inverters are coming down rapidly and the proposed solution may be commercially attractive over a narrow range of PV and storage plants. 2). This particular comment applies only for plants connected directly to the transmission system/bulk power system - If the design is unable to get to 35 kV and the highest voltage remains around 13 kV, specialized transformers or two stages of transformation may be required to get to 230 kV transmission levels, perhaps reducing the overall cost benefit of this solution.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 6 |
| Collaborates with sufficient stakeholders | 4 | 3 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Good overall progress towards objectives with the proof of concept. Framework and/or factors used in determining LCOE would be helpful in assessment of milestones and appropriate measurements. Might suggest additional stakeholders, advisers, or collaborators from the utility/operator and or manufacturing sector for scalability and performance aspects. As the medium voltage isolation is one of the key challenges, is there a projected susceptibility when operating in a utility grid scenario that can be projected or estimated? Are there perceived limits of this approach?

**Reviewer 2:** The accomplished milestones include a scaled low-voltage testbed was developed; medium-voltage PCBs were manufactured and new decentralized control strategies were developed. The team plans to form an industry advisory board however no detailed information was released in the project report. Disseminating the results of research include one journal paper and seven conference paper - excellent.

**Reviewer 3:** The project report states that one of the original partners, Wolfspeed, had to drop out of the project, but that work was picked up by other members within the team. The project report does not show any deviations from the original schedule. Different tasks are being done by different partners on schedule demonstrating proper collaboration.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, each step clearly outlines the incremental value towards the experimental verification, but unclear on steps to take to final stage of the project in the form of a market plan and what existing approaches are considered for comparison.

**Reviewer 2:** Score: 4. Comments: The tasks were mentioned in the report; however, no detailed descriptions were presented.

**Reviewer 3:** Score: 6. Comments: The project has not been explicitly categorized into tasks. However, looking at the budget periods and the work planned, it is clear that the actions at each stage are unique and important to achieve the overall goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Nothing noted other than what has been mentioned in previous sections.

**Reviewer 2:** No significant "blind spots" are noted.

**Reviewer 3:** 1) The costs of all PV and storage inverters, including central and conventional string, are constantly decreasing; and, the efficiencies are increasing. 2) The project solution may be less commercially competitive for transmission-connected plants if ac voltage of 35 kV is not achieved eventually.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Might suggest additional stakeholders, advisers, or collaborators from the utility/operator and or manufacturing sector for scalability, go to market plan, regulatory, and performance/grid interaction aspects.

**Reviewer 2:** IAB with diverse background.

**Reviewer 3:** The project has a strong team with two universities and a national lab. The project team plans to have an Industry Advisory Board (IAB) in the latter half of the project. This would be a very useful addition to be able to get an industry perspective. But, to get the full benefit of the expertise in the IAB, it will be important to provide the IAB (or select members) with more than superficial information about the project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Novel approaches are needed to reduce the cost of PV plants, and medium voltage output inverters, without the use of conventional transformers is a primary path to achieve this goal. 2) Noting, or at least mentioning, aspects of using this type of technology/topology in utility PV plant environments would be helpful. Medium voltage isolation challenges appear to be significant, and based on this information alone, it seems that this could be susceptible to grid transients and issues with grid management...but perhaps too early to tell. 3) Additional development work needed before able to generate market transition plan - hard to assess based on information provided.

**Reviewer 2:** 1) Printed PCBs have the capability to withstand medium voltage. 2) Cost analysis. 3) Technology-to-market.

**Reviewer 3:** 1) This project has a strong team. 2) Component costs are constantly decreasing, component efficiencies are constantly increasing. 3) If 35 kV is not achieved in the course of this project, it could become a new follow-up project.

## Ultra-Compact Electrolyte-Free Microinverter with Megahertz Switching – $1,031,317

*Virginia Polytechnic Institute and State University | Blacksburg, VA | Principal Investigator: Jason Lai*

This project is working to develop a cost-effective photovoltaic microinverter that fully utilizes the potential of wide-bandgap semiconductor devices, like gallium-nitride devices, which have shown potential of switching at megahertz frequencies. By operating the microinverter at such high frequencies, passive component size can be drastically reduced while still maintaining ultra-high efficiency of the microinverter. With the tallest component in the entire package measuring less than 0.2 inch, the potting compound material can be reduced by 80 percent as compared to typical designs with a one inch tall package, further reducing the cost of the product.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project shows potential for advancing the use of new materials and electrolyte-free inverter technology. Appears to share SETO objectives of cost reduction and reliability, and integration of panel level inverter technology. Commercialization of AC PV modules (especially with potted inverter J-boxes) has faced challenges in the past that could be better addressed in this project for long term impact and operation/maintenance. In addition, an overview or plan for addressing compliance to emerging standards and regulatory trends, as well as strengths/weaknesses with respect to transients, faults, etc. would be beneficial. Technology is novel and has potential for transforming portions of the market. Application through commercialization needs a bit more attention.

**Reviewer 2:** The project aims to design a commercialization ready prototype, including the proof-of-concept prototype in the first 2 years and the pre-production ready prototype in the 3rd year. The proposed approach - computer simulation, device selection and open-loop test in year 1, controller design and integration in year 2, and final design optimization in year 3 - are reasonable and piratical. The impacts include higher efficiency, >35 years equipment life, reduced component materials.

**Reviewer 3:** Strengths: The project has a good plan and a strong project team. The project is proposing innovative technology. Potential Weaknesses: Cost of conventional solar inverters of all sizes are constantly decreasing, and efficiencies are increasing. Will this technology remain commercial competitive?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 3 | 3 | 6 |
| Collaborates with sufficient stakeholders | 2 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project plan, and milestone execution to date is reasonable and on track. With only one participant, the project could benefit from additional stakeholders in the regulatory and manufacturing (PV?) space to bring additional value and path to commercialization/market.

**Reviewer 2:** One paper has been published in IEEE Trans. on Circuits and Systems. Need more stakeholders from a diverse background.

**Reviewer 3:** The project report shows that all schedule and performance targets have been met or exceeded. All members of the team belong to a single organization. They meet weekly and must be working well together to be able to exceed targets.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: This is a fairly straightforward project plan with developed, achievable, and measurable milestones, with each step informing the next. Additional tasks showing path from validation to commercialization and associated risks would be helpful.

**Reviewer 2:** Score: 5. Comments: The tasks appears to be reasonable.

**Reviewer 3:** Score: 4. Comments: Specific milestones and tasks have not been identified in the project report or the poster. But given that the project is exceeding their targets, the project team must be working efficiently without undue overlap of tasks.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Go to market and commercialization strategy relative to past attempt for integrated potted module level inverter technology, and why this is different, could be better explained. IEEE1547-2018 may be the predominant standard by the time this comes to market. Is this application able to comply with full Rule 21 or 14 H, for example? Revisit cost target relative to overall function/value.

**Reviewer 2:** No 'blind spot' has been identified.

**Reviewer 3:** Developments in capacitor technology may allow small volume film capacitors to be used with conventional inverter topologies.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Collaboration with a national lab, PV or associated manufacturing partner, O&M specialist, and a regulatory/program preservative could be beneficial to the success of this project.

**Reviewer 2:** Need involve more project participants out of VT.

**Reviewer 3:** A commercial micro-inverter manufacturer or a consultant in the micro-inverter space would have been a good addition to the team.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) PV module level inverter technology has been an emerging concept for many years, and the adoption has been relatively independent of technology, but rather application. While this brings value and possible cost reduction through lower cost more reliable components, how is this application different that will make this successful. 2) Long term impact of this approach needs to be further evaluated for LCOE, and avoid obsolescence and other commercial/market barriers. 3) Partnership with industry is important for success in these type of projects.

**Reviewer 2:** 1) Technology-to-market. 2) External stakeholder. 3) Future work.

**Reviewer 3:** 1) The project is being executed well and is ahead of schedule. This is a possible advantage of the full team belonging to a single organization. 2) The above should be weighed against the benefits from teaming with other stakeholders, especially for industry and especially for projects for larger scope and more funding. 3) As with all solar inverters, costs are coming down constantly and efficiencies are increasing.

# Soft Costs

# List of Reviewers

**Ben Airth**, Center for Sustainable Resources

**Harshul Banthia**, Offset Renewables

**Gilbert Campbell**, Volt Energy

**Marni Carroll**, One Energy Renewables

**Danielle Deane-Ryan**, Nathan Cummings Foundation

**Josh Earn**, National Housing Trust

**Isabelle Hazlewood**, CT Green Bank

**Luther Jackson**, NOVA Workforce

**Brian Jones**, Center for Sustainable Resources

**Philip Jordan**, BW Research

**Richard Keiser**, Common Energy

**Jacqueline Patterson**, NAACP

**Mary Ann Ralls**, National Rural Electric Cooperative Association

**Noah Shaw**, Hodgson Russ

**MJ Shiao**, Arcadia Power

**Karen Wayland**, kW Energy Strategies

# Analysis Methodology

Reviewers had evaluation criteria for each project and scored them on a 1–6 scale:

**1** – Strongly Disagree

**2** – Disagree

**3** – Slightly Disagree

**4** – Slightly Agree

**5** – Agree

**6** – Strongly Agree

In addition to numeric scores, reviewers were asked to provide qualitative comments and feedback to justify the scores awarded to projects. Other criteria only required qualitative feedback.

# Project Evaluation Form

**1. The project's goals, approach, and expected impact:**

a. Align well with this topic's goals and support SETO's mission (1-6)

b. Set critical challenges to overcome (1-6)

c. Implement a high-risk, high-impact approach (1-6)

d. Match well with the level of DOE funding and planned project duration (1-6)

e. Add significant value to existing research outside DOE-funded efforts (1-6)

f. Advance the US solar industry substantially (1-6)

*Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.*

**2. Based on performance to date, the project team:**

a. Meets important milestones within reasonable timeframes and budgets (1-6)

b. Measures impact appropriately (e.g. quantitative) (1-6)

c. Disseminates results frequently and actively engages partners (1-6)

d. Collaborates with sufficient stakeholders (1-6)

*Using the above criteria, please summarize the performance of this project in 100-200 words.*

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

*Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.*

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

# Project Reviews

Independent review is an important part of SETO's overall portfolio management process, as it provides alternative viewpoints from leaders in industry and academia on current project activities and strategies. Reviewers who participated in the virtual peer review evaluated projects by assessing project reports and posters written by each project's principal investigator. Any questions about the project were addressed via email exchange between the principal investigator and the reviewer. Each project was assigned two or three reviewers.

Below, you will find a list of the projects reviewed organized by track and topic. Projects are alphabetized by the awardee name and represented in the following format:

**Project Title – Funding Program, Amount Awarded**

*Awardee Name | Awardee Location | Principal Investigator*

Project Description

Project evaluations completed by reviewers are found after the descriptions.

# Solar Energy Access

## Developing Socially and Economically Generative, Resilient Photovoltaic Energy Systems for Low- and Moderate-Income Communities: Applications to Puerto Rico – $1,215,891

*Arizona State University | Tempe, AZ | Principal Investigator: Clark Miller*

The project team is developing innovative approaches and models to enable Puerto Rico's low- and moderate-income communities to better understand how they can use solar energy to improve resilience and energy affordability. The team is analyzing and modeling different approaches for expanding solar energy access, including household, business, community, and utility-based solar solutions. Researchers are mapping the solar opportunity for low- and moderate-income communities in Puerto Rico and conducting deeper analysis of specific representative communities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 6 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 6 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Conceptually, this project has a lot of potential as it focuses on a critical constituency to advancing the goal of expanding solar access. It also aims to explicitly provide co-benefits, namely poverty alleviation. Furthermore, it focuses on a unique constituency in the United States given the myriad special circumstances in Puerto Rico and the extensive needs. By identifying solutions that work for the LMI community in Puerto Rico, this project's success could have a significant impact on providing findings that can form the basis for scaling models that expand access in Puerto Rico and the findings can be transferrable and customized to areas that share similar attributes in the United States. Though the impact is potentially quite high, I wouldn't necessarily say that the risk is high with the exception of the fact that if the blind spots are not addressed, the value of the findings could be compromised. The costs seem commiserate with the planned activities and outputs.

**Reviewer 2:** One critical strength is the projects ability to drill down on how to create resiliency for LMI communities particularly ones that annually face natural disaster challenges. Siting may be an issue as the project matures to the installation phase.

**Reviewer 3:** Project has focused but multi-faceted approach to tackling LMI in specific geography. Plan is well thought out to determine need and opportunity and help create accesses for LMI in PR with obvious potential to replicate findings to LMI communities in other parts of the country.

2. **Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 4 |
| Collaborates with sufficient stakeholders | 4 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Besides the setback in the NREL component of this project, having accomplished the 100+ interviews reflects good progress in meeting milestones and budget spend down appears appropriate. The sharing of the early findings and the analysis that went into that sharing demonstrates good dissemination. It's unclear if these results were fed back to the interviewees...if so, this would be even better. While the fact that this centers interviews with community is promising, the emphasis on business leaders, industry and policy makers with all others relegated to a non-specific "other stakeholders" begs the question of who among the LMI community was engaged as critical stakeholders and thus, a determination of sufficiency is challenging.

**Reviewer 2:** This project has performed well after its first year of operation. They have laid out a tangible hypothesis through the energy-poverty nexus, identified ways in which Puerto Rico's solar ecosystem can be unlocked to help LMI individuals and communities create sustainability and resiliency and bolster wealth. This project has true replicability as it can be applied as a blueprint in LMI communities across the United States and have many of the same results.

**Reviewer 3:** Project appears well organized with strong 2 strong working groups of multiple collaborators. It is unclear how and when information will be shared. No results have been achieved. The goals seem relatively challenging to quantify.

3. **Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: This project has a sound methodology and set of tasks to achieve its outcomes. Mapping the markets, policies, and existing initiatives should be the foundation of any project seeking to scale or expand opportunities. Engaging the community in examining the relationship between energy and poverty and determining solutions are essential to the goal of determining what is socially and economically generative. The only caveat is that the extent to which these tasks truly add unique and important value lies in how the tasks are executed. But at the basic level, the steps are the right ones!

**Reviewer 2:** Score: 6. Comments: It's less about the project's uniqueness but rather its ability to create a blueprint to help undercut social ills, namely the energy burden, and provide LMI customers with opportunities to participate in the solar economy. Receiving benefits through solar can help change not only the financial health of individuals but it also creates a sense of pride in as their choices go beyond the self and extend to beliefs in helping the environment and broader world.

**Reviewer 3:** Score: 5. Comments: The project's split of activities over each 12 month period is well thought out and should position the team to achieve its goals.

**What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The summary is fairly brief and much has to be assumed such as the extent to which the models account for the disaster-prone nature of Puerto Rico. Though the post-disaster context is acknowledged, what are the implications for solar given that further disasters are inevitable? Is the project examining multiple models of ownership from individual to community to utility owned? If so, how does insurance figure into the different models? What are the implications for poverty if a system is installed on a household one day and it blows away the next day given the inevitability of disasters in Puerto Rico?

**Reviewer 2:** The technical consideration of installations in LMI communities could be a critical point to consider. Grid hosting capacity, interconnection and permitting could cause unforeseen barriers.

**Reviewer 3:** None that are obvious.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It would also be ideal to have at least one community-based organization as the language of the project doesn't present communities as having agency and evaluative capacity. Other than engagement with business leaders, industry, and policymakers, the community is predominantly spoken of as an impoverished recipient rather than active agent of analysis, implementation, decision making, self-transformation, and a collaborator in evaluation of efficacy. If the aim is to address poverty in an enduring way, it would be ideal if, in addition to the current partners, there was a partner who was explicitly focused on economic development, including workforce development. Though there is an entity focused on poverty and this is important, anti-poverty tends to be a deficit model with limited aspiration and limited expertise in building financial security and wealth for sustained change.

**Reviewer 2:** This project considers the multitude of stakeholders that are critical to the project's success both from a top down and bottoms up approach. From the community members to industry stakeholders, governmental entities and educational institutions, this project has the necessary stakeholders to deliver on the objectives.

**Reviewer 3:** All seem strong, unclear if there is a community based group working with the team.

**What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Appreciative of a project that focuses on Puerto Rico and the need is so great.

In the vein of community participatory research and sovereignty, I strongly recommend that a community group should be a main partner in the initiative. It would be good to have more clarity around the ownership and financial liability/risk aspects.

**Reviewer 2:** 1) It moves the needle on how LMI communities can gain access to solar energy. 2) Utilizes the appropriate team members and stakeholders. 3) Thought through the steps necessary to provide robust data for analysis leading to appropriate implementation.

**Reviewer 3:** 1) This is very important work and the exact kind of thing SETO should be funding. 2) Notable that the project's focus on LMI is the forefront of the work being done. 3) Having ultimate goals of implementation or plans for implementation would be beneficial.

## Bringing Low- and Moderate-Income Solar Financing Models to Scale – $1,103,239

*Clean Energy States Alliance | Montpelier, VT | Principal Investigator: Warren Leon*

There have been several pilot and small-scale efforts to tackle the challenges of financing low- and moderate-income solar energy projects, but there hasn't been a multi-state or regional initiative. This project researches three new solar program designs and associated financing models to expand and scale solar access to low- and moderate-income single family homes, mobile homes, and multifamily homes. The project focuses on analyzing the outcomes of these newly piloted business models and, when appropriate, assessing how they could be scaled to multiple states. Specifically, the team is analyzing: the Connecticut Green Bank model to serve low- and moderate-income single family homeowners; the New Mexico state model to develop "Photovoltaics on a pole" prototypes that can be inexpensively manufactured and installed widely at mobile homes; and the Clean Energy Group model to work with affordable housing organizations to use non-government funded loan guarantees and other strategies to finance solar and solar plus battery storage for multifamily affordable housing buildings.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Plan is based on a model and city that had very successful implementation in an LMI community and commitment to equity. Demand from the states where support is being offered is clear. Project team brings together a diverse set of stakeholders in the public, private, NGO and philanthropic sectors, and includes partners with significant experience engaging with LMI community concerns. We need to see more of this at DOE and the national labs so there will be significant lessons to share. Weakness: This is an impressive team of partners and I don't see major weaknesses. It would be good through to address the lack of clarity around estimates of how many dwellings will be complete by the end of the project timelines. It's not clear whether communications expertise is lined up to ensure states and LMI community stakeholders who are under-resourced will be able to digest the lessons learned in an accessible way.

**Reviewer 2:** This project aims to build upon learnings from a prior SETO-funded project that supported six states (including the District of Columbia) to develop and implement LMI solar programs. Specifically, this project aims to scale a successful model from Connecticut, continue to investigate solutions for manufactured housing, and explore an improved financing model for affordable multifamily housing. Overall, I believe that these are all important areas to explore in improving access to renewable energy, and that the peer-to-peer learning, and replication of successful models between states is an effective approach. The project seems well-positioned to have a significant impact and is clearly aligned with SETO's objectives for reducing soft cost and improving access for LMI communities.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is young (6 months) but already has seen success in states wanting to engage after early outreach. It is a good milestone that the project is seeing outstanding participation in outreach activities like a webinar about its pioneering partnership with the Kresge Foundation. It is groundbreaking to have a foundation of Kresge's size and prestige join as a loan guarantee partner. If this prompts a meaningful jump in the philanthropic foundations contributing to advance LMI solar, the long-term impact could really be a game changer, both in terms of resources and the reputation of the viability LMI solar. Additional clarity is needed about installations expected within the project period. The project write up notes that "Because it takes time to help these entities to initiate LMI solar programs, the number of installations in place by the end of the project period will be only a small fraction of the number that will ultimately be installed." It would be good to get a ballpark estimate of what constitutes a "small fraction." Stakeholders and advisors demonstrate greater level of diversity and experience with LMI communities than is typically seen in the SETO portfolio. It might be good for SETO to consider using its convening power to discuss best practices on stakeholder engagement and rigor on equity analytics

**Reviewer 2:** This project only launched a few months ago, so it is difficult to comment on how well it has achieved milestones and measured impact, especially with the limited materials provided. Based on a conversation with the PI, it sounds as if this project has been successful at garnering interest from other states, and that working group meetings were ongoing, suggesting that the project is well on its way to success.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Yes. It is a strength that the work disaggregates different subsets of the LMI community and has taken care to find partners that are specialists. Project is also realistic up front about the time that it takes to plan before implementation starts and there will be lessons learned from the process that should also be valuable when disseminated.

**Reviewer 2:** Score: 6. Comments: While I don't have access to a work breakdown structure or description of tasks, the materials provided also seem to describe tasks that are core to achieving the project's objectives, and each has a very specific sector or financing model it addresses. There doesn't appear to be redundancy between the focus areas, or extraneous research that may not contribute to the core project objectives.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Communications with, and outreach to, resource-constrained LMI partners needs special attention, and will help generate demands for additional states to pay attention to solar. It's not clear if how communications that will help mobilize energy equity and energy access partners that are not part of typical solar and research networks. It will be important to get rigorous evaluation from the different partners about the process so that lessons can be learned and shared about how different stakeholders are able to engage and the support they need.

**Reviewer 2:** I'm not able to identify any potential blind spots of the PI at this time. There may be value in involving solar industry representatives in the conversations, to get their perspective on what makes for effective LMI solar program design, what type of consumer protection is most effective, and how states can support the growth of a solar industry that effectively serves LMI customers beyond the end of state programs.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Communications experts that have deep experience working with and mobilizing the LMI community and foundations would be valuable. It is important to bring communications experts on early. This will help maximize awareness, provide a channel for feedback from those the project seeks to serve, and increase the odds of getting a jump in the number of philanthropic institutions following the Kresge Foundation's lead. This will help with long term financial sustainability as well getting support beyond the DOE grant period.

**Reviewer 2:** As mentioned above, if the project team is not actively engaging with solar industry representatives, it may be worth looking for opportunities to bring them into the conversation, and gain their perspective on the specific challenges of serving LMI communities.

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Plan to survey the different types of stakeholders about how they think process is going, and to surface different levels of support needed for engagement. 2) Bring communications experts on early who specialize in engaging philanthropy investors and LMI communities. 3) Improved specificity on targets for number of installations by the end of the project period would be valuable.

**Reviewer 2:** 1) This is important work, and should continue to be supported by SETO as long as participating states are actively engaging, gaining value from the process, and implementing LMI solar programs as a result (for the most part, some states may not be able to move ahead with programs). 2) The PI seems to have the right approach to understanding each state's unique circumstances and constraints, and that there is no "one size fits all" solution. Continuing to share the results of this project can help send the message to states that may not have engaged to this point, or considered implementing LMI solar programs, that there are a range of actions they can take based on their available resources and political realities.
3) I'd encourage engagement with the solar industry to understand their perspective, if that is not already occurring.

## State Strategies to Bring Solar to Low- and Moderate-Income Communities – $1,730,000

*Clean Energy States Alliance | Montpelier, VT | Principal Investigator: Warren Leon*

This project works with the state governments of Connecticut, Minnesota, New Mexico, Oregon, Rhode Island, and the District of Columbia to provide technical assistance necessary to develop and implement strategies for expanding the amount of solar available to low- and moderate-income residents and communities. Each participating state is developing goals and plans of action that match its programmatic needs, demographic profile, solar potential, and financial resources.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 |
| Set critical challenges to overcome | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project appears to have achieved significant success in helping five states and Washington DC to identify and implement LMI solar strategies that are well-suited to their particular needs. Beyond the general challenges associated with LMI solar adoption, the project didn't seem to necessarily establish clear challenges for these states from the onset, but rather helped the states determine what they wanted to achieve with their LMI solar initiatives. The success of this project has translated into an additional DOE-funded project, engaging with 13 states and looking to replicate a number of successful LMI solar initiatives. Overall, it seems that these projects are making significant progress, with a relatively modest budget amount, to advance LMI solar throughout the US.

**Reviewer 2:** Strengths: Project aims for widespread collaboration across multiple states which allows for collaborative problem solving and learning. Each state was allowed to define specific mechanisms best suited to its market, providing proof of concept for multiple potential approaches to be replicated in other states. Solutions developed were programmatic in nature, allowing for scaling and replication. Participants from each state are key stakeholders, allowing for significant progress to be implemented. Sole focus on LMI solutions allowed for targeted programs vs creation of generalized programs with LMI carve outs Weaknesses: Programmatic implementation of developed solutions to new states will required high degree of ongoing technical assistance and government funding (i.e. not a market driven program).

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Despite encountering some obstacles, this project seems to have met its major milestones on time. While the project highlights some notable achievements by participating states, such as Connecticut's Solar for All campaign, it is difficult to ascertain exactly what the quantitative impacts are from some of the state initiatives. Indeed, many of these initiatives are longer term in nature, and likely have market transformation as part of their goals, so these results are difficult to measure when many of the states are still in the planning phase. This project seemed to do an exceptional job engaging with stakeholders and disseminating results through written reports and webinars.

**Reviewer 2:** Project report states that all team members were in constant interactions with monthly calls in addition to ad hoc communications. While the project goals were not quantitative in nature, the resulting programs that were implemented are tangible evidence of the work initiated and supported through the process. Deliverables including reports and webinars were included as links in the project report.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: From the material provided, I cannot see each of the tasks for this project, however the work described in the provided materials all seems to be related to the core project.

**Reviewer 2:** Score: 5. Comments: All tasks conducted were not specified in the report, however the coordination role by the PI would have been necessary and important when trying to collaborate across a diverse group of participants. Each task by the individual state participants were not specified either, but the end result was a number of programs implemented which benefited LMI populations in different ways.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** In reviewing the material provided and speaking with the PI, no obvious 'blind spots' occur to me. The PI seems to have a very strong understanding of the diverse needs and constraints of different states, and is flexible enough to help them identify and implement pragmatic solutions.

**Reviewer 2:** The PI's role was management and coordination, while allowing each state to develop innovative solutions, there does not seem to be a major blind spot in this approach.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The PI seems to be engaging with the right stakeholders and organizations, and specifically discussed the importance of engaging with community-based organizations that advocate for low-income rights and environmental justice. Further engagement with solar project developers and/or industry associations may add value by helping participating states understand how they can craft programs that are more likely to 1) induce healthy competition among solar developers, and 2) build the foundation for a solar industry that can continue to serve LMI customers beyond the end of state programs, or through the phase-out of incentives.

**Reviewer 2:** The participants were predominantly government/government related entities. For a wider approach to LMI problem solving, the inclusion of financing entities and development entities could be beneficial for expanding the range of solutions developed.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The PI appears to have leveraged vast knowledge of the solar industry, and exhibited an important degree of flexibility in helping the six participating states (including the District of Columbia) to develop LMI solar programs. The PI is well aware that there is no "one size fits all" solution for states. 2) As long as states continue to find value in this type of peer-to-peer learning, and it results in many participating states implementing LMI solar programs, this is an area of work that SETO should continue to support. 3) Additional input from the solar industry may be useful in helping participating states to understand the kind of signals industry is looking for from LMI solar programs, and how to ensure programs result in high quality installations, strong customer protections, and contribute to the development of a solar industry that continues to effectively serve LMI customers beyond the end of the program.

**Reviewer 2:** 1) Broad ranging collaboration on specific topics, with major regional stakeholders provides significant value to the industry by allowing program development meant to impact whole populations. 2) The novel approach to allowing each state autonomy to structure its own program resulted in a grab bag of models, each with pros and cons, and allows for further study and refinement. It also allows new states to choose from a menu (or develop their own) programs. 3) Further projects of this nature should be encouraged to create programmatic solutions to existing challenges.

## An Online Marketplace that Allows Consumers to Comparison Shop for Solar Equipment, Financing, and Labor, Independently – $1,599,839

*EnergySage | Boston, MA | Principal Investigator: Vikram Aggarwal*

This project applies best practices from online shopping in other industries to the solar shopping process to lower customer acquisition costs and the installed price of solar photovoltaic systems. The approach focuses on scalable online tools that facilitate consumer decision making, while streamlining the sales process for suppliers. By adopting best practices from other industries, this project aims to better align the consumer experience with consumer expectations, reduce customer acquisition costs, and increase solar deployment.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project aims to fundamentally disrupt the solar buying experience for homeowners by allowing them to conduct a significant amount of research on system size, components and pricing prior to engaging with an installation contractor. It requires the type of customer who is willing to make that kind of investment of time and energy, as opposed to a customer who simply wants the contractor to design a system for them, so it will be limited in its impact in that way. Nevertheless, providing additional transparency into pricing along the supply chain, while allowing customers to self-educate and reduce the amount of education that has to be done by contractors represents an opportunity for significant reduction of soft costs, and an improvement in customer financials when purchasing their system. While this project clearly contributes to reducing soft costs, it is less clear how it benefits “Solar Access”, particularly for LMI customers. While it is certainly feasible that an LMI customer could use the tool, it is more geared towards purchased or financed systems, as opposed to third-party owned systems, which are more likely to be suitable for an LMI customer who is not able to purchase or finance a system.

**Reviewer 2:** Unique and useful idea and important tool. Given complexity of the product, it doesn’t seem clear that it’s increasing access to solar energy, so much as reducing costs for average and above average incomes. No mention of LMI households at all.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project appears to have performed well, meeting key milestones on time, and capturing some important learnings along the way, such as the challenges involved with multi-party fulfillment, and constraints on the part of manufacturers providing prices of equipment. This project aims to disrupt the typical solar buying experience, so these types of challenges are expected. The project has done a good job of quantifying the impact on reducing customer acquisition cost, which is an important component of soft costs for solar projects.

**Reviewer 2:** Goals appear to have been met and larger numbers of both consumers and companies have been engaged with. No analysis of data included.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The milestones seem to progress logically, and add value to the overall project. Other than that, I don’t have enough insight into the project workplan or tasks to provide meaningful feedback here.

**Reviewer 2:** Score: 5. Comments: The 5 go/no-go milestones were well thought out and consistent with goals of bring the product to market.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** As noted above, the product developed through this project does not appear to benefit LMI customers. Higher income customers are a huge segment of the market, and can clearly benefit from this product if they are willing to invest the time into researching an unbundled solar PV offering. Some of these benefits of increased transparency may trickle down to LMI customers, but it's not apparent how, especially with third-party owned systems.

**Reviewer 2:** The biggest question seems to be who is truly benefiting from the software? Also from an access to solar lens, is there anything that will ensure the customer acquisition cost savings get passed to the consumer?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Considering the PI's expressed opinion that EnergySage should move away from trying to solve fulfillment issues, I believe they are engaging with the right stakeholders. If they were aiming to directly address the fulfillment issues that have arisen during this project, then I believe they would need to engage more actively with various supply chain stakeholders to develop a workable model.

**Reviewer 2:** LMI individuals. Also unclear who target consumer is, and therefore difficult to know if appropriate stakeholders, especially on financing are being engaged.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) For a certain subset of general market customers, this tool is hugely valuable, and is truly disruptive to how solar PV systems are currently packaged and sold. 2) For general market customers that prefer a bundled solution, and, in particular, for LMI customers, the value of this product is less apparent. 3) The PI's shift in focus away from solving fulfillment issues feels like the right direction for this product.

**Reviewer 2:** 1) Zero in on target consumer and what consumers will benefit. 2) Consider data analysis and confirm set up is best option for consumers. 3) Dive into whether cost savings are truly providing access for additional consumers.

## Revolving Program Related Investments Energy Savings Fund – $999,470

*Grid Alternatives | Washington, DC | Principal Investigator: Jacob Bobrow*

This project is designing, building, testing, and scaling an innovative financing and project-development model that could expand photovoltaic access to low- and moderate-income Americans. The model, which incorporates new sources of capital, aims to lower solar electricity costs and reduce creditworthiness as a barrier of entry, particularly in the development of multifamily rooftop and ground-mounted community solar projects that are 50-500 kilowatts.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project represents a high-risk, high-return approach to attracting additional capital for financing of LMI solar on terms that stand to greatly reduce customer utility bills, render projects feasible that might not normally go ahead with conventional debt/tax equity financing, and result in more installed solar that benefits LMI customers. Leveraging PRI as an underutilized source of low-cost capital for projects whose outcomes align with those of philanthropic institutions, while simultaneously de-risking investments for conventional debt/tax equity investors is an innovative, and potentially highly impactful approach.

**Reviewer 2:** Strengths: Project team has significant experience in LMI solar development. Quantifiable milestone targets identified including MW of solar and PRI capital commitments, some already achieved by first milestone date. PRI fills gap for LMI financing that traditional financing markets cannot provide, while remaining an investment (i.e. not a grant/donation). Weaknesses: Unclear how project results will be open sourced with the industry as a whole as justification for federal funding. Uncertain whether foundations will follow standardized financing model without bespoke requirements. Equity capital as part of the capital stack is omitted, unclear how the project equity is being sources/integrated.

**Reviewer 3:** This project presents a very promising model for streamlining investment in LMI solar projects. The solar access hub has the potential to significantly simplify the process of investing in LMI solar projects for foundations, and standardize investment terms and processes more broadly. However, streamlining and standardizing processes with a wide variety of stakeholders is inevitably challenging and there is a risk that the platform may not be able to independently satisfy the needs of all parties.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project is relatively new, but has met its milestones to date. The PI mentioned longer than anticipated timelines for project development, as well as the impacts that the COVID-19 pandemic has had on project timelines, but they do not seem to have encountered issues in the core activities of engaging with stakeholders and raising an initial tranche of PRI. I would be more concerned with the project's ability to advance on schedule if they had struggled to raise the PRI, or were not successfully engaging with philanthropic institutions, which does not appear to be the case.

**Reviewer 2:** Project has achieved initial milestones including v1.0 of the platform and securing tax equity and PRI capital for its initial projects.

**Reviewer 3:** The project team appears to be moving forward on schedule and within budget, while also attracting significant interest and support from stakeholders. They have already developed an initial version of the online platform and secured initial funding for project development. The project looks to be on track to meet all of its goals and milestones.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: I don't have a clear task breakdown in the materials provided, but the general progression of activities seems to be logical, and build upon the previous set of activities.

**Reviewer 2:** Score: 5. Comments: The tasks for this project are additive, and the milestones are based on tangible progress towards solar installation and capital deployment.

**Reviewer 3:** Score: 6. Comments: The project is well organized and appears to be adequately working on all topic areas needed to achieve the ultimate project goals (i.e. legal, technical, IT, R&D, stakeholder engagement, fund raising).

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Working with a diverse group of charitable organizations may cause issues that the PI hasn't anticipated or accounted for. For example, some institutions may have programmatic requirements outside the confines of LMI solar, and want projects that they fund to have additional benefits or social outcomes - it may be difficult to accommodate this within a narrowly defined LMI solar project.

**Reviewer 2:** Equity capital has not been mentioned in the project report or poster diagrams, need to ensure full capital stack is being represented.

**Reviewer 3:** Standardization is always a challenge, no matter the industry or participants. While the PIs mention challenges with respect to how foundations typically make PRIs, there may also be challenges in getting buy in from all stakeholders to accept the standardized approach the platform offers. It is not clear how well the platform and processes established as part of this project will meet all parties' standards for due diligence, return or other custom standards they may have.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I don't see that any critical stakeholders or collaborations are missing here. If the model is successful, they may run into certain limits, for example caps on community solar MW in certain states, that could hinder additional growth. In that case, it may be necessary to engage with PUC or similar regulatory bodies to ensure that these caps don't stunt the continued growth of projects.

**Reviewer 2:** The report mentions engagement with legal experts, for the level of new financial structuring and negotiation, a legal firm should be a major participant in the project.

**Reviewer 3:** If the goal of the project is to develop a platform that can be used by multiple solar developers to connect to financing for LMI solar projects, the project team should consult other developers to make sure the platform meets their needs in addition to foundations as these stakeholder needs may be different.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) This is a high-risk, high-return type of project that has the potential to unlock large amounts of private financing and charitable foundations funding for LMI solar. 2) The project team should work to ensure active engagement with charitable foundations, and attempt to quantify the potential scale of impact - i.e. how many MWs of solar, how many LMI customers could benefit, etc. 3) Standardized documents may still need to be flexible to accommodate specific needs of foundations providing PRI.

**Reviewer 2:** Project focuses on making non-viable LMI projects financeable using a non-traditional financing source which is conceptually already mission aligned, allowing the project both get built as well as refinanced after proving concept and financial performance. Project has clearly defined tangible goals they can be held responsible for, and has already achieved some success by the first milestone. Dissemination of the financing structure details, relevant PRI investor contacts, and suite of legal documents will be key to making the project results open source and useful for the industry as a whole.

**Reviewer 3:** 1) The project has the potential to significantly transform how investors and in particular foundations contribute to LMI solar projects. 2) The project has the potential to significantly reduce soft costs. 3) There is a risk that not all aspects of solar project and fund development will be able to be streamlined to the extent that it can all be handled through the platform.

## Accelerating Low-Income Financing and Transactions for Solar Access Everywhere – $1,499,988

*Groundswell | Washington, DC | Principal Investigator: Michelle Moore*

This project assesses the replicability and scalability of a variety of solar financing models that could enable greater solar access, including: a private finance option similar to a utility credit structure; a “pay as you save” structure that pays for solar with shared savings; and a credit enhancement model that leverages alternative financing like loss reserves offered through foundations, municipal authorities, or public-private partnerships. The team will analyze adoption rates and performance data from ongoing projects, with an eye toward optimizing the models for scale.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 5 |
| Set critical challenges to overcome | 6 | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 4 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: innovative approach to benchmark LMI customer enrollment in community solar programs with established energy efficiency programs. Energy efficiency programs may provide similar financial value to customers as community solar program so to benchmark and/or compare the two might provide unknown data and/or benefits that could be useful to the project team. Weakness: this project is similar in scope and goals as other LMI community solar projects and results may be duplicative.

**Reviewer 2:** Strengths: Creative collaboration between organizations that are all individually impressive and complement each other- to be applauded. Collectively, project partners have relatively diverse leadership and have been attentive to inclusion compared to many in sector and among SETO proposals read. Successful implementation and communications could reverse negative communications narratives about LMI adoption. Financing innovations being experimented with are critically needed as DOE/SETO has made clear that a huge challenge now is reducing soft costs. Potential is high for project to maximize co-benefits for LMI communities AND solar industry. One of best (clearest) project summaries written. Weaknesses: Not clear if data being analyzed is rigorous in disaggregating subsegments of the LMI community to be attentive to equity even within the LMI segment of market. As models and recommendations are developed and implemented, vital to assess if impact disparities are popping up, even if net impact/average impact us positive. Will results be able to analyzed by race, age groups, or rural/urban? Room for improvement on the Research Advisory Council. If one stated goal is community empowerment, not just industry success, it would be good to add independent leaders accountable to LMI communities.

**Reviewer 3:** This project is strong. The goals are essential to solar access and the plan acknowledges the main challenges involved in this work. The team is first rate and the advisory council is strong. The focus on LMI access could not be stronger and clearer. If a weakness must be found, it would be nice to see some thought around ultimate implementation of the toolkit.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** One year into the project, the project team has completed eight tasks, which is substantial. The creation of the Research Advisory Committee is a significant task as it encompasses a robust of stakeholders who will provide a wealth of insight to the project team while the completion of their initial research plan allows them to move the project forward.

**Reviewer 2:** Excellent progress, especially re overcoming data privacy/disclosure challenges to get data needed. Would be helpful to be more specific (quantitative) about the reported "robust participation to date in the project's LMI project finance data call." The Research Advisory Committee (RAC) could be improved by adding one or two more mission driven LMI stakeholders accountable to the community, who work on economic equity, climate justice or something related. This would ensure are sufficient independent eyes on best practices for LMI communities, to balance to financial institutions' representatives since a complementary stated goal is empowering the LMI community. This is not to discount that it is a compliment to the project that RAC stakeholders include utilities, energy service providers, and project finance providers that will be credible with organizations needed to take project to scale.

**Reviewer 3**: The project has already achieved several of its objectives and appears to be on track to succeed in achieving all benchmarks. The challenges identified and overcome are likely to help them to continue to perform as needed.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The project tasks fall within a blueprint of typical grant funded research projects. No one task is necessarily unique but they are additive to each other. However, the task aimed at creating a tool kit that is designed for use and application by stakeholders is too abstract and should have a more defined purpose.

**Reviewer 2:** Score: 6. Comments: Yes. This is a complex undertaking quantitatively, as well as in terms of number of partners to be managed, together with ambitious goals for like developing a tool kit, communications and wanting to see adoption in 20 states. Project is still relatively young and progressing steadily.

**Reviewer 3:** Score: 6. Comments: The work plan is well thought out and the components of the primary objectives are likely to lead to successful outcome.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Understanding the preferences of LMI customers is critical to gaining insight into what type of financial and enrollment models will work for them but it's also important to consider the preferences of financial institutions and banks to help determine a middle ground of what solutions will work.

**Reviewer 2:** Since project aims to benefit LMI customers, hope project partners might consider adding leaders, who are independent of the project partners organizations, and accountable to LMI communities who are mission driven to improve economic equity, and understand best practices for disseminating actionable information for LMI communities. Also in the datasets and modelling and impacts, will be important to be rigorous about disparities even within LMI cohorts (race, age cohorts, rural/urban). It is worth noting that this is a collaborative group that has already demonstrated concern on equity and inclusion issues. Congrats for instance to Groundswell on last year's Nov. 19th report "Solar Empowers... Some" report, and to Clean Energy Works for its rural focus and Pay As You Save (PAYS) work.

**Reviewer 3:** The PI appears not to have any obvious blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** While the Research Advisory Council is made up of a broad group of stakeholders, including financial institutions, having a bank or another lending institution that has experience with community solar projects and financing could have bolstered the project team with the experience of a critical player in this market.

**Reviewer 2:** Emphasizing a consistent theme in this review, since project aims to benefit LMI customers, and to have dissemination/update at scale, it might be good for the RAC to add members that are at organizations that emerged within LMI communities. These could be climate equity policy and or economic equity leaders who are starting to look more at the clean energy economy. Not clear if any CDCUs (community development credit unions) looking at EE/RE are in the mix, as one potential example. It is understandable that project needs the brands of the industry heavyweights currently on the RAC to increase credibility of recommendations among finance community. But the RAC could be more balanced. This is important for communications and replication beyond the project's targets as well. It will be important to ground truth recommendations that will be developed about improving customer experience with LMI community leaders, and likely will lead to more creativity on the dissemination end, to increase odds of replication and scale.

**Reviewer 3:** The team itself and the research advisory council are extremely strong and represent a wide swath of the landscape of people who do this work and can influence it. The one missing group is some of the more non-traditional financing sources for this kind of work including community development finance institutions. It's also worth considering if more representation of the communities they aim to serve would be helpful on the RAC. That being said, the participants themselves likely can serve the capacity.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Benchmarking LMI community solar customer data with LMI participation in energy efficiency programs is novel and may uncover results that are unique and useful to community solar research. 2) Attempting to understand preferences of optimal finance and customer finance models for each utility service type can be a large overwhelming task. Perhaps focusing on the utility environment that has the most barriers of community solar, could benefit the project through a tighter focus. 3) This project is similar in many ways to previously funded projects. Coalescing projects around specific themes could be more appropriate.

**Reviewer 2:** 1) Congratulations on pulling together an impressive collaboration between diverse project partners and the RAC to focus on such a critical issue! 2) Consider beefing up the RAC members that have delivered for LMI communities and that are independent (not conflicted by being one of the project team members). It will help to prevent blind spots and likely improve communication effectiveness. 3) As experiments and implementation moves forward, be rigorous on breaking out the LMI results in the analysis by demographic group. This will make sure net improvements don't hide disparities. Within LMI communities, even controlling for income, there are likely to have important distinctions by demographic group (e.g. ethnicity, age groups, rural/urban). It would be good to catch these early.

**Reviewer 3:** 1) Truly excellent project and model for SETO. 2) Are their other people who would strengthen the already strong RAC? 3) Is there more than can be done to lay the ground work for adoption and implementation of the tool kit.

## Activating Opportunity Zones for Rapid Solar Plus Storage Deployment in Low- and Moderate-Income Communities – $500,000

*Houston Advanced Research Center | Spring, TX | Principal Investigator: Gavin Dillingham*

This project is developing a cost-effective solar financing program in low- to moderate-income opportunity zones in the underserved Texas deregulated power market to accelerate solar deployment. The project plans to research and develop new ownership and financing structures, leveraging opportunity zones, to increase the accessibility to solar energy among low-income communities.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 6 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** If this project team can crack the nut on using opportunity zone tax benefits for low income solar it could have significant implications for development of solar in low income communities nationwide. This project has the potential to develop new financing models for low income solar plus storage projects that may be able to be replicated elsewhere given similar market conditions.

**Reviewer 2:** This is an excellent project with solid, aspirational goals that, if accomplished, will add significantly to the field of solar development by demonstrating a feasible approach to overcoming financing, as one of the biggest barriers to LI household access to solar. The goals of the project are directly in-line with the access goals of SETO and the project duration and resources are commiserate with the intended outcomes. The two ways that I can see the contribution and impact enhanced are by: 1) Defining equity beyond income as some communities/households can be higher income and low wealth, which would also result in access challenges. Does that change the approach? 2) Ensuring deeper, more enduring financial co-benefits by piloting a model where communities aren't just leasing in perpetuity but financing towards ownership.

**Reviewer 3:** Strengths: Project incorporates multiple topics to address, leading to greater chance that even partial progress can produce tangible long term benefits to the industry. Outside of real estate, not many QOZ investment opportunities exist, solar could be attractive alternative and thus bring in much needed lower cost of capital to LMI projects. QOZ solution is replicable for a large number of LMI communities. Financial structure solutions can be replicated and scaled easily by large funds. Financial team has requisite experience to be able to understand and navigate challenges. Weaknesses: This project is ambitious and complex, adding risk in achieving the stated goals. Starting with an OZ solution for solar standalone may have been an easier approach to start with and implement, with complexities and costs of storage financing to be addressed in a future phase/project. Basis step up for deferred gains exists only until the end of 2021 which eliminates some of the benefits before this project completes, though the 10-year deferral for new gains still applies. Texas economics may not be replicable in other states. Project could have been more impactful if the team also committed to specific installation goals and creation and funding of a QOF within the 2-year project timeline.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has ambitious goals within a relatively short amount of time, but seems to have a reasonable budget. The project team may not be able to meet all of its goals within budget period, but if achieved the project could have significant impacts. The project team could benefit from additional collaborators in the financial services industry.

**Reviewer 2:** The projected scope of work is substantive and ambitious, in a good way. As there is no performance to date, I can only speak to what's planned. The PIs have done a good job of identifying several key critical challenges that, if overcome, will go a long way towards advancing critical barriers in the industry and capitalizing on a widely available financing opportunity, Opportunity Zones. It would be good if there were additional modalities for results dissemination that ensured that this information reached frontline organizers. It would also be good if the stakeholders explicitly included frontline communities, groups representing marginalized constituencies, etc.

**Reviewer 3:** This project just started in March 2020, therefore there is no track record yet to comment on.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: All of the project tasks and objectives appear to contribute to the overall goals of the project but it is unclear whether the goals of the project could be met without necessarily solving all aspects of the project. For example, could OZ incentives enable the deployment of low cost solar + storage without blending onsite solar with utility-scale solar? The team may want to explore whether certain aspects of the proposal could achieve the project goals independently, while combining them could achieve deeper savings, or whether it is necessary for all components to be present in order for the model to work.

**Reviewer 2:** Score: 6. Comments: This project brings a unique examination of a finance mechanism which by design differentially engages low income communities. As such, it has enormous potential to bridge the well-known access gap with low income communities.

**Reviewer 3:** Score: 5. Comments: QOZ financing structures are still being developed, and have not yet been widely adopted by the solar industry. The effort to develop a replicable structure, especially as there will be large overlap with LMI population, enhances LMI access to solar at a lower cost of capital. Solar + storage is still expensive, and will require creative solutions to be able to implement for LMI communities.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** While OZ incentives may entice new investors to participate with a lower cost of capital, there is little mention of the perceived or real risks of developing solar plus storage projects that serve low income households. The PIs should give some consideration to whether these risks will deteriorate capital cost savings provided by OZ benefits.

**Reviewer 2:** From reading the fairly brief summary, there appears to be a lack of consideration of longer term co-benefits of individual/community solar infrastructure ownership, which would not only strengthen resilience but for some it would also serve as a greater incentive.

**Reviewer 3:** The project report touches on most of the points required, and as this project has not yet started, there is limited information to be able to comment on any blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Low income and equity advocates should be involved in the conversation to ensure the ultimate model/product developed by this project meets the needs of the low income population in Texas.

**Reviewer 2:** Consumer/constituency-based groups should ideally be involved at the partner level to enhance identification of engagement strategies and to structure pathways to individual/community ownership.

**Reviewer 3:** Key collaborators that could be added (and perhaps the team will engage with after the project has started) are: - Legal firms with expertise in solar + storage and QOZs. - Local LMI representatives and community organizations – these are always critical for community feedback and acceptance

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) If successful this project can unlock additional incentives via opportunity zones that can reduce capital costs for LI solar + storage projects. 2) The project team should engage low income organizations to ensure that these potential investments provide tangible benefits to the community. 3) The project team should investigate whether parts of their model can achieve solar plus storage deployment in low income communities without necessarily combining all aspects of what they are proposing.

**Reviewer 2:** The three areas that could bear improvement are: 1) Engagement of consumer/constituency based groups at the partner level; 2) Integration of enduring wealth building as a resilience strategy and enhanced incentive through a lease to own model; and 3) Expansion of modalities for results dissemination to ensure that this information gets in the hands of frontline and constituency based groups.

**Reviewer 3:** 1) Project is complex and has multiple avenues of moving the industry's knowledge forward for financing solar + storage, which is beneficial even for a partial solution. 2) QOZ solutions overlap with LMI communities, adding additional incentive to increase deployment in these areas, but QOZ benefits will continue to step down over the next few years.
3) Solutions are most powerful when implemented, focus on how to ensure the project results in tangible installations as case studies and QOF fund creation.

## Developing and Piloting Solar Financing Models to Expand Photovoltaic Access to Low- and Moderate-Income Americans – $999,935

*International Center for Appropriate and Sustainable Technology | Denver, CO | Principal Investigator: Ravi Malhora*

This project partners with utilities, multifamily affordable housing projects, and private investors to create and validate an aggregated shared solar financing model. This financing model aims to reduce project costs and risks, which has prevented multifamily affordable housing projects solar development.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 5 |
| Advance the U.S. solar industry substantially | 3 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The strength of this project is that it has identified a way to deliver the benefits of solar to tenants of qualified low-income multifamily properties by offering savings that amount to a minimum of 20% utility bill savings. Another strength, if it comes to fruition, lies in the projects ability to get utility by-in on the installation of solar that provides direct customer benefits. However, while this is beneficial, weaknesses lie in the fact that this is solar installed offsite and on the terms of the utility.

**Reviewer 2:** If successful, this project offers a potential alternative model that could result in significant deployment of solar PV on multifamily affordable housing, but advancing the solar industry while also reducing utility bills for LMI customers. While these reductions may be relatively modest, they are certainly better than a counterfactual where those customers never benefit from solar in the first place due to a lack of viable financing mechanisms, or inability of state and local governments to heavily subsidize solar installation.

**Reviewer 3:** The multifamily market has traditionally been a "hard to serve" market, particularly for individually metered buildings and 1-4 unit properties. The idea of aggregating demand from affordable multifamily housing providers has the potential to lower development costs and increase the financeability of these projects. However, there is a risk that aggregating demand via multiple behind the meter projects will not necessary equate to economies of scale and actual costs reductions, this model may only be suitable for markets with some form of community solar or virtual net metering available to multifamily property owners and tenants.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 6 |
| Collaborates with sufficient stakeholders | 4 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** To date, the project is in budget period 1 and has 2-3 sites for their pilot project is standardizing the process for aggregating solar and storage into one financial portfolio.

**Reviewer 2:** This project is relatively new, and appears to be meeting its milestones, based on the information provided. t is difficult to tell at this point how well they are disseminating results, as they are still in the early stages. It seems as if they are collaborating with a diverse set of stakeholders, and have the right people in the room to develop this financing model.

**Reviewer 3:** The project team has met a large number of milestones in the first year of operation, including securing agreements to participate in pilot projects with several utilities and MFAH providers. The project team engages a wide variety of relevant stakeholders and partners and has produced several case studies in BP1 of the project.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: This project is more of a demonstration project that is proving a business model of offsite solar and storage aggregation that benefits discreet deed restricted MF properties. At its completion, it should provide unique value in filling the void within a niche market that does not use Virtual Net Metering, a proven method to deliver solar to deed restricted MF properties.

**Reviewer 2:** Score: 5. Comments: As far as I can tell, all of the tasks described here add unique and important value to the project.

**Reviewer 3:** Score: 5. Comments: The project tasks build on each other in order to achieve the projects ultimate goals. The analyses conducted as part of the project are necessary to determine the feasibility of the model and location-specific projects, however the analyses may not necessarily be valuable to others looking to replicate the model in other contexts.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** If utilities are unwilling to own projects, the business model falls apart.

**Reviewer 2:** It is unclear to what extent the PI has consulted with tenants of MFAH, and how willing they are to participate in this type of project. I understand that the model would be designed as an "opt-out" scenario for the tenants, and that the shared solar would be tied to a meter, not an individual, however it still seems as if there needs to be some sort of engagement with tenants/customers, if for no other reason than to make them aware that they are benefiting from renewable energy and experiencing lower bills.

**Reviewer 3:** Whether sited behind the meter or in front of the meter, it appears that this project relies on some form of virtual net metering/billing policy or shared solar policy to be in place to be successful. This structural requirement may limit the scalability of the project in jurisdictions that do not have these policies.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project could use more insights and input from regional solar associations or directly from MF solar developers.

**Reviewer 2:** If they have not already, engaging with tenants-rights advocates, or low-income advocates could be beneficial in understanding how to engage with LMI customers and/or make them aware that they are participating in, and benefiting from, a renewable energy project.

**Reviewer 3:** The project appears to have a robust team of stakeholders engaged in the project including utilities, MFAH providers, and legal and financial experts. The team may also want to engage low income advocacy organizations and possibly policy makers.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Nail down the type of financing to ensure replicability. 2) Have a fall back in the case utilities do not want to participate. 3) Reduce stated MW goals and participating tenant beneficiaries.

**Reviewer 2:** 1) Projects like this one that aim to develop novel financing models for LMI solar projects are high-risk, high-return endeavors that, if successful, could potentially unlock significant access to capital. 2) Even if the model aims to avoid direct one-by-one enrollment of tenants, it feels like there needs to be some form of tenant engagement. 3) If successfully piloted, it would be important to understand how widely applicable this model is, or if there are specific drivers of participation for the utilities participating in the pilot project.

**Reviewer 3:** 1) This project is tackling the difficult issue of solar on MFAH and has the potential to deliver unique financing solutions for this market segment. 2) Consideration should be given to whether the goals of this project can be achieved through other means (i.e. community solar). 3) Consideration should be given to whether this approach is scalable in markets without community solar of virtual billing/crediting available to MF properties.

## National Community Solar Partnership – $10,000,000

*Multiple Awardees | United States of America*

The National Community Solar Partnership is a coalition of community solar stakeholders working to expand access to affordable community solar to every American household by 2025. This partnership is developing multi-stakeholder teams to convene around specific goals, provide technical assistance for unique local challenges, and develop an online community platform to support information exchange.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 3 |
| Advance the U.S. solar industry substantially | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Having worked with a couple of communities who engaged in the Solar in Your Community initiative and reading about the scope and scale of the results that mirrored the projects with which I was familiar, I can attest to the potential of this initiative and its deep alignment with SETO's goals. The challenges are many, as outlined in the chart. However, if the project engages the right stakeholders, the challenges can be overcome through sound strategizing. And, in so the solar industry will certainly be substantially advanced. As long as results are well documented and strategically and thoroughly disseminated, again, in partnership in key stakeholders, this can amplify the results. The budget for this project is significant. So are the potential outcomes. With the extreme amount of the budget particularly given the relatively short duration, they PIs must hold themselves to an ambitious and aggressively high standard in order to demonstrate responsible stewardship of such a large amount of taxpayer dollars.

**Reviewer 2:** This project has a lot of potential to help expand community solar nationwide. As someone who has led large low-income solar programs and currently enrolls LMI subscribers in CDG, I would like to add a caution. In my opinion there is an outsized emphasis on inclusion, that risks other success factors. While inclusion of all incomes is a very worthy goal, it should not hold up sensible programs that accelerate access to 70+% of the population. These two goals, including the word "every", are utopian and not achievable: "The program has three broad goals: (1) make community solar accessible to every U.S. household, (2) ensure community solar is affordable for every U.S. household." There are 130MM households in the US and a certain portion of them are too dangerous to serve. A certain portion have and continue to default on all types of payments. The PI did not provide sufficiently discuss an approach to signing up individual LMI households that can be low cost. It is expensive to sign up individual LMI subscribers. This may be difficult to do at low cost at scale on an optional basis. Few options to provide LMI at scale is either (a) opt out programs, i.e., the program is structured as a guaranteed savings program and the utility pushes it to all qualified ratepayers based on census tracts, for example; or (b) signing up housing authorities. One on one, i.e., individual LMI homeowners/renters, one at a time, will never become cost effective. The goal of this program should be to get every state in the country to implement a CDG program that expands access to affordable clean energy. Over-emphasizing "everyone" will drive costs up, not down.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 |
| Disseminates results frequently and actively engages partners | 4 | 3 |
| Collaborates with sufficient stakeholders | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** With a total of $10m allocated to this project over 24 months, I humbly assert that ideally more would have been achieved by now in terms of milestones. I would have preferred to see a more aggressive pace to more swiftly optimize the use of such a large amount of resources. It would be ideal to see quantifiable outcomes set forth beyond goals to establish infrastructure and execute activities. I would recommend metrics with indicators such as # of community solar projects established with support of the information/technical assistance of the project. I would say that the results of the 6 months of the project so far and the collaboration with sufficient stakeholders are connected in that I work with many groups endeavoring to expand access to solar nationwide and none have mentioned collaboration with this project and/or being aware that it is on the horizon.

**Reviewer 2:** It looks like a well thought out plan, referencing comments above.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Each task in this project has tremendous value in achieving the overall goals of the project. The tasks laid out are just the ones that are needed to advance the goals and fill a gap in the overall solar industry, including convening, which is critical and missing, providing technical assistance, which is also critical and missing, and finally, providing an online platform to provide much needed information to groups seeking to learn more and optimize engagement.

**Reviewer 2:** Score: 4. Comments: There are only 5-6 states in the country that have at-scale, or marginally at scale CDG programs. Expanding CDG is a valuable objective because it can be adopted Much faster than residential solar.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It would be ideal to see the inclusion of equity, including explicitly addressing race and ethnicity disparities in access in addition to the existing emphasis on LMI communities. The description does reference "other community-serving entities face significant barriers to affordable solar deployment," but given the extreme racial/ethnic disparities, an explicit, named focus is warranted.

**Reviewer 2:** Per above, over-emphasis on LMI.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Deep and extensive engagement with environmental and climate justice organizations as well as organizations representing and serving racial and ethnic groups.

**Reviewer 2:** Community Solar Service providers must be included. Project developers are fundamentally construction teams. They are fundamentally B-to-B companies and rarely have any experience in, or insights about B-to-C, and what it actually takes to enroll consumers. The servicers--Arcadia, Common, Solstice, PowerMarket--are on the front lines of enrollment and know what works and what doesn't. What drives costs and what lowers them.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Excellent project components with tremendous potential and would benefit from quantifiable access outcomes as well as more aggressive pacing of implementation. Needs more emphasis on equity, including explicit focus on race and ethnicity. Need increased partnerships with environmental and climate justice organizations and communities.

**Reviewer 2:** 1) Focus on developing program guidelines that can enable every state to implement a viable, at-scale program, i.e., at least 1GW per state. 2) Do not let LMI issues dominate broader program goals. 3) Actively engage with state-level and decision makers to make program goals are met and sensible policies are implemented. 4) Provide appropriate oversight and penalties to make sure utilities do not thwart/delay/obstruct program success. Proper incentives drive action.

## Inclusive Shared Solar Initiative – $1,000,000

*National Association of State Energy Officials | Arlington, VA | Principal Investigator: Sandy Fazeli*

In partnership with the National Energy Assistance Directors Association and the Energy Programs Consortium, this project team brings together state agencies, utilities, solar providers, and financial institutions to pilot low-income community solar programs. This project, inspired by the New York State Solar for All program, leverages the federal Low Income Home Energy Assistance Program, state and local incentives, and other capital funding sources to promote the development of community solar for low- to moderate-income customers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: ISSI project is tackling critical issue. When solar access is not equitable, it compromises public support for scaling solar and misses opportunities to save consumers money. Great that ISSI plans to have an "Advisory Group" of diverse stakeholders, including representative from "an organization dedicated to expanding energy equity and accessibility for LMI households." NASEO's network will help with rapid spread of best practices. Weaknesses: There is a blind spot with regard to the types of financial firms being engaged. Project aims to engage large financial firms that are motivated by the fact that they have already invested in clean energy significantly. This is one important motivator, yes. But large mainstream financial firms can have blind spots and trust issues with LMI customer base. Recommend Advisory Group consider adding advisor from a financial firm whose mission is investing in and building wealth of LMI communities. This could be a CDCU (Community Development Credit Union) similar mission-driven financial institution. Project also seems to undervalue how critical it is to ensure that energy equity access partners *appropriately resourced* as part of budget, to serve this critical role in advisory group. This is vital for strategy and replication in other states.

**Reviewer 2:** This project advances the access goal through piloting innovative facilitation of financiers, public entities, and end users. The PIs have identified the critical challenge of the need for subsidies in order to bridge affordability gaps, which hampers scalability. This approach pilots measures to overcome this challenge. Building on past success of implantation of a similar pilot, this project sets an ambitious and aggressive pace for achievement, which responds to the demand for accelerated scaling. If successful, this will make a substantial contribution to a heretofore significant weakness in the roll out of solar.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 |
| Collaborates with sufficient stakeholders | 2 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project hasn't yet started, so could not rate some these. However based on the strengths and weaknesses noted previously in approach of project: Recommend the ISSI Advisory Group consider adding not just one *but two* organizations "dedicated to expanding energy equity and accessibility for LMI households." The ISSI calls for reps from two utility orgs, 2 community solar providers etc., so it would not be unusual to have a second rep from the energy equity/accessibility area given the project goal. Since all aspects of the NY/model experience might not carry over the other states, the equity representatives will be especially valuable; Recommend budget include compensation of some kind should be provided to the planned organizational rep(s) that focused on expanding energy equity and accessibility for LMI households. Recommend addition mission-driven LMI focused financial institution to the advisory group and kinds of financial institutions targeted for scale up.

**Reviewer 2:** Given the projected scope, scale, and impact of this project, the budget and timeframe are appropriate and reasonable. The measures of impact are clear and quantifiable and include number of relationships forged and the number of LMI customers engaged, with a qualitative measure of scalability. Without any data on implementation, given its nascent stage, it is hard to judge results dissemination but the plans appear solid and feasible. The right stakeholders are involved, though I would consider adding a consumer group such as a tenants' rights association, as a primary partner and stakeholder.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: NASEO recognizes, overall, the importance of relationship building and trust among a range of stakeholders. But project seems to undervalue how critical it will be to have (1) community partners focused on energy equity/access that are *appropriately resourced* to be part of the advisory group and (2) advice from finance partners that are mission driven to help LMI community. This will be critical for strategy and scaling up guidance. The non-equity/access partners on the advisory group are not as resource constrained, so there is an equity issue as equity/access will be asked to volunteer. Current best practice is to compensate organizations in some way. With COVID-19 crisis also impacting economy, financial constraints are likely to be worse now. So financial support is even more critical for nonprofit/equity focused partners. Recommend *adding a second* access/equity rep. The ISSI calls for reps from 2 utility orgs, 2 community solar providers etc, so it would not be atypical to have a second rep from the energy equity/accessibility area given project goal. Since all aspects of the NY/model experience might not carry over the other states, the equity representatives will be especially valuable.

**Reviewer 2:** Score: 5. Comments: The convening of the advisory body first and foremost is critical. Again, the value of this body will only be as good as its membership. It would be good to have a sense of who is deemed to be an "expert." It's very good to see that one of the categories of advisory board members is an equity expert but again, it would be ideal to verify that expertise is not equated with letters behind one's name as community members are the best judges of what is equitable. It may be a language/interpretation issue but the task of recruiting state partners to host and implement community solar projects without mentioning the task of identifying community hosts seems to be missing a step? But perhaps the states commit and then they identify which communities would host? And is it assumed that the states will disseminate findings to communities? More language and intentionality around centering communities as having agency and leadership in each task of this process would be good. Otherwise, the tasks definitely appear to be both unique and critical.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project is the Inclusive Shared Solar Initiative (ISSI) initiative but there appears to be a need for greater input from experts with inclusion best practices, and with experience with how to put inclusion into practice in the project plan and budget. Recommend that the Advisory Group and operational plan (timeline/tasks/budget) be updated to: - Ensure stronger and compensated engagement from energy equity/access partners (not just one) that have demonstrated success with and are accountable to the LMI community. The project risks falling far short of the potential without this. Include outreach/advice from to mission driven financial institutions that have experience serving LMI customers (rather than just large banks). Some are looking at the clean energy realm as well - it could be mutually beneficial. - Additionally, communications support from experts with experience in LMI communities will be important for dissemination to have impact. It is good to see NASEO focused on trying to address inclusion. If they get this project right it could be of significant value and model best practices as we seek to get to scale and inclusion on solar.

**Reviewer 2:** A key nuance is around the subscriber model. One thing that's unclear is if the LMI community members are subscribers in perpetuity while someone else maintains ownership stake? Or is this a more sustainable, enduring, local and individual wealth building model of "rent to own"? If it's not the latter, I would recommend that this be an explicit nuance to the model being piloted.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This is addressed in the weaknesses section above and emphasizing here again: Given the project goal, project needs strengthening with regard to representation of energy equity /access representatives that are compensated for their time and that don't all come from one organization. Since lessons from NY will be applicable but need some tailoring most likely, this will be important. They are inclusion specialists. Perspective from a CDCU (Community Development Credit Union) similar LMI-focused mission-driven financial institution would offer valuable insights and broaden the kinds of financial institutions that could contribute to scaling. They are economic inclusion specialists. Early engagement of communication partner with experience in LMI communities important.

**Reviewer 2:** I recommend strengthening the inclusion and leadership of communities and groups representing LMI community members, including various community groups and tenants' rights associations.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** SETO should ask more probing questions in the proposal application when engaging with and serving LMI communities is important. Specifically: (1) What compensation is planned for partners from equity/access stakeholders that are likely to be resource constrained compared to other partners. (2) Where private sector partners are involved, what is their experience and expertise with LMI communities. Recommend considering *adding a second* access/equity rep. The ISSI calls for reps from 2 utility orgs, 2 community solar providers etc., so it would not be atypical to have a second rep from the energy equity/ accessibility area given project goal. Since all aspects of the NY/model experience might not carry over the other states, the equity representatives will be especially valuable. Communications experts seem to be missing. This is likely to be vital.

**Reviewer 2:** These goals and the methods for this project are clear and potentially impactful an will be enhanced by a clear definition of equity experts that embodies the expertise that local community members bring. It would be ideal to include tenants' rights groups in the collaboration/partnerships. Finally, I would advise that the finance model leads to ownership not perpetual subscribership, if this isn't already the design.

## Research and Development of Flexible Financial Credit Agreements – $600,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Paul Schwabe*

This project team is working to reduce barriers to solar access through innovative financing programs that serve low- to moderate-income communities. The team is researching, designing, and implementing flexible financial credit agreements to increase low- to moderate-income customer choice and solar affordability, addressing barriers to solar adoption such as long-term contracting requirements, nontransferable solar subscriptions, low credit, and seasonal income fluctuations.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project is broad in scope and it is not clear whether the outcome will have a meaningful impact on the LMI solar industry. However, the project does have the potential to increase solar access for LMI households. At minimum the research will provide a helpful baseline for establishing a universal understanding of FFCAs and whether they are an appropriate mechanism for LMI households interested in solar adoption.

**Reviewer 2:** Strength: focused pathway of developing Flexible Financial Credit Agreements (FFCA) that may be helpful determining new approaches to facilitating LMI participation in community solar projects. Another strength is the enumerated examples of what barriers FFCA's may be able to address, such as long-term contracting requirements, nontransferable solar subscriptions, low credit scores, seasonal income fluctuations, product skepticism by non-adopters, and limited mechanisms to multiply or leverage the economic benefits from a solar project. Compared to other projects I have reviewed, this list of possible examples illuminates concrete possibilities compared to vague outcomes. Weakness: it would have been helpful if the project team could have determined and listed the names and total number of industry participants and stakeholders they intend to work with.

**Reviewer 3:** Project has not started. Concerned that this effort being duplicative or that conveners are not the best suited for this. Compared to most of the other project summaries read that also haven't started, and given meaningful budget size, the proposal and rationale is quite then. For example grant was made even with advisory group composition not being fleshed out.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 5 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Given the scope of the project, the timeline and budget seem appropriate. While the milestones are somewhat vague, it is understandable given that much of what the project team will uncover throughout this project is not known. However, the project team mentions that they will need substantial collaboration from industry thought leaders and only NYSERDA is listed as an actual project partner. If the project team cannot engage the necessary stakeholders, it will be difficult to execute the project as planned.

**Reviewer 2:** This project was launched on March 1 of this year so no results currently exist. However, in order to not reduce the project's overall score based on its state of infancy, I gave the project 5's in lieu there being a Not Applicable score.

**Reviewer 3:** Project has not started, and scores reflect that compared to other project summaries, detail and rationale was lacking. Aspirational goals and milestones as they are seem logical, if the theory of change proves sound. However the larger question is that difficult to assess whether a brand new effort on this important topic is needed, vs taking an approach of scanning to see what other efforts by stakeholders with deep experience on economic and financial inclusion exist, and figuring out how to be additive.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: All tasks in the project provide value and sequentially build to the ultimate project goal. It is necessary for the project team to first research FFCAs and their applicability to LMI solar before actually determining whether these mechanisms will deliver greater flexibility and inclusion for LMI households and promoting FFCAs for solar to the financial industry.

**Reviewer 2:** Score: 5. Comments: The project team has built out a robust set of tasks that are logical progressive in nature. Task 1 consists of exploration and research to understand the lay of the land uncover ideas around possible FFCA and to develop an advisory group of industry experts. This is a critical task that matches well with their largest challenge and key objective of getting the right stakeholders to engage with the project team to develop thought leadership. The remaining tasks play well into the advancing FFCAs from early concept stage to the creation of tangible financial products that can be employed with real community solar developments. And finally, the task of building long-term momentum to continue the value of the FFCAs beyond the funding period is an important task that not all projects explicitly describe.

**Reviewer 3:** Score: 3. Comments: Too little information to tell. The challenge that needs to be addressed is real. The clarity of rationale for this particular approach is not.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The PIs believe that FFCAs have the potential to expand LMI solar access and increase flexibility in solar product design, but there is no discussion of the impact of FFCAs on LMI households. While credit is not always the best indicator of a customer's willingness and ability to pay for solar (especially when they are net positive financially from the arrangement), there are risks with increasing credit flexibility. The PIs should also consider the risks for FFCAs and whether such arrangements could potentially put an LMI household in a position of financial hardship.

**Reviewer 2:** At this early stage in the project, I don't view any blind spots namely due to the robust nature of the project design and the project team. However, with all DOE funded research projects, it's anticipated that blind spots will pop up and the project team should be prepared to deal with them.

**Reviewer 3:** Not sure if end users who will have to adopt and implement the product are surveyed to demonstrate demand for this project, and if the end users feel that a critical challenge is the lack of a thought leadership community best convened by an institution like NREL.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team is planning to engage a wide variety of stakeholders including industry experts. To the extent that the project team can identify organizations that are actively using FFCAs, they should try to engage them in the project.

**Reviewer 2:** The project team does not name the project stakeholders that will make up their thought leadership community or network but they do state they will work with industry advisers, financing innovators, and practitioners. Although they are probably grouped with financing innovators, banks and similar financial institutions are key project stakeholders that the project stakeholder team should ensure they connect with.

**Reviewer 3:** For the advisory group, ensure advisory group includes experts from a range of types of financial institutions, including those that are mission driven to support the LMI community. For example, credit unions that have experience with LMI community.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) If successful, this project could provide a meaningful starting point for the greater incorporation of FFCAs in solar financing and expand access to solar energy for LMI households as well as increase product flexibility. 2) There is a risk that the project will determine that FFCAs are not an appropriate tool for LMI solar finance. 3) The project team should consider the potential risk to LMI households in addition to the benefit.

**Reviewer 2:** 1) The end goal of creating FFCAs is a distinct deliverable that can easily be measured for impact and replicability. 2) The project team has a well though-out plan to ensure the FFCAs developed with DOE funding live on past the expiration of the project. This critical to ensure to ensure the community solar market continues to evolve through seed funding provided by the DOE. 3) Benefit of this project the anticipated results outweigh the level of funding provided by DOE.

**Reviewer 3:** 1) Flesh out more clearly that theory of change for this project. 2) Ensure advisory group includes experts from a range of types of financial institutions, including those that are mission driven to support the LMI community, as a complement to mainstream banks. For example, credit unions that have experience with LMI community.

## Sharing the Sun: Community Solar Cost, Design, and Deployment – $579,669

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jenny Heeter*

This project collects and analyzes data on existing community solar programs, benchmarks community solar costs compared to other solar options, and identifies pathways for new community solar program designs, such as community solar paired with storage. Working with experts in the solar industry, academia, and other relevant entities, the project team is developing a streamlined data-reporting process that could help to lower the cost of community solar projects, as well as next-generation community solar programs that can provide enhanced grid reliability.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 | 5 |
| Set critical challenges to overcome | 4 | 3 | 5 |
| Implement a high-risk, high-impact approach | 4 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 4 | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 5 |
| Advance the U.S. solar industry substantially | 5 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: This project has an excellent team (NREL and University of Minnesota) that will make an impact. The LMI data that is being collected is critical. Weaknesses/Areas of Opportunities: The lack of approvals from SETO to share the information with the public.

**Reviewer 2:** There appear to be two very different objectives in this project: (1) The first relates to a national community solar database. This, and its insights, would be valuable to the community solar industry, but it is not clear if has value beyond that. (2) The second relates to community solar program design, which again could be valuable, provided its goal is to lower cost and speed adoption. With respect to (1), the current dataset is very incomplete and needs to be substantially expanded for 2018-20. For example, years 2018 and 2019 in the published data account for less than 5% of the total installed volume over the analysis period. Relying on these data will only present a picture of the distant past, which will not be valuable to anyone. The researchers seem to think that (2) is dependent on (1), which I do not fully understand. Program design should be analyzed at the program level, which is primarily at the state level. In particular, the policies of MN, NY, MA, MD, IL, CO, ME and NJ could be analyzed and summarized without substantial project level to develop best practices. It would be very valuable for there to be set of "guidelines" for implementing CDG programs and also valuable if this information were used to drive policy. I assume that this will be part of the National Community Solar Partnership.

**Reviewer 3:** Strengths: Provides industry wide community solar data and aggregated statistics which are useful for industry advancement and benchmarking. Neutral third party allows for better data collection than market participant. Community solar still figuring out standards, any specific information regarding structures, subscriber contracts, LMI initiatives can assist with quicker convergence to a standardized and efficient model, thereby reducing costs and cost of capital Weaknesses: Project specifies certain information to be collected on each project, however the list could be much more robust regarding project and subscriber characteristics to be more useful to the industry. Project will need a way to quickly update 2019 and 2020 data, as the faster new information is integrated, the better.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 5 |
| Collaborates with sufficient stakeholders | 5 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Great project and nothing really different from my comments above.

**Reviewer 2:** (a) the researchers seem to be raising an issue that SETO is blocking the publication of their results. (b) the dataset of CDG projects needs to be either expanded to be more comprehensive, both from a project list and the depth of information about each project, i.e., time from permit to PTO, interconnection cost, LMI requirement/percent, etc., or abandoned to the private sector.

**Reviewer 3:** Per the project report, the project team has met its milestone goals and disseminated the information collected and aggregated.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project has clearly defined tasks and SMART goals that I'm confident that will be achieved.

**Reviewer 2:** Score: 3. Comments: If this project is essentially the research part of the National Community Solar Partnership, then it can be a valuable part of the effort. To do that, a framework needs to be developed around CDG program design, e.g., application process, interconnect process, AHJ permitting process, subscription offering, crediting mechanism, payment mechanism, LMI or no LMI, LMI subscription requirements, etc. Then the different programs can be described and evaluated on these criteria to develop guidelines.

**Reviewer 3:** Score: 5. Comments: The tasks for this project seem appropriate and necessary for the final goal of aggregating and publishing data regarding the community solar activity nationwide.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** 1) Please continue to focus on LMI data. 2) COVIDs impact on the solar industry.

**Reviewer 2:** See previous responses.

**Reviewer 3:** The PI has identified most of the key elements required for the aggregation of community solar activity data, however there can be more focus on the project structures used and range of subscriber contract terms.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Solar developers that do community solar projects. Policymakers that have passed community solar and/or that have run into a roadblock. Existing and potential LMI customers to get their feedback.

**Reviewer 2:** See previous responses.

**Reviewer 3:** The project is already interfacing with community solar developers to gather actual project data, they could potentially reach out to community solar subscriber management firms, investors, and/or legal firms for additional color on project and contract structures.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Focus on LMI. 2) Prepare for the impact of COVID-19. 3) Include policymakers.

**Reviewer 2:** See previous responses.

**Reviewer 3**: 1) Aggregation and publication of current market activity with statistics related to costs and structures help the industry benchmark projects and influence investor decisions, so this project adds significant value in reducing both customer costs and cost of capital. 2) There are many more project and contract terms that will be useful to collect and compile as part of this project, including contract length, pricing structure, discount, FICO requirements, termination fees, etc. 3) This project has the most value if data is kept up to date, so a mechanism to add recent data should be prioritized.

## Unlocking Widespread Solar Adoption: Understanding Preferences of Low- to Moderate-Income Households to Create Scalable, Sustainable Models – $1,350,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Benjamin Sigrin*

This project focuses on identifying novel, data-driven, and evidence-based strategies that could dramatically scale up solar adoption rates in low- and moderate-income communities. The goal is to develop pathways for reaching parity in solar penetration rates across socioeconomic groups. This project serves a core need for developing objective tools and datasets for policymakers and identifying the barriers that have previously limited deployment. The primary focus of this project is to rate the technical solar potential of buildings in low- and moderate-income communities across the country, develop predictive models to understand previous deployment, and then work with a national nonprofit solar installation group to determine how communication about solar energy usage occurs within these communities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** There is no greater need than identifying key barriers and more importantly solutions to LMI decision making around solar. The project appears to be strong with no real weaknesses in approach. One potential weakness is that it appears the focus was on single family housing and presumably home ownership where many members of the target communities are renters.

**Reviewer 2:** While, I'm gratified to see this data and do believe that having this evidence based assertion of referrals being the best way to advance solar uptake in LMI customers, what's paradoxically galling is that we who serve LMI communities have known this all along. So to see the time and resources spent coming to the same conclusion we knew intuitively is a bit disconcerting. Nonetheless, if this study is what it takes for the industry to catch up and recognize what it needs to do to effectively engage LMI customers, then it has immense value. That being said, my other challenge with this project is its approach. Though the outcomes/results tracks the reality with which I'm familiar, it's likely because it's so blaringly obvious. It is not taking any particular risks though, if dissemination of results is done well, then the impact can be high if the solar industry adopts an outreach strategy that is centered on intra-community referrals. If this transition is achieved, this project will definitely be worth the resource investment.

**Reviewer 3:** This was a research-based project with some useful findings that I believe can contribute greatly to advancing LMI solar. The project highlights the untapped potential for solar on LMI housing, as well as provides best practices to low-income solar program administrators at how to cost-effectively recruit additional participants through referrals, and what drives decisions to participate in low-income solar programs among LMI customers. While primarily academic, project results are directly applicable and actionable.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has performed well, carrying out all tasks and planned and now simply wrapping up by seeking out opportunities to publish findings.

**Reviewer 2:** Milestones are on track according to the stated timeline, which is good. Metrics and indicators are commiserate with project goals and objectives. It would be ideal if the dissemination goes considerably beyond the applied and academic conferences referenced, as well as the handful of other measures including, laudably one social media article. There needs to be extensive effort to engage a broad swath of constituency based organizations. One of the most important results of this project has yet to be rendered and that's the outcomes of demonstrating the referral methodology. It would be good to know exactly how the sample is selected for this approach and what exactly the referral methodology is and with whom, beyond the primary partners, this group is engaging with in terms of stakeholders. Sufficient stakeholders would have to include direct engagement with frontline community groups and constituency-based groups, such as tenant rights organizations and others.

**Reviewer 3:** This project appears to have met its major milestones on time. The results of the project have been well disseminated, but it seems to be largely within the realm of peer-reviewed papers and academic conferences. While this is certainly an important avenue for disseminating novel research, it was less apparent if results were being actively shared with solar contractors, low-income solar program administrators, or legislative and regulatory bodies that have decision-making ability over funding levels for LMI solar programs. It's entirely possible the results have, in fact, reached these audiences, and it simply wasn't apparent from the materials provided, but these feel like important audiences to ensure the results of this research are applied.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The 3 distinct projects within this project all had important value and use for both the project and broader use.

**Reviewer 2:** Score: 5. Comments: Assessing rooftop suitability, documenting LMI adopter attitudes and testing methods for engagement of LMI customers is a solid mix of tasks that have a high likelihood of achieving the intended results. There is a lot of commentary both from residents considering rooftop solar and from utility industry entities advocating against rooftop solar, about the lack of suitability of roofs so gathering the real data on roofs that can accommodate solar installations is critical. Though the documenting of attitudes of LMI residents is important, having GRID Alternatives (which does fantastic work) as the avenue for accessing LMI residents is limited, especially as they lament their own challenges with engaging this population at scale. Looking forward to seeing the results of piloting methodology based on referrals and also seeing the details of the referral process and any sub-cultural nuances.

**Reviewer 3:** Score: 4. Comments: The research questions for this project, while both important, did feel a bit disjointed. It was unclear how quantifying the technical feasibility of reaching parity in solar penetration rates across income groups related to the behavioral science aspect of understanding motivations for adoption and effectiveness of referral models.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It appears the PI has not addressed the large percentage of population that rents housing, however, it's possible in more detailed materials they have addressed this. Little mention of capital access/affordability and solutions in think about solar adoption among LMI.

**Reviewer 2:** It seems that the data that led to the conclusion of the best way to reach LMI customers is based on how the LMI customers that were engaged were reached. That seems like it should only be part of the data. It would be ideal to have measurable data on why other LMI customers aren't engaged. Does the model assume by default that the only reason that people aren't engaged is that they weren't reached by informal referrals because the difference between those who ae engaged and those who aren't is referrals versus not referrals? If so, that's not enough. Also, it would be ideal to include examination of nuances within the LMI populations including race/ethnicity, language access, geography, cultural factors, etc.

**Reviewer 3:** I don't see any obvious blind spots in this project, aside from the aforementioned focus on being sure to disseminate results beyond the academic community.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project appears to have done an excellent job of engagement. As noted it's not clear any engagement was done around renters.

**Reviewer 2:** Direct engagement of frontline community and constituency based groups as principals in the research study is a glaring omission as a basic principle of research should be that it's not outsiders conducting research on communities but instead providing resources for communities to be in the lead on determining the internal factors impacting their realities.

**Reviewer 3:** I don't see any key collaborations or stakeholders missing from this project to achieve the project success. By partnering with GRID Alternatives, the researchers have engaged with an entity with plenty of on-the-ground experience to inform the more academic aspects of this work. As stated earlier, it's important to disseminate these results to key decision-makers, as well as share them with other low-income solar program implementers so that best practices can be adopted.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Excellent use of SETO resources. 2) Results should be shared broadly. 3) Project's holistic approach to problem solving (4 broad ranging interconnect questions) was central to success.

**Reviewer 2:** 1) Engagement of frontline, constituency-based groups as principal partners should be essential. 2) The project should engage communities for input that do not have a relationship with the solar industry to determine how to reach those who are hardest to reach. 3) Not only should the project do better with dissemination, but it must also seek feedback from frontline communities and other constituency-based organizations as results begin to manifest to do ground truth testing.

**Reviewer 3:** 1) This project produced some very important novel research on both the potential of LMI solar, as well as best practices in engaging with LMI customers. 2) Results from this project should be shared broadly to help inform decision-makers and spread best practices to ensure the efficient use of limited low-income solar program funding. 3) It was unclear exactly how the analysis of technical feasibility of LMI solar adoption addressed a real or perceived barrier. If there was a misperception that low-income housing does not have adequate rooftop solar potential, I was not aware of that.

## Cooperatives Achieving Rural Equity in Solar – $1,000,000

*National Rural Electric Cooperative Association | Arlington, VA | Principal Investigator: Deb Roepke*

This project provides models, best practices, and other materials for cooperative utilities, solar developers, and community and regional financial institutions to expand solar affordability in low- to moderate-income communities. The team is investigating solutions that will streamline customer access to solar, enable small-scale solar projects to more easily obtain the economic benefits available to larger-scale projects, and use financial mechanisms that leverage opportunity zone benefits, among other challenges. The project incorporates participation from rural electric cooperatives, community and regional financial institutions, nonprofits, foundations, solar developers, economic development agencies, and current and potential customers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project and scale are significant and the goals are excellent. Identifying the impact cooperatives can have in providing access to solar for LMI families is a great idea and with potential. The only area for improvement I note is the need for a deeper dive into the challenges they are trying to overcome. The stigma of identifying as low-income seems relatively minor in the grand scheme of things since creating programs that work for anyone and vary based on income seems doable. There are multiple models of renters benefiting from community solar. Given that this is a research project, calling it high risk/high impact is difficult.

**Reviewer 2:** Strength: Appreciate the thoughtfulness and amount of detail included in the milestone chart is great. Seems like the project participating orgs are also the right list of folks. Weakness: Suggest first milestone should be coordination with other SETO funded LMI efforts-there should be a lot of existing materials that can be adopted,, which would then allow more time to run the program and assess their success. PNNL's stated role in the narrative is "Research the potential for monetization of grid services to further improve the economics of solar." I didn't understand from the materials how this exactly fits within the rest of the topic. In general, it is an important subject, just don't see the tie-in.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project hasn't really started, but goals seem reasonable.

**Reviewer 2**: The objective in the narrative states: Convene financial, non-profit, philanthropic, educational, economic development, community, solar-related and cooperative stakeholders committed to achieving equitable access to solar for all. Glad to see the two farmers bank participating orgs, but Suggest adding financiers who have participated in the MA community solar market-which had a LMI component and is the biggest and most established community solar program. There is now over 3+ years of real world experience in many state community solar programs.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The workplan is well thought out and creates measurable and impactful goals.

**Reviewer 2:** Score: 6. Comments: I'm glad to see this extension of NRECA's SUNDA program with such a focus on implementation.

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** At this point it's not clear that there are significant blind spots.

**Reviewer 2:** Per comments above, consider more focus at the early stage on usage of existing materials and coordination with other LMI program research.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** There are many groups already working in the LMI space and it's not clear that the CARES will be engaging with them.

**Reviewer 2:** More input from financial institutions that currently fund LMI projects should be part of the initial data collection effort.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** 1) Make sure to engage others who have engaged on the LMI access question. 2) The rural focus here is immensely important, but SETO should also consider, if successful, the results have other implications. 3) Important to consider whether the 6 models (or those that are successful) are truly scale able or unique to their markets.

**Reviewer 2:** Highly support SETO funding of this project. Per the above, most important to consider how existing toolkit materials from groups like Solar United Neighbors and other non-profits and other grantees can accelerate implementation.

## Community Solar for the Southeast – $1,000,000

*North Carolina Clean Energy Technology Center | Raleigh, NC | Principal Investigator: David Sarkisian*

This project makes solar more affordable and accessible through shared solar projects developed by cooperative and municipal utilities across the Southeast. The North Carolina Clean Energy Technology Center leads a stakeholder process with rural cooperative and municipal electric utilities, which can influence many states within the Southeast region. The project is expected to result in a dramatic increase of shared and community solar projects in the region.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 3 |
| Set critical challenges to overcome | 6 | 6 | 1 |
| Implement a high-risk, high-impact approach | 4 | 6 | 1 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 2 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 1 |
| Advance the U.S. solar industry substantially | 6 | 6 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is very focused and supports the development of solar in a specific context. The resources developed and assistance provided have resulted in real solar PV projects and facilitated the expansion of the community solar market in municipal and coop utility territories in the southeast.

**Reviewer 2:** Because rural electric co-ops and munis serve the majority of residents in some sections of the Southeast, this project is critical to the mission of making solar universally available. As such its goals align well with this topic and with SETO's mission. The challenges presented are important and I would also add that there is a challenge with democratization of rural electric co-ops. In the Southeast especially, many of the member-owners of rural electric co-ops do not know they are member owners much less do they actively participate in governance. Lack of full participation harms any democracy and thus, I would name this as a challenge. If successful, the results of this project could have tremendous impact for many groups that are actively seeking to engage rural electric co-ops in solar. The funding and the planned duration of the project are appropriately commiserate with its intended activities and outcomes. However, it would have been preferred to have slightly more ambitious outcomes in terms of shovel ready projects or projects being implemented by the end of the project duration.

Reviewer 3: This project cannot achieve its objectives without substantial change in state-level policy and/or funding. It should be rolled into the National Community Solar Partnership.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 1 |
| Measures impact appropriately (e.g. quantitative) | 6 | 6 | 1 |
| Disseminates results frequently and actively engages partners | 6 | 4 | 1 |
| Collaborates with sufficient stakeholders | 6 | 5 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team includes a diverse set of stakeholders including utilities, solar developers and technical experts. The project team produced a significant number of materials and met its milestones within the grant period, as well as resulted in actual projects coming online and expanding solar access for utility customers in the southeast.

**Reviewer 2**: Though the project has been behind on milestones and has requested and secured a no-cost extension, it has progressed through many of its planned activities, primarily providing technical assistance to multiple utilities. The impact measures have been met, though on a slower pace. In looking at the guidance document produced as part of the results dissemination, it falls short of the level of expansive detail that would be most helpful for utilities seeking to replicate. As such, it would be concerning the extent to which it will have the impact on the industry that it could. I would advise a revision of the guidance document and making it into a much more user-friendly toolkit with details on replication. Regarding dissemination of results and engaging partners, as a practitioner in the space of working with rural electric co-ops to advance solar, it was unfortunate that I didn't know about the guidance document nor do I think that if I did, I would be able to use it as a resource to follow to amass partners and replicate what was done through this project. Finally, in order to fully realize the intent of this project, I would suggest that engaging other stakeholders, such as environmental justice organizations and others on the frontline, to strengthen outcomes as well as usability of resulting guidelines.

**Reviewer 3:** See previous response.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1**: Score: 6. Comments: In order to expand community solar in southeast municipal and coop utility territories the team took on the critical first steps of educating grid operators on community solar and implementation strategies. They also provided technical assistance to the participating municipalities as they developed community solar programs, resulting in actual installations and operating community solar projects. All of these tasks combined resulted in a successful project.

**Reviewer 2:** Score: 5. Comments: The tasks including developing the written resource materials and providing direct technical assistance are appropriate to the intended outcomes. However, the value lies in the quality of the written products and the quality of the technical assistance. The completed Fayetteville project gives hope that there is a robust enough content to create a viable and successful project. Perhaps the quality of the technical assistance needs to be better matched with the quality of the written products. The procurement toolkit seems quite substantive...it would be good to see the implementation guide be equally as robust.

**Reviewer 3:** Score: 2. Comments: There is some useful knowledge that can be gained, the extent that expanding CDG to the SE will have to address some of the same challenges the group is facing at the muni-level. However, as noted above, this project's activities should be rolled into/replaced by the National effort.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It would be interesting for the PIs to consider whether or not the resources and technical support they provided to municipal and coop utilities in the southeast could also be applied/useful to investor-owned utilities. While IOUs face more regulatory barriers that muni and coop utilities, it could be helpful to see if any lessons-learned could be applied to IOUs as well.

**Reviewer 2:** Equity is a blind spot here. What was the criteria used to select the nine utilities? Was there an examination of race and/or income demographics so that the outcomes and the methodology has results that are applicable to multiple contexts, taking into account any nuances that might vary by income/wealth or race indicators?

**Reviewer 3:** See previous response.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team appears to have a very robust set of project partners. Perhaps getting feedback from IOUs on the models developed in this project could help determine how much of this project team's work could be replicated in that context.

**Reviewer 2:** Engaging organizations specializing in an equity analysis and implementation of equity based projects and environmental justice organizations would enhance the methodology and outcomes.

**Reviewer 3:** See previous responses.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The focused scope of this project and robust list of team members appears to have contributed to its success. 2) Further analysis could be done to explore how the models used by muni/coop utilities could apply to IOUs. 3) It is still unclear how successful the community solar projects will be with utility customers as subscriber enrollment only began in January 2020, and the project does not appear to focus on achieving energy burden reductions for LMI customers.

**Reviewer 2:** It is positive that the PIs looked at various models of ownership which is too often missing as projects just seek to advance solar by any means necessary without enough consideration of co-benefits. Otherwise, deepening the equity analysis and engaging environmental justice organizations would be the two recommendations for improvement.

**Reviewer 3:** See previous responses.

## Data-Driven Understanding of Low- to Moderate-Income Customers' Adoption and Financial Qualification in Community Solar – $816,092

*Solstice Initiative | Cambridge, MA | Principal Investigator: Stephanie Speirs*

This project gathers customer data to assess the assumption that metrics other than a traditional FICO score can and should be used to qualify customers for community solar. Using customer data on income, FICO score, and utility, rent, and cell phone repayment history, the project tests whether new qualifying metrics open up the community solar market to additional households. This new model is then tested by enrolling customers in community solar and comparing actual payment. This project identifies and tests better ways to finance and perform due diligence on solar purchases for nontraditional adopters.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 6 |
| Advance the U.S. solar industry substantially | 3 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The strength of this project is in the ability of the Energy Score to qualify a larger swath of LMI customer for participation in community solar projects by using a more accurate credit worthiness indicator. One weakness lies in the inability for the project to access geographically quantitative data that will help test the understanding of the data indicators used within the tool.

**Reviewer 2:** If successful, this project has the potential to unlock access to community solar for what appears to be a significant number of households that would not have qualified based on their FICO scores alone. It was difficult to ascertain exactly how large this impact could be, as Solstice did not have a nationwide estimate of additional LMI households that would qualify. Additionally, there are other barriers to community solar beyond simple eligibility, some of which Solstice is addressing in a subsequent SETO project.

**Reviewer 3:** The Energy Score developed as part of this project has significant potential to expand the pool of customers eligible for community solar projects and potentially increase LMI solar access. The project design and milestones indicate that the team has made significant progress in developing their tool and has a solid path forward for determining its efficacy in the marketplace.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team has done a good job of staying on task and ensuring deliverable's and milestones have been met. One point that has slowed the project down lies in the length the Project team has spent dealing with the legality of determining fair credit score practices and in the contractual process for their pilot projects.

**Reviewer 2:** The project appears to have performed well, achieving all major milestones, and is wrapping up in July 2020. They seem to have engaged the right stakeholders, and have published their results in the peer-reviewed literature. While the project team did a good job of quantifying results of the EnergyScore (e.g. in the NBER paper) in terms of inclusivity above and beyond typical FICO score ranges, as well as impact on projected 90-day delinquency, I would have liked to see the number of additional LMI households that would be eligible more clearly quantified. Without understanding the number of additional households or customers, it is difficult to ascertain exactly how large the potential impact is.

**Reviewer 3:** The project team has established meaningful and measurable milestones for measuring its progress and has assembled a project team with the expertise and means to develop this product and test its validity.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: To ensure LMI customers can participate and gain access to the solar economy, community solar is one critical opportunity. If credit scores are limiting and bias towards the financial health of LMI customers, a new methodology is needed. In this vain, the EnergyScore is vital tool that will help capture the eligibility of significantly more LMI customers breaking down barriers to their participation.

**Reviewer 2:** Score: 5. Comments: The materials provided didn't have the work broken up by task, per se, however the progression of work through the three budget periods seemed logical, moving from research and analysis, to pilot development, to enrollment of pilot participants.

**Reviewer 3:** Score: 6. Comments: The project design builds upon previous steps and work to achieve its ultimate goals, all steps in the project are necessary to complete the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** As stated earlier, the underlying data used to test EnergyScore outcomes, is from a fairly confined geographic region that limits the test case due to nuanced factors. Receiving data from more states a will allow them to understand a broader set of dynamics.

**Reviewer 2:** The willingness of developers/financiers to adopt a new metric for assessing risk in community solar projects still feels like a significant obstacle. While it's not a "blind spot", because the project team is well aware of it, it does pose an ongoing challenge. Another potential "blind spot" could be the fact that analysis to develop the EnergyScore utilized data from a period of relatively high employment. It would be important to understand how low-FICO score households that qualify through an EnergyScore fare during an economic downturn like the one we are currently experiencing. Are they more negatively impacted, relative to their higher-FICO score counterparts?

**Reviewer 3:** It will likely be challenging for many solar developers and financiers to completely abandon FICO scores as the "go-to" method for approving customers. The project team might consider first trying to market Energy Score as a "second look" option for customers that don't meet a particular FICO threshold, but could still be good candidates for community solar.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** The engagement with national labs and academia with the work done on community solar seems to be missing.

**Reviewer 2:** The materials provided focused largely on engagement with community solar developers and financiers, which are clearly very important stakeholder groups to engage with. Based on the materials provided, it does not seem that the project team has engaged extensively with low-income advocacy groups, who are an important stakeholder for understanding the myriad challenges LMI households face in accessing solar. While this project focused on score-based eligibility, there may be important insights these types of organizations can provide. Additionally, it was unclear to what extent the project team has engaged with policymakers. This could be an important avenue for policy-driven implementation of something like the EnergyScore, especially in states or jurisdictions that wish to focus on improving access to solar for LMI customers.

**Reviewer 3:** Community organizations should be consulted to provide insight into the ease of implementation of Energy Score as an evaluation metric (i.e. is the required information to calculated an energy score feasible from an implementation standpoint). Complex information requirements to approve LMI customers can be a barrier to participation.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** Because the outcome of the project is a tangible asset that community solar developers can build into their process of enrolling LMI customers and due to the anticipated ability to encompass LMI customers with lower FICO scores, this is the type of project that DOE can tout as providing innovation and moving the needle.

**Reviewer 2:** 1) This approach has a lot of merit, and represents a solution that could easily scale and have broad impact on the industry. The project team seems to have done a very good job in delivering this project over its term and disseminating results. 2) The team could benefit from further quantifying how many additional LMI customers/households may be able to access community solar through use of the EnergyScore, to better understand the project's impact. 3) Continue to engage with community solar developers and financiers to promote the use of this alternative metric for eligibility, but also understand that there are additional barriers to community solar for LMI customers which also require attention.

**Reviewer 3:** 1) The project team has made significant progress in developing a tool that has the potential to expand solar access. 2) While Energy Score has a lot of potential, widespread adoption may be a challenge. 3) For utility-run community solar programs, the project team might consider presenting their methodology as a way of pre-qualifying customers for community solar since they will have utility repayment history.

## Product Innovation to Increase Low- to Moderate-Income Customers' Adoption of Community Solar Photovoltaics – $1,235,634

*Solstice Initiative | Cambridge, MA | Principal Investigator: Stephanie Speirs*

Approximately 77 percent of U.S. households cannot access rooftop solar and 40 percent of homes earning less than $40,000 per year only make up less than five percent of U.S. solar installations. Low- and moderate-income households are often excluded from community solar because of information asymmetries, prohibitively high credit score requirements, and restrictive contract terms. This project aims to expand photovoltaic solar access to households by evaluating the use of an alternate credit score, previously developed by Solstice Initiative, and performing tests to understand the most suitable contract terms for different low- and moderate-income customer segments. The project explores ways to deploy alternative capital in partnership with foundations, community development financial institutions, and others to produce and pilot a suite of community and shared solar contracts that can meet the needs of low- and moderate-income households. The team will then perform rigorous data analysis concerning the factors that affect the financial viability of low- and moderate-income-inclusive projects. This will help to expand the solar market, lower customer acquisition costs, and increase solar affordability.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and supports SETO mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 4 |
| Advance the U.S. solar industry substantially | 3 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: project will help to uncover new methods to increasing LMI access through understanding LMI customer preferences weighed against the needs of project developers. Weakness: end goal of developing a "best practices contract" that will "develop a more inclusive product that can be readily adopted by developers in this space" does not seem to move the needle in lieu of the funding given.

**Reviewer 2:** Similar to Solstice's other SETO project that is wrapping up this year, this project presents a logical approach to addressing barriers to community solar for LMI communities. Whereas their previous project addressed FICO score criteria as a barrier, this project looks at a lack of standardization and general opacity in terms around community solar contracts, which LMI customers may find unpalatable. While the scale of under participation by LMI households is clearly presented, it is difficult to fully understand the potential impact of this work as it's unclear how many additional households may be able to participate in community solar as a result of standardizing contract terms, as well as how much of a barrier this currently poses. Additionally, it is unclear what the level of interest is among community solar developers/financiers to further engage with LMI communities - do they see a lot of untapped potential? Is the general market becoming saturated? Is policy driving developers to be more inclusive of LMI communities?

**Reviewer 3:** Strengths: Community solar contracts require development, and efforts toward standardization will greatly benefit the entire industry. Community solar is one of the easiest ways for LMI participation, so focus on. Churn and default rates research and analysis will be invaluable to the industry and enticing investors to scale back credit requirements and encourage more LMI participation. Weaknesses: Project team does not specifically mention legal collaborators who active in the market for the development of contracts. Focus is solely on LMI acceptable contract terms, however concerns of non-LMI subscribers also need to be considered and integrated into the contracts in order to have wide ranging adoption. There could be more specific tangible goals committed to, given the timelines and budget. Timelines and budget are higher than expected for scope of work.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 5 |
| Disseminates results frequently and actively engage partners | 4 | 4 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is still in its infancy and has yet to reach its milestone date and finalized objectives. However, they have laid out the standard blueprint in BP1 of researching community solar landscape and determine their study methodology, gaining access to relevant data and connecting with stakeholders. This groundwork will help the project team successfully meet the deliverables in the coming tasks and budget periods.

**Reviewer 2:** This project is in very early stages, so it is difficult to comment on how well it is progressing and achieving milestones. Based on conversations with the project team, it seems as if the project is progressing well, and that they are engaging with important stakeholders. It will be interesting to see if project developers are willing to provide data on typical churn, which seems to be a very important piece of this research. Based on conversations with the program team, developers and financiers seem somewhat guarded about sharing information that they may deem confidential and/or key to their business model and competitive advantage.

**Reviewer 3:** The project has met its initial milestones in a timely manner. The report mentions interactions with stakeholders and industry experts as part of completing these tasks, however specific stakeholders (namely legal) are not mentioned by name.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: It seems more appropriate that these two discreet tasks, 1) collect data on customer and developer/financier community solar program priorities 2) and to scope out the viability of establishing a guarantee fund for mitigating project risk, should have been designated to have been completed upfront during BP1. While it can be imagined that data collection is an ongoing activity, it should have been spelled out earlier as should the viability of establishing a guarantee fund for project risk.

**Reviewer 2:** Score: 5. Comments: The Budget Period work plan follows a logical progression and seems to follow a reasonable timeframe. None of the work here seems tangential, or unrelated to the core project.

**Reviewer 3:** Score: 5. Comments: The tasks as laid out provide a roadmap for the necessary survey data required and the subsequent steps to create the "best practices" contract. The survey data regarding LMI preferences as well as the churn and default data will be valuable also as standalone products of the project.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** I believe the PI is underestimating the value to industry and the advancement in the state-of-the-art of consumer financial products this project will provide. The other Solstice product is providing a tangible product through the creation of the EnergyScore while this project lacks a true focus. Alternative methods to determining an LMI customers interest can be made through other methods as seen through other DOE funded projects.

**Reviewer 2:** A potential "blind spot" could be a general unwillingness on the part of community solar developers/financiers to engage with this project, and allow Solstice to pull back the proverbial curtain on their standard (or non-standard?) contract terms, rates of churn, and customer information, all of which are critical to this project achieving meaningful results. Additionally, the scalability of the results of this project rest on the assumption that there is a level of standardization of contract terms that will meet the needs of geographically and demographically diverse LMI communities. It's likely that there are many barriers to participating in community solar that are context-specific to certain communities, and that standardized contract terms can only go so far in addressing. Often times, the case is, "if you know one LMI community, you know one LMI community" - don't assume what works for one will work for all.

**Reviewer 3:** The project mentions focus on LMI preferences in the contract and palatability to investors, however most project will be a mix of LMI and non-LMI subscribers.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** All necessary stakeholders seem to have been informed with the projects approach and currently Solstice is negotiating with the University of Minnesota for help with data analysis. However, it seems that Solstice needs to work closer with community solar developers to access a broader set of contractual provisions that will help the project team uncover a wider variety of variables in the marketplace.

**Reviewer 2:** If they are not already doing so, the project team would do well to engage with low-income advocacy and environmental justice organizations, who are well-placed to inform on their constituent communities' perceptions of community solar, and perceived barriers to participating. The project team proposes to survey LMI communities, which may pose a significant challenge in and of itself.

**Reviewer 3:** The project should strongly consider the addition of a dedicated legal firm with experience in community solar contract construction and up to speed with current market trends.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Intended goal of a "best practices contract" that finds a middle ground between LMI customer preferences and developer risk is a worthy outcome but may not move the needle towards great LMI customer adoption. 2) Cost of the project may outweigh the project benefit. 3) Project should encompass a more robust and dynamic goal.

**Reviewer 2:** 1) If successful, this project has the potential to remove barriers to LMI household participation in community solar, which is important, and contributes directly to SETO's objectives. 2) Engaging with community solar developers and financiers appears to pose a significant challenge for the project team, but will be critical for obtaining the data required to perform the proposed analysis. 3) There may be limits on applicability of standardized contract terms, as each community is unique, and may have different reservations or concerns about participating in community solar.

**Reviewer 3:** 1) This project is addressing a core need for the community solar market which is standardized contracts which can include most of the population, and reduce friction with customer acquisition and management, ultimately leading to lower project costs and quicker solar deployment. 2) Data collection mentioned in the tasks will be relevant and useful even as a standalone product of the project. 3) Project scope encompasses the required steps, however timeline and budget look higher than would be expected.

## Advancing Solar Innovation for Low- and Moderate-Income Households – $733,104

*University of Georgia | Athens, GA | Principal Investigator: Jacqueline Hettel Tidwell*

This project identifies key socioeconomic factors and social values that enable and constrain solar adoption in low- and moderate-income communities. The team is developing an accessible and easy-to-understand database of social drivers for solar adoption and non-adoption in low- and moderate-income communities. By closely studying the areas that represent a large portion of the state's population, this project provides insights regarding low- and moderate-income adoption patterns that will not be observed in larger-scale national studies.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 5 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project on LMI and solar adoption has some red flags, but some very good work has been done. Weaknesses, if addressed, could allow project to reach hoped-for impact. Strengths: Focuses on critical issue of how to get LMI communities to increase solar adoption, so that communities and industry benefit. Project is creating and collating interviews, analysis (qualitative/ quantitative), and protocols online in open-source way. Projects hopes for best practices that will be replicable beyond Georgia. This could lead to LMI solar policies that are community centered, which is sorely needed for success. It is good that the DC Department of Energy and Environment requested self-interviewing prototype. Weaknesses: It is not clear if demographics (e.g. race, age) distinctions are sufficiently analyzed. This could be a communications issue - but information doesn't jump out from materials/ website. There are likely to be important differences among LMI communities by race in Georgia, for instance. These need to be highlighted if recommendations to policymakers and businesses to succeed in practice. Communications updates on Solar Smart website seem to have gone dormant this year Project documents noted the significant scaling back in interview methods and scale.

**Reviewer 2:** Strengths: Focuses on a fundamental need to understand market segments and provide data for the solar industry to be able to utilize to better communicate and engage with LMI and rural populations. Project partners with on the ground local organizations to extend reach and interactions with LMI and rural communities. Weaknesses: Academic and research studies will illuminate the challenges that exist and some of the reasons for them, but needs to be paired with / have a handoff to the creation and implementation of solutions to those challenges (for SETO team to address). Some of the findings in terms of knowledge gaps are known to participants in the industry (if anecdotally).

**Reviewer 3:** The project tackles a significant issue-LMI consumers interest and participation in solar. Any insights into LMI adoption will be very helpful. A couple of thoughts: Can this type of project be replicated in other states? Is there DOE funding for another similar one? This would be very beneficial and replication would require less funding since the framework is here. The project report acknowledges that GA residents (LMI or otherwise) don't fit the norms of other solar markets. Also, there were challenges getting LMI consumers to participate. Both of these may confine the value of the project findings, which is unfortunate.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 4 |
| Collaborates with sufficient stakeholders | 3 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** It is good that the project report was frank about problems, and team worked hard on course corrections when expected success on planned interviewing approach and scale fell quite short. Some problems could not be anticipated (impact of hurricane). But some problems perhaps could have been better anticipated. It would be valuable for LMI stakeholders and business to share not just just successes, but what assumptions, messengers, training protocols and conflicting priorities could have been better anticipated. This will improve odds of success for others wanting to leverage this project's efforts and replicability. Publication success is very good to see. Not clear if level of impact desired by stakeholders beyond academia is happening at hoped for level. It is very good sign though to see that DC Department of Energy and Environment has requested self-interview protocol. Website communications have gone quiet in 2020. Twitter appears to not have any recent posts. This raises questions about dissemination plans. SolarSmart Advisory Board does not appear to have African American members in a state that is 30% Black. Guidance on effective stakeholder collaboration and dissemination be impacted by this.

**Reviewer 2:** Per the report, project team seems to be tracking and reporting on milestones and required quantitative metrics. Delays to the timeline and adjustments to the budget were identified and explained. A significantly more detailed report would need to be reviewed to provide additional feedback.

**Reviewer 3:** The project participants are very open about unforeseen challenges, which they tried to overcome. I will be very interested in the portal results.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Interview methodology, analytical tools and results will be useful information for many stakeholders now that course corrections have been made and project is back on track in many ways. An important caveat is that depending on the demographic distinctions and stakeholder engagement, there could be blind spots or information that will end up being too generic depending on what segment of the LMI platform is being engaged. It is good that energy was put into ensuring an accessible online platform. The wealth of information is a valuable even given the gaps. It would be interesting to assess which stakeholders are mostly using the site, especially within Georgia. It is good that there is participation in relevant energy summits that address LMI issues to share findings, engagement with the Public Service Commission and good collaboration with the Georgia Cooperative Extension Service (COES) for the project. It would be good to elaborate on the conflicts that caused the COES to have conflicting priorities when doing interviews and higher than expected levels of success, since these could continue to surface as COES is part of the implementation.

**Reviewer 2:** Score: 5. Comments: Understanding of LMI and rural population's existing knowledge of and approach to solar is important to creating solutions to increase access, so the project in that way adds value to the industry. The uniqueness of this project is not as relevant as the data being collected and reported will be additive to any other similar studies.

**Reviewer 3:** Score: 5. Comments: Since there is little research on LMI solar adoption, each task added value to the goal. Mitigating soft cost for LMI is especially valuable.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It is not clear if demographics (e.g. race, age) distinctions are sufficiently analyzed. This could be a communications issue - but information doesn't jump out from materials/ website. There are likely to be important differences among LMI communities by race in Georgia, for instance. These need to be highlighted in the analysis clearly if recommendations to policymakers and businesses to succeed in practice. Georgia Cooperative Extension Service (COES) is a key partner but were not able to deliver as expected on the interview phase. It would be good to elaborate on the conflicts mentioned that caused the COES to have conflicting priorities when doing interviews. These could continue to surface as COES is part of the implementation, so good to understand clearly.

**Reviewer 2:** The PI may be focused on the knowledge gap, however there are multiple other non-economic reasons for the disparity in LMI vs non-LMI adoption that can be considered and investigated in tandem with the current effort.

**Reviewer 3:** Project has already acknowledged it-insufficient understanding of the LMI community.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Representatives of organizations that are from communities of color in Georgia, since communities of color are a key subgroup of the LMI community where solar could bring benefits and help grow the industry. SolarSmart Advisory Board, for instance, doesn't appear to have African American members in a state that is 30% Black. Guidance on effective stakeholder collaboration and dissemination be impacted by this. Communications experts that have experience with the different segments of the LMI community and could be a bridge between business and policy leaders, this project, and the communities where we want to see scaled up solar adoption. Perhaps communications experts could have spotted that the interview protocols and language and incentives of the interviewers would lead to reticence by interviewees.

**Reviewer 2:** The report identified significant challenges in the ability to have LMI and rural populations participate. This would perhaps indicate that additional local and community organizations needed to be involved to be able to effectively liaise and provide more thorough data.

**Reviewer 3:** Did the team try to recruit electric co-ops, or the GA cooperative statewide association? Co-ops receive higher scores from consumers than any other electric utility sector-they know their communities. While I can understand why all co-ops might not have been interested in participating, some might, especially if the co-op understood that the objective was not to urge consumers to adopt solar.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Given the Georgia is very diverse, and that we want replicability outside of Georgia, might be good to make more visible the demographic distinctions in the analysis in the materials; AND related, to add to the SolarSMART Advisory Board leaders that have experience in the LMI segments of the African American community. (This is at the very least- there are other smaller communities of color as well.) 2) Communications expertise could be of value. They might have guidance on how to keep website updated more frequently but in a way that is efficient and not heavy a time burden. Of course there are other avenues for collaboration and dissemination beyond academic circles, but the website is likely to be a critical window for the project. (Twitter account was established, and also has not seen activity in a long time.) 3) It will be important, as COES continues to be a partner, to feel confident that lessons learned about the conflicting priorities are well understood and factored into the execution phase.

**Reviewer 2:** 1) Research projects are important to provide baseline data that the industry can build off of both from a commercial and policy standpoint, however the project might be more impactful if there was a clear handoff or next steps plan to be able to utilize the data in a tangible way in market solutions. 2) Some of the findings regarding the knowledge gap are already known to market participants who interact regularly with LMI and rural communities. 3) Project focuses on knowledge gap, however there are multiple other non-economic reasons that should be considered and investigated as part of the same effort.

**Reviewer 3:** Provided that the results are objective in identifying barriers and educating LMIs, please consider funding similar projects!

## Developing Shared Capitalization Platforms for Low-Income Solar Finance – $1,200,000

*University of New Hampshire | Durham, NH | Principal Investigator: Eric Hangen*

This project team works with community finance institutions to create training programs and shared capitalization platforms that enable credit unions, community banks, and community development financial institutions to expand their engagement in solar finance in low-income communities. Completion of these web-based trainings on the tools and techniques of solar finance will yield a certificate from the University of New Hampshire. The team strives to have at least 300 staff at community finance institutions participate in the trainings during the project period.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 6 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** CDFIs could play a significant role in providing low cost capital to solar projects serving low income communities, but a lack of knowledge around solar projects and their development and/or financing models that are not aligned with their capacity may be a barrier to their engagement. The project lays out a strong roadmap for both educating CDFIs on solar for LMI households as well as developing innovative new financial tools that can both support solar PV deployment as well as design new products well-suited for LMI households to go solar. While the project could significantly expand available capital for low income solar projects, I would not necessarily classify the educational aspect of the project a "high risk" approach, but project participants could face risks in the implementation of the financial instruments developed through this project.

**Reviewer 2:** Overall excellent strategy and approach. Mass training of community finance institutions would create, eventually, a landscape that is no different than the current one for assets such as Affordable Housing. 3rd objective, "mobilizing capital" seems slightly light and underrated as real challenge for this work. Current market for community development institutions to access large amounts of useful capital for solar is extremely underdeveloped. Access to solar for LMI is clearly at the heart of this proposal.

**Reviewer 3:** Strengths: Project team includes multiple participants who are well positioned to execute the goals. Inclusion of all levels of the financial industry, including community banks and CDFIs can create a robust marketplace necessary to serve smaller as well as underserved population groups. Education of smaller bank professionals has been identified as the key gating issue. Program for small bank education and product development in replicable. Weaknesses: Project objectives could be stronger with higher quantitative thresholds given the timeline and level of funding, especially as it relates to execution of financing targets (currently targeting 1,000 households and >300 LMI households over 3 years). Focus is on creation of lending solutions, however for streamlined market activity integration is required with other financiers for the remaining parts of the capital stack, project report does not address plans for education regarding or engagement with equity/tax equity as will be required.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project engages a wide range of stakeholders with significant expertise to achieve its goals. The milestones and deliverables are quantifiable and significant. The educational materials developed through this project will have longstanding benefits, even to organizations outside the scope of this project.

**Reviewer 2:** There is very little performance to date so not a lot to comment on. Project should consider measurements that capture new activity as a result of this work as opposed to counting institutions and projects financed. This work will likely be beneficial even to institutions who are already deploying capital in this space. As such they should be engaged with, but their activity isn't necessarily a measure of success for the project.

**Reviewer 3:** Project has not yet started.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each of the tasks in this project builds off of previous task to achieve the project's ultimate goals. By building the educational base to enable CDFIs to engage with solar lending, the project can move on to more complex tasks like recruiting participants and actually mobilizing investments. However, it may be possible to achieve the projects goals without devoting quite as much time to education as outlined in the project.

**Reviewer 2:** Score: 6. Comments: The work plan is well thought out and detailed and the 3 objectives are clear and impactful.

**Reviewer 3:** Score: 5. Comments: The project objectives are all sequentially additive to the overall goals of the project. The outreach to smaller financial institutions is not unique, however given the number of such institutions any formalized outreach process is beneficial and additive to previous efforts. The focus on education and collaborative product development is an important value add for this market segment that would otherwise be unable to deploy capital into solar.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project mentions that participating CDFIs engage in a wide range of financing options including consumer level loans, as well as community solar or commercial-scale products. Depending on the organization, it may be challenging for CDFIs to establish a consumer lending product on the household level, especially for low income solar. The PIs may need to adjust their project goals once education takes place to determine what types of projects CDFIs may feel most comfortable lending to.

**Reviewer 2:** As noted, the project seems to downplay the real challenge for community finance institutions to access the capital needed to invest/lend in solar in a scaled way.

**Reviewer 3:** The PI is focused on lending solutions, however to be most effective, careful consideration needs to be given o how lending will interact with other capital types to create one unified and seamless financing solution for the customer.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project should also incorporate the perspective of solar developers to ensure the financing products the CDFIs are developing are in line with the needs of the industry.

**Reviewer 2:** The collaborative is clearly a very strong group. The only note is that while there is some plan to engage with providers of capital to the organizations the project is working with, but it appears light given the associated challenges. Changing CRA landscape is mentioned as a challenge but even the current CRA landscape is challenging for community finance institutions with respect to solar.

**Reviewer 3:** The project already has several project members, who collectively should be well positioned to implement the project activities and goals stated.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The educational materials developed under this grant will have far reaching benefits, potentially even outside of the community lending space. 2) It may be challenging to get interest from CDFIs to finance all the types of solar arrangements mentioned in the project description. 3) Particular focus should be given to ensuring that products developed as part of this initiative/projects support deliver meaningful reductions in energy burdens for low income households.

**Reviewer 2:** 1) Very important work and exactly how to expand access for LMI families. 2)Needs more focus on access to capital. 3) Seems important to provide project flexibility in later years to adapt plan if lessons learned around lack of current participation in solar markets by Community Finance Institutions is result of unexpected factors.

**Reviewer 3:** 1) The focus on education has importantly been identified as a foundational piece which will have far reaching impacts on any future activities and interactions with these institutions. 2) The project goals could be more robust in terms of capital deployment and households financed through the three years of the timeline. 3) The project team consists of multiple parties who should be well positioned to implement the project activities and goals stated.

## Knowledge Spillovers and Cost Reductions in Solar Soft Costs – $1,250,000

*University of Texas at Austin | Austin, TX | Principal Investigator: Varun Rai*

This project studies the size and mechanism of knowledge spillovers in the solar industry, specifically how best practices related to solar soft cost issues are transferred. These best practices include installation processes, permitting processes, customer acquisition, and overhead costs. The project examines how important knowledge spillovers are, what types of knowledge are most likely to spill over, and how policies can be designed to address them.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 2 |
| Set critical challenges to overcome | 4 | 5 | 2 |
| Implement a high-risk, high-impact approach | 4 | 4 | 1 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 1 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 1 |
| Advance the U.S. solar industry substantially | 4 | 4 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** It's unclear how the project will assist with access to solar technology however carrying out an overall analysis of the soft cost landscape will be a useful asset.

**Reviewer 2:** Strengths: Focuses on core part of SETO's goals: soft cost reductions. Project lead and team have applied a methodical approach to soft cost classification, data collection and analysis, and key results are clearly stated. Weaknesses: Project report provides support for the fact that knowledge spillover is important for soft cost reductions, there could perhaps be further actionable recommendations or thoughts on implementation of systems which would enhance knowledge spillover.

**Reviewer 3:** This is a research project of academic interest but it's not sufficiently obvious that this work adds significant value to practitioners. Knowledge is transmitted by employees who change jobs, industry benchmarking and events, and competitive analysis by relevant actors, though I do not claim to be an expert in this area. The data in the analysis set, 2000-2015, does not seem relevant today. The project summary states they have achieved their objectives: "We have largely achieved what we set out to do in quantifying the impact of knowledge spillovers, understanding the mechanisms of soft cost knowledge flows, and identifying the relevant actors in the soft cost knowledge ecosystem."

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 1 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 1 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 1 |
| Collaborates with sufficient stakeholders | 4 | 5 | 1 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** It's difficult, based on the report to provide feedback on progress to date.

**Reviewer 2:** Project has almost reached completion and has finished all but one milestone.

**Reviewer 3:** See previous comments.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Again, difficult to identify based on report provided.

**Reviewer 2:** Score: 5. Comments: The various tasks mentioned did seem critical as a basis for achieving the final result of the study.

**Reviewer 3:** Score: 1. Comments: See previous comments.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** This is not an area of expertise so unclear what the PI is missing, if anything.

**Reviewer 2:** None specifically identified given the PI defined the project very specifically as examining the effects of knowledge spillovers.

**Reviewer 3:** See previous comments.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project has clearly worked hard to identify necessary data to examine project goals.

**Reviewer 2:** The specific collaborators (outside the project participants) were not specifically mentioned, however the types of data and case studies mentioned in the report would indicate that the project team had access to the relevant industry organizations necessary.

**Reviewer 3:** See previous comments.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Is there a way to use findings to help LMI families. 2) Can the findings be use to drive down soft costs? 3) Is there a way to communicate findings in language that non-experts can understand?

**Reviewer 2:** 1) Project aimed to put formal framework around the discussion and analysis of soft costs, which directly furthers SETO's goals. 2) Results, while showing conceptual mechanism by which soft costs can be reduced, did not recommend distinct tangible next steps for implementation of hand off to other industry participants.

**Reviewer 3:** See previous comments.

## Using Behavioral Science to Target Low- and Moderate-Income and High-Value Solar Installations – $1,350,000

*Yale University | New Haven, CT | Principal Investigator: Kenneth Gillingham*

This project is testing new messaging, financing, and shared solar approaches for enhancing the diffusion of solar energy in low- and moderate-income populations. The project also quantifies the benefits to the electricity grid from programs that expedite and increase deployment of solar energy in areas where solar provides additional value to the grid. In addition, pilot projects within three states test the models developed under this work in the field with the intent to use lessons learned from messaging studies to encourage more populations to go solar, particularly in areas of high grid congestion.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: this is a robust project that ties the study of solar diffusion within LMI communities to location based solar that provides a continued value to the electric grid. The project creates a blueprint for how solar campaigns can find a middle ground with utilities by integrating with the utility grid in locations that provide benefits to the grid and ratepayers.

**Reviewer 2:** This is a highly valuable academic research project, the results of which stand to significantly advance LMI solar adoption if disseminated widely, and to the right audiences. The findings around effective messaging are directly applicable to solar developers conducting outreach to LMI customers, and can reduce soft costs by ensuring that messaging is aligned with the findings of this study. Additionally, the feeder-level analysis for where solar has the most value on the grid is important for helping to reduce resistance from the interconnecting utility, and/or expensive distribution grid upgrades. This study also indirectly helped to highlight how policy/regulatory barriers can inhibit the adoption of solar, as customers interested in community solar were put on a waiting list when community solar became fully subscribed in South Carolina, and the capping out of net metering likely discouraged individual homeowners from signing contracts.

**Reviewer 3:** Project is well thought out with broad coordinated approach that addresses a variety of the most important questions around solar installation with a specific focus on LMI households.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 6 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project was high performing based on the significant number of field experiments that tested the deployment of solar among income levels based on a pro-social and self-interest campaigns. The pro-social and self-interest approaches were novel as they measured a consumers mind set on what type of solar messaging appeals to them and by randomizing among income levels the project team was able to find that self-interest messaging was most appealing. The project team also measured solar messaging campaigns against circuits that showed solarize campaigns, in specific regions of the grid where solar is needed, is valued at $60-$100 per MWh, due to the value of energy, capacity and avoided emissions. Altogether, this project has completed many highly involved and robust tasks that have uncovered a significant amount of invaluable results that will ultimately push the solar market forward.

**Reviewer 2:** This project seemed to be particularly active in disseminating results, though it was a bit unclear who the audiences included. It seems especially important that these results reach solar developers (especially those focused on LMI customers), utilities, regulatory bodies and policymakers. Academic papers, while important, are likely not the best vehicle to reach these audiences, so the PI should make efforts (if they've not already done so) to disseminate their results beyond the academic community.

**Reviewer 3:** Prolific publications combined with specific data around households and installed capacity.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: All tasks and phases have been defined and well thought out. It was critical that they performed well due to the progressive nature each task had. For example, phase one consisted of solar campaigns in Connecticut and South Carolina where the results were needed to prepare the build out of phase two that identified regions of the grid where solar campaigns could provide important benefits to grid circuits. The final phase is spent reviewing the results of the project and preparing marketing and dissemination material to a broad audience of solar stakeholders.

**Reviewer 2:** Score: 4. Comments: As with a similar research-based project, there was a geographic analysis component married with a behavioral diffusion component. While these two components are complementary, and both contribute to soft cost reductions, it wasn't entirely apparent that they were closely related. Nevertheless, the results of both of these analyses are valuable. Beyond the broad work areas, I didn't have access to detailed tasks or a work breakdown structure, so am not entirely able to comment on the unique and important value of each task.

**Reviewer 3:** Score: 6. Comments: The project clearly lays out the 8 tasks they set out to carry out and has assembled a broad team to carry it out. The questions being asked are key to solar access.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** It's import to consider the method and fashion in which results are disseminated and for such an academic project that can have significant impacts on solar industry stakeholders such as marketing directors of small to medium size contractors and solar developers, materials should be published in the simplest of terms. Doing so will help the results become socialized quickly.

**Reviewer 2:** One potential blind spot, though I did not get to explore this with the PI, is around how willing a utility would be to take the results of the "value to the grid" analysis, and if/how this would actually translate to reduced friction in siting and interconnecting solar projects. If the PI has not engaged with utilities to understand their position and potential constraints, the findings of the study may not necessarily align with realities encountered in the field.

**Reviewer 3:** It's not clear that a great deal was done to dive into obstacles for LMI consumers that might not be behavior/ messaging based.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team should consider engaging with state solar associations to ensure the results quickly make it down to the solar contractor level. State solar associations are the closest to the solar contractors and can help spread project results through webinars, emails blasts and conference calls.

**Reviewer 2:** It seems that the project has broadly engaged with the right sets of stakeholders. It was unclear from the materials provided what level of engagement had occurred with utilities. This would be an important stakeholder to engage with when considering "value to the grid," and how demonstrating/mapping that value can actually result in a reduction to soft costs.

**Reviewer 3:** The breadth and knowledge of the participants and stakeholders appears to be more than adequate.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The project had many moving parts yet they all worked together to create a singular focus and well defined outcome. 2) Multi-state projects sometimes may have too broad of a reach but this project was able to complement the results from the solar campaigns in each state to uncover critical outcomes. 3) This project is highly replicable and I am excited to see it tested in other regions that could utilize it.

**Reviewer 2:** 1) The research performed in this project is very valuable provided the results get in front of the right audiences and are applied, beyond the solar adoption that resulted directly from the Solarize campaigns conducted as part of the project. 2) Engagement with utilities is a critical piece to understanding how the results of the "value to the grid" portion of this project can lead to actual soft costs reductions - i.e. do utilities agree with these findings, and see the potential for reducing issues associated with siting and interconnecting solar? 3) It would be helpful to somehow quantify the actual impact on soft costs as a result of solar developers implementing the findings around effective messaging and the agent-based diffusion model.

**Reviewer 3:** 1) Based on projects I've reviewed, this appear to be a model for how soft cost project should work. 2) Clearly engaged and prolific sharing of information is extremely beneficial. 3) The challenges they have had in South Carolina, beg the question of whether there are other ways to produce meaningful and useful research given the different barriers to access in almost infinite jurisdictions.

## Developing a Deep Learning-Computer Vision Framework to Monitor Avian Interactions with Solar Energy Facility Infrastructure – $1,300,000♦

*Argonne National Laboratory | Lemont, IL | Principal Investigator: Yuki Hamada*

This project uses deep learning and networks of high-definition cameras for automated detection of avian-solar interaction, specifically fly-through, perching, and collisions. The team is training the deep learning models using data from video of birds and deploy the trained models at solar facilities to validate their performance. This project could improve the efficiency and effectiveness of detecting avian collisions around solar facilities, inform mitigation strategies, and reduce monitoring costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 2 |
| Set critical challenges to overcome | 3 | 4 |
| Implement a high-risk, high-impact approach | 1 | 3 |
| Match well with the level of DOE funding and planned project duration | 3 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 3 |
| Advance the U.S. solar industry substantially | 2 | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Would like to have seen the 1 month progress report-please send it even if it is after the review period wraps up. I hope the project has more success metrics than what is listed and more check points on success. Demonstration of need: would like to see a survey done demonstrating the demand for the research from technology providers and from solar developers. Would like to see a better description of how the project meets criteria 1.5.

**Reviewer 2:** Strengths: Project is looking to implement a replicable solution that benefits utility scale solar, and thus will have an impact on GW of installations. Technology could be useful for other technologies including CSP and potentially wind farms where the effects from avian interaction are more significant than in PV. Weaknesses: While an important environmental issue, it is unclear how this will substantially benefit or increase the rate of utility scale solar installation. Unclear how any costs savings from the development of this technology will translate into material LCOE reduction and achievement of SETO's goals. Field trials will start 3+ years from the project start date thus creating a long timeline for market adoption and tangible benefits to be realized.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 1 | 5 |
| Disseminates results frequently and actively engages partners | 1 | 5 |
| Collaborates with sufficient stakeholders | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** I have concerns about the go/no go first milestone being 1 year out. Within 6 months I think there should be a report on how the risks are being mitigated and demonstrating sufficient input is being considered by industry and agency stakeholders. Permitting is going on now for projects that will be in the ground in the next 3 years. Glad to see so many state agencies involved, by why not USFWS? Make sure that stakeholder engagement focuses on USFWS as they are the ones who need to provide the permits to projects. Local BLM and local USFWS collaboration is critical-local offices often do not follow federal level guidance. Equally critical is to inform the counties planning boards and commissions most likely to have large scale solar (there are not actually that many of them, and county level is critical). Education out to these groups should be happening on a rolling basis, not at the end of the research.

**Reviewer 2:** Project just initiated in March 2020, therefore no track record on which to comment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Per above, more detail is needed as to how stakeholder engagement task will be scheduled-how to effectively disseminate the information early to the key agencies even if results are not yet in. Just knowing the research is happening can help a lot as developers face questions from communities who oppose solar.

**Reviewer 2:** Score: 5. Comments: The project itself seems well laid out in terms of tasks, and there do not seem to be any similar existing solutions in the marketplace. The value that the project adds seems to be heavily on the environmental side.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Consideration should be given to presenting the positive impacts solar has on decreasing climate change impacts to avian species. This is an important point that is often lost. Suggest trying to get Audubon to play a role.

**Reviewer 2:** As the project has not yet started, unable to comment on any blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

Reviewer 1: Where will lessons learned from similar technology approaches for birds and bat impacts from wind be included? I worked for Iberdrola which was a test site in Texas (Penescal) for bat radar sensing. I remember the technology actually didn't perform well, and there were only two companies to choose from which led to it being a expensive technology that the company did not consider scaling to its other wind farms.

**Reviewer 2:** This project has not yet started, however other potential stakeholders are mentioned in the report, including participants in the solar industry and environmental organizations.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** See the description of the areas above-would have liked a more detailed description, more involvement from environmental groups and USFWS, earlier check-in points, and demonstration that if successful the industry will truly use the technology (that it will be const effective).

**Reviewer 2:** 1) While the work being done could have important environmental and wildlife benefits, the project does not provide any data on quantitative impact to LCOE, and in general does not seem to fit in SETO's goals. 2) SETO team should look at evidence to support the need for this technology based on impacts to project implementation timelines and perhaps even project cancellations. There should also be a methodology to measure the impact of this potential technology in a quantitative way on LCOE or installation rates. 3) The project will produce technology which could be in field trials over 3 years from now, the timeline for market adoption and tangible impact from this funding is far in the future.-

## Unmanned Aircraft Systems and Light Detection and Ranging/Camera Technologies to Detect Avian Events and Other Environmental Measures at Utility-Scale Power Plants – $1,400,000

*Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Christian Newman*

This project develops machine-learning models for monitoring birds at solar facilities using two complementary remote sensing technologies: drones and three-dimensional imaging. The drones are used to detect bird carcasses and nests while simultaneously performing other site inspection tasks, and the 3-D imaging is used to detect avian collisions. The team is developing and testing both technologies in the field to compare them and validate their effectiveness and cost.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 4 |
| Set critical challenges to overcome | 5 |
| Implement a high-risk, high-impact approach | 4 |
| Match well with the level of DOE funding and planned project duration | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 |
| Advance the U.S. solar industry substantially | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: I believe this research is of vital importance if solar is to be widely adopted. O+M costs of post-construction monitoring can be very significant. Weakness: Grantee needs to give thought and plan for how the research will be disseminated.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 |
| Disseminates results frequently and actively engages partners | 1 |
| Collaborates with sufficient stakeholders | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Only comment is there should be more planning as to how stakeholders will be informed of the research. It is not really fair to judge the grantee in this category given the project has not begun, however I do support the breadth of experience in the project team and believe the planned research, if successful, will be very beneficial to solar adoption.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Believe the planned tasks are appropriate to the goals of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Groups like Audubon have stated that the biggest risk to avian populations is climate change and therefore embraced (smart-sited) solar projects even at utility scale. Research like this should put the avian impacts into context of other energy sources's impact and solar's beneficial impacts to avian species by decreasing climate change.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See above questions as to confirmed interested EPRI members wiling to host the systems.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** As the narrative put it, the scientific credibility research like this to the public and to permitting agencies s an important role that only government funded research like this can provide. I believe this research is of vital importance if solar is to be widely adopted. Post-construction monitoring for a 100 MW, 500 ac solar farm can cost upwards of more than $100,000 per year to a solar farm operator. That is a significant impact to operating costs. As mentioned above, research like this should put the avian impacts into context of other energy sources' impact and solar's beneficial impacts to avian species by decreasing climate change.

## Application of Manufacturing Quality Management Principles to Photovoltaic System Installations – $1,489,675

*Institute for Building Technology and Safety | Ashburn, VA | Principal Investigator: Rudolph Saporite*

This project develops an independent quality management system for photovoltaic installations that is low-cost and accessible to local and regional photovoltaic installers. Third-party inspections for systems can be costly and inconsistent across the industry. This team is working to standardize quality control processes, enable remote review of photovoltaic systems through photos and documents, and implement an industry-recognized quality scoring system for participating installers. The team is working with a broad group of industry stakeholders to define and test the software's functionality. Through use of the product, installers will increase the quality of their projects, which will in turn increase the overall value of photovoltaic systems across their lifetimes and improve investor confidence in the solar asset class over time.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 4 |
| Set critical challenges to overcome | 5 | 4 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 | 3 |
| Advance the U.S. solar industry substantially | 5 | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** In that quality control is a critical element of trust and willingness to adopt solar, advancement of this quality management tool is mission critical to the goal of solar proliferation to the greatest extent possible. If done successfully, by instilling consistent quality control and thereby boosting trust and confidence, this software will certainly add value to DOE's research agenda and advance the solar industry. Given the intricacies and the numerous hurdles to overcome, this is definitely a high risk, high impact endeavor. The budget and the time allocated to achieve the intended outcomes are appropriate.

**Reviewer 2:** Bringing a cloud-based platform to inspection and quality is a worthy program/objective. There needs to be a broader vision of how this interfaces with the SolarAPP program for permitting, because there needs to be continuity from permit submission to inspection. This coordination is something SETO should seek to provide/assist.

**Reviewer 3:** Although this isn't my area, I would think that developing software to streamline installation and inspection of PV would certainly benefit the industry, especially in driving down associated soft costs. My only questions are: how will tools streamlining installation/inspection be applied to multiple sets of standards that seem to intersect-installation/safety/fire codes? If these codes/standards change, will the software still be valuable. These may not be issues, but I wondered about them.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 3 | 3 |
| Measures impact appropriately (e.g. quantitative) | 6 | 2 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 2 | 3 |
| Collaborates with sufficient stakeholders | 5 | 2 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Performance to date is appropriate with the team having accomplished development of the focal software. Impact measures appear to be robust and appropriate. Results dissemination seems to be through tradeshows and direct engagement with stakeholders, which makes sense. With regard to stakeholder collaboration, the leadership and implementers of this project are dominated by those with technical expertise which is necessary but not sufficient when it comes to an intervention that requires interest in engagement by a wide swath of end users.

**Reviewer 2:** It looks like the team is not making as much progress as one would expect: "The team is currently working to complete the first two major milestones in the project which are engaging with industry stakeholders, and creating the scoping and architecture documents." Even with Covid19, they have still had 4 months. SETO should review and see who is involved on the stakeholder side and who has been engaged for software development, and the team's expertise in cloud-based platform development.

**Reviewer 3:** I'm not in a position to say whether the time frame or funds are warranted for developing this software.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The tasks for defining user needs, designing and testing the focal software, and then piloting the use of the software are all basic, logical steps in achieving the ultimate goal of having a workable, effective quality management system.

**Reviewer 2:** Score: 4. Comments: High-quality, high-impact cloud-based platforms offer significant advantages to ADJs which have no hope of developing such tools themselves. This project should be tracked for management/progress as early signs suggest delays.

**Reviewer 3:** Score: 4. Comments: Reducing soft costs for assessing installation/inspection is important, but it's predicated on use of the software, especially as applied to multiple integrated standards. See my previous comments.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project is devoid of mentioning measures to ensure equity, including attention to access and use of this product by disadvantaged business enterprises. (minority and women owned businesses)

**Reviewer 2:** Inspection and quality is only after the fact, and so the approach may be a little myopic. In practice, quality issues in installation rarely start at installation. They begin in site survey, when the measurements are taken for the design.

Similarly, inspection quality assessment needs the benefit of the original permit and design to compare.

**Reviewer 3:** Can't think of any.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Explicit engagement of Disadvantaged Business Enterprise vendors and trade associations.

**Reviewer 2:** High volume installers, inspectors, AHJ permitting offices.

**Reviewer 3:** Can't think of any.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The three areas warranting greater attention by the PI are: 1) Explicit attention to Equity; 2) Engagement of an equity focused partner to ensure greater attention to equity in the roll out and access; 3) Ensuring access to this software by disadvantaged business enterprises.

**Reviewer 2:** 1) Project-specific management and team skills issues. 2) if there is a gap between the worthy, holistic nature of Quality that the group is attempting to address, and the focus on inspection-phase, i.e., back-end tools.

**Reviewer 3:** What will the value of the software be if the codes/standards change?

## Solar at Scale: Improving the Local Rules of the Game for Large Scale Solar – $1,000,000

*International City/County Management Association | Washington, DC | Principal Investigator: Tad McGalliard*

This project team brings together public- and private-sector stakeholders to identify best practices for local governments, special districts, and other authorities that have jurisdiction to install large-scale solar projects. They are developing tools and resources for procedures, analysis, and communications related to permitting, zoning, regulations, and planning for these installations, especially on public and municipal lands, brownfields, and in rural areas. The team will disseminate this information through workshops, trainings, and other programming.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and supports SETO mission | 6 | 4 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 3 | 2 |
| Match well with the level of DOE funding and planned project duration | 3 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 2 |
| Advance the U.S. solar industry substantially | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** My comments here follow my comments on the project regarding permitting. Pls consult those for additional perspective. 1) it is highly likely that large scale solar adoption is one of the only ways through which the United States and other countries can shift to a clean energy infrastructure fast enough to mitigate effects of climate change. As such, this project has the potential to be very important. 2) However, the current goals of the project as stated are to (a) develop a guidebook; and (b) disseminate the information. These goals need to be re-oriented toward adoption and measurable time decreases in Application-to-Permission to Operate (PTO) cycle times. The approach should be: (a) get representatives from the top 10 utility scale developers and the utilities with the highest number of large scale solar systems into a room with the prospect of lower adoption costs to all parties who participate; (b) collaboratively design a "new" process for bringing utility scale solar to market at 1/10th the time and cost; (c) pilot the new process with a couple projects; (d) measure, refine, repeat.

**Reviewer 2:** I am not sure this project adds significantly to existing programs-would have liked to seen a needs assessment surveying other such efforts. A quick google search shows SunShot already developed a number of toolkits and guidebooks (particularly good one from NYSERDA). How is this different? Is the grant to try to advance solar on municipal lands, or is it a guide to permitting large scale solar projects owned by third parties? I don't think it can do both in this timeframe. Most importantly, I strongly recommend walking back the use of the word large scale solar if the focus is the former. Few government owned properties are suitable to a project over 10 MWs, and for a 'large' project, the entity would have to sit through 3-5 years of interconnection studies. If they go out for RFP and ask a developer to do it, it is likely they will not have a high enough power purchase rate to convince developers that the project is more viable than a community solar scale project. That has at least been my experience in the Maryland market. I like the idea of highlighting opportunities for municipal projects but don't call them large scale. The biggest viable project I have seen is a 18 MW project in Annapolis on a brownfield, but that took 8 years to develop. A better use of funds than a guidebook and outreach would to help municipalities who can't fund a feasibility study to do so. A study on if municipalities have any viable land near IX would be much more effective. On the topic of brownfields: Solar on brownfields is also twice as expensive due to the added liability and expense of a ballasted versus driven pile foundation system. EPA data has overestimate the potential across the US for solar on brownfields. The case is well laid out in this report: http://www.mdcounties.org/DocumentCenter/View/2924/USSEC-Analysis-of-Solar-Potential-on-MD-Contaminated-Lands---FINAL-10918

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 2 | 2 |
| Disseminates results frequently and actively engages partners | 3 | 0 |
| Collaborates with sufficient stakeholders | 3 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The provided poster does not provide enough information about progress to date, as such, I have given a 3 for every metric, except measuring impact appropriately. Per that, the goals and measurement should be re-oriented per my comments above.

**Reviewer 2:** See comments above. I recommend the grantee rework the program objectives and narrow the goals and associated tasks.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project has very high potential and with different goals should be tracked and invested in by SETO. To state the obvious: For utility scale you need one permit to construct a 1GW facility. The same impact would require 167,000 residential permits, each taking 1 week to 4 months.

**Reviewer 2:** Score: 3. Comments: See comments above. Believe this project should be re-envisioned before it begins.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Re-orient toward impact. Measurable decreases in permitting times, not guidebooks.

**Reviewer 2:** See brownfields comments above. Municipalities also often go out with RFPs asking for a 'menu' of options- SREC revenue, energy, energy for residents as well through community solar, and rent. Many do not understand that it is not viable to give all these revenue streams to them unless the project is fully developed and owned by the muni with no third party developer (in which case most can't utilitize the ITC, so the project economics do not work).

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The key people/groups are: largest utility scale developers, e.g., 8 minute energy; utilities with largest utility scale solar installations; anyone at the local level who can slow projects; environmental and non-profit and advocacy groups who can put pressure to drive change.

**Reviewer 2:** There seem to be a lot of stakeholders missing, especially to ensure past work through Sunshot is built upon; for example, The Solar Foundation, SEPA, IREC, and NARUC. Also consider Maryland Association of County Organizations (MACO) who have consistently opposed solar and pushed for moratoriums against large scale solar. Similar associations of counties (outside of just ICMA) must exist in other states. Perhaps look at the states with the strongest RPS targets and most installed solar and see what associations there might be able to share lessons learned.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1**: See previous comments.

**Reviewer 2:** This grant is attempting to accomplish too many disparate goals. I am skeptical about the effectiveness of another guidebook/toolkit and not convinced why this is different, then state guides sponsored by Sunshot. If it is a continuation and expansion, then the grantee needs to explain that. Many more stakeholders should be included. The word large scale is not really appropriate here. Few publicly owned lands have the right mix of criteria (no environmental risks, sufficient land area, and most importantly access to available transmission lines) for a project over 2-5 MWs.

## Develop Consensus Recommendations to Address Challenges with Solar and Solar Plus Storage Code Enforcement and Permitting Approvals – $1,500,000

*Interstate Renewable Energy Council | Latham, NY | Principal Investigator: Larry Sherwood*

This project addresses challenges to efficient permitting approvals by focusing on filling knowledge gaps. The team surveys stakeholders to learn what complicates code enforcement and creates a regular web conference call forum for interested stakeholders to discuss issues. This project team will develop consensus recommendations that advance adoption of data-driven permitting and inspection best practices, ultimately leading to growth in new markets and cutting red tape for safe solar and solar-plus-storage projects.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 4 |
| Set critical challenges to overcome | 4 |
| Implement a high-risk, high-impact approach | 4 |
| Match well with the level of DOE funding and planned project duration | 3 |
| Add significant value to existing research outside DOE-funded efforts | 4 |
| Advance the U.S. solar industry substantially | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goals of this project are worthwhile and consistent with overall SETO objectives. However, it's unclear the extent to which this project will actually impact soft costs-given the multiple layers of standards/codes that are included. I question whether the project goals are realistic: getting a uniform standard for battery energy storage systems within the utility sector is difficult enough; overlaying that on federal and state fire and safety codes and needs will be especially difficult. The project report notes these challenges and the diverse stakeholder group. If the end result is to start a dialogue-then that's one thing, if it's to get consensus-that's another. Back to soft costs-a dialogue isn't very actionable or quantifiable. Will there be a business implementation plan? Conversely, if the result is to get consensus, then the impact on soft costs would be more quantifiable, but more difficult to achieve.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 |
| Measures impact appropriately (e.g. quantitative) | 3 |
| Disseminates results frequently and actively engage partners | 5 |
| Collaborates with sufficient stakeholders | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is just getting started, so some of these scores aren't relevant.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task is important. I just question whether they can be accomplished and the actual value in bringing down cost costs.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Difficulty in bringing together diverse stakeholders/codes to achieve a result. Also, why no utility participants?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** There don't appear to be any utility stakeholders.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Is the stakeholder group sufficiently diverse? Is the overall goal to get a conversation started about uniform standard, or achieve consensus on a set of recommendations? If the latter, is that actually doable?-

## Interoperable Energy Information Database for Real Estate – $450,000

*Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Ben Hoen*

Solar is growing rapidly, but data about the accurate valuation of homes with photovoltaic solar is lacking, as is information-sharing between solar data sources and real estate multiple listing services. Building on past work, this project combines previous ad hoc efforts to auto-populate photovoltaic data in multiple listing service databases. This database holds energy-efficiency data and software infrastructure from the Home Energy Labeling Information Exchange repository, and this project would result in a solar-data-enhanced version of the HELIX package. Guided by an industry advisory team, the team will partner with the HELIX project leader and software developers to enable HELIX to accept solar data and disseminate information about it.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 6 |
| Set critical challenges to overcome | 6 | 4 | 6 |
| Implement a high-risk, high-impact approach | 4 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 6 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The projects strength is in the innovative modification of the Home Energy Labeling Information eXchange (HELIX) tool to allow it to accept solar data from the PV Auto-Population (PVAP) so it can become a hub to connect solar data to MLS services nationally. Another strength is how the project is building off past research projects aimed at MLS auto population. One weakness is the lack of a national or even state standard that is mandated. Without a mandate, regional MLS services will incorporate at their own pace if at all.

**Reviewer 2:** Strengths: Project should ultimately allow homeowners to see the tangible benefit of installing solar when selling the property, may ease initial purchase friction and accelerate adoption. Project is partnering with several large MLS, real estate service providers, states, and utilities. Project is looking to achieve self-sufficiency as a standalone business. Weaknesses: Unclear what impact this will have on LCOE or solar adoption rates, or that the impact would be quantifiable. Significant challenges identified in terms of getting major players to engage and commit (e.g. CT), thereby risking delays and project goals. Project is technologically focused without significant reference to financial impact and progress towards SETO's goals.

**Reviewer 3:** Project is very ambitious in trying to influence and change the way the real estate industry works. This is the definition of high risk / high reward. While current real estate transaction with residential solar attached are, by definition, more limited than new build - having the model built in will yield long-term benefits. However, the overall sector is quite small and the problem is acute in the near term. Strengths: ambitious - looking to actually have these models implemented in live MLS services; Working with a broad stakeholder group and not looking to replicate something that already exists via private industry. Weaknesses: An important piece of long-term solar adoption but one that has limited direct impact today.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 6 |
| Collaborates with sufficient stakeholders | 4 | 5 | 5 |

Using the above criteria, please summarize the performance of this project in 100-200 words.

**Reviewer 1:** This project is making healthy strides toward their goal of expanding the use of PVAP through the inclusion of standardized solar data in the HELIX tool. It's also making strides in testing the data through pilots in the Northeast. The project team has done a good job of staying on task and working with stakeholders to ensure barriers to MLS integration are known and dealt with.

**Reviewer 2:** Per the project report, all milestones to date have been met, with the exception of the state threshold, due to external party delays. The project team has created an advisory committee and seems be in regular contact.

**Reviewer 3:** Funding level vs. the change being implemented seems like an incredible value for SETO. Project appears to be on budget. Very strong performance to see live implementations. Slightly concerned by the continued target of 20 implementations nationwide given the slow start and difficulty getting adopted. Would encourage SETO to dig in and understand whether team expects adoption to become easier with a few implementations already in place.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The organization of the project tasks are logical and additive to each other. Task one provides distinct value through the modification of the HELIX database to accommodate solar data while task two is aimed at expanded the use of PVAP use in 4 northeastern states while task 3 is creating a network of stakeholders to help expand the use of the tools.

**Reviewer 2:** Score: 4. Comments: The tasks identified seem to be additive to the final goal of widespread deployment of the system and solar data inclusion in real estate listings. The specific tasks do not seem to overlap, and critical items such as data clean up and integration with third party systems have been identified.

**Reviewer 3:** Score: 6. Comments: Project phases are logically laid out. Target is ambitious and later phases focus on scaling up implementations. May have missed anywhere that discusses a look back at existing implementations and adjusting for friendlier adoption/better modeling.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Because of the length of time and the stakeholders that have been engaged in this project, the project team is very aware of the steps needed to complete this project and the difficulties in expanding the national reach. With that said, I don't believe there are blind spots that are unknown the PI and project team.

**Reviewer 2:** The project seems to be focused on the technological and data benefits of the project, however the financial benefits to the customer and more importantly to the industry overall have not been appropriately identified and quantified in the summary report.

**Reviewer 3:** It's not sufficiently obvious that there is a feedback loop on the existing implementations so that future adoption is simpler and better.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team has done a great job of connecting with solar industry stakeholder as well as the real estate industry to disseminate the benefit of this project. They've also worked with academic and non-profit energy companies to pull the value provided these entities. No other organizations come to mind to collaborate with.

**Reviewer 2:** This project, though focused on the technological aspects of data integration, could benefit from collaboration with solar marketing and development firms to help provide context for the benefits of this initiative.

**Reviewer 3:** All of the right stakeholders appear to be involved.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) This is a valuable project to integrate the solar ecosystem with an established system (MLS) that is critical to the resale of homes. 2) After the completion of this project there will remain further effort to saturate every market throughout the United States with this information. Further learning, funding and collaboration will be required. 3) Project team is meeting their milestones and deliverables and looks to finish the project on time and on budget.

**Reviewer 2:** 1) Project could provide potential customers comfort around real estate value increase from solar thereby raising adoption rates. 2) Project is technologically focused but has not quantified benefit to industry and progress towards SETO's goals. SETO should focus on evidence to support the thesis of increased adoption and create measurement techniques to show decrease in customer acquisition costs or other effects on soft costs and LCOE. 3) Much of the project's success is dependent upon interfacing and pushing sometimes reluctant third parties to implement systems, creating risks for delays and / or missing project goals

**Reviewer 3:** 1) Since a big goal of the effort is to gain real estate industry acceptance, SETO should confirm that such a need exists and that private industry is not already building similar, more readily adoptable, tools. 2) Compared to other projects, this project has a very tight budget while effectuating change in a very slow moving industry. Very impressive. 3) This work does not sufficiently highlight how the limited immediate impact (i.e., residential re-sales) compare to the broader goals / priorities of SETO.

## Solar Photovoltaics and Real Estate: Harnessing Big Data to Drive Demand, Increase Transparency, and Lower Balance of System Costs – $1,771,229

*Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Ben Hoen*

This project analyzes the extent to which photovoltaics can add value to real estate properties. Past analyses have shown that solar adds value to host-owned residential properties, but there is a lack of information for residential properties with third-party owned systems and commercial properties. This project analyzes the impact of these systems on home values and other factors, which allows for increased growth of the solar market by providing real estate professionals and potential adopters with accurate valuations.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 5 |
| Set critical challenges to overcome | 4 |
| Implement a high-risk, high-impact approach | 5 |
| Match well with the level of DOE funding and planned project duration | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 |
| Advance the U.S. solar industry substantially | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Project sets 4 goals - (1) home pricing impacts, (2) feed solar deployment data into MLSes, (3) commercial deployment patterns and (4) impacts on property values from houses near solar installations. Each of these goals are laid out well, with good combination of technical and industry collaboration. Overall, some concern on the focus on residential re-sale value (items 1 and 2), which is by definition, a subset of the residential market. Potential for what's created today to have a long lasting effect but near term impact may be light. Commercial deployment patterns is an interesting goal and may be useful for industry. Since it involves a contained scope, primarily including data gathering, data cleaning and data analysis - dedicated resources can and should likely be contained. Large-scale PV property impacts could have immediate impact in reducing industry permitting and siting concerns. Unclear how these results will be delivered to the appropriate people. Strengths: Contained goals that all circle around similar topics and presumably stakeholders. (Although commercial deployment analysis is an odd one to include). Collaborating with important stakeholders (i.e., Fannie Mae). Weaknesses: Outreach of results is unclear. Fannie Mae's participation is helpful, but how will this be further disseminated into MLSs and/or permitting committees (or industry)? Budget seems fairly high given that there seems to be contained to data gathering and data analysis. Modeling work (i.e., satellite imagery analysis) may be the cause?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 |
| Disseminates results frequently and actively engages partners | 3 |
| Collaborates with sufficient stakeholders | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Budgets seem fairly high but looks to be on track and under budget. Measures impact primarily by showing citations in academic publications and number of downloads off of website. But no verification or analysis on if these studies are getting to the right people who can act on the conclusions. Collaboration with Fannie Mae is a strong plus - would like to see additional evidence that it has affected standards/policies/models/process, etc. Other similar projects worked with local MLSs - could be an opportunity here.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 0. Comments: Each milestone is well laid out, but goals stop short of outreach and pushing for a clearer impact. Publication should not be the goal - influence should be. Would like to see better communications and outreach as a result.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** How will collaboration with Fannie Mae trickle down into the real estate market more broadly? Fannie Mae collaboration is good, but is only part of the journey.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Other similar project worked with local MLS listings. Would that be an opportunity for additional stakeholders?

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** How will the results and conclusions of this projects be disseminated? In a short funding scenario, could this be combined with the other project dealing with a similar topic? The impact of large solar projects on home valuations seems to be a less touched on piece - and would have a great effect in the right hands if solar developers can successfully argue to local town boards, etc. that large solar installations do not have a deflationary effect on solar valuations. The outreach and communication of these results should be a key goal for this component.

## The Energizer Bunny: Dual-Use Photovoltaic and Pasture-Raised Rabbit Farms – $200,000

*Michigan Technological University | Houghton, MI | Principal Investigator: Joshua Pearce*

This project evaluates the technical, economic, environmental, and social feasibility of raising rabbits on land with a photovoltaic solar energy system. Solar installations provide shade and protection from aerial predators, which may lead to increased reproduction and higher profits. The team aims to produce a free, publicly accessible, comprehensive manual that includes data about solar with rabbit farms and their effects on economics, market size, and operations.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 3 | 5 |
| Set critical challenges to overcome | 3 | 3 | 3 |
| Implement a high-risk, high-impact approach | 1 | 3 | 1 |
| Match well with the level of DOE funding and planned project duration | 1 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 3 | 1 |
| Advance the U.S. solar industry substantially | 2 | 3 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Good to be exploring, big picture, how we can get land to multi-task for solar and other uses. Engaging on agriculture co-use in general could boost support for solar by making land able to bring in additional resources. Weaknesses: It is very doubtful that the acreage needed by rabbits and demand for rabbits make for the significant impact and scale. SETO should perhaps have gone back to the drawing board on outreach to get more proposals that are less niche and have opportunity to be applicable to a wider range of farms/animals.

**Reviewer 2:** Raising rabbits on a solar farm as a way to gain more economic value from the land and make the array more socially attractive is a nice break from reading about hosting capacity! I don't know enough about incenting agrarian solar development to address the overall value of the project, especially whether or not there's a market for the findings. Also, is a comparison with cattle farming realistic? Will data from the project be sufficient to demonstrate an impact on soft costs?

**Reviewer 3:** This project has admirable goals, however I'm not convinced by the narrative that the project is scalable. How many rabbit farms are there in the US and how many are interested in hosting solar? How have rabbits been shown to be effective at weed reduction, how many rabbits do you need to have in order for that to be the case? Significant work is needed on the financial analysis methodology being used here. I develop solar projects and I don't understand the metric they seem to be using for economic viability. The reduced O+M costs per acre seem really high (mowing is not that expensive) especially with the added liability of fencing that is attached to racking posts, which introduces a liability to the racking manufacturer's warranted of the installation. Is the solar generation revenue per acre based on a fixed tilt or tracking system and is it net of installation costs? Seems very high. There is reference to this being done on a 'commercially viable sized PV system'. The poster references a 314kW system, but the narrative references a A 30kW size? Neither are economically viable except for on-farm use (net metered projects). If that is the structure, the solar energy generation revenue is too high because that owner cannot sell power beyond what they use on site. The researchers should seek out guidance from the participants in NREL Inspire program. The project seems islanded and should be using more standard cost-benefit analysis techniques and methodologies employed by other co-location projects.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 3 | 3 | 1 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 2 |
| Collaborates with sufficient stakeholders | 4 | 4 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project is new this year and difficult to assess progress. However there might be an under appreciation for the communications and culture change it would take for rabbits to become a mainstream enough demand for this project, even if successful, to be replicated at scale and have meaningful impact on soft costs for the sector.

Reviewer 2: Apart from questioning resulting data on cost costs, I see the project meeting its goals.

**Reviewer 3:** I am concerned the researcher's bias in favor of a positive income will influence the field studies. The project has not yet begun, and yet it is already presenting extensive theoretical cost savings and solar generation revenue numbers without much explanation as to how they arrived at these numbers. I'm not convinced a one-acre site will be sufficient to validate the impacts described.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Not clear if workplan for the project leads to level of applicability one would want. Not clear if potential for impact at scale is being assessed.

**Reviewer 2:** Score: 3. Comments: Did each task seem to support the overall goal? Yes. Is there overall value in the project? Would there be more value if the project studied other agrarian uses for the land.

**Reviewer 3:** Score: 5. Comments: Budget period 1 should include outreach to other projects conducting dual-use analysis to set the methodology. Suggest adding a task to survey solar farm owners to determine the scale of project that would be able to host rabbit farms. I suspect community solar projects that are smaller in size, 1 MW for example would be a better match in terms of willingness and just in terms of scale. That subset of owners can then be surveyed to how those o+m activities create liabilities (how often does someone need to be in the facility monitoring and fed and caring for the rabbits, what happens if a fence is down, etc) and if those liabilities can be addressed. I also suggest looking at the Yale research: https://cbey.yale.edu/research/maximizing-land-use-benefits-from-utility-scale-solar

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Hard to understand whether PIs and SETO factored in what dramatic changes in culinary tastes and scale would be needed. Overall project could open SETO/PIs up for criticism from the farming community is project doesn't have needed level of relevance.

**Reviewer 2:** Can't think of any.

**Reviewer 3:** See my comments in question 1.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Not clear that enough outreach was done by SETO to get broader range of proposals that have the potential for higher impact. We understand from the live (virtual) peer review meeting that this will is already being revamped. The potential for small family farms as well as large commercial farms to benefit from co-use is very high, so would be terrific to have this area of work overall get investment.

**Reviewer 2:** Possibly other farming communities, see comments above.

**Reviewer 3:** See my comments in question 1.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Make clearer the grazing land estimates and projections needed for solar, and assess degree to different kinds of low-methane animal rearing will get to serious scale and have impact. 2) Also in this area, recall not that there are ethical and substandard farms in terms of how animals are treated. As this area of work expands, don't want solar to lose the environmental high ground by co-locating with farms that are very damaging to the environment or inhumane for animals.

**Reviewer 2:** Overall applicability of the project to the solar industry. Whether the project can collect data sufficient to demonstrate an impact on soft costs.

**Reviewer 3:** This project seems islanded and should be using more standard cost-benefit analysis techniques and methodologies employed by other co-location projects. The researchers should seek out guidance from the participants in NREL Inspire program.

## Minnesota Solar Pathways: Illuminating Pathways to 10 Percent Solar – $1,999,964

*Minnesota Department of Commerce | St. Paul, MN | Principal Investigator: Michelle Gransee*

This project uses a scenario-based tool to examine the potential for key technologies and management approaches—such as demand management strategies, storage, and synergy with wind—to overcome grid integration challenges with increased solar penetration. This project identifies barriers to deployment while laying a technical foundation to understand how much solar capacity potential exists across Minnesota. In addition, it tackles grid management approaches to overcoming solar integration challenges.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Though I would hesitate to say that this project would advance the solar industry substantially, it certainly will contribute, in the vein of any modeling that will demonstrate how to improve uptake has value. It is useful in the technical area of showing how the balance of curtailment and storage combined with increasing solar capacity can interact to advance feasibility. Given the results, it is worth the investment, particularly given that the lessons learned can be applied in other states. I do not necessarily see this as having high risk but I would say it has moderate impact.

**Reviewer 2:** The project's goals are very comprehensive, addressing several issues associated with increasing solar development in a logical sequence. The project is realistic in defining the need for DR, storage in order to meet MN's solar goal. The challenge may be how the resulting data sets for meeting specific objectives-determining the need for back-up for solar, forecasting hosting capacity needs, etc. -can be applied more broadly. In this regard, I wonder if the project is attempting to cover too much ground, especially when there were challenges obtaining data.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Though it did not meet the timeframe due to a time setback that was outside of the control of the partners, the findings/results were successful and were achieved in a reasonable time frame and will contribute to the body of research necessary to have a range of practices that can be utilized to scale up solar at the state level. The challenge is the collaboration with sufficient stakeholders, given the omission of environmental justice groups as funded partners.

**Reviewer 2:** The MN SolarPathways resources are widely used today as a framework for tackling these issues. As noted above, that may be separate from the extent to which specific data sets can be applied more broadly.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The main task that has the most value for this project was the modeling of combining interventions and technologies to optimize expanded solar usage with demonstrated lowered costs. The task of helping communities determine value was diminished by the lack of intentionality and focus on equity and engagement of environmental justice communities.

**Reviewer 2:** Score: 5. Comments: As noted earlier, these are important topics.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** An equity lens appears to be missing. There is no mention of equity considerations with regard to acceptance barriers. It would be good to know for whom the mitigating factors listed were effective in removing acceptance barriers. From a socio-cultural perspective, they do not look like land-uses that would be of wide appeal to a diverse population. It does note that these were anecdotal observations.

**Reviewer 2:** Possibly, is the project attempting to resolve too many issues.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** From perusing the list of funded partners, there appears to be a lack of environmental justice organizations. Given the large number of EJ organizations in MN, many of whom are working on clean energy/solar, this appears to be a significant oversight that tracks with the blind spot noted above, regarding a lack of mention of any equity analysis.

**Reviewer 2:** Can't think of any.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) A project that describes how to scale solar at the state level to a 10% is a valuable study with transferability. 2) Even anecdotally, the analysis around land-use that will enhance acceptance of solar is also useful, particularly given that this is not a widely discussed aspect. 3) The area that could use significant improvement is engagement of environmental justice groups and strengthening of an equity analysis.

**Reviewer 2:** Scope of project might have been too broad for one project.

## Enabling Solar Cybersecurity Solutions through State Energy Office and Public Utility Commission Engagement with Private Sector Partners – $500,000

*National Association of State Energy Officials | Arlington, VA | Principal Investigator: Sandy Fazeli*

This project team, which includes the National Association of Regulatory Utility Commissioners, is creating a solar cybersecurity working group to improve the ability to respond to cybersecurity threats related to solar energy and other distributed energy resources. The group includes state energy officials, public utility commissioners, solar industry stakeholders, cybersecurity experts, utility representatives, and others. The project team is working to develop an online cybersecurity tool kit to help solar industry decision-makers, regulators, utilities, and state and local governments pursue policies, plans, and partnerships for cyber-secure solar infrastructure in their jurisdictions.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 2 |
| Set critical challenges to overcome | 1 |
| Implement a high-risk, high-impact approach | 2 |
| Match well with the level of DOE funding and planned project duration | 3 |
| Add significant value to existing research outside DOE-funded efforts | 2 |
| Advance the U.S. solar industry substantially | 2 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** While I support the idea of sharing best practices on cyber-security for DER, I'm not convinced the project will result in significant impact. NREL, Sandia, and DOD have all been tackling this issue. Are similar education efforts already occurring? I would like to have seen the literature review occur prior to beginning of the grant and why this will address a knowledge gap. Which states are already undergoing cybersecurity assessments as part of grid monetization rulemakings? I know there are at least such multi-year processes going on in MD and NY. At a minimum, would have liked to see a survey of NASEO members to justify the need rather than just an explanation of the issue at hand.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 |
| Measures impact appropriately (e.g. quantitative) | 2 |
| Disseminates results frequently and actively engages partners | 2 |
| Collaborates with sufficient stakeholders | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** As the project hasn't started and some of the first tasks are to establish a stakeholder working group, this category of questions isn't really applicable. Regardless, in terms of the milestones, I hope since the first few can potentially occur virtually that the COVID restrictions will not delay the grant's start.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Agree that each task adds value to achieving the goals.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The grant presumes that solar is a risk to the grid only. Where is the broader context-what about the benefits ground mounted net metered and community solar projects brings to local resiliency? What about the upgrades to transmission lines that large scale solar facilitates? How can states ensure equity in the kinds of cybersecurity related costs being imposed on solar vs other technologies?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See comments above. Also EEI members should be used as a resource for industry feedback.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** No further comments beyond what I described above.

## Addressing Regulatory Barriers to Tribal Adoption of Solar Photovoltaics – $1,400,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Sherry Stout*

This project works with Native American tribes to help address nationwide interconnection challenges and other barriers to solar photovoltaic and solar-plus-storage systems on tribal lands. The team plans to discuss the challenges with stakeholders and then conduct analysis and workshops to design regulatory solutions and find opportunities for solar energy on tribal lands. The team aims to provide technical assistance to identify ways for tribes to develop favorable contract terms and conditions, and create a guidebook with a list of options for Native American tribes across the country.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 4 |
| Set critical challenges to overcome | 6 | 6 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 6 | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Tribal access to solar is a laudable goal and a national effort to create a guide to solar adoption for tribal solar makes is important and consistent with SETO's goals. It would be helpful to understand how the project is thinking about access to solar technologies for tribal residents versus tribes themselves.

**Reviewer 2:** Great to see a collaboration with NREL and tribal entity Midwest Tribal Energy Resources Association (MTERA). It is good that evaluation is built in along the way, and evaluation questions should be co-created and have room for open ended comments. It would be good to make clear how final decisions will be made if differences of opinion emerge between the two partners. Communications products and approach need to be examined to ensure maximum usefulness by others that were not part of the process, especially since project summary anticipates turnover among those leading the effort. It is not clear if there is a very experience facilitator is engaged. This might be a good investment since there will be cultural differences in ways of working, and capacity differences, between NREL and MTERA/stakeholder participants.

**Reviewer 3:** There is a need for understanding and dialogue about the siting and interconnection issues associated with tribal solar development. Likewise, exploring funding opportunities will be helpful. Mitigating soft costs for tribes has value too! (Although I don't know enough about this topic to weigh in on whether or not that impact can be quantified.) To the extent that the project develops a set of regulatory options that may address these challenges, I hope that those options are presented in an agnostic manner-and not as solutions that must or even should be undertaken. The SETO Portfolio describes this project as providing assistance to tribes to develop favorable contractual terms and conditions. However, I couldn't find much in the project report that elaborates on this. Is this still part of the scope, contracts with whom?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has not yet begun so there is little to comment on.

**Reviewer 2:** Project has not started. This program could be a critical model for replication by tribal nations beyond the ones directly involved. It would be good for some forums along the way could be recorded, and the final products to be very interactive. Otherwise it will limit uptake and replicability given that many tribes often have capacity challenges.

**Reviewer 3:** No comment.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: In general the tasks and the project are unique and add value. Little detail is provided around year 1 tasks and milestones, fleshing them out would be helpful to lay the groundwork for success in year 2 and year 3.

**Reviewer 2:** Score: 5. Comments: Yes. However final products would be strengthened by investing in more interactive online complementary resources to accompany the guidebook.

**Reviewer 3:** Score: 4. Comments: Each task is important to the overall goal. The question will be whether or not quantitative analysis of the various regulations and the impact on soft costs of developing solar can be achieved. Also, providing contractual t&c seems questionable.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Again, the project not having started, it's difficult to identify blind spots. I would encourage the PI to consider the interplay between the communities and their residents.

**Reviewer 2:** It is not clear if there is a very experienced facilitator is engaged. This might be a good investment since there will likely be cultural differences in ways of working, and capacity differences, between NREL and MTERA/stakeholder participants.

**Reviewer 3:** Not necessarily a blind spot, but adherence to objectivity will be essential for the value of the output. The scope of stakeholders seems very balanced, so the output can be as well.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project has not begun in earnest, however the workplan and identified partner appear to be sufficient for identifying and engaging needed stakeholders. Again, confirmation that community members will be considered and engaged would be beneficial.

**Reviewer 2:** Not clear if very skilled facilitators and communications partners that are skilled in working across cultural differences are engaged. Collaborations with experts in online communications experts important both for the real time efforts that will be virtual, and, so that hopefully recording will take place given the anticipated turnover and, to have the work be useful to other tribal entities.

**Reviewer 3:** Can't think of any.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Excellent example of using funds to scale access for hard to reach populations. 2) Make sure project addresses access for LMI residents of tribal lands. 3) Consider at end of project where lessons learned can be applied to other jurisdictions.

**Reviewer 2:** 1) Even if the NREL staff as deep experience working over time with tribal communities, diversity and inclusion training/refresher would be wise. Even with that, an independent skilled facilitator trusted by both parties should be engaged. 2) Communications team should be highly skilled in working across cultural differences, to ensure that final products are as interactive and as well organized as possible. Record virtual sessions where possible. Otherwise potential impact will not be realized. This is critical since turnover is anticipated, and many other tribes could benefit from the lessons and recommendations. 3) It is good that evaluation is built in along the way, and evaluation questions should be co-created and have room for open ended comments. Expect to have to make mid-course corrections. It would be good to make clear early how final decisions will be made if differences of opinion emerge between the two partners.

**Reviewer 3:** Primarily, the need for the guidance materials to reflect a balanced, objective analysis of regulatory policies.

## Data Analytics for Residential Photovoltaics from Permit to Interconnect – $500,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jeff Cook*

This project aims to provide novel insights into the effects of personally identifiable information processes on photovoltaic system installations, in particular the relationship between these processes, timelines, and customer cancellations. The team plans to use these analyses to clarify the potential effect of certain process changes on reducing personally identifiable information timelines, customer cancellation rates, and related costs nationwide.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 6 | 5 |
| Set critical challenges to overcome | 3 | 5 | 5 |
| Implement a high-risk, high-impact approach | 3 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 5 |
| Advance the U.S. solar industry substantially | 3 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Permitting is one of the most expensive aspects of solar installation, in particular for residential solar. As such, analyzing and understanding the different permitting processes is valuable and necessary. As such, this project, correctly re-oriented should bring high value. However based on its current expressed focus, does not appear to have significant high impact outcomes. This worthy project needs to be re-oriented to substantially increase its impact. This is what I suggest:

(1) use the permitting analyses from this project to develop 1-3 “universal” permit processes and applications that will be acceptable to 80% of the AHJs with the highest residential solar potential based on most potentially viable single family homes by zip codes. (2) these new processes/permit application requirements should be codified in the SolarApp project, which should be embodied in a cloud-based SAAS platform, that is easy for any of the 20,000 AHJ’s to adopt, i.e., zero on-site installation. Adoption should be driven by (a) lower costs for the AHJ’s--some are swimming in permits; and (b) prospects for jobs/economic activity. This App could form the basis of a company seeded by SETO/DOE. (3) This platform should then be incorporated into a broader--also re-oriented--SolSmart, again to drive adoption. The SolSmart program should be kept but its components/levels revised to drive speed and lower cost at the local level. Efforts that are heavily research oriented without an explicit focus on accelerating adoption and lowering cost should be de-emphasized.

**Reviewer 2:** Strengths: Attempts to provide transparency and normalized data around one of the most frustrating and fragmented areas of the solar process given the number of AHJs, utilities, and states. Partners with several large solar installers to gather substantial amounts of data. Data should allow for additional analysis by developers and policy makers and guide streamlining wherever possible. NREL is well positioned to be able to aggregate data from multiple competitors and produce an unbiased report. Weaknesses: Project focuses on correlating PII delays to customer cancellation rates, however there may be other ways soft costs are inflated due to extended PII timelines which could be considered as well in furtherance of SETO’s overall goals.

**Reviewer 3:** Research is aimed at a critical piece of soft costs in the industry in tackling permitting, inspection and interconnection costs. Much ink has been spilled over best practices but few, if any, studies have targeted the same scale of data-driven analysis. This research is inherently high-risk given the size and lack of uniformity in the data set but, if systemic trends can be uncovered, it can provide a roadmap for tackling a nebulous soft cost center for residential solar. Strengths: Large data set with wide coverage that covers small through large installers. Ambitious “cleaning” effort on the data set to normalize data. Ambitious scope. PII is inherently nebulous and varied by geography. Aims to create public knowledge through mapping of data that can improve actual business operations. Weaknesses: PII is a small piece of the overall cost stack (NREL estimates PII at 2-3% of overall cost stack). Will large improvements be important enough to justify costs? (Researchers reference cancellations - would want to see the impact a little more: how much would cancellations due to PII delays increase other soft costs such as customer acquisition or “wasted effort for example – It’s not sufficiently articulated that the insights garnered from this work will be more than what’s already known by businesses operating in the space. The value of this work may be around the “unbiased” analysis from the national lab and removing false narrative that’s not supported by data but just perception or biased experience.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 3 | 5 | 6 |
| Disseminates results frequently and actively engages partners | 3 | 5 | 4 |
| Collaborates with sufficient stakeholders | 3 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project summary says they have received data from 3659 AHJs, and 226 utilities. This is an incredibly valuable data set. Per comments above, this project has high potential if its goals can be re-oriented toward more impactful outcomes driven by the analysis size.

**Reviewer 2:** The project set quantitative goals for systems, AHJs, utilities and states. For permitting and inspection, all thresholds were met for Task 1. For interconnection, the utility coverage though under threshold was still significant.

**Reviewer 3:** Research kicked off in July 2019 and is only 12% into budget with <12 months to go until its completion in January 2021. Seems well in line with estimates. Looks to have achieved a significant portion of work in collecting data from industry partners, including the top 3 residential solar installers and efficiently collected data from small installers via SEIA. Uncertain if group is providing frequent updates to stakeholders – but also uncertain what those updates would be ahead of any actual analysis of results Would be especially interested for the DOE to monitor the workshops that researchers propose to host. For impact/scalability, would want Researchers to include AHJs in those conversations.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Re-orient the project with the goal of developing a "standard" or 1-3 "standard" permitting forms that can be adopted by 80% of the relevant AHJs. The team already has enough data to do that and should not need further data collection at this time.

**Reviewer 2:** Score: 5. Comments: Historical data for the PII process is limited, and given the rapid increase in the solar industry and constant changes to regulations, ongoing studies and data analysis are necessary. The data that the project indicates it will provide should be valuable to both developer looking to expand their level of activity, and for policy makers to provide pressure in streamlining for the benefit of the consumers and the industry.

**Reviewer 3:** Score: 5. Comments: Steps / phases seem logically laid out, with data collection mostly achieved. Cleaning -> analysis piece makes sense, with clarifications around data ongoing (i.e., checking with large installers whether cancellations after the PII stage were resulted from delays during PII stage). Looks to analyze permitting / inspection separately from interconnection stage -- logical given the separate AHJs that govern those parts of the installation process. Final analysis looks to combine research, which again, is a logical step. Would want to see some further discussion on how result dissemination with respect to early results may be disseminated -- or whether intermediary workshops will be convened to help guide the best completion / conclusions in the final analysis.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** It seems like this project is currently a statistical effort to develop a model about how different permitting processes impact process times. This appears to be purely an academic work. Consider expanding the scope like designing a permitting process that (a) results in same day or next day permits at less than $50/permit to the developer; and (b) can be reasonably adopted by 80% of the highest value zip codes/AHJs. It's not sufficiently well-articulated that there is a strong connection between this work and the Solar App.

**Reviewer 2:** The PI should consider other costs besides customer cancellations related to the PII process including hard costs as well as increased levels of other soft/hard costs due to PII delays.

**Reviewer 3:** PI has identified that it intends to discover if cancellations after the PII process occurred due to delays in the PII process. While not necessarily a "blind spot", residential installers have an incentive to shift blame to AHJs rather than their internal processes. It's important that the PI is willing to be objective in sharing results given the inherent bias of the project's data sources.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** See prior responses.

**Reviewer 2:** NREL as a neutral party is positioned well to be the organization to run this project.

**Reviewer 3:** Data from AHJs, whether utilities or large municipalities, seems to be missing, which could serve as a quality check to the installer-provided data. This would be helpful for the team to preserve the desired "unbiased" nature of the analysis.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** See prior responses.

**Reviewer 2:** 1) PII is an area that Is especially important to the solar industry as delays in the process are highly detrimental to adoption. 2) Focus should include all impacts of PII process delays. 3) SETO should consider future projects that look at similar data for C&I projects as the PII process issue is significantly more pronounced for non-residential projects.

**Reviewer 3:** 1) It's not sufficiently clear that targeting market intelligence for PII - a small component of the residential solar cost stack - justify the cost of the study. 2) It's not adequately discussed how the PI would remove or adjust for the inherent bias stemming from its data sources. 3) Instead of relying on installers for the data, the discussion about how engagement with AHJs and utilities is not sufficient. Utilities may be able to provide large data sets spanning multiple jurisdictions, help with the analysis and/or help disseminate or effectuate the conclusions.

## Improving Solar and Solar Plus Storage Screening Techniques to Reduce Utility Interconnection Time and Costs – $1,000,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Julieta Giraldez*

The laboratory team is developing a new method for mapping secondary low-voltage circuits, which aims to help utilities speed up their interconnection processes for approving solar connections onto the grid. These tools should enable grid operators to improve resilience and assess their capacity for new interconnections more rapidly. The team is also forming an advisory board to engage with stakeholders throughout the project and disseminate the findings nationwide.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 5 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Very specific focus and targeted outcome; Strong industry partners (Pepco and others) and NREL is the lead; Helps reduce a big hurdle in moving solar and storage projects forward. Weaknesses: Need more utilities involved.

**Reviewer 2:** Strength: I've very glad to see this important research being funded. Solar project financial models are extremely sensitive to interconnection costs, since they are not eligible for the ITC. There are often lower cost integration solutions than what the utilities as require solar generators to install. Utilities usually will not be willing to consider solutions that have worked in other states or utility territories. In addition, just the length of time to study and estimate costs and the mismatch between those studies and expectations from permitting agencies has a huge impact on projects. Weakness: There are little specifics as to the role of storage in the mitigation strategies and inclusion of storage developers. Although I have developed multiple solar farms at various scales including distribution level interconnection, I am not understanding from this narrative what missing secondary circuit data means and I would like to see the project move faster. Why does the mapping and establishing metrics of success take a full year? Is not the metric of success cost reduction in upgrades the utility requires of the generator while maintaining the same level of reliability? At a minimum, a draft metric of success should have been drafted and the first milestone could then be socializing and receiving stakeholder input as on those metrics. In addition, should have been a budget breakdown.

**Reviewer 3:** Streamlining the process for assessing secondary-circuit DER interconnections is an important objective and one that fits w/in the SETO objectives for decreasing soft costs. The impact on the industry would be significant. My only question is the methodology will be useful to all utility sectors. Larger IOUs are participating, but will smaller, more rural utilities be able to utilize the tools as well? This isn't my area, but the value overall to the industry depends on the broader application.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 2 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** NREL is a strong lead and the outcomes are SMART goals that will move the industry forward. The milestones are quarterly which is also a major plus.

**Reviewer 2:** I cannot score this project as it has not started, however I do believe it has the right mix of project sponsors to accomplish the goal. I gave it a 5 so as not to negatively impact my support for the research topic in the scoring. Suggest that reviewers should have had the ability to give this category a n/a rating and remove it from the overall score.

**Reviewer 3:** This project just started, however, the future timeframe and milestones seem appropriate.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Same comments as above.

**Reviewer 2:** Score: 5. Comments: See comments above re: level of detail provided in this summary and desire to understand why the tasks can't move faster.

**Reviewer 3:** Score: 4. Comments: The sequential tasks build upon each other.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Just the need for more utilities involved and input from developers.

**Reviewer 2:** The study should consider the benefits solar provides to local grid reliability.

**Reviewer 3:** None that the project hasn't already identified.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Solar and energy storage developers.

**Reviewer 2:** National developers active in multiple markets should be included, or at a minimum SEIA and other local industry associations.

**Reviewer 3:** Can't think of any.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Continue to invest in projects like this. 2) May make sense to add a partner like EEI, that will allow for more utilities to be included. 3) Seek feedback from solar developers and storage companies.

**Reviewer 2:** 1) The study should consider the benefits solar provides to local grid reliability. 2) National developers active in multiple markets should be included, or at a minimum SEIA and other local industry associations. 3) This kind of research is vitally important to reducing solar project costs. The fact that the projects has two utility partners with such large territories and ones with aggressive state renewable targets will help the research have a significant impact.

**Reviewer 3:** Given challenges in data gathering, how useful will the mapping metrics be to other utilities? Since this project is just getting started, is there anything additional that the project participants can do to expand the value of the methodology to other utilities?

## inSPIRE 2.0: Facilitating Low-Impact Solar Development through Data and Analysis for Environmental Resiliency and Compatibility – $1,889,928

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jordan Macknick*

This project conducts field-based research to address data gaps relative to expanding solar in agricultural areas. Specifically, there is a lack of data about how solar projects on agricultural land affect revenues, which solar configurations best meet agricultural needs, and how solar and agriculture co-location results differ regionally. In addition, the project is conducting three analysis and modeling studies to augment field research, including an analysis of land-management practices at existing solar facilities, an economic assessment of low-impact operations and maintenance practices at solar facilities, and a quantification of ecological services, such as pollinator services and erosion control, provided by solar-agriculture co-location. The team will develop a Wiki-style data portal with user-input capabilities for co-location research data.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 6 |
| Set critical challenges to overcome | 6 | 4 | 6 |
| Implement a high-risk, high-impact approach | 6 | 3 | 6 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 6 |
| Advance the U.S. solar industry substantially | 6 | 3 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: This project adds significant value to the solar industry and I'm glad to see it was able to overcome the initial challenges of finding sites and O+M data. It is getting harder and harder to find counties and communities that do not perceive solar as an 'industrial use' that should not be on ag land. Developers need neutral third-party research like to validate the arguments we make that that solar is a lighter, less permanent use than more intensive land use that actual can go hand in hand with agricultural practices. Strength: This is also the most impressive project I have reviewed at disseminating the information. The grantees have done a great job of getting the research out via webinars, workshops and publications. Weakness: Would like to see more emphasis in the communication of this work on the 'low impact' versus the 'co-location'. Co-location is often not possible for a number of reasons (liability of a outside party in an electrical facility, ability to locate a reliable farmer/beekeeper, landowner not willing to host sheep/cows), but the low impact methodology is something solar developers can always commit to incorporate.

**Reviewer 2:** Finding common solution sets for solar and agricultural development is a worthy goal. In rural areas in particular, the focus on pollinator certification is an important issue. Quantifying the benefits and developing a data base will be very helpful. My only question goes to the identification of applicable soft costs and measuring the impacts on them. However, this isn't my field, so I may be missing the soft cost data points in the report.

**Reviewer 3:** Project targets a critical piece of moving the distributed solar policy forward – especially for sectors like community solar. Project is high risk, using live sites to demonstrate results. Results seem to have drawn the attention of state agencies, which demonstrates real potential impact. Strengths: Strong collaboration between local academic experts, solar industry – particularly on live projects, not just test sites – and national laboratories. Geographically diverse set of projects/partners that will help nationalize results, while providing local color Strong policymaker interest indicates that there is a high likelihood of lasting impact Substantial publications – both academic and mainstream – leads to higher likelihood of visibility by key policymakers and decision makers. Conferences/workshops with land conversation groups seems to be a very impactful piece of the outreach. Weaknesses: Unclear how data will be disseminated beyond academic publications or what such open data set could / would look like.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 6 |
| Disseminates results frequently and actively engage partners | 6 | 4 | 5 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has executed an impressive amount of collaboration to get the test sites up and running and to include stakeholder input from the onset. I'm very glad to see the funding extended from the initial program so that it could address the topics that came up from the first round. This research is very important to those of us involved on the front lines of interfacing with communities and dissuading their fears around what is often perceived as a 'new' and 'industrial' use. I'm also glad to see the geographic spread of test site locations and the emphasize on co-location species that work for different climates. As a solar developer, my team in the west often struggles with how to add this value stream versus projects we work on in the Midwest and east.

**Reviewer 2:** Please see my earlier comments.

**Reviewer 3:** Project appears on/ahead of budget, but with much substantial work still to be done. Project appears to be slightly behind but has reached critical milestones of implementing research before the close of growing seasons. Given the dependence on natural processes that cannot be accelerated, would be prudent for DOE to monitor timelines closely. Primarily measuring performance / impact via publications and outreach/communication. This is the right metric as it will be the determinant for policy adoption. Would also like to see how industry partners perceive any changes to design or any benefits garnered - whether on the initial permitting or on long-term O&M (as discussed) While supporting state policymakers (e.g., Maryland, Massachusetts, etc.) may be out of scope, may consider how to direct funding towards supporting those efforts in a future funding opportunity.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Project tasks are appropriate to achieving the goals.

**Reviewer 2:** Score: 4. Comments: The project's scope is very comprehensive and each task makes sequential sense.

**Reviewer 3:** Score: 6. Comments: Phases seem logically constructed. An entire BP focused on outreach and communication is critical in ensuring this research will create impact.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The wide dissemination of the research has had some unintended consequences. Permit agencies and landowners see the pretty pictures and assume that there is no cost to add crop production or grazing along with solar. It is still an electrical facility and having sheep graze alongside panels can cause damage to equipment and other liabilities that need to be factored in. The project should be caveating that these practices cannot always be incorporated at scale. I would have like to have seen what size each installed solar project is and if it is fixed tilt or single axis tracker. Many older sites, if used in the study, will likely be fixed tilt, which will have very different outcomes in terms of shading and is no long what the industry is using except for on very hilly locations.

**Reviewer 2:** A realistic timeline possibly.

**Reviewer 3:** No comment.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project has done a terrific job including stakeholders. As a follow-on project, would like to see even more funding go towards educating financiers and understanding what challenges prevent them from incorporating these practices into projects. Would also like to see even more funding go to educating permitting agencies on these benefits that solar can provide.

**Reviewer 2:** Can't think of any.

**Reviewer 3:** Would local landowners or AHJs be a valuable source of input? Could that be garnered through industry partners or local academic partners?

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This project adds significant value to the solar industry and has done an impressive amount of education and dissemination in a short amount of time. Only significant comment is I would like to see more emphasis in the communication of this work on the 'low impact' versus the 'co-location'. Co-location is often not possible for a number of reasons (liability of an outside party in an electrical facility, ability to locate a reliable farmer/beekeeper, landowner not willing to host sheep/cows), but the low impact methodology is something solar developers can always commit to incorporate.

**Reviewer 2:** Good foundation in an area that doesn't have a lot of resources. Scope is comprehensive and project task outline is designed to address the scope.

**Reviewer 3:** 1) SETO should consider how to assist states looking for technical / policy making assistance with respect to this topic. 2) Outreach to land conservation groups and more mainstream / trade media outlets is great and will be helpful to multiply the impact of the academic research. 3) Consider how much of the industry this may affect (i.e., what sectors within solar?) and is that a significant slide of the MWs that will be deployed?

## Photovoltaic Storm Water Management Research and Testing – $800,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Megan Day*

This project is working to identify the co-benefits of solar facilities, specifically regarding storm water management and water quality. The team is conducting field research on storm water infiltration and runoff at solar installation sites; validating a model to understand, predict, and manage water resources; identifying best practices for storm water management; and engaging with local jurisdictions. This project will reduce soft costs and break down regulatory barriers to solar projects.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 6 |
| Set critical challenges to overcome | 5 | 3 | 6 |
| Implement a high-risk, high-impact approach | 5 | 3 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 3 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Will provide high quality information. Not clear whether solar manufacturing firms have done any collaborative work in this area, and not clear whether industry has raised this as a major impediment under the umbrella of soft costs. Certainly will be useful for storm water managers so an intrinsically good thing to have as course.

**Reviewer 2:** This project aims to cover a very specific and narrow piece of the industry landscape. That is good for focus of the study, but the question of impact remains unanswered - and the extent to which the model results will be utilized vs. sit on the shelf is unclear. Strengths: Very focused on a singular study with a clear objective result (i.e., water look ups). Builds off of existing relationships and partnerships (i.e., InSpire sites) - which may reduce contracting burdens. Weaknesses: Utilizing pollinator-friendly sites that may not have broad applicability. Attempts to use artificial constructs or modeling to solve. Why not just find other sites? Uncertain whether the lookup tables will be adopted. No clear outreach plan.

**Reviewer 3:** Strength: I do not know of any other research that is tackling this issue comprehensively, and it is a critically important one for the solar industry. I appreciate the level of thought put into the project action plan and especially how the results will be disseminated to stakeholders. Weakness: Suggest including a survey of current practices at the onset that could go through state soil conservation district associations or other such associations of county governments to understand current trends in stormwater maintenance requirements.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 3 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Thoughtfully put together task force representatives and partners. Not clear if insurance stakeholders are also at the table. InSPIRE sites were chosen for convenience reasons, but that limits real world conditions as documents note. Also, should more real-world sites have been added in addition to test sites. Current approach might limit somewhat the applicability of the results and applying the models. While test results will be high quality, not clear if big picture sectoral impact measures will include ones that highlight cumulative impact for soft costs, if best practices are widely implemented. This is not to downplay the inherent good of wanting to address stormwater runoff. But it is important in the project documents to have clarity on what problem(s) researchers are most focused on solving for with this investment. Attention to communications and outreach appear to be above average compared to other science-focused projects reviewed.

**Reviewer 2:** Budget seems reasonable given geographic breadth and work on live processes on active solar sites. Could use additional stakeholder engagement. What about wastewater experts? Private industry? Are there any associations or standards bodies that could be include? Beyond building models / look up tables, there does not seem to be any clear stakeholder outreach.

**Reviewer 3:** Project has not begun but believe it outlines a good plan to achieve its goals.

#### 3. Each task in this project adds unique and important value to achieving the overall goals of the project. (1-6)

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks add value with caveat that overall applied potential impact (vs different from scientific excellence per se) not as clear.

**Reviewer 2:** Score: 0. Comments: Steps are laid out logically but stops short of ensuring the results (lookups tables) are actually disseminated and utilized.

**Reviewer 3:** Score: 5. Comments: The tasks are appropriate to achieving the goals of the project.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Good to see partnership of diverse stakeholders and early outreach/communications thinking about how to be creative and efficient to get uptake among leaders that need to implement best practices. Need to better contextualize in the materials why challenge being tackled is a critical issue vs being "useful to have", among the major stubborn soft cost challenges that exist.

**Reviewer 2:** Are standards bodies or private industry experts able to help disseminate the results?

**Reviewer 3:** I hope the project will discuss the results in the broader context of the stormwater impacts of other land uses. Recommend using Maryland as one of the five states for case studies. Stormwater regulation has varied widely from county to county, despite guidance laid out by the state.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Good diverse group of stakeholders, from the research and communications end to the policymakers. Not clear under the umbrella of "industry leaders" if range of leaders all along the business chain will be included. Not clear if insurance leaders relevant to this issue need targeted outreach.

**Reviewer 2:** Standards bodies, associations of permit agencies or any other organizations that could disseminate best practices.

**Reviewer 3:** Suggest including Fire Departments, Department of Public Works and Soil Conservation Districts. Gravel underneath panels is often requested by Fire Department. Sometimes Counties approve our discretionary permit, but then we get to what is supposed to be the more straightforward part like building/grading permits, and these agencies impose measures that increase costs significantly. I developed a project that would cost $2m to build, but then the Dept of Public Work required installation of level spreaders for perceived stormwater impacts along the drip edge which added an additional $1million to the project. On another project, a County required large amounts of grading on a site that was between 0-5% slope, despite state guidance that vegetative management and row spacing were sufficient mitigation measures.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Good to see partnership of diverse stakeholders and early outreach/communications thinking about how to be creative and efficient to get uptake among leaders that need to implement best practices. 2) Need to better contextualize in the materials why challenge being tackled is a critical issue vs being "useful to have", among the major stubborn soft cost challenges that exist.

**Reviewer 2:** 1) Is this an important enough barrier for SETO to fund a potential solution? With lookup tables in place, what does this unlock for US solar deployments? 2) Why is the group choosing existing sites that are unsuitable for their study? Should encourage the group to pursue sites that give the best results, not just the most convenient. 3) What is the outreach plan?

**Reviewer 3:** I strongly believe this is critical research if solar is to be widely adapted in the U.S. There is a wide misconception that solar increases stormwater runoff and it is used as an excuse by neighbors to oppose solar projects. This research addresses a critical information gap and can go a long way towards educating AHJs and communities about the stormwater benefits with properly sited solar.

## SolarAPP – $695,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jeff Cook*

This project builds on the lab's existing software capabilities to commercialize the Solar Automated Permit Processing software platform known as SolarAPP. This tool provides installers with a standard portal for entering permit information for residential solar systems across all authorities having jurisdiction who adopt this tool, providing a streamlined form, transparency into permitting timelines, and required specifications. Authorities having jurisdiction will then be able to approve those permits without overburdening personnel, with confidence that the permitted systems meet code requirements.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 6 |
| Set critical challenges to overcome | 6 |
| Implement a high-risk, high-impact approach | 6 |
| Match well with the level of DOE funding and planned project duration | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 |
| Advance the U.S. solar industry substantially | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Supporting this research is one of the most important things SETO can do to advance adoption of residential solar. I appreciate how many stakeholders are involved especially the industry association.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 |
| Disseminates results frequently and actively engages partners | 6 |
| Collaborates with sufficient stakeholders | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Based on the materials provided, the grantees have accomplished a great deal and accomplishing the initial tasks while appropriately involving stakeholders at all stages.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks seem appropriate. Suggest adding a task establishing metrics for suggestion. There is no discussion in the narrative as to how the results (increase in # of solar apps processed or decrease in time to process applications by X days/hrs).

**4. What 'blind spots' the principal investigator has, in this project, that are important to consider?**

**Reviewer 1:** No concerns based on the materials provided.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Would like to see more project contributors from groups like ICMA or other county government associations. Suggest adding ePlan software to the list when evaluating software current AHJ's are using. The software is has a lot of flaws and is mainly just a place to upload and download data and still requires paper submissions. It does reduce some paper, but doesn't seem to reduce time to process. Despite this it seems to be adapted widely throughout Maryland. (https://www.montgomerycountymd.gov/DPS/eplans/Commercial-ePlans.html) Suggest inclusion of Departments of Public Work staff who are in charge of processing building permit/stormwater/electrical final permits vs. the initial applications. These are often separate entities. Suggest inclusion of third party reviewers that AHJ's often hire to do the reviews on their behalf. One such county is Prince George's County in Maryland: https://www.princegeorgescountymd.gov/1494/Peer-Review-Program

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1**: Very much support this research!

## Solar Energy Innovation Network – $10,000,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Eric Lockhart*

This project brings together teams of stakeholders from across the United States—including utilities, state and local governments, nonprofits, innovative companies, and electric system operators. With the support of technical experts from national laboratories and other research institutions, these teams work to implement innovative applications of solar and distributed energy resources in their unique locations and contexts. The solutions developed by the teams are demonstrated and validated in real-world contexts, making them ready for replication and scale.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 6 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Project is bringing people from different jurisdictions together and so helps facilitate information exchange, learning and technical support. Efforts to gather regular participant feedback through surveys and other methods, conceptually, demonstrates a valuing of regular feedback. Highlights challenges that could be helped by technical support and then disseminated so that you get replication to help others who are not part of the Solar Energy Innovation Network. Weaknesses: It is not clear that economic equity issues that can arise from these projects are being systematically considered. This could lead to problems down the road, especially when it comes to replicability. It is good to see the next cohort will look at rural communities. It is not clear whether methods for selecting the teams, and then at the end with dissemination to get replication, are inclusive and reach a broad range of stakeholders. This is important especially given the very large $10 million dollar investment in this project - one of the highest budgets for soft costs. Evaluation survey questions mentioned make it hard to measure applied uptake and problem solving (in addition to being in touch and sharing of information).) Project completion date is a year more than planned. It would be good know what lessons were learned in the planning stages that might have led to more accurate estimation.

**Reviewer 2:** The scope of SEIN has a number of positive elements: the overall goal covers solar writ large, so each team may focus on a common set of challenges many of which are cutting edge; each team can focus on the soft costs associated with its specific challenges; and the project recognizes that solar development in rural areas can present unique or differently-weighted challenges. However, it's unclear to me what or if there will be a unifying theme or a clear, cohesive end product. Is there a conclusion on impact on soft costs? Does there have to be?

**Reviewer 3:** The Solar Innovation Network attempts to tackle "solutions to real world challenges" by bringing together multiple stakeholders, providing technical assistance through the National Labs and deploying funding. How is this differentiated from SETO's role? This seems to be simply another layer of deploying funding for the same types of projects and research SETO would otherwise sponsor. Otherwise, the network seems to function as a sort of academic incubator. Strengths: successful in bringing together many groups and delivering results in the form research papers and tools. Seems to be well connected within the academic world and has connected teams looking at academic issues. Weaknesses: Exposure to new ideas and to follow-up, publications, etc. are nice goals but do not measure real world impact. Are these tools actively used by industry or policy makers? Where can the group point to real world examples of adoption? Would expect more collaboration with industry, especially with "innovation" in its name.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 3 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** 1) Regarding milestones, it is not exactly clear why the due date of the project was pushed back by more than a year. The report noted "In follow-up interviews, each of the 9 teams noted that their projects proved much more challenging and complex than they had initially anticipated." Was this the reason? Lessons learned? 2) Regarding measuring impact, it is good that evaluation surveys are being done, but measures highlighted seem to capture more activity, research/modeling and networking than impact measures per se. The network engagement and being in touch is of course a good sign. But as we look ahead to potential replicability, it would be good to get more specific examples of solutions that the activity contributed to. 3) On dissemination and stakeholder collaboration, It is unclear how innovative and inclusive dissemination methods are beyond the members of SEIN, given the goal of sharing the new open source models and research beyond the network and replicability. Who has primary responsibility for communicating to a broad range of stakeholders? Not sure if this is RMI. This could be important especially for problems that often have environmental justice concerns, like "black start," combining solar PV with EV charging and the upcoming rural work (all mentioned in the report).

**Reviewer 2:** Lots of positives, just uncertain as to final takeaways. See comments above.

**Reviewer 3:** Budget seems outsized but also seems to fund the same types of projects that SETO would otherwise fund. Industry stakeholders, research and real world adoption seems lacking or not sufficiently shown. Outcome should be on adoption of ideas, not just the generation of ideas (i.e., where is industry and policymaker engagement/assistance vs. papers published?)

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Tasks add value. It isn't clear on the communications outreach front whether a diversity of types of stakeholders are being strategically engaged, to ensure the spread of the new research and tools.

**Reviewer 2:** Score: 5. Comments: The value is that stakeholders with shared issues have the leeway to identify what they are and how to address them. It seems that this project entailed a great deal of effort from the national labs to help with analyzing data. Also, as noted earlier, acknowledgement of rural challenges, as opposed to other projects that take more of a cookie cutter approach, is very valuable.

**Reviewer 3:** Score: 0. Comments: Would like to see engagement with outside/groups not previously engaged in the innovation network included in the process much earlier. For innovation to spread, groups should be included in the early stages, not just engaged when results have been achieved.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** Analysis are at the meta level and it looks like rigor could be improved in answering questions of equity and engaging diverse stakeholders - in particular environmental justice/energy access nonprofits and government participants that have an equity/inclusion mandate. Communications in accessible language and to a range of stakeholders could also be a weakness here, given that a key goal is replication.

**Reviewer 2:** Can't think of any.

**Reviewer 3:** Does not seem to engage industry or regulatory parties that could be engaged early in the process to help steer projects or otherwise adopt and execute on findings. Measurement of success should be pointing to engagement outside of the SIN, not just publications and connections within the group.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** Environmental justice and economic inclusion experts. Communications experts skilled in translating technical findings into accessible language and doing creative outreach to diverse stakeholders.

**Reviewer 2:** Can't think of any.

**Reviewer 3:** Industry stakeholders, utilities, grid operators seem to be missing, although project states that these groups could be members.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) To ensure equity issues are not overlooked, add environmental justice and economic inclusion experts to the stakeholders and projects; and ensure that quantitative modeling looks at differential impacts, not just net impacts. This will help ensure replicability and impact reach full potential and scale. 2) Survey feedback could be fine-tuned to make impact and problem solving from the project clearer. Currently it is very clear that there are great modeling and research outputs, and networking. But impact on the ground and uptake by stakeholders is less clear and this is important for replicability. 3) Engage (if not on board already) communications experts skilled in translating technical findings into accessible language and doing creative outreach to diverse stakeholders. If not, models and research could stay within the network of "usual suspects" and not maximize the potential impact and potential for replicability.

**Reviewer 2:** The framework for establishing teams for this project made it possible. Recognizing differences w/in a stakeholder group is essential to the success of that task.

**Reviewer 3:** 1) Does this overlap with SETO's mandate in such a way that it has the same objectives just with less oversight? 2) What are the real-world adoptions of the research and projects produced by this group? 3) Is there a way to encourage more utilities, grid operators, industry players to participate and publish/adopt results?

## Forida Alliance for Accelerating Solar and Storage Technology Readiness – $1,750,000

*Nhu Energy | Tallahassee, FL | Principal Investigator: Rick Meeker*

This project conducts analysis and planning activities in Florida to increase solar deployment and maximize the benefits of solar, including combining solar with other distributed energy resources like energy storage and demand response. This project lays the foundation to enable Florida municipal and cooperative utilities to reach 10 percent of solar in their electricity capacity in less than 10 years.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 1 | 5 |
| Set critical challenges to overcome | 4 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 6 |
| Advance the U.S. solar industry substantially | 5 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The overall goal is to increase determine ways to solar penetration for FL munis and co-ops that make sense for them, as well as other stakeholders. I understand that co-ops will be invited to public sessions for this project, however, to date there are no co-ops participating in any role. While the individual objectives may have merit, the mismatch between scope and participants is an issue. Absent co-op input, the possibility that the conclusions from this project may be perceived as a model for co-ops is a concern, and the project is set to wrap up this June. Among other things, co-ops and munis have different business, financial and regulatory structures, all of which go into decisions about solar.

**Reviewer 2:** The project seems broad, ambitious and nebulous at the core: helping municipal utilities better understand technical, economic and regulatory barriers to solar, conduct analysis on the value proposition of solar to local utilities, develop scenarios and strategies for best locating "solar+" resources and provide ongoing assistance to begin incorporating the results and strategies. Each one of these items could be a large study. Strengths: "end-to-end" analytical and strategic support to local muni and coops who may not otherwise have the bandwidth to analyze something necessary but out of their core strengths. Strong stakeholder group that includes large municipal utilities, strong technical resources in the national laboratories and the FL PSC Seems to have strong engagement through workshops and dissemination of results through conferences and papers, including those published by LBNL and to dGen model improvement. Results may have meaningful effect on pushing actual utilities to move and adjust strategy Weaknesses: Sole focus on Florida is important for tangible results, but would have liked to see open models or processes or roadmaps that could be applied outside of Florida Would like to see more dissemination specifically targeted at other municipalities and coops nationally.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 2 | 4 |
| Disseminates results frequently and actively engages partners | 3 | 6 |
| Collaborates with sufficient stakeholders | 1 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** See my comments above about overall scope v participants and concerns. This project is almost over.

**Reviewer 2:** Project seems to have come within the costs budgeted and is being extended at no additional cost. Project is ambitious so understandable that substantial costs were incurred. Would have liked to see more engagement to disseminate results to other municipal utilities and co-ops outside of Florida beyond broad industry conferences. Stakeholder group and engagement seems to be very strong and appears to have gotten strong buy-in from core members. Good to see that strong specialized technical groups like LBNL and NREL were brought to the stakeholder group. Measuring performance was a bit more difficult ascertain. Large focus on study results but little on whether utility partners have been motivated to act or incorporate study results into planning.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Again, the individual tasks may have merit.

**Reviewer 2:** Score: 5. Comments: Task list is comprehensive and ambitious. Perhaps a narrower set of tasks would have helped to focus the study, but each step seems critical and logical to pulling together the big picture. At the core, a key project objective was to help local utilities with broad, ambitious assessment, which would require all of the groundwork described and performed.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Scope and application of goal to participants.

**Reviewer 2:** To what extent is a Florida specific model or roadmap more broadly applicable beyond the state? This was not a stated goal of the project, but should be a criteria for the DOE in evaluating the project's impact.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Again, co-ops.

**Reviewer 2:** Industry partners seemed missing. Utilities and academia tend to have a view of solar and storage costs that lags current results given the speed of cost declines. In addition, forecasts may be overly conservative. SACE is named as a stakeholder - but to my understanding is typically more of an advocacy group.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Make certain goals and participants align. Make certain that goals, as written, are even remotely achievable.

**Reviewer 2:** 1) How can this group or any follow-on study open the results and stakeholder journey to something more broadly applicable than just to the state of Florida? 2) Has the group achieved the goal of influencing municipal and coop utility strategy and planning around "solar+"? 3) Now that the project is nearing completion, was such an ambitious scope - spanning from technical/economic barriers through consulting on utility strategy - necessary to achieve the end results? Or would a tighter scope (and associated reduced funding) been more efficient and as effective?

## SPARC SolSmart Technical Assistance – $11,599,996

*The Solar Foundation | Washington, DC | Principal Investigator: Theresa Perry*

This project provides technical assistance support to communities pursuing SolSmart designation, enabling more than 300 communities and counting across the U.S. to qualify via a three-pronged approach to delivering technical assistance: one-on-one technical assistance delivery to communities from a team of experienced national experts; the use of SolSmart Corps Fellows to help select communities identify and reduce soft cost barriers; and peer mentorship and learning.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 6 |
| Set critical challenges to overcome | 5 |
| Implement a high-risk, high-impact approach | 5 |
| Match well with the level of DOE funding and planned project duration | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 |
| Advance the U.S. solar industry substantially | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project represents a boots-on-the-ground approach to working with jurisdictions across the country to reduce soft cost barriers to solar installation. As such, it clearly contributes to SETO's goals and objectives, with tangible results. Many of the requirements for the SolSmart designation are proven to solutions to barriers to solar PV installation, like streamlined permitting, solar as a right, and a publicly available solar permitting checklist. While the project addresses real barriers, it is unclear exactly how much impact implementing the requirements for SolSmart designation will have on reducing soft costs. A project evaluation is forthcoming that will hopefully provide more insight here. Additionally, technical assistance is a high-touch method, yet is needed to help jurisdictions achieve SolSmart designation - this has implications on the scalability and financial sustainability of the designation beyond DOE funding.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 |
| Disseminates results frequently and actively engages partners | 5 |
| Collaborates with sufficient stakeholders | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project achieved its major deliverable of 300 SolSmart designees one year ahead of schedule, with all other major milestones being achieved on schedule. While it is evident that achieving the designation requires jurisdictions to improve zoning and permitting processes, it remains unquantified exactly how much these actions reduce soft costs (subject to a forthcoming third party evaluation). While this should be addressed in the third party evaluation, it may be useful for the project team to collect information from SolSmart designees, such as average timelines for permitting, for the purposes of benchmarking, and helping the designees understand the impact their decision to participate has had on solar installation timelines.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: It's difficult to ascertain this from the information provided. As presented, the project wasn't broken up into tasks, but rather distinct budget periods with a certain number of target designations. However, none of the work performed appears to be extraneous, or unrelated to the core project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I think the PI would do well to focus on quantifying the benefits of SolSmart designation to encourage additional participation. In discussions with the PI, this is currently being evaluated by a third party, and so there may be some restrictions on their ability to do an independent analysis using DOE funding, however this feels like a core piece of their pitch to additional potential designees. As the designation moves beyond largely urban, and relatively well-resourced jurisdictions, to smaller, more rural jurisdictions, it will become increasingly important to be able to make the business case for participation. Additionally, the PI did not have a ballpark quote at hand for the cost of TA for an individual jurisdiction. While I understand it can be difficult to precisely isolate costs, I think this will be an important exercise as they continue to develop a financial model moving forward. Finally, a topic area that I did not get to explore with the PI is the idea of additionality - how many of the participating jurisdictions were already in the process of implementing some or all of the required changes? Some may be driven by state policy, but would gladly take Technical Assistance to help meet these requirements. This would be an interesting question for the third-party evaluator to explore.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I think that the project team has engaged with the right stakeholders that are critical to project success. There may be opportunities to get electric utilities involved and working more closely with local jurisdictions. While utilities and their regulatory structures are out of scope for this designation, which focuses more on removing zoning and permitting barriers, there is strong interplay between utilities and local jurisdictions related to interconnection and permitting, and there may be some additional barriers that can be reduced through that type of coordination.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The SolSmart designation and Technical Assistance program clearly contribute to SETO goals by reducing zoning and permitting barriers, however the magnitude of that impact, and additionality of the designation, remain to be seen, and should be born out by a forthcoming third-party evaluation. 2) Efforts to develop a sustainable financing model for the designation and technical assistance should continue - if the designation is really significantly reducing soft costs, and leading to more solar installations, there should be plenty of value created to make the designation self-sustaining. 3) Efforts should be made to further "productize" the technical assistance - e.g. typical costs for support in achieving Bronze, Silver or Gold designation. This will aid in refining financial models developed in point 2 above.

## Building a Framework to Genetically Characterize "Feather Spots" and Understand Demographic Impacts of Solar Energy Sites on Migratory Bird Populations – $1,600,000

*University of California, Los Angeles | Los Angeles, CA | Principal Investigator: Ryan Harrigan*

This project plans to improve data on bird mortality at solar facilities by applying new genetic-based methodologies to characterize feathers recovered from solar energy facilities by species, population of origin, and individual. The resulting data will be used to develop models to evaluate the risk of solar energy facilities to specific bird populations. The results of this project can be used to develop cost-effective bird monitoring and mitigation strategies at solar facilities.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 4 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 3 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 5 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Provides very necessary research that will help the solar industry. Strong project team. Weaknesses/Areas of Opportunities: Opportunity to share findings or include organizations that are in the Mid-West and East Coast.

**Reviewer 2:** Strengths: Targets an understudied piece of the solar industry, and one that may cause go/no go decisions on solar projects. Targets sustainability by the creation of a non-profit, fee-for-service organization to carry on the work beyond Federal funding period. Weaknesses: Uncertain how much bird migration impacts are a barrier to solar deployment. This may be an issue for bird/conservation, but is it a concern for solar? Is SETO the most appropriate government funding source? Unclear if sites have been identified yet and whether project will have appropriate access to feather spots.

**Reviewer 3:** The projects fits well with SETO's mission. Solar developers rely on research like this to help communicate the impact of solar to the public and to permitting agencies.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is very well defined with SMART goals. I'm confident this project will succeed.

**Reviewer 2:** Project has not identified any private industry partners that will be critical for providing site access and ability to collect feather spot samples. Unclear what the demand will be for the future "Fee-for-Service" center that will be established (although this Reviewer is extremely supportive that the project has looked to sustain the efforts outside of additional federal funding). Beyond peer-reviewed research, how will results and data sets be put into the right hands? What is the outreach and communication plan? Broad statements on engaging stakeholders but unclear what that will actually mean.

**Reviewer 3:** I like the idea of establishing the non-profit to build on UCLA's database and expand the program's reach. Would like to have also seen more specific organizations like Audubon identified and a more complete education and outreach program. Industry trade associations are missing from the list and should be a participant.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The tasks are clearly defined and are both unique and will contribute significant value to the goals of the project.

**Reviewer 2:** Score: 5. Comments: The tasks are logically constructed and push towards the end result. Success will be in the execution. Project should take under advisement others' experience that contracting for site access on live projects will take significant time.

**Reviewer 3:** Score: 4. Comments: The project tasks seem appropriate to achieving the project goals.

#### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** I can't think of any that stand out.

**Reviewer 2:** What will be the source of demand for the fee-for-service center? Is it actually sustainable as a business model even as a non-profit? Contracting for access on live solar sites or other means of collecting feather spot data may take much longer than expected. Once patterns are established, how will this data increase solar deployments?

**Reviewer 3:** I am concerned this methodology may overestimate the impacts of solar to avian species. I hope the research is put into the broader context of impacts from other energy generation sources and other forms of land use.

#### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** I would only include stakeholders that are more geographically diverse outside of California and Colorado.

**Reviewer 2:** Many "types" of stakeholders are discussed but few specific entities are identified. Would encourage SETO to push for a list of actual entities that Project intends to engage.

**Reviewer 3:** Have operating solar farm owners expressed willingness to contribute to the project? What average size solar farm are you targeting? People define 'large scale' solar in different ways. Are the total goals for feather collection (thousands) viable in the time frame identified? What are the 12 species identified in the narrative as most commonly impacted by solar. If they are, as I suspect, golden and bald eagles and other raptors, there has been a lot of research through the BLM multi-agency avian-solar working group. How will this research make sure that group's work in incorporated?

#### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) Excellent project that is well defined. 2) How can the solar industry better assist this project? 3) Expand the project to other geographic areas including urban areas.

**Reviewer 2:** 1) Will having an understanding of bird migratory patterns actually remove a significant barrier for solar deployment? 2) What entities (specific groups, not just broad stakeholder types) will the project engage with? 3) Does the Project have actual solar site access currently - and if not, will it reasonably be able to get it?

**Reviewer 3:** 1) I am not clear that they have sufficiently reached out to industry to validate willingness to share the samples and participate in the research. 2) I hope there is a discussion of scale-that projects under 10 or 20 MWs with a much smaller, 50-100 ac footprint, versus some of the large-scale projects of +500 acres. I am also concerned this methodology may overestimate the impacts of solar to avian species. I hope the research is put into the broader context of impacts from other energy generation sources and other forms of land use. 3) As an aside, I haven't seen any avian grants that focus on Midwest or eastern solar locations, or any research on how solar farms can provide benefits for ground-nesting pheasants, quail and other birds. Would like to see the next round of solicitation create a diversity of sponsors not just those based in the west.

## Quantifying and Valuing Fundamental Characteristics and Benefits of Floating Photovoltaic Systems – $850,000

*University of Central Florida | Orlando, FL | Principal Investigator: John Sherwin*

This project undertakes a systematic and comprehensive collection of floating photovoltaic-related techno-ecological data at four sites in Florida, Colorado, and California. The data will be used to examine floating photovoltaic performance, assess potential environmental risks and benefits, and provide data that can aid in the development of research protocols to more fully understand the impacts of floating photovoltaics.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 4 |
| Set critical challenges to overcome | 4 | 5 | 2 |
| Implement a high-risk, high-impact approach | 3 | 5 | 2 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 4 | 4 |
| Advance the U.S. solar industry substantially | 3 | 3 | 1 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strength: Research is groundbreaking technically because it is a "first-of-its-kind" analysis in the US for floating PV, so information will be useful. Predictive algorithms will be useful to others. Information will be publicly available. Weakness: Summary project documents do not highlight sufficiently, in looking at US context, the relative potential for floating PV to be high impact and in high demand in the US. For instance, US land scarcity context is quite different compared to other countries that are using these systems at greater scale. This is important to consider in weighing priorities for deploying federal risk capital. If there are substantial niche applications (e.g. near airports was mentioned), cumulative potential needs to be illuminated.

**Reviewer 2:** Strengths: Only federal and state funds for projects like these can help new technologies overcome the 'valley of death' in the innovation timeline and the barriers between early stage funding and commercial adaptation. Weakness: Would have liked to see much more information on scalability/impact, in particular an assessment of floating solar's potential in MWs and market receptivity. Not entirely clear that this should be a soft costs grant as opposed to a technology R+D track. Would like to have seen more than one technology provider involved.

**Reviewer 3:** The project aims to monitor the performance and ecological impacts of floating PV. FPV is an understudied resource but is an extremely niche sector. Global capacity for floating PV is in the single digit percentage points and the runway for PV in the U.S. will be on ground-based systems, not floating PV. While floating PV may be a need or additionally viable in the future, baseline research that is simply short-run performance based seems of questionable value. Strengths: tapping into a very understudied, greenfield research piece. Weaknesses: While by definition, this study will unlock a lot of new areas of knowledge, the primary question is whether FPV is a large enough sector to warrant a $1.06 million outlay currently. Given the budget of other research efforts that tackle more widespread, systemic barriers to PV adoption, this reviewer finds it difficult to justify. Unclear how scalable these results will be - with only 4 sites under one industry partner, how much is site / developer specific vs. a broadly applicable data set?

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 3 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 4 | 3 | 3 |
| Collaborates with sufficient stakeholders | 3 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project had not started as of the time of receipt of project documents, but is laying the groundwork. It is good that project will deliver independent evaluation of the targeted floating PV systems. However echoing comments above, it is not clear which stakeholders - in the context of wanting to be high-impact with soft costs - should be targeted to get them interested and ground truth potential for this to be in demand. The answers to these questions would highlight whether existing stakeholder collaboration is sufficient.

**Reviewer 2:** There is not sufficient detail in the materials to assess what stakeholders will be engage and the plan to do so.

**Reviewer 3:** Budget seems outsized to the value of the sector. In addition, budget seems large in comparison to the work being described, which seems to be just establishing baseline monitoring. Given the monitoring of natural processes at live sites, longer study window seems appropriate. To what extent have these groups engaged industry?

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Overall plan and steps towards stated technical goals seem well thought out. Please see caveats noted in other sections though about the context and stakeholder collaboration, clarity needed.

**Reviewer 2:** Score: 3. Comments: Tasks seem appropriate to the research topic however per the above, much more planning should have already been done to engage stakeholders and disseminate results.

**Reviewer 3:** Score: 0. Comments: Tasks are laid out logically and achieve the objective stated. Objective should go beyond just publishing a data set - what does outreach and dissemination look like?

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** While the project is technical in nature, always good to note contextual challenges in communications about the project in the solar landscape. There is a critical need for solar to expand as the US seeks an urgent transition to a cleaner energy economy. SETO staff noted hard costs have come down very significantly and that the challenge is getting soft costs to come down much more than they have in the past. As written, project documents lead one to wonder, is this a "nice to have" in terms of scientific exploration, or something that could be a game changer relative to competing priorities.

**Reviewer 2:** What environmental concerns are there and how is the research going to address them? Why is there no mention of dissemination around the advantages of floating solar vs. land based solar?

**Reviewer 3:** To what extent will this data be more broadly applicable? NREL SAM is a useful academic tool but seldom used in industry modeling. A path to greater adoption of modeled results should target industry accepted modeling or design tools, e.g., PVSyst, Helioscope, etc.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It is good that the information will be made available to the public, but not clear which stakeholders will be demonstrating demand for this. Or, which stakeholders - in the context of wanting to be high-impact - should be targeted to get them interested. The answers to these questions would likely surface additional stakeholder recommendations.

**Reviewer 2:** See comments above. In addition-the little I know about floating solar is that it has been a good match for wastewater treatment plants and city/county reservoirs. Recommend considering including interested parties in that category to host a system or otherwise participate in the research.

**Reviewer 3:** Stakeholders should be broader on the industry side but the available interested stakeholders is inherently small. Project finance space may be a route to engage to help FPV gain greater acceptance.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** As noted, there is a critical need for solar to expand as the US seeks an urgent transition to a cleaner energy economy. Yes, project is "first of its kind" and we need many tools in the toolbox. But as written, the project documents needs to make the case with greater clarity for whether floating PV is "nice to have" in terms of scientific exploration, or something that could be applied at enough scale to be a game changer relative to competing priorities for funding.

**Reviewer 2:** The grantees need to provide better justification of demand for this kind of research, why the technology has wide application if these soft cost barriers can be overcome and much more thought into how to disseminate results.

**Reviewer 3:** Is FPV a worthwhile niche to fund research? Needs significantly more details on outreach, what kind of data and research will be disseminated. How will this group ensure that they find willing live sites to work with?

## Solar Plus Strategies for Oregon and Washington – $2,050,000

*Washington Department of Commerce | Olympia, WA | Principal Investigator: Linda Irvine*

This project manages a regional effort to plan and implement state strategies in Oregon and Washington to achieve the full technical, social, and economic benefits of solar. With state-level plans that leverage the added social and economic benefits of solar, the project works to accelerate market growth in the Pacific Northwest and triple solar capacity over three years, reduce installed costs for rooftop solar by almost half, and add 5,000 solar jobs, which would double the solar-related employment in the region. This will be done, in large part, through community solar projects.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 |
| Advance the U.S. solar industry substantially | 6 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The goals of enrolling participants, engaging a stakeholder group, executing a workforce diversity study, and more, are ambitious yet critical tasks. The all-hands-on deck approach to achieving these tasks is the only possible way to deliver on such an ambitious agenda. The design is budget conscious with high impact and high risk given the myriad challenges, yet there are well articulated measures to mitigate the challenges. The impact is already significant with more to come by the end of the requested extended period. Given the project's success, in terms of advancing the solar industry, this type of model and design should be the gold standard.

**Reviewer 2:** This project helps advance SETO's mission and sets critical challenges to overcome by researching resiliency utilizing solar + energy storage, workforce development through solar installs and how solar can be an economic benefiting tool for LMI customers through Solarize campaigns. The strengths of this project exist through the diverse engagement of communities in a variety of solar projects that would not have otherwise happened without the leadership of the project team. The project team also created a pathway to disseminating solar + storage with utilities who again, would not have otherwise have engaged without the project. The other strength exists through the projects unintended uncovering of the co-locations benefit of solar on agricultural land. The weakness exists in the project team tying their community solar subscription goals to the rulemaking of Oregon and Washington regulatory arena. Because these states, in particular Oregon, were slow to implement legislation that created their community solar program, the project team's goal of 10,000 customers enrolled was not met.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 3 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has deliberatively established ambitious yet achievable milestones towards the ultimate goal, it has assembled a robust set of stakeholders to design, implement, and evaluate success, it has developed and distributed very informative, user friendly materials detailing results, and the impacts have been measured and the shortfalls in achieving intended outcomes in the planned for timeframe, have been reasonably explained and adjusted.

**Reviewer 2:** This project did a great job of working with a variety of stakeholders to get buy-in and to further project objectives. However, they missed out on several critical milestones due to over-calculating community preferences on siting community solar as well as through regulatory drag, as mentioned above. However, the project team made good strides in pivoting away from their challenges and creating a set of robust outcomes.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Yes, this project covers the continuum necessary for an equity centered approach to delivering the goals. From convening, to training, to implementation, all governed by a diverse, equity centered work group, each of the identified tasks span the continuum that have already proven to be the formula to achieve the goals.

**Reviewer 2:** Score: 4. Comments: Tasks were not necessarily additive and instead stood alone in their effort and outcome. Most importantly, this project determined that solar planning was best done with local stakeholders who were able to provide their thoughts on preferences and potential outcomes.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** One blind spot might be how broad the definition of equity is...keeping in mind that this might be there in the weeds, given that this is just a summary. Another blind spot might be how deep the definition of resilience is, specifically whether this model centers on community owned solar.

**Reviewer 2:** The blind spot, as stated previously, was in creating goals around community solar subscriptions that relied on the regulatory process to institute. Projects need to be thoughtful on how the regulatory process can hinder or help reach project goals.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Stakeholders to consider, in addition to the multi-racial groups and the groups representing Asian American and Indigenous constituencies, would be traditionally African American groups such as the Urban League, NAACP, etc. and similarly Latino groups, as well as disability rights group, LGBTQ groups, women's groups, veteran's groups, etc. Not sure if these groups are already included but there just wasn't enough space in the brief summaries.

**Reviewer 2:** The project team could have considered engaging with financial institutions to help them understand the nuances of community solar finance.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is a phenomenal project, with an excellent, equity centered analysis and focus. Fantastic that it's rooted in equity principles, including community leadership in decision-making. One question is the extent to which, in addition to the multi-racial groups and the groups representing Asian American and Indigenous constituencies, is whether there was outreach to traditionally African American groups such as the Urban League, NAACP, etc. and similarly Latino groups. Secondly, also, within the equity frame, was there explicit outreach to disability rights group, LGBTQ groups, women's groups, veteran's groups, etc. Finally, is the model focused on community owned solar as a key to enduring resilience and wealth building

**Reviewer 2:** 1) A single state focus could have help the project reach their goals through re-calibrated objectives. 2) Impressive for a non-profit such as Spark NW to work so closely with Washington Department of Commerce. 3) Impacts of this project will be felt beyond the funding period.

## Enhanced Distributed Solar Photovoltaic Deployment via Barrier Mitigation or Removal in the Western Interconnection – $2,020,000

*Western Interstate Energy Board | Denver, CO | Principal Investigator: Maury Galbraith*

This project with the Western Interstate Energy Board, an organization of 11 western states that provides the instruments and framework for cooperative state efforts on energy, focuses on removing or reducing the impact of barriers to distributed solar photovoltaic deployment in the Western Interconnection. If successful, the project will result in greater deployment of distributed solar photovoltaics in the Western Interconnection than is currently predicted.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project takes an important first step at looking at the future of the transmission grid with high levels of solar PV penetration. It provides significant value to grid operators and the solar industry in the Western Interconnection territory by helping them understand the barriers to increased solar PV deployment in this area. Hopefully the results of this project can inform other interconnection territories. However, if the research is only applicable to Western Interconnection the results of this research may not be applicable outside of this service territory.

**Reviewer 2:** The project sits in an ambitious backdrop - how to remove barriers to distributed solar PV generation in the Western Interconnect over the next 10 years, focusing on interconnection timelines, rate design and reliability concerns. While these are 3 important barriers to solve, it is not clear how closely this project ties the 3 together. Interconnection timelines and reliability concerns may be related. To the extent that reliability factors are included in rate design (e.g., firm capacity value), there may also be links. These do not seem to be clearly made through this project, which depending on their actual existence, may be a missed opportunity. Strengths: Identifies and analyzes 3 important barriers to future distributed PV growth. Aims to disseminate results directly with policy makers and regulators. Weaknesses: The study's aimed outcome seems to be measured in outreach and not necessarily outcomes. Components of the study do not seem to tie together and rather seem like 3 very distinct buckets. There is nothing inherently wrong with this, but would studies be in a better position if the team were focused on one of the three tasks rather than all 3?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 4 |
| Collaborates with sufficient stakeholders | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team has made significant progress in researching and quantifying the impact of increased solar PV deployment on the grid from the perspective of reliability and rate design. The team has reached the logical next step of meeting policy and regulatory leaders in participating states to disseminate the project team's research and assist in the development of strategies to increase solar PV penetration in this territory. The team has met all relevant milestones and deliverables despite delays in their project timeline due to required report approvals but appears on track to complete their project by June 30, 2020.

**Reviewer 2:** Project is under budget and request for extension was based on DOE bandwidth, not necessarily projects internal milestone slippage. Outcomes are based on outreach to regulators and policy stakeholders. Would prefer if there were a goal to actually attempt implementation or adoption into strategy, but understood that that would be a very ambitious goal. Strong technical stakeholders. Unclear the extent to which grid operators or utility rate design experts were consulted. Some results in the form of papers but unclear what the feedback to stakeholders is. Study on average and aggregate interconnection costs - with breakout by type, could be a valuable data set for utilities, grid operators and solar developers, especially if the data is sufficiently granular.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project team identified 3 topic areas to investigate where barriers may arise to increased solar PV deployment in the Western Interconnection. While not necessarily cumulative, they are all commonly brought up issues when regulators and policy makers consider increased solar PV deployment and the appropriate compensation mechanisms for solar PV generators. Ultimately, for the solar PV industry to continue to grow grid operators, policy makers and regulators will need a consensus on the impact of increased PV deployment on grid operations, costs and the value of DERs to sustain the industry's growth. The research the project team has conducted to date forms a strong basis for these conversations amongst stakeholders in the Western Interconnection territory and may have applicability outside of this region as well.

**Reviewer 2:** Score: 5. Comments: All tasks are aimed towards completely the goal of identifying barriers with the aim of removing them. However, the 3 topics seem completely parallel.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project focuses on the Western Interconnection territory but there inevitably going to be significant variability in solar PV deployment, grid conditions, policy landscapes and opinions about rate design in a territory that large. Often times decisions about these topics are made with in the context of local (i.e. state) frameworks and the findings and recommendations in these reports may not be applicable or well received by all parties.

**Reviewer 2:** Poster describes rate design options - both of which assume an increase in utility ROE and earnings. Would not a better framework to present be to control for utility earnings and ROE (i.e., regulated return) and determine the impact on different classes of ratepayers? To what extent were rate design experts consulted?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project team appears to have engaged the right groups of stakeholders, including utilities and solar developers as well as technical experts.

**Reviewer 2:** It does not appear solar industry interconnection and rate design experts were consulted.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** The project investigates areas of key importance to the future of the PV industry. It is hard to say whether the project will result in barrier mitigation or elimination at this stage. Grid operator and regulator feedback is critical to understand whether decision-makers will find these analyses useful and actionable.

**Reviewer 2:** How does SETO feel about what appears to be three parallel studies that do not seem to rely on the same data set or analytical frameworks/models? Would it not be more effective to have the group focus on a single stream? SETO should consider if whether continued outreach and presentation to regulators should be part of the goal, i.e., funding for ongoing engagement rather than just a presentation to check a box. To what extent were rate design experts with different viewpoints consulted?

## Addressing Regulatory Burdens to Accessing Solar Among Municipal, Commercial and Institutional Customers – $600,000

*World Resources Institute | Washington, DC | Principal Investigator: Lori Bird*

This project helps cities and towns evaluate opportunities for solar energy by training them to effectively engage in the wholesale market and utility planning processes. The team is developing educational materials for stakeholders on how wholesale markets and utility planning and accounting affect solar energy procurement, as well as convene stakeholders to potential solutions. This work aims to foster collaborative partnerships and enable stakeholders to share findings to break down regulatory or institutional barriers more rapidly.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score |
|---|---|
| Align well with this topic's goals and support SETO's mission | 5 |
| Set critical challenges to overcome | 5 |
| Implement a high-risk, high-impact approach | 4 |
| Match well with the level of DOE funding and planned project duration | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 |
| Advance the U.S. solar industry substantially | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project proposes an innovative approach to incorporating customer demand for solar PV in to state resource planning initiatives. Local governments may often not be heard in these types of planning processes and the proposed project will provide education and resources that will enable these types of entities to engage. However, there are risks that even with education it will be challenging for local governments to get involved in resource planning due to general constraints. Regulatory proceedings are often dense and complex and local governments may not have the bandwidth to participate even with the right education and desire.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score |
|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 |
| Disseminates results frequently and actively engages partners | 6 |
| Collaborates with sufficient stakeholders | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project's development timeline is appropriate given the goals it seeks to achieve and the topics it plans to cover. The project engages a broad range of applicable stakeholders in its research. However, the project outputs are primarily research and informational materials and does not measure success by how much customer demand is incorporated in IRP processes as a result of the project.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project investigates multiple perspectives critical to IRP including both consumers and utilities. This holistic approach helps support better outcomes and a higher likelihood of success in integrating additional viewpoints into resource planning.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** There is wide variety in the processes and procedures states use for resource planning, some of which may be more or less collaborative. It may be challenging to create literature that addresses each state's unique characteristics and even "best practices" would need an internal champion to implement changes in states that could improve upon their IRPs. Given capacity limitations it may be difficult for local governments to play this role.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The project appears to have identified a broad network of stakeholders that will contribute to its success.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The project topic is innovative and investigates a strong area of opportunity for stakeholders to better advocate for increased solar deployment. 2) While the research is valuable it may not actually result in greater collaboration in developing IRPs. 3) Changing the participatory processes or achieving greater participation by certain market actors will require a "champion" which could be a challenge given stakeholder capacity constraints.

# Solar Workforce

## Multi-Sector Solar Career Training Initiative for Native Americans and Veterans – $599,999

*Blue Lake Rancheria | Blue Lake, CA | Principal Investigator: Stephen Kullmann*

This project provides integrated solar-career training for Native Americans, veterans, and Native American veterans. Blue Lake Rancheria offers workshops, training, and hands-on learning experiences for a variety of solar-related skill sets. The training emphasizes cross-sector skill building as well as the needs and experiences of veterans and Native Americans. Trainings are tailored to areas of likely growth in the solar industry as well as the skills of the program participants.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 5 |
| Set critical challenges to overcome | 3 | 4 | 2 |
| Implement a high-risk, high-impact approach | 3 | 4 | 2 |
| Match well with the level of DOE funding and planned project duration | 2 | 5 | 3 |
| Add significant value to existing research outside DOE-funded efforts | 2 | 5 | 3 |
| Advance the U.S. solar industry substantially | 2 | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: The project provides access to in-demand careers for populations with limited menus of career options and is addressing an underserved population and addressing challenges of dispersed geography and working with multiple tribal groups. Weaknesses: Due to change in project scope, trainees are limited to entry-level installer position with no clear ladders to higher-skill careers in the solar industry or in the greenhouse gas reduction power collection and distribution ecosystem. There is a lack of named employer partnerships beyond "potential employers" through GRID Alternatives. There is no evidence of career development and career navigation skills training. There are no upskilling opportunities. COVID-19 could pose major disruption to in-person training components. There is a lack of broader partnerships with community colleges, workforce investment agencies and unions.

**Reviewer 2:** This is a very difficult program to review. The implementation plan has been amended significantly due to unforeseen delays. Almost no money has been spent over the 8-month period. The primary partner underwent structural change, and no real work has been done yet. The program does not lay out a theory of change. It does not propose any hypotheses for why Native Americans are participating at a lower rate in the solar industry. It does not explain how the stipend and transportation vouchers work. It does not identify meaningful training impacts or pathways. It does not connect to longer term, more sustainable jobs in the industry. It is hard to identify key strengths or weaknesses in the program because the program largely does not exist yet. However, I hope that the program will consider significant thought around meaningful career pathways and identifying clear obstacles to long-term employment, and not just a focus on basic solar installation skills.

**Reviewer 3:** Strengths: This project addresses the lack of diversity in the solar industry with Native Americans. Grid Alternatives has a good training program for installation. Weaknesses: This project lacks job training outside of installation, which limits the opportunities for the trainees. There should be training on solar financing, project management, sales/marketing, and other job functions that could pay more. This projects lacks training in growing areas that support solar like EVs, storage, etc. There is only one industry partner and there should be more employers driving the project and training.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 3 | 3 | 2 |
| Measures impact appropriately (e.g. quantitative) | 2 | 3 | 2 |
| Disseminates results frequently and actively engages partners | 3 | 3 | 2 |
| Collaborates with sufficient stakeholders | 2 | 3 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project is off to a slow start due to change in scope. Other than preliminary results, there is insufficient data to measure progress. It is difficult to definitively respond to questions about sufficient stakeholders because it's not clear if the geographical isolation and lack of institutional networks are limiting access to traditional stakeholders like colleges, workforce boards, and unions.

**Reviewer 2:** The partners in the project, outside of GRID Alternatives, are not adequately mentioned or described. There was no information provided about how the communications to partners are performed or how frequently they are made. There are no quantitative or even qualitative metrics provided about numbers of individuals trained or employed, and the only reference really to any metrics is the two training seminars offered. Even the development stage does not define success. What does a needs assessment look like? Who needs to participate? How many employers? How many responses? What will be done with the information. Again, it is very hard to judge progress to date because nearly nothing has been done and almost no funds have been expended to date. While much of this appears to be outside of the control of the grantee, much more work should be done to define success and identify a reasonable project plan for the go/no-go decision.

**Reviewer 3:** Per my comments above, I don't see how this project is helping the trainees for long term success and options in solar and other high growth clean tech jobs. It seems very short sighted in just focusing on solar installation.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: There are insufficient data to determine how the project is addressing the challenges of geographical isolation and lack of institutional networks.

**Reviewer 2:** Score: 5. Comments: I always like to see a research phase come first, followed by research-driven action plans.

**Reviewer 3:** Score: 3. Comments: GRID has a good track record of training for solar installations. The tasks outlined will achieve that goal.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** There must be more definite plans to connect with employers in order to inform the curriculum and to provide a defined bridge from education to employment. There is a need for defined career development plans and upskilling opportunities for graduates.

**Reviewer 2:** It is hard to imagine how this project can be successful by 2022 at this level of activity, when the program still has not identified the needs for the community.

**Reviewer 3:** What options exists for the trainees after the GRID project is over? The PI should demand that a diverse set of industry employers are involved in the project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the success?**

**Reviewer 1:** The project must have committed employer relationships as well as connections with colleges and universities, workforce agencies, unions and other CBOs.

**Reviewer 2:** Connections to higher education or labor unions might be very important here to ensure long term career development.

**Reviewer 3:** Solar employers; Energy storage employers; EV employers; Recruiting firms; Small business training.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Addressing challenges caused by the traumas of poverty and social isolation as well as physical isolation requires major investments – well beyond this grant budget. Strong employer connections with associated commitments – to offer career exploration, mentoring, internships/apprenticeships and hiring – are essential. In the future, how might SETO connect projects focusing on populations with multiple barriers with projects creating the future of the industry in order to develop true career paths enabling non-traditional talent to contribute to the future of the industry?

**Reviewer 2:** Not much has happened to date, not the fault of the program; What is proposed is rather weak, and there is still not a clear description of the theory of change or how the program will impact the problem statement; There are no included quantitative or qualitative measures of success.

**Reviewer 3:** 1) Think bigger for the training to anticipate current and future needs of the solar workforce. 2) Engage more potential employers. 3) Provide training on small business opportunities for the trainees.

## Grid-Ready Energy Analytics Training with Data – $6,532,977

*Electric Power Research Institute | Knoxville, TN | Principal Investigator: Thomas Reddoch*

This initiative enhances workforce readiness in the electric utility industry by focusing on the intersection of power systems and digital systems. The project is working to develop and deliver open-source professional training and university course content in data science, cybersecurity, integration of solar photovoltaic and other distributed energy resources, and information and communication technology for power systems workers in transmission and distribution. Through collaboration with utility and university partners, this project will result in certifications, credentials, qualifications, and standards for the training and education needed in the electric utility workplace to help transform the grid of the future.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 6 | 4 |
| Implement a high-risk, high-impact approach | 6 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 | 6 |
| Advance the U.S. solar industry substantially | 6 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Because of speed of technological changes, many workforce programs are also playing catch up. IGEN is forward looking, understanding current trends and creating the future. It addresses the challenge that increasingly industry designations are becoming narrow and outmoded. Rather than preparing workers and students to thrive in the solar industry (limited), it is holistic and preparing them to lead a decarbonized electric power ecosystem. Advancing knowledge transfer through multiple means – university research, industry short courses and train the trainer. Accessible training materials for both professionals and university. Creation of Data Analytics Center of Excellence as an accessible repository that sustains. The following are not weaknesses but questions: These are the jobs of the future. From an access standpoint, who gets to create the future and benefit from the career opportunities? The project's connections with UC Riverside (Latinx students) and HBCUs (Tuskegee and North Carolina A & T) are a start.

**Reviewer 2:** This is an example of an effective program that provides transferable skills that are critical for the solar industry while preparing workers for opportunities in IT, data services, and the energy sector more broadly. The program sets high expectations for participants and has a diverse and broad set of partners to deliver content. The program and associated skills are aligned with critical needs of the industry and grid. There is a strong set of academic partners, though HBCUs and other minority-serving institutions are not included in the program design. In terms of weaknesses, the program could do more to target disadvantaged or underrepresented populations, especially because it focuses on higher skill, higher wage occupations. The program documents could also be clearer about long term impacts of the program on partners and prospective solar trainees. Metrics are rather vague.

**Reviewer 3:** Strengths: Great mix of both academia and utility personnel from all over the country. Target audience is diverse as well (ranging from new hires to seasoned personnel). Very focused project with specific outcomes. Not focuses on traditional solar competencies like installation and design - Should be able to leverage outside utility investment (human and financial capital). Weaknesses/Opportunities: Don't see any outcomes with job placement. Intentionally attract diverse participants in the project.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 3 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Methodical and rigorous approaches to collecting research data and expanding. Creating the communication hubs to communicate with a broad-based team. Adequate project management to move forward.

**Reviewer 2:** The program has an excellent slate of stakeholders and communication; however, it lacks a meaningful or intentional commitment to diversity. No HBCUs, Hispanic-serving universities, or tribes seem to be partners on the project, nor does there seem to be any effort to target any discrete populations of workers. Objectives should align better with milestone status. Current description does not identify the metrics well at all. The descriptions are quite vague. While it appears that a lot of progress has been made and that the budget has not been spent down significantly, it is hard to understand exactly how success will be measured with concrete, quantifiable terms. It is also unclear as to how the program focuses on discrete populations of underserved workers.

**Reviewer 3:** This project is very specific with outcomes that should yield to a higher success rate. As mentioned above, the collaboration with academia and the utility industry will help drive outcomes and is scalable. Power systems classes are in very high demand.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project has a strong vision and there is an understanding of the component elements required to meet that vision. There is an appreciation of the right partners required to bring the project to fruition and what goals needs to be accomplished. The building of committees and communication hubs are essential given the project's national scope and multiple partners.

**Reviewer 2:** Score: 6. Comments: Very well thought out design. Each step appears to be necessary to move to the next and the program builds coalitions along the way.

**Reviewer 3:** Score: 6. Comments: The tasks are very specific, unique, and value added.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

Reviewer 1: The project has addressed the need for diversity but I think it would be easy for anyone associated with upper-level technical degree instruction in a university and in a forward-looking industry to undervalue the hidden talent available in populations without access to the best universities and without access to potent professional networks. I would encourage

PIs to add additional resources in order to engage individuals with technical backgrounds and to determine roles for union training programs in this project. An appropriate design question is: how might a talented and energetic solar installer gain access to the careers of the future as outlined in this project?

**Reviewer 2:** Diversity is lacking and should be more strongly considered by the PI.

**Reviewer 3:** The project is very utility heavy and should include more renewable energy players.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** I would consider addition union training programs, technical training programs and exploring opportunities to connect with high school programs in order to build out educational pathways.

**Reviewer 2:** HBCUs, Hispanic-serving institutions, and tribes.

**Reviewer 3:** Historically black colleges and universities, renewable energy firms, and laboratories.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** This should be a model for future investments because of its focus on leverage knowledge of industry trends and building consistent programs and connecting solar to a more holistic ecosystem. The project leaders have been thoughtful about connecting the new knowledge to multiple stakeholders within the academy and with industry. Continue to work with the PI to determine how to transfer knowledge and opportunities associated with the project to more diverse populations – including high schools and technical training programs.

**Reviewer 2:** Excellent career pathways that focus on in-demand careers with meaningful transferability of skills; Vague success metrics that do not clearly define success; Lack of diversity plan and little involvement of minority serving institutions.

**Reviewer 3:** This project has tremendous potential and is probably the most scalable.

## Expanding the Solar Workforce through the Illinois Community College System – $1,250,000

*Lewis and Clark Community College | Godfrey, IL | Principal Investigator: Katie Davis*

This project expands the solar workforce through a statewide program that strengthens the connections between education and training providers, job seekers, industry, and local communities. The team is building upon current solar-related courses and programs available at Illinois community colleges and making improvements through credentialing, instructional design, and new industry partnerships to better align with employer needs. The program also ensures that licensure is embedded within the program and leverage all potential talent pools, including veterans.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 4 | 4 |
| Set critical challenges to overcome | 6 | 4 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 3 |
| Advance the U.S. solar industry substantially | 5 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The project has multiple strengths including: Focusing on colleges, which are probably the most diverse and accessible institutions of higher learning in the state. Collaborative in position to drive state solar education/training strategy. Colleges are working as a cohesive network – rare. Business engagement with a dedicated biz engagement manager. Good menu of business contributions: career exposure, mentoring, interview and resume support, internship (discussions) and hopefully jobs. Skill upgrades available for incumbent workers. Budget aligns with goals. A potential weakness is related to COVID-19 where there is a hands-on in person requirement for the spring semester and some training through adult ed and community ed were delayed or cancelled.

**Reviewer 2:** The program aids the solar industry by focusing on aligning curricula across a diverse state community college network. The level of training and employment included in the metrics are high and, if met, would represent a respectable return on investment (ROI) for the program. There are several identified weaknesses in the program. The program does not identify which segments of the solar workforce it addresses. It is unclear whether it is geared towards installers, developers, sales, manufacturing, or other roles. Further, it does not specify how or whether there is academic credit associated with the program or whether it is run through noncredit, career and technical education (CTE) programs. Another weakness is that the program does not identify whether there are any lasting benefits following the three-year investment from DOE. Is there a mechanism to keep curricula current? Are any of the funds used for meaningful technology or infrastructure investments with longer life span?

**Reviewer 3:** Strengths of Project: Good consortium of Illinois community colleges. Smart to have advisory group of solar industry private sector companies and organizations. Program seems solid on solar design and installation training. Weaknesses/Opportunities of Project: Needs to focus more on job placement. Maybe explore partnerships with staffing companies and other recruiting firms. Exelon/ComEd is based in Chicago and could be a good partner for job placement. They are investing in clean energy and have an unregulated company that invests and builds solar projects on a large scale. Curriculum should also expand to include training on solar financing, project management, sales, marketing, and other key functions outside of just installation and design.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has multiple strengths including: Focuses on colleges, which are probably the most diverse and accessible institutions of higher learning in the state. Collaborative in place to drive state solar education/training strategy. Colleges are working as a cohesive network. Business engagement with a dedicated business engagement manager. Good menu of business contributions: career exposure, mentoring, interview and resume support, internship (discussions) and hopefully jobs. Skill upgrades available for incumbent workers. Budget aligns with goals. The weaknesses are questions: Addressing COVID-19 (need to address the hands-on in person requirement for the spring semester. Come trainings through adult ed, community ed were delayed or cancelled). Will installers be able to advance as the industry changes and grows? Employers have expressed interest in direct employment of graduates – will this come to pass? Will business follow through with establishing internships and apprenticeships? Will there be partnerships with IBEW and workforce agencies?

**Reviewer 2:** Performance is reasonably good given the required and approved changes. The primary considerations are whether partners include labor unions, workforce development boards, or other training providers. It is also unclear as to whether NABCEP or other recognized credentialing is part of the program or whether the effort is intended to create new signals (certificates, credentials, etc.) that may be valuable to employers. That said, just coordinating within a single system and six distinct colleges is a difficult task. In terms of metrics, trained students and placed students are the most important metrics and it is positive that they are included. It would be particularly useful if the program also identified more long-term impacts on how the partner colleges might benefit (through additional training opportunities, etc.) due to the funding. Communication, particularly in this COVID environment, is well above average. All that said, the program seems to have been able to meet the expected milestones under budget.

**Reviewer 3:** The project seems strong on recruitment and training outcomes. Per my comments above, I think the opportunity is to add more industry partners that can yield more job opportunities. Additionally, the training needs to be expanded to meet the needs of solar firms now and in the near future. Placing workers in 3 months seems very ambitious, especially with the current pandemic.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Based on my experience with solar and decarbonization projects in Silicon Valley, IGEN has created a holistic formula for education-industry training and employment success, with the appropriate elements in place. The project has identified the essential partners, and created the elements (curricula development and coordination, partner communication strategy, business engagement infrastructure and establishment of advisory group) to realize project goals.

**Reviewer 2:** Score: 6. Comments: The program makes sense from a logistical standpoint, given the complexities of navigating across a community college system.

**Reviewer 3:** Score: 4. Comments: I'm struggling to see how this project is unique but I think with some tweaks, that it can be slightly. Community colleges are the way to go with job training and skills. That is a major value add with this project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** There are not many blind spots. The key partners are in place. I would like to see a stronger connection to the workforce development system (that may be in the plans, I forgot to address this in my questions to the PI). A connection with the excellent IBEW union apprenticeship system would be ideal. But the PI is aware of this opportunity and will continue to pursue.

**Reviewer 2:** It was unclear how the program benefits key populations mentioned (e.g., Veterans) and it would be good to include diversity and veteran status demographics of the 6 colleges.

**Reviewer 3:** The major blind spots are all of my comments above. These include: Diversifying the solar job competencies outside of installation and design; More industry partners are needed that what they currently have; 3-month job placement seems very ambitious, even without the current pandemic.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Unions and workforce agencies. Workforce agencies and community colleges systems often operate in parallel universes, often with identical goals and a shared need for industry engagement – but – all too often – with a lack of coordination and often competition for scarce resources.

**Reviewer 2:** Workforce development boards and labor unions.

**Reviewer 3:** Recruiters/Staffing companies; More industry partners; New and emerging partners (EV and storage firms).

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Thoughtful employer engagement strategies – as displayed with IGEN – are foundational to the goal of preparing a solar workforce that meets current skill demands and has the capacity to upgrade skills and grow as the industry changes. essential to the success of training. 2) IGEN has devised a compelling success formula that should be studied by other organizations seeking approaches to bridging students from education to career. 3) Because of their diverse student bodies and relatively affordable tuition and accessibility to students statewide, an investment in functional community college partners is important.

**Reviewer 2:** 1) Not as innovative as some of the other programs. 2) Did not identify key populations served. 3) Met a critical challenge of alignment across community college system.

**Reviewer 3:** Diversify the training and add more partners.

## Solar Ready Wisconsin – $800,000

*Midwest Renewable Energy Association | Custer, WI | Principal Investigator: Nick Hylla*

This project supports the development of a statewide network of industry stakeholders, training providers, and nonprofit organizations working to develop solar workforce capacity in Wisconsin and the surrounding region. In collaboration with a network of local community colleges, the team is creating a program called the Wisconsin Solar Corps to provide job training and facilitate job placement for qualified candidates in the solar industry. The goal is to make Solar Ready Wisconsin a replicable program that has the potential to be used across the Midwest.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 4 |
| Set critical challenges to overcome | 5 | 4 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 4 | 3 |
| Advance the U.S. solar industry substantially | 5 | 4 | 3 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: 160-hour internships (paid, part time, no benefits) and 70% were offered regular employment according to 2019 data. Goal to scale to ten colleges Industry advancement opportunities through continuing education courses and NABCET certs. Variety of career opportunities from Installers to project management, advanced design, sales, solar installation contracting and solar instruction. The project includes career development career navigation training. To promote systemic sustainability the project is building a labor exchange platform that will connect talent supply with industry demand. Weaknesses: There are challenges inherent with facilitating college collaboration and curriculum coordination as well as major COVID-19 impacts. The virus presents significant challenges to the energy efficiency and distributed generation industry, specifically those businesses serving residential and commercial customers. But several of the partnering contractors, as well as some of our technical college partners, have indicated that if internship work experiences are impossible this spring, there is potential to provide internship hours during the summer and fall of 2020.

**Reviewer 2:** The program seeks to build out a multi-college framework for training and include 36 internships. A strength of the program is that it provides an important blueprint for cross institutional curriculum development and approval and it engages stakeholders at meaningful events. Weaknesses include an apparent lack of focus on equity or diversity. There does not seem to be any specific outreach or engagement with historically disadvantaged or underrepresented communities. Discussion focused on specific engagement with employers, beyond some travel stipends and invitations, is weak. The return on investment is difficult to calculate given the relatively few internships (36) and no quantitative metrics on how many students will receive training and education, and whether the programs carry academic credit (only continuing education credits for instructors were referenced). As a result, it looks rather expensive for what is actually being delivered. Perhaps this is just a weakness in the material provided and that an in-person opportunity to discuss with PI would have resolved these questions.

**Reviewer 3:** Strengths: Very focused solar installation jobs training program. MREA is a great lead with an overall understanding of the solar market in Wisconsin. Weaknesses/Areas of Opportunities: Need more industry partners that would employ trainees. Would like to see diversity as a focus as well.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** MREA's significant experience and access to industry and educational resources have provided this project with a broad range of appropriate stakeholders. The solar energy website is a key communications device for partners and stakeholders. The Impact measures are appropriate, particularly the student internship goals.

**Reviewer 2:** Performance of the project is somewhat hard to measure because it is still early and coordination can take time. The milestones do not seem to connect to expenses very well, however, as there do not seem to be much meaningful activity, mostly focused on attending meetings. At the same time, not much money has been spent (11% or so) to date so it is hard to evaluate. There does not seem to be any specific outreach or engagement with historically disadvantaged or underrepresented communities. Discussion focused on specific engagement with employers, beyond some travel stipends and invitations, is weak. The return on investment is difficult to calculate given the relatively few internships (36) and no quantitative metrics on how many students will receive training and education, and whether the programs carry academic credit (only continuing education credits for instructors were referenced). As a result, it looks rather expensive for what is actually being delivered. Again, probably due to limited information available.

**Reviewer 3:** I think the project will be successful in its stated scope of work.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: The project has taken a prudent approach building infrastructure for project success, particularly allocating resources to broadly share information about project goals with statewide stakeholders. There is also a sophisticated communications plan in place to connect current and potential stakeholders.

**Reviewer 2:** Score: 6. Comments: This is true in the abstract, however, it appears most of the money to date has been spent on attending conferences and meetings.

**Reviewer 3:** Score: 4. Comments: The project clearly outlines the necessary steps and value of the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** There is little discussion about diversity and access to opportunity for harder-to-serve populations although I the community college focus could be seen as a proxy for diversity and access.

**Reviewer 2:** Diversity and equity seem to be blind spots, as well as meaningful engagement with employers.

**Reviewer 3:** Impact of COVID-19 on the project.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** While some of the colleges have connections with union-based apprenticeship training, there is no formal project connection to IBEW and other unions. Partnership with workforce development boards would be a plus. Following the example of Chippewa Valley Tech College and its collaboration with a local school district, there is value in making younger students aware of these education and career opportunities through career exposure, exploration and inspiration experiences.

**Reviewer 2:** Labor unions, affinity groups, and employers.

**Reviewer 3:** Stakeholders with access to diverse pool of candidates. More solar firms that are employers to help drive the project.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Internships, apprenticeships and other earn and learn opportunities are essential to project success because of the transparent connections to employment and the clearest possible sign of employer commitment. Goals to scale to ten colleges and throughout Midwest are significant and – if successful – would represent a significant return on SETO's investment. There is great value in having experienced and well-resourced agencies like MREA serve as backbone for these grant partnerships.

**Reviewer 2:** 1) Not much activity to date so hard to evaluate. 2) No clear plan for equity or diversity, and not much in the way of novel development. 3) Success metrics not terribly clear.

**Reviewer 3:** I've mentioned this above but diversity trainee pool, broaden training program beyond installation, and add more employers as partners.

## Collegiate Solar Innovation Challenge: Solar District Cup – $1,550,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joe Simon*

The Solar District Cup is a multidisciplinary collegiate competition that challenges student teams to design and model distributed solar energy systems for multiple buildings on a local electrical distribution network. These systems integrate solar, storage, and other distributed technologies and capabilities across mixed-use districts, or groups of buildings served by a common electrical distribution feeder, such as a campus, a development, or an urban area. The competition engages students across the engineering, urban planning, finance, and business disciplines to re-imagine how energy is generated, managed, and used in a district.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 5 |
| Set critical challenges to overcome | 5 | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 6 |
| Advance the U.S. solar industry substantially | 5 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: This project provides a similar experience as mechanical engineering students who participate in the Society of Automotive Engineers car building competitions. Participants gain essential career and teamwork skills that are generally not taught in college. This is a holistic training experience encompassing system design, finance, distribution and optimization and it mirrors the workplace experience. This competition also exposes students to career options and presents an opportunity for students to show their skills to potential employers. There are intentional efforts to reach out to diverse populations through participation by Historically Black Colleges and Universities, Latinx-serving universities and tribal colleges. Students also receive career development advice from industry. Weaknesses: Because of COVID-19 the Solar and Energy Storage Southeast event has been postponed and replaced with live video conference. This will lead to a loss of networking opportunities but money will be repurposed to connect participants to future conferences. The virus could also reduce the number of final design projects submitted.

**Reviewer 2:** This program hits all of the elements of importance to the SETO goals. It has broad, mutli stakeholder engagement, significant in-kind cost share, academic/industry partnerships, and focus on lowering costs. Program intentionally engaged HBCUs, tribes, and Hispanic-serving colleges. The program is cost-effective and has strong metrics for success. The program is particularly strong in that it uses a competition model to create innovative solutions to the industry's most pressing problems. Each of the key areas where innovation is critical is included, such as solar system design, finance, development planning, distribution systems, optimization, and storage. No significant weaknesses are identified.

**Reviewer 3:** This project aligns wonderfully with the topic's goals, SETO's mission, and a critical need in the solar industry. It has a pragmatic and suitable approach to reaching the goal and it has identified critical challenges to address. An additional challenge set out to be explicitly overcome should be ensuring diversity, equity, and inclusion in the competition. It's well known that African American students and others are significantly under-represented in the STEM fields and specifically in the solar industry. To optimize the contribution, this project would ideally incorporate intentionality around diversifying this field. In terms of co-benefits, this would not only meet the direct goals of workforce development but by having more diversity in the workforce and industry, there would be an increased likelihood of household uptake in solar among communities of color. The budget and project duration appear to be commiserate with the intended outcomes. Though it will certainly be high impact, I don't necessarily view it as high risk as the components of the project will logically result in the aims put forth...by adding the challenge of diversity, equity, and inclusion, it would add more of a risk as the team seeks to customize to bridge the access and inclusion gap that has plagued the industry since its inception.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 6 | 5 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 6 |
| Collaborates with sufficient stakeholders | 5 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project promotes collaboration with important stakeholders for students. The strong in-kind support from industry shows industry "skin in the game," though it is not clear why this in-kind support is not included in the project budget. The industry engagement supports efforts to sustain this initiative beyond the end of the project period. This project is a solid value at less than $1,300 per participant considering the career development opportunities.

**Reviewer 2:** Program has exceeded performance objectives to date. It is currently providing critical training and competition participation at less than $1,300 per participant. Program appears to be replicable. The program has engaged with more than 50 institutions and a dozen industry partners, obtaining more than $400,000 in match funding through in-kind donations. The teams are interdisciplinary and focused on the industry's key challenges. The coordination is exceptional and the metrics used for success appear aligned with SETO goals. While COVID may impact the ability of teams to collaborate in 2020 and 2021 competitions, the program seemed on track prior to this disruption.

**Reviewer 3:** The performance so far has been excellent with critical milestones reach regarding institutional and individual student engagement. The project has clear, quantifiable measures of the objectives it set out to meet and it would be ideal to see further objectives integrated and measured around diversity, equity and inclusion. The dissemination of results appears appropriate. In terms of stakeholders, while it is good that New Mexico University as a predominantly Latino Minority Serving Institution (MSI) was included, it would be further optimized by the inclusion of a Historically Black College/University (HBCU) as a primary partner. It is good that it seems that some HBCUs engaged as participating institutions and it would be good to know how many of each MSI participated and if there were any particular measures employed that resulted in their participation.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The appropriate elements are in place to meet project deliverables.

**Reviewer 2:** Score: 6. Comments: Program design is well thought out, with multiple steps to ensure that key stakeholders have access to curriculum and online training.

**Reviewer 3:** Score: 6. Comments: The project does engage young, creative minds in advancing innovation in the solar industry in a way that prepares and positions them as the future workforce and leadership we need in this industry.

**4. What ‘blind spots’ does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Blind spots are not evident.

**Reviewer 2:** It is hard to identify any blind spots of the PI.

**Reviewer 3:** It would be good to have an explicit equity, diversity, and inclusion focused objective and corresponding activities, indicators, and metrics.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Consider including community colleges in future, if not currently engaged. This would create an opportunity to increase diversity and access to a broader range of participants.

**Reviewer 2:** The program has engaged more than 50 institutions and has included HBCUs, tribal organizations, and Hispanic-serving institutions.

**Reviewer 3:** If it’s not already the case, within having university partners, it would be ideal to engage student led groups? Also, in addition to having a predominantly Latino MSI, it would be ideal to have as primary partners at least one HBCU and a predominantly indigenous institution.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is an excellent model that stimulates academic learning and provides a springboard to employment. It provides a significant career exposure opportunity, particularly in a fast-growing industry like solar. This is a cost-effective opportunity to evangelize solar careers for students.

**Reviewer 2:** The program is very thoughtful about diversity, intentionally addressing HBCUs, Hispanic-serving institutions, and tribes. The program is very cost effective at less than $1,300 per participant. The programs focus is aligned particularly well with SETO goals.

**Reviewer 3:** It’s unclear whether the results including engagement of MSIs was something that was measured after the fact or if there was intentionality and pre-determined metrics on MSIs? If the former, it would be good to include equity aims and corresponding customized methodology. Also, the results should include the differential impact of customized engagement methodology, to inform others who are trying to advance equity-based models of student/college engagement on solar technology innovation. Finally, in addition to engaging educational institutions, it would be good to explicitly engage with student led groups.

## Hands-On Photovoltaic Experience Core Capability – $225,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Adele Tamboli*

This program, also known as HOPE, is a one-week summer school program held at the National Renewable Energy Laboratory each year to train graduate student researchers in photovoltaic fundamentals, as well as specific cell technologies and techniques in measurement and characterization. The program brings in students from across the United States and their faculty advisors for an in-depth, intensive program that includes hands-on lab experiences in solar cell fabrication and testing. This program aims to train future photovoltaic researchers and increase collaboration among the students, faculty, and staff at the lab. HOPE is a selective program with a competitive application process and is limited to approximately 12-15 students each year.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 6 | 6 |
| Set critical challenges to overcome | 3 | 5 | 4 |
| Implement a high-risk, high-impact approach | 3 | 5 | 3 |
| Match well with the level of DOE funding and planned project duration | 3 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 6 | 6 |
| Advance the U.S. solar industry substantially | 3 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Strong track record with the HOPE program with client satisfaction. Several program participants have moved on to work for NREL. Small student subset that is very focused on project objectives. Weaknesses/Areas of Opportunities: How is this scalable to include more students? Is there an outreach to include diversity in the project? Should the program be longer than 1 week? Can energy storage be included?

**Reviewer 2:** The project strengths include, career exposure for graduate students, opportunities for NREL to evangelize about industry, providing a pipeline of talent to NREL, increased diversity due to increased advertising and preference given to new participants, connecting students to the future of the industry and providing students with access to multiple subject matter experts. There are also professional networking opportunities with students with NREL staff and students with each other as well as career skill development including teamwork, writing scientific papers and making effective presentations. The weakness are related to COVID-19 uncertainty. The worst case scenario is to cancel the project, the medium case is to provide virtual content with uncertain access to labs and the best case is that NRE reopens in late April and HOPE 2020 proceeds.

**Reviewer 3:** The program offers important opportunities for collaboration and important skill development. The approach is innovative and brings together multidisciplinary teams for hands on learning. Many NREL staff (40+) are involved and there is a broad array of research activities represented. The program is lower cost at only $75 thousand per year, which translates to about $2,500-$3,000 per student or faculty advisor. The program is highly competitive and attracts talent from a broad range of universities and academic institutions. Eight years into the program, it does seem reasonable to see if there are cost-saving or impact-enhancing measures that incorporate technology and learning beyond a single week. While the current cost is certainly reasonable based on impact, it might be useful to think of ways that impact could be deepened with a longer engagement that incorporates some virtual elements during the school year to emphasize learning and increase collaboration.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 5 |
| Collaborates with sufficient stakeholders | 4 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has high performance based on the participant feedback.

**Reviewer 2:** With multiple years of experience, this project is well-oiled machine. The cohort size of 12-15 works for all parties. The HOPE/NREL website keeps stakeholders informed.

**Reviewer 3:** Performance is consistent over an eight-year period. The program offers important opportunities for collaboration and important skill development. The approach is innovative and brings together multidisciplinary teams for hands on learning. Many NREL staff (40+) are involved and there is a broad array of research activities represented. The program is lower cost at only $75 thousand per year, which translates to about $2,500-$3,000 per student or faculty advisor. The program is highly competitive and attracts talent from a broad range of universities and academic institutions. Surveys suggest high satisfaction with the program by participants. This satisfaction and impact does seem to persist based on longitudinal follow up. Again, for the low cost, the program seems to be performing at standard. It is appropriate to consider whether enhancements and changes can be made this late into development that could improve the program in meaningful ways.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Agree with this statement.

**Reviewer 2:** Score: 5. Comments: Yes.

**Reviewer 3:** Score: 6. Comments: It is a short program so it is hard to determine a great number of steps.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The blind spots are my questions posed above, which are: How is this scalable to include more students? Is there an outreach to include diversity in the project? Should the program be longer than 1 week? Can energy storage be included?

**Reviewer 2:** None are evident.

**Reviewer 3:** The program does not emphasize diversity or target populations of disadvantaged or under-represented communities in any way.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Graduate programs that you are not working with. Are there any Historically Black Colleges and Universities (HBCUs) that you work with?

**Reviewer 2:** The project should continue to reach out nationally to ensure a diverse array of universities.

**Reviewer 3:** HBCUs, Hispanic-serving institutions, tribes, veterans' groups, and other key organizations focused on discrete demographic groups.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Project is strong and participants see good value. 2) Please ensure that diversity is part of the outreach for program participants. 3) Can the project be extended beyond 1 week?

**Reviewer 2:** The project should continue to promote diversity, promote this opportunity with undergraduate students contemplating graduate work in solar and the clean energy ecosystem and seek opportunities to attract employer engagement, perhaps as funders.

**Reviewer 3:** 1) Equity issues are not referenced at all, which is problematic. 2) No clear COVID plan, general lack of technology supports to reduce cost/maximize impact. 3) Very effective program as is for short dollars.

## Stakeholder Training for IEEE 1547-2018 – $750,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: David Narang*

The revised IEEE 1547 standard for interconnection and interoperability of distributed energy resources at the distribution level was published in April 2018. The updated standard is significantly different, with new concepts and new technical requirements, and requires educational material on the application of these changes. The National Renewable Energy Laboratory had a principal role in accelerating the revision process though its chairmanship of the IEEE 1547 working group to revise the standard and through technical support provided to the working group. Under this project, the team is compiling and developing education materials for IEEE 1547-2018 and make them publicly available. This includes the formation of a Technical Education Committee of stakeholders; the development of a series of educational modules; the publishing of educational materials online; the development of a guide for adoption of IEEE 1547-2018 to aid state regulators; and providing technical assistance to stakeholders. Coordination of education and dissemination with other entities will be completed to avoid duplication of efforts.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Methodical approach to facilitate the adoption of the IEEE Std 1547-2018 standard via education. Great group of stakeholders. Excellent leadership running the project. Well defined outcomes and understanding of the challenges. Weaknesses/Areas of Opportunity: Leverage private sector resources (human and financial capital), if not already doing so.

**Reviewer 2:** Strengths: The project foundational to facilitating DER interconnection and grid modernization. There is an accessible online platform to showcase educational materials. The project team has taken a methodical approach to assembling the right partners (TEC), determining gaps in knowledge, creating accessible educational materials and providing ongoing technical assistance. Weaknesses: COVID-19 challenges could impact technical assistance activities. Stakeholders are also experiencing delays in project plans. The project team has already requested a no-cost, 6-month project extension to address contingencies. Fortunately, the project team made presentations to high impact conference prior to shelter in place orders.

**Reviewer 3:** Project is highly technical and meets the needs and goals of SETO. The budget is reasonable and the need is clear. The return on investment is high. The multi-stakeholder team is impressive and includes a diverse array of stakeholders. The guide for incorporating IEEE Std 1547-2018, and the process to achieve it, into interconnection rules will aid state regulators and other authorities governing interconnection requirements in developing individual roadmaps specific to their jurisdictions. NREL is coordinating education and dissemination with other entities to avoid duplication of efforts. This is a critical need for the solar industry and this will advance the industry significantly.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 6 | 5 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The performance of this project is very solid, as highlighted in my comments above. I'm very confident that this will be a successful project.

**Reviewer 2:** The team is making significant progress but COVID-19 could disrupt plans, as noted above. Regarding stakeholders, given the important of the project, it is important that the distribution list of materials be extended widely with focus a on geographical and demographic diversity.

**Reviewer 3:** The program is highly successful in meeting its objectives: Fill the need for publicly-available, authoritative educational material on IEEE Std 1547-2018 for key stakeholders; Coordinate with the Technical Education Committee (TEC) and other stakeholders to develop; joint plan for education material and dissemination; Provide a highly visible, well-cataloged and accessible online platform for showcasing the educational material; and provide technical assistance, including a guide for regulators, to help accelerate the understanding and adoption of the standard. To date, the program has put together an advisory team, catalogued existing information, and disseminated it accordingly.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Well defined unique tasks and specific outcomes will ensure success.

**Reviewer 2:** Score: 5. Comments: The project appears to be a methodical and thoughtful approach to tackling this challenge.

**Reviewer 3:** Score: 6. Comments: The project plan is well thought out and each member of the highly technical team has the ability to ensure that the project will move along according to plan.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** I can't think of any.

**Reviewer 2:** Regarding the goals of promoting data access, there could be gaps in distribution. But that is just speculation without additional project data.

**Reviewer 3:** I do not see any blind spots that I can identify.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** I can't think of any that aren't included already.

**Reviewer 2:** As cited above, are there additional stakeholders whose addition to increase access to this critical standard?

**Reviewer 3:** The team is already quite comprehensive.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) How will COVID-19 impact the project, if at all. 2) Can this project and team go further to address other issues to move the solar industry forward. 3) Great project and just leverage the TEC as much as possible.

**Reviewer 2:** The Initiative appears to be foundational to promote SETO's goals regarding the future of the grid. The project methodology seems appropriate, particularly with the availability of extensive technical assistance. Inclusive outreach strategies are essential to fill in any gaps in regional knowledge of new standards.

**Reviewer 3:** This is an extremely necessary program for the advancement of the industry; The team assembled, and the communication plan among them, is top-notch; The budget is reasonable for the impact.

## Bright Solar Futures – $1,250,000

*Philadelphia Energy Authority | Philadelphia, PA | Principal Investigator: Laura Rigell*

This project expands existing efforts in Philadelphia to develop a new, replicable workforce training program for the region's growing solar industry. The curriculum includes solar installation, construction safety, an introduction to solar sales and design, and other job-readiness programs. Successful program graduates will be placed in internships with local employers and get ongoing support from the program to increase the likelihood of job retention.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 4 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: The project is the first CTE program in solar in the state, provides opportunities for opportunity youth and has paid internships for all with passing grade (70% and above). This project is particularly important in Philadelphia given loss of manufacturing jobs and the challenges of many populations to gain access to growing tech and professional jobs. There is college credit associated with the project and a bridge to higher education. There is also support for students wishing to enter IBEW apprenticeship programs. Weaknesses: The cost per participants seems high but I am not sure I have adequate information to judge. COVID-19 will have major impacts, including the ability of the project to build out its high school solar lab. The virus crisis has delayed internships and the introductory high school programs has been suspended.

**Reviewer 2:** The program has several significant strengths and overcomes administrative burdens for curriculum improvement. Career and Technical Education (CTE) and other public vocational programming can be very difficult systems to navigate, particularly when dealing with braided funding. This project appears to have done an excellent job managing the stakeholders and coordinating the different sets of regulations and funding requirements to maximize the impact for a targeted population that is often overlooked. The curriculum appears to be well aligned with need in the region, and employer engagement appears to have been successful to date. The focus on high school students and opportunity youth is critically important, given the lack of diversity in the solar sector. Identification and recruitment in high school is key to serving opportunity youth. The primary weakness is that the review does not illustrate how funds have aided in reducing future costs beyond the three year program and whether any of the expenses are for capital that can be used beyond the period. As a result, the cost per completion is quite high ($12,500+ per student), that goes down, which is hard to understand, when the program shift from 120 hours to 1,080 hours. I think this is not an actual critique and that the information would have been available with in-person meetings. A major improvement would be if there could be a broader menu of opportunities. I'd love to see this program get more funding to expand the outreach and engagement to higher wage careers!

**Reviewer 3:** Strengths: Unique program that is the first that I've ever heard of; Laser focus on underserved communities with barriers to enter the solar workforce. Diversity is very much needed in the solar industry; Great collaboration with city and state organizations; Partnership with F.A.V.O.R. and PowerCorpsPHL. Weaknesses and Areas of Opportunities: Expand the solar training program beyond just solar installation and design. Solar jobs also entail customer service, sales/marketing, finance, engineering, project and construction management, media relations, and many other job functions that will make graduates more marketable to employers; Great opportunity to focus on other clean tech areas that many solar companies will diversify their services to offer. This includes EVs, energy storage, grid integration, microgrids, and others.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The timeframe seems adequate but the budget seems high for number of students. The quantitative impact of the program is not crystal clear. A comprehensive list of stakeholders means that students entering the program will have multiple career options through multiple partners.

**Reviewer 2:** The short-term performance exceeds expectations. In less than one year, the team has identified and removed significant barriers to implementation, including braiding funding across Perkins funding, WIOA OY funding, and DOE funding. The program has received approval from the state education board in Pennsylvania, identified sites, and launched an internship/fellowship. Developing an approved CIP code is no small feat, which could have broad implications across the state and in other states. DOE should consider how to facilitate this type of scaling and expansion as a potential major success of the initiative. Given the adjusted budget and later start date, the progress made is significant. It will be important for DOE to be flexible on future reviews given the major disruption to public schools from COVID-19.

**Reviewer 3:** The program is very well structured to meet its current objectives but has the opportunity to go a lot further and add tremendous value to its students and the future workforce of our country.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: The project is creating the building blocks to support students and provide them with career options.

**Reviewer 2:** Score: 6. Comments: The grant appears to fund infrastructure and system alignment, primarily. The former is critical but difficult to scale. The latter is very difficult to implement but highly scalable if managed correctly. The program has taken the time and followed the correct steps to bring multiple stakeholders on board so that different types of students can be identified, recruited, and trained, including directly through public schools as well as through the workforce development board's Opportunity Youth Program.

**Reviewer 3:** Score: 5. Comments: I think the tasks are properly outlined and the value of the project is definitely unique and needed.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** The project's budgeted cost per participant is not crystal clear.

**Reviewer 2:** Perhaps a PI blind spot is in the tremendous potential for impact beyond the current program. This may not be fair, however, as the PI is likely (and rightly) focused currently on short-term objectives. So I would say that it is less of an identified blind spot and more of a caution to not allow it to become one!

**Reviewer 3:** Impact of COVID-19 on the industry. This is a blind spot for everyone. Need more private industry involved to shape curriculum and training. Need are always changing and must be able to adapt to provide the workforce that the industry needs.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** The diverse team of stakeholders is a strength of the project.

**Reviewer 2:** Perhaps community colleges and labor unions could play more significant roles here for hand off to other jobs or training that build on the skillsets, broadening the impact.

**Reviewer 3:** Private employers in solar, wind, EVs, energy storage, utility companies (PECO/Exelon).

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is an excellent example of the importance of community collaboration in promoting participant success. There should be consideration of developing future programming connecting this project to middle and elementary schools. This project provides an initial benchmark for determining the appropriate budget for creating and operating a high school based program.

**Reviewer 2:** 1) Aligning CTE, public education, WIOA, and DOE funding is no small task and they seem to have done it well. 2) CIP approval in one year is impressive and is a potential major scalable accomplishment that could impact other schools in PA and across the country. 3) Program should identify additional benefits for the investment. Currently, $12,500 per pupil for a 100 hour cost seems high because I think there are other unidentified benefits that would improve the ROI analysis, therefore increasing the perceived value of the program. This is not unreasonable for 1,080 hours, but it is unclear how this can be delivered at a lower cost than the 100 hour program. Wish this could be funded to link to the Grid Integration grant - I'd bet there are students in this program with ability and interest to start on those career paths!

**Reviewer 3:** 1) Broaden the scope of the training. 2) Invite more employers to the table and don't limit the geography of employers to just PA. Many solar developers and installers are not just local. 3) Create an Advisory Group of industry experts from across the country.

## Safer's Solar Energy Demand Skills Training Program – $800,000

*Safer Foundation | Chicago, IL | Principal Investigator: Marketer Ash*

The Safer Foundation, which focuses on workforce development and programming for people in the criminal justice system, is advancing its Solar Energy Demand Skills Training program to fill the growing workforce needs of the solar industry. The Safer Foundation and its partners across the state of Illinois are providing participants with a comprehensive program based on interests and aptitudes. Experienced solar industry trainers, employers, and supervisors will combine classroom training, hands-on experience in the lab, and real-world installations to enable participants to better understand the sales, design, and installation fields.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 6 |
| Set critical challenges to overcome | 4 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 3 | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 3 |
| Advance the U.S. solar industry substantially | 3 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Deep and sustainable community partnerships that can assist students in access to solar and other employment. Students have options. Partnerships include: Workforce development board – with access to other positions beyond solar. There are also possible apprenticeship referrals to IBEW locals 134 and 21. The project features a relatively broad career menu including installer, systems design, project management and customer service. The plan includes on the job training opportunities with employers. Weaknesses: There is a lack of form employer commitments to date. There is a lack of solar employment in the Chicago area and It is not clear at this point if there is demand in Chicago for talent from this justice involved channel. Safer's proposed pivot to considering an installation project on its own site underscores the apparent lack of market opportunities in the region.

**Reviewer 2:** The program is ambitious, seeking to place employees with a criminal background into the solar industry. Employment of formerly incarcerated individuals is very challenging as-is and especially so when most of the employment in the Chicago area would be focused on residential and smaller commercial installations. This is typically not a very good fit, so it will be interesting to see if the program can have success. Strengths include selecting a very challenging population and setting high standards. Additional strengths include relevant training. Weaknesses include an apparent lack of uptake in Chicago. While this was made transparent, it is fair to ask whether this is systemic and or solvable. Other weaknesses include a lack of clarity of the transferability of skills and what the bootcamp provides as a standalone training program that might aid in employment outcomes.

**Reviewer 3:** Strengths: Focuses on providing much needed opportunities for Americans with a criminal past; Good training partner. Weaknesses/Areas of Opportunity: Expand the career paths beyond installation; Include more industry partners and potential employers.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 4 | 3 |
| Measures impact appropriately (e.g. quantitative) | 4 | 4 | 3 |
| Disseminates results frequently and actively engages partners | 3 | 4 | 4 |
| Collaborates with sufficient stakeholders | 3 | 4 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** There have been some bumps and COVID-19 is certainly a challenge. The shelter in place order has further hurt efforts to convene industry stakeholders. Community stakeholder engagement is strong.

**Reviewer 2:** There have been some challenges to success, including the lack of solar activity and hiring in Chicago. Without a better understanding of the value of each of the success metrics (pre-screening, enrollment in bootcamp, enrollment in Kankakee program) it is hard to know how well the program is functioning. It is notable that agreed to milestones have mostly been met, despite some higher costs from training providers. It is unclear whether academic credit is available to participants or whether the programs are run through non-credit career and technical or vocational programs. This could have a significant impact on the value of the program. The program is not terribly innovative or novel, nor does it have obvious employer partners or other champions. It seems to assume that the challenges to hiring are skills or general employability based and does not identify strategies for how to convince potentially skeptical employers about the risks to hiring formerly incarcerated workers to residential job sites. However, and this is critical, if Safer can succeed it will be a major success, perhaps more so than any other program I reviewed. It is high risk but also extremely high reward.

**Reviewer 3:** Similar to my comments above, the project needs to include more stakeholders that can help expand the career paths.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 3. Comments: Lack of employer and employment commitments are problematic. Otherwise, appropriate community partners are in place and – thanks to experience with and connections to appropriate community partners – Safer understands the unique needs of working with this justice involved population.

**Reviewer 2:** Score: 4. Comments: Again, it is unclear as to how well the tasks are aligning given the challenges in Chicago.

**Reviewer 3:** Score: 4. Comments: The training program appears to be solid and I think the trainees will benefit from learning how to install solar.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Did the PI miscalculate the demand for justice involved talent in Chicago? Also concerning are the lack of commitments for employment opportunities when training is completed.

**Reviewer 2:** What specific obstacles do formerly incarcerated people face, particularly where a large percentage of labor in the region is focused on residential installations?

**Reviewer 3:** Please consult more employers about their needs, barriers to hire individuals with criminal backgrounds, and other valuable information.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** If employer commitment challenge can be solved, Safer has the key stakeholders covered.

**Reviewer 2:** Labor unions and the public workforce system.

**Reviewer 3:** Potential employers, life skills coaches.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Evidence of employer commitments in the grant application process is critical. The Safer project shows the value of a holistic, community-based approach to supporting trainees, particularly those with significant barriers. I appreciate their aspirations to provide participants with a broad array of solar-related career options.

**Reviewer 2:** 1) Program has not identified specific interventions to address the perception of increased risk of hiring a formerly incarcerated worker. 2) Success metrics are difficult to measure because there are not clear indicators of what each program provides to trainees (e.g. bootcamp v. screening, etc.). 3) Massively high risk but also even higher reward and government works best in filling those gaps. With some tweaks (perhaps), this could be a major success.

**Reviewer 3:** 1) Expand training to include other career paths in solar. 2) Please feel free to reach out to me, if you need an industry employer perspective or connections to employers in IL. 3) Continue the focus on trainees with criminal backgrounds with an emphasis on diversity.

## CyberGuardians and STEM Warriors – $1,250,000

*SunSpec Alliance | San Jose, CA | Principal Investigator: Tom Tansy*

Veterans with information technology skills and the ability to use advanced digital tools can lead efforts to modernize the electricity grid and improve the integration of distributed energy resources. This project supports veterans with cybersecurity and information technology training to further develop these skills through new online training modules, accredited curricula, and hybrid training programs in distributed energy resource system designs, grid operations, data analytics, cyber security, and investment decision support. The program recruits veterans and transitioning military personnel from military bases and through existing veterans programs and facilitate job placement with utilities, grid operators, and other companies in the distributed energy resource industry. This helps to increase the pool of veterans to help fill positions critical to the security of the U.S. electrical grid.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 | 5 |
| Set critical challenges to overcome | 5 | 6 | 4 |
| Implement a high-risk, high-impact approach | 5 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 2 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: This project focuses on advanced skills instead of the entry level focus popular in other veteran's programs and those for other targeted populations. There are opportunities for both veterans and transitioning military. There is an intentional career focus which includes introducing participants to hiring managers. NABCEP is a partner to align curriculum to industry skill demands. There are also internships and direct placements. Weaknesses: If these skills are in demand and the program expects to enroll 620 students, why is the program only projecting 51 hires? Regarding COVID-19, the programming is already remote but the crisis could disrupt to job interview process if participants are not prepared for virtual interviews.

**Reviewer 2:** The program has several key strengths, including: Focuses on key roles in the industry. Multi-partner focused on diverse set of learners; Focus on important population (Veterans); Skill development has broad application beyond solar. There are two specific weaknesses with the program. First, it is hard to see from the application how the development of academic and professional curriculum meets the needs of employers for "boots on the ground" training. More should be shown about the hands-on elements of the training. As of now, the proposal reads very academic, which seems in contrast to what employers suggested they need. Second, the success metrics are not very ambitious. 51 jobs for $1.25 m is quite expensive per job. The grantee should provide more information about ongoing benefits from investments in the three years of funding, for which I presume would be large, but it is not stated. Assume this would have been more readily apparent if we had the in-person convening as originally planned.

**Reviewer 3:** Strengths: Focuses on veterans, which is great; Program is not just focused on installation but DER as a whole; Great partners. Weaknesses/Areas of Opportunity: I would recommend also focusing on diverse veterans as part of the recruitment process (women and underrepresented minorities); I would also recommend to have more employer input from potential employers including electric utility companies.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 | 4 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 6 | 3 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project is still in the early phase. The measures are clear and milestones seem reasonable. The partner communication mechanism is not readily apparent. In order to broaden career options for participants the list of stakeholders should expand to include workforce development boards and union apprenticeship and training programs. It is not clear why 620 enrollees will ultimately yield only 51 hires.

**Reviewer 2:** The program seems to be progressing well, with new curriculum coming online. More quantitative data will be available in year 2. The metrics for success are questionable because they do not account for whether students pay for the education and that those costs should be added to the ROI analysis.

**Reviewer 3:** I think the performance of this project is good and theirs is good collaboration with the partners including UCSD and NABCEP.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: All of the pieces are in place - curriculum, employer partnerships and student outreach – to build a successful project.

**Reviewer 2:** Score: 5. Comments: Program seems very important in that it meets a higher wage, higher impact need in the industry. The partners are well equipped to develop and deliver the training and the skills are highly transferable.

**Reviewer 3:** Score: 4. Comments: Agree that each task is unique and adding value to the project.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I am concerned about the gap between number of enrollees and participants hired, as cited above.

**Reviewer 2:** What are the existing resources and capabilities that could be leveraged to lower cost or maximize impact?

**Reviewer 3:** I would just engage as many employers as possible. The California investor owned utility companies have great training and career opportunities and they should be at the table.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Additional stakeholders should include unions – especially IBEW and the workforce development system – to broaden participant career options.

**Reviewer 2:** None. The project team seems quite comprehensive and impressive.

**Reviewer 3:** Utility companies, Recruiting firms for job placement, Organizations that can recruit diverse vets into the program.

**6. What are the three most important pieces of feedback for this project you would SETO to consider?**

**Reviewer 1:** The project's focus on higher skill careers is significant. Because of its appreciation of the value of military transferrable skills, the project views veterans more as a source of untapped talent as opposed to objects of pity and charity. SETO should work with the PI to address opportunities to boost the hiring forecasts, particularly given the anticipated market demand.

**Reviewer 2:** 1) Cost per success - are the outcomes worth 1.25 million? 2) Longevity - can the program/curriculum be made freely available to other institutions to maximize impact? 3) What populations beyond veterans could benefit from this type of program? Could it help with other disadvantaged populations?

**Reviewer 3:** 1) Continue to focus on diverse career paths in the clean energy space to ensure that the project participants have a diverse skill set. 2) Focus on diversity and inclusion. 3) Get the California utilities like San Diego Gas & Electric involved.

## National Solar Jobs Accelerator – $2,000,000

*The Solar Foundation | Washington, DC | Principal Investigator: Richard Lawrence*

Building off of the Solar Ready Vets pilot program, the National Solar Jobs Accelerator program works to increase the pipeline of transitioning service members and veterans into the U.S. solar industry via two complementary efforts. The team offers a work-based learning "fellowship" model for transitioning service members and a matchmaking system that will channel veterans into appropriate training or employment opportunities. The Accelerator also undertakes high-impact capacity-building activities that enhance and streamline veterans' options for pursuing solar training and employment opportunities and incent employers' participation over the long-term.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 6 | 5 |
| Match well with the level of DOE funding and planned project duration | 6 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is mission essential, both because it provides avenues for employment for veterans and it utilizes talented, committed persons to fulfill solar workforce gaps. By fulfilling workforce gaps, it advances the solar industry and the only reason I didn't provide full points on this aspect is because of the lack of equity analysis and attention to attention within the veteran population. There is more that can be done to optimize engagement with this population by centering equity. It has ambition goals for the project duration and the budget is commiserate with the aims, mechanics, and intended outcomes. Given the challenges articulated, I would say it is high risk yet the proposed remedies seem workable so if the challenges are overcome, the research findings and the advancements of vets in the solar workforce will have high impacts directly for the individuals and companies involved, and to the field of workforce development more broadly.

**Reviewer 2:** Strengths: The project programs address both for veterans and on the job training opportunities for transitioning services members. It is building grant infrastructure to include ability to leverage GI bill benefits for NABCEP PV training. The project is pursuing apprenticeship – the gold standard for bridging education and employment. The project is also developing six vet/service member-friendly solar certifications by 2021, thus supporting sustainability goals. Project is leveraging transferrable skills from military service and has capacity for participants to upskill and grow with the industry. Weaknesses: Without additional details about the six solar certifications, it's difficult to assess the project's ability to connect participants with a diverse array of solar careers with opportunity to upskill as the industry evolves. In addition, diversity and access goal were not spelled out.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 4 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is exceedingly well-crafted. It has established an appropriately paced timeline, a prudent use of resources, and clear, measurable, substantive intended outcomes with fitting metrics/indicators. The only areas that could merit attention would be having primary partners that include equity focused organizations as actively engaged stakeholders and implementers as well as evaluators.

**Reviewer 2:** The project is off to a good start, but it's still early. The project is covering its foundational bases including engaging in apprenticeship discussion with DOL, exploring opportunities for GI Bill benefits and building a website.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: The project design has left few stones unturned! It is thorough in that it focuses on readiness, training, partnerships, certification and job placement, the entire continuum of the workforce development cycle!

**Reviewer 2:** Score: 5. Comments: As addressed in question 2.5, the project has identified to appropriate elements to deliver its outcomes.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I scored this project very highly as I view it as sound, thorough, and engaging a critical constituency. By increasing its equity focused to include marginalized sub populations within the veterans' constituency, this project has high potential to reach sheer perfection. For example, studies show that African American vets fare worse than other vets in multiple areas from homelessness to unemployment to health outcomes. What is this project doing to identify and provide specialized pathways for marginalized veterans?

**Reviewer 2:** Diversity goals and career advancement goals were not explicit in the report.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Ideally, this project would explicitly engage equity focused groups as primary partners, including groups engaged with vets experiencing homelessness or groups working with African Americans, or groups like the Emerald Cities Collaborative that do equity centered workforce development work.

**Reviewer 2:** Future success and opportunities for additional career advancement within both the solar industry and the broader greenhouse gas reduction ecosystem will be dependent upon expanding beyond the boundaries of the military/vets institutions to include colleges, workforce boards and unions. It appears as if the project is on the road to putting the important partners in place.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Excellent progress that would benefit from: 1) Attention to DEI in hiring for this large project; 2) Integrating equity focused indicators and metrics; and 3) Engaging equity focused partners and stakeholders.

**Reviewer 2:** The apprenticeship focus is important. In the future, how might SETO leverage this grant experience to promote apprenticeship and other earn and learn opportunities. The training for transitioning service members is significant and promotes career visibility, transparency and career navigation, addressing the needs of workers and industry. Despite increasing emphasis, veterans remain an untapped source of talent with significant leadership and transferrable technical skills.

# Strategy & Planning

# List of Reviewers

**Sharon Allen**, Smart Electric Power Alliance

**Sander Cohan**, Enel Green Power North America

**Kathleen Hogan**, Former U.S. Department of Energy

**Danny Kennedy**, New Energy Nexus

**Joe Stekli**, Electric Power Research Institute

# Analysis Methodology

Reviewers had evaluation criteria for each project and scored them on a 1–6 scale:

**1** – Strongly Disagree

**2** – Disagree

**3** – Slightly Disagree

**4** – Slightly Agree

**5** – Agree

**6** – Strongly Agree

In addition to numeric scores, reviewers were asked to provide qualitative comments and feedback to justify the scores awarded to projects. Other criteria only required qualitative feedback.

# Project Evaluation Form

**1. The project's goals, approach, and expected impact:**

a. Align well with this topic's goals and support SETO's mission (1-6)

b. Set critical challenges to overcome (1-6)

c. Implement a high-risk, high-impact approach (1-6)

d. Match well with the level of DOE funding and planned project duration (1-6)

e. Add significant value to existing research outside DOE-funded efforts (1-6)

f. Advance the US solar industry substantially (1-6)

*Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.*

**2. Based on performance to date, the project team:**

a. Meets important milestones within reasonable timeframes and budgets (1-6)

b. Measures impact appropriately (e.g. quantitative) (1-6)

c. Disseminates results frequently and actively engages partners (1-6)

d. Collaborates with sufficient stakeholders (1-6)

*Using the above criteria, please summarize the performance of this project in 100-200 words.*

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

*Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.*

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

# Project Reviews

Independent review is an important part of SETO's overall portfolio management process, as it provides alternative viewpoints from leaders in industry and academia on current project activities and strategies. Reviewers who participated in the virtual peer review evaluated projects by assessing project reports and posters written by each project's principal investigator. Any questions about the project were addressed via email exchange between the principal investigator and the reviewer. Each project was assigned two or three reviewers.

Below, you will find a list of the projects reviewed organized by track and topic. Projects are alphabetized by the awardee name and represented in the following format:

**Project Title – Funding Program, Amount Awarded**

*Awardee Name | Awardee Location | Principal Investigator*

Project Description

Project evaluations completed by reviewers are found after the descriptions.

# Visioning, Strategic Positioning, and Evaluation

## Aligning Utility and Solar Interests: Utility Regulation and Planning for a SunShot Future – $1,450,000

*Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Galen Barbose*

This project assesses emerging and innovative options for aligning high solar deployment with utility shareholder and ratepayer interests. The team is evaluating the potential for bankable demand charge savings and identifying best practices for incorporating solar into resource planning studies. Through this combination of targeted analyses and stakeholder engagement, the project empowers key decision-makers to alleviate market barriers in order to increase deployment and lower business risks and market inefficiencies that inflate soft costs.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 3 | 6 |
| Set critical challenges to overcome | 6 | 4 | 4 |
| Implement a high-risk, high-impact approach | 6 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 3 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 6 |
| Advance the U.S. solar industry substantially | 6 | 3 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a very broad, very high impact suite of studies to look at the intersection of markets and technology for solar energy. As with many other studies in this cohort, the advantage of this study is the scope and depth -- it looks across the industry, to a wide range of stakeholders and performs the fundamental market research and modeling required to understand the value of solar energy. Similarly it is the kind of study that the private sector, due to its need to focus on projects and immediate returns, is unlikely to undertake. Ironically, the development of these studies and the KPIs associated with them, provide the required baselines for these market developments to grow. The strength, then, of this study is the breadth and depth of the individual tasks, and the approach that leverages the impartiality of the national laboratory system and the Department of Energy. The disadvantage of this study is the size relative to the funding. It appears look to capture and model an entire market in all of its complexity, on top of a relatively small budget. The fact that this is the third three-year renewal of this project is an indicator of how difficult the individual tasks are to characterize. Entire consulting firms have been created to address a sub-section of the topics addressed under this project.

**Reviewer 2:** It seems to be posited in this work that the utility system we have is the one we will have and we're fitting PV into it. I think that presumption is wrong or at least not likely to be the case. SETO's role is to advance solar not utility companies as we know them. While some of the information garnered with this project may be of use to the solar industry the focus and resourcing may be misallocated.

Reviewer 3: This project delivers valuable information to the industry that is challenged be done by one company because of the cost and thus the government funding helps to produce the works. One challenge is that the industry is still evolving so the reviews of the 2014 IRPs would really need to be redone as the 2016 report at this stage is old. Information becomes stagnant as a result of change.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 3 | 4 |
| Collaborates with sufficient stakeholders | 6 | 4 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project team is well versed in approaching the challenges of the tasks outlined. What is great to see in the project is the approach to quantitative rigor -- that the complexity of the topics is well understood, and the effort has been made to incorporate as many experts in the field as possible. The tasks have a lot of moving parts to them, however, and continuous research is probably needed to ensure that the individual variables have been incorporated and understood appropriately. The scope of the project is large, and it is encouraging to note that they are very nearly done with the entire proposed scope of this phase of the project. It appears that the results are being well distributed, disseminated and discussed. The number of downloads and discussions inspired by the task deliverables are indicators that the results are being well accepted and consumed by the project stakeholders. As a consequence, the project is doing an excellent job furthering the mission of the DOE SETO office and providing opportunities for developers and policymakers to address challenges posed by the expansion of solar markets.

**Reviewer 2:** I worry that due to the setup of the exercise the stakeholders consulted were utilities not solar innovators. This technology is going to disrupt the whole market - solar and storage has only just started to be felt. This seems to come at that reality from the incumbent not the insurgent POV, which I think means we may miss some learning.

**Reviewer 3:** The project team mentions that they deliver the information in various formats and deliver it in various channels. Impact is not just about delivering of information but reaching the audiences such that they use the information. A measure of impact might be the number of regulatory proceedings or dockets with the information cited or the number of utilities leveraging the information.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: Yes. As noted before, the rigor that the project team uses to approach each individual problem posed by each task is impressive and important. The primary challenge in this project is presenting a model that not only makes sense, but that also addresses market complexity to a degree that assuages the comments from critics that the market is too complex to understand and characterize.

**Reviewer 2:** Score: 3. Comments: I am not convinced it is unique (I am sure the utility industry is thinking through this in its defensive posture as it reels with change) nor is it important to protect companies from disruptive change so much as the communities they serve, people they employ, etc.

**Reviewer 3:** Score: 6. Comments: The value is the research, analysis, and dissemination of information.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I think there needs to be a strong editor in the team, to resist the urge to try to characterize everything and everyone in a single project funding period. To that end, the project team indicates that they are attempting to do that.

**Reviewer 2:** Incumbents. I know we like to think we are "on the side of solar" but by examining the problems PV presents to old guard utilities from their PoV I think we miss the PoV of the innovators too often.

**Reviewer 3:** PI appears to have a broad advisory group consisting of utilities, ISOs/RTOs, public agencies, solar industry organizations, and a wide variety of topical experts that should help with avoiding blind spots.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** This project requires critical input from almost all market actors, from consumers and owners of solar technology, to the developers approaching the marketplace with specific products and services, to the regulators and policymakers trying to both ensure that solar markets are fair while also creating new opportunities to pull these technologies into the market.

**Reviewer 2:** Solar advocates and visionaries driving massive adoption at many times the scale currently achieved. Companies and institutions pushing the boundaries of what we think is reasonable.

**Reviewer 3:** The team appears to be interacting with a wide set of stakeholders. The only thought I can present is listing the stakeholders would lend one to believe that all of them are engaged in the projects (aka papers)... if that is indeed the cast then great. If the PI finds that the same set of folks are the ones always on the call, the PI might want to make sure the group's diversification is not compromised.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Ensure that the topic areas are connected thematically and build upon each other, not trying to capture the whole world on the head of a pin. 2) Ensure that there are appropriate stakeholders -- include utility stakeholders and regulators, but also technology and project developers, who might have a different approach than the utility capacity owners. Work to incorporate industry consortia. 3) Budget is a concern -- this is a massive scope of work on a relatively small budget. Entire consulting firms have been created in the private sector to address the problems from just this funding period.

**Reviewer 2:** For every job we do for utilities make sure we are doing one for a new model electricity company; the solar industry offers a different business to the big boys' current version of electricity company - we must be open to it. Ensure the limited funding is truly additive.

**Reviewer 3:** 1) Consider redoing the IRP analysis and integration with distribution in light of the integrated distribution planning occurring. 2) Nice work team.

## Solar Market Data Tracking and Analysis – $4,000,000

*Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Ryan Wiser*

This project expands the availability of high-quality data and information on solar energy through extensive data collection, curation of shared databases, and timely analysis. The team is tracking and analyzing solar technology, cost, performance, access, and market trends through foundational annual reports, publicly available data sets, and objective new analyses. Covering utility-scale and distributed solar, this work supports the Department of Energy and the energy industry more broadly by harnessing big data to track progress toward DOE goals. It also facilitates market transparency, affordability, and consumer choice and protection by reducing information barriers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 4 | 5 | 6 |
| Implement a high-risk, high-impact approach | 4 | 6 | 6 |
| Match well with the level of DOE funding and planned project duration | 3 | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 6 | 6 |
| Advance the U.S. solar industry substantially | 4 | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** LBNL's tracking of solar data has provided considerable value in the past. It is worth asking, however, when responsibility for some of the datasets moves to either other government agencies (e.g., EIA) or is being adequately handled by private entities (e.g., GTM, BNEF, EnergySage). Each of these groups mentioned already produce datasets that have partial or complete overlap (or, in some cases, LBNL itself pulls from) with the LBNL work - which doesn't devalue past or even current efforts, necessarily, but does raise questions that should be answered about future activities.

**Reviewer 2:** This is a great project, specifically because it enables so much other work. Nothing can happen, really without a strong, credible data source to underpin projects. Having this as a resource provides a way to understand and evaluate the progression of the industry towards long term production, technology, and cost goals outlined in the SETO mission. There are other data sets out there, for sure, but having a third-party source of information that is readily available as a benchmark is very important.

**Reviewer 3:** Great Job team. Very impactful information and the data and reports has been used well. Keep doing what you are doing. My only suggestion might be that while your track your audiences do you dissect them to determine what else you should do to reach any underserved audiences?

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 6 | 6 |
| Measures impact appropriately (e.g. quantitative) | 3 | 6 | 6 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 6 |
| Collaborates with sufficient stakeholders | 6 | 6 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project appears to engage with sufficient stakeholders/collaborators. Simply measuring publications and/or news mentions seems inadequate at this point in time - other datasets (BNEF, GTM) would dwarf these numbers if that was truly the measuring stick. There should be some attempt to measure unique value over other, similar datasets to justify the ongoing (and substantial) gov't investment in the effort.

**Reviewer 2:** Its impressive that the project is very nearly complete, relatively on time and substantially under budget. As evidenced by the groundswell of support, the availability of the data was certainly needed and is already having impact. A goal for the future would be to expand and disseminate the data and results further.

**Reviewer 3:** While your major data reports are on a timeline you have executed you mention that hold up of two reports that are awaiting DOE approval. Is it possible in the future to schedule those reviews or reserve time from DOE in advance to ensure things are not delayed?

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Document does not contain specific task list - in general, each primary "project" listed appears to be unique and valuable, at least within the context of the award itself.

**Reviewer 2:** Score: 6. Comments: For sure, the progression of the tasks follows a logical scope of building up data sets from a wide variety of public, private, and academic resources. This data is then logically compiled into a database. Taking the further step of publications is important, highlighting the availability of the data and indicating to the market logical ways to understand and consume the data and findings from the data.

**Reviewer 3:** Score: 6. Comments: The important value is the collection of the data and dissemination for wide use. The tasks aren't unique but the value is having an independent entity do the collection and analysis.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Reiterated from above, but there should be some consideration of the unique offering the data collected here is offering moving forward and, if certain datasets are no longer providing significant unique value, a plan to either pivot to an existing gap and/or a plan to ensure past data is captured/accessible while handing over responsibility for ongoing data collection and update to another entity.

**Reviewer 2:** I think it's important to consider what might happen to this data project beyond the end of the funding period -- how does the PI and his team see the future role of this database, how will it be funded and supported going forward?

**Reviewer 3:** The "External Validation and Outreach: Execute suite of activities to ensure that work products reach the largest possible audience, execute 'user survey' to identify opportunities for improvement, engage Advisory Committee to support efforts on solar-access and demographics," is an important activity and making sure your Advisory Committee encompasses a strong cross section of the industry is important. Also I would review who your requests are from... if all California, then think about what other states, utilities, etc. could leverage your data and have specific plans for how to grow impact of your targets. I saw no utilities on your advisory group nor did I see any of the two largest national solar organizations.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Broad industry engagement appears to be a strength of this effort.

**Reviewer 2:** A database of this sort requires active participation from a wide variety of stakeholders, starting with industry and progressing through government (state and federal) and academia. Active and enthusiastic participation from all of these stakeholders will be required to ensure that the datasets here remain relevant.

**Reviewer 3:** First and foremost I didn't see any utilities listed as a stakeholder for collaboration.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) This effort has been valuable in the past - the question is it offering unique value moving forward in the future. 2) Number of publications and/or press mentions aren't the right measures of success - if that's simply it, GTM/BNEF dwarf this project for similar/same data.

**Reviewer 2:** 1) Data is supremely important to all efforts in Solar research, development and deployment efforts. 2) Keeping this as a third-party resource from a national lab or government agency is important to maintain the credibility of the data, and ensure that it is available and usable. To this end, considering that there are many private sources of data, this does not need to be a completely definitive dataset, but it needs to have enough data to serve as a contrast to private party datasets and give researchers a baseline for comparison. 3) Consider mechanisms to fund this program on a regular basis so that it can serve as a baseline for other analytics efforts.

**Reviewer 3:** 1) Setting a plan to get even higher impact... how you do you get S&P, Platts, BNEF to use your datasets as example. 2) Consider how to give others access to the data and how to run analysis themselves for their specific purposes.

## Solar-to-Grid (S2G): Analytic Support to Inform Reliability, Market Value, and Affordability – $825,000

*Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Andrew Mills*

Along with the cost of a photovoltaic solar system, the competitiveness of solar energy depends on its market value and how solar interacts with other technologies in electricity markets. This project aims to better understand the location-specific market value of solar, the contribution of solar to grid reliability, and the impact of solar on the power system. The project team combines historical production and performance data from solar energy systems across the United States with electricity market data to identify trends in the historical value of solar and its contribution to grid reliability. To assess the impact of solar on the power system, the team relies on market data to observe trends in wholesale prices and the resulting incentives to invest in flexible resources, like combined-cycle gas turbines and storage. The geographically specific results will be communicated through three annual reports, each building on and updating data from the previous year, to help inform stakeholders on planning, procurement, market design, and grid operations.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 4 | 5 | 5 |
| Set critical challenges to overcome | 5 | 3 | 4 |
| Implement a high-risk, high-impact approach | 6 | 3 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 4 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 4 |
| Advance the U.S. solar industry substantially | 4 | 3 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** The strength of this project is twofold. The first is that it attempts to put numbers and methodology to a phenomenon that to this date is understood anecdotally -- the value of solar in a marketplace depending on temporal conditions -- and contrast it with a phenomenon that we understand pretty well, the cost of solar energy. I agree that this is useful for two reasons, the first to evaluate whether the current market rules in any given location adequately create the appropriate incentive for solar technology, the second to understand whether or not the cost structure of solar is well matched to market conditions, and provide insight into how to focus efforts on managing solar cost components. The second strength is the scale of the project, working with the various reliability bodies to understand the regional variations of the market value of solar energy across the different RTOs and ISOs. A weakness of the project is well described in the document, related to the uncertainty and lack of data granularity to back-cast the solar data and match production to market conditions. Furthermore, it is not clear to me the end goal of such a study. While it is interesting to see the market value of solar relative to its cost, I would need more information to understand how such data is actionable, and for whom it is actionable. I would look to future task reports to maybe make this connection more explicit.

**Reviewer 2:** This is interesting work but I am not convinced it is timely to the market evolution because of the age of the datasets being used. A series of annual reports may not be enough to inform big investments like gas-fired power in a system. Stranded assets are occurring because backdated datasets inform decision-making. I know this claims a trend analysis but it does not seem sufficient.

**Reviewer 3:** One goal is to measure the contribution of solar to grid reliability; In reading further the measurement was "capacity credit". This seems a bit misleading and perhaps your objective should be revised to say looking at contributions to resource adequacy. I recognize that Grid reliability has several definitions. The North American Electric Reliability Corporation defined reliability as "the degree to which the performances of the elements of the electric system result in power being delivered to consumers within accepted standards and in the amount desired" (Hirst and Kirby 2000, p 7). Osborn and Kawann (2001) viewed reliability as "the ability of the power system components to deliver electricity to all points of consumption, in the quantity and with the quality demanded by the customer" (p 2). Reliability is measured by outage indices as illustrated by the Institute of Electrical and Electronics Engineers' Standard 1366. The National Academies of Sciences, Engineering, and Medicine (2017) published "Enhancing the Resilience of the Nation's Electricity System" in response to Congress's call for an independent assessment to "conduct a national-level comprehensive study on the future resilience and reliability of the nation's electric power transmission and distribution system." Throughout this report, the committee highlighted all elements of grid reliability. Saying one object is to see how Solar contributes to reliability and then using such a narrow element can be misleading.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 3 |
| Disseminates results frequently and actively engages partners | 6 | 4 | 4 |
| Collaborates with sufficient stakeholders | 6 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The first phase of this project has yielded interesting results showing the regional differences in solar market value based on time and weather condition. The first phase of the project was completed in a reasonable amount of time, accounting for delays that enhanced the value of the project rather than creating detriment. In general the quantitative approach is sound, and uses existing datasets in ways that have not been explored quite yet. The scope of stakeholders is appropriate, leveraging the quantitative expertise of the national laboratories and the on-the-ground data expertise of the reliability organizations and system operators.

**Reviewer 2:** Two private sector advisers does not seem sufficient to the task given the scale and range of players in the industry. In particular, I'd look at how the insurance and finance industry assess these trends. The actuarial calculations on the conclusions being made for investment decisions in non-energy sector institutions may be helpful to augment this.

**Reviewer 3:** In terms of this project having impact, the teams states "Outreach hinges on a strong advisory group with a diverse set of experts and thought-leaders to provide ongoing guidance, with the objective of ensuring that the work is responsive to industry and market needs, accessible to practitioners, and complementary to other ongoing activities." Without any metrics or indication of that happens it is hard to say whether this project is reaching the right audiences and having impact.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 6. Comments: I agree. The challenge of this project was to align several heterogeneous datasets together. Once aligned the project's first phase yielded some compelling insights into the mismatch between market mechanisms and the value of solar in the marketplace.

**Reviewer 2:** Score: 3. Comments: This work is important but is being done by others in the market and may be being done better. Again I'd get some insurance and others in finance to look at it before drawing too many conclusions. I think we need higher resolution (quarterly not annual) fresher data.

**Reviewer 3:** Score: 4. Comments: The project team states "Fifth, as part of the expansion of geographic scope in year 2, we developed a process for estimating solar value metrics outside of organized wholesale market regions and solicited comments from multiple utilities." Depending on those estimates the resulting outputs could be poor or good... there are a number of 'value of solar' reports floating around the industry and not sure how well utilized they are today.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The focus, thus far (and rightly) has been on the market managers (ISOs and RTOs). It would be interesting to contrast this with the experience of developers who are building projects on a combination of fixed PPA and merchant contracts. The assumption is that solar is working on a 100% merchant basis, but often solar projects are sold in as a combination of fixed and merchant contracts.

**Reviewer 2:** Data from small independents in the market. Coops. Others might be useful as well as the insights from finance / insurance mentioned above to really calibrate the analysis and look at the trends.

**Reviewer 3:** View of Reliability... especially if you start talking outside wholesale market.

### 5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?

**Reviewer 1:** See above, I think it would be important to look at the role of developers, and specifically trends in fixed and merchant price contracts for solar.

**Reviewer 2:** More private sector players especially from finance and insurance to inform this information generation. Academia has missed the reality of the solar market's rise for too long and it would be a shame if the SETO were caught in the same dynamic.

**Reviewer 3:** I saw no utilities on the current advisory council.

### 6. What are the three most important pieces of feedback for this project you would like SETO to consider?

**Reviewer 1:** 1) The scope of the study is impressive -- comparing and contrasting regions yields interesting insights into how solar is valued. 2) Taking an "inverse" look at solar -- focusing on market value rather than cost structure -- can provide good insight into how solar technology can develop or how policymakers can better craft incentives. 3) I am concerned that the market is more complex than this already complex study -- while the framework in place will yield some general insights, I'm not sure the holistic approach captures some of the nuance present in each regional market and solar project.

**Reviewer 2:** Keep more current and refer to more stakeholders, especially those doing the work in the field. Work out how to get information to market in the same year it is generated - this market moves so fast older information can distort decision-making. If you cannot do that be aware of the trends and build that in to models and analysis derived from them.

**Reviewer 3:** Whether this project is truly correlating solar's contribution to reliability.

## Concentrating Solar-Thermal Power Analysis – $2,249,627

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Chad Augustine*

This project addresses upgrades to the System Advisor Model (SAM) related to concentrating solar-thermal power, including the development of new modules within SAM to expand the types of CSP systems that can be simulated and new tools for evaluating CSP subsystem performance or optimizing CSP system layouts; for example, SolarPILOT and SolTrace. The project evaluates the potential cost and performance of new CSP-relevant technologies and generally includes assessment of CSP technologies.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 6 | 6 | 6 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 3 | 4 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** In general, appears aligned with the CSP program goal. There is an open question as to how-well this supports the US solar community anymore - there are no longer any major US CSP technology providers nor any plans for CSP deployment for electricity applications in the US.

**Reviewer 2:** This is an important research task towards making sure that CSP research, development and deployment efforts continue. Including CSP in commonly used project development tools will allow SETO to drive market development and movement towards solar LCOE targets. The advantages of this project is that it ensures that the NREL tools -- central to project development of solar technologies, poses up to date cost and technology metrics to remain in-line with the state of the industry. The disadvantage of this study is that it covers a technology scope (CSP components) that is substantially smaller and more heterogeneous than the photovoltaic industry. As a result, the data sources are smaller and harder to find in the open market, and thus more difficult to validate and develop a series of data that the project team will be able to generalize into a series of model inputs.

**Reviewer 3:** Cost tracking and modeling to depict impacts to cost provides focus where the greatest impacts for cost reduction can be made and is useful to the industry. One task mentions being on the SolarPaces international group but there is no description on how information is captured or shared. Does the information go to DOE only or the broader industry?

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 5 |
| Measures impact appropriately (e.g. quantitative) | 1 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 5 | 4 |
| Collaborates with sufficient stakeholders | 6 | 3 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Collaboration appears sufficient, if difficult given the state of the CSP industry. No real measure of impact is offered - milestones are given, but their ultimate impact isn't discussed in the write-up.

**Reviewer 2:** The nature of this project is quantitative -- updating the inputs for the NREL solar modeling tools. In general the methodology to do so appears to be sound in terms of surveying, evaluating, and modeling the data sources. The problems appear to drive from the heterogeneous nature of the CSP market -- it is small and in relatively early stages, so data about certain components was harder to get than initially expected.

**Reviewer 3:** The project writeup appears like the information is all directed to the DOE SETO office and not industry. The team states "The intended outcome of the project is objective and accurate analysis that informs SETO and helps them identify impactful research areas and promising new technologies." If the reason for this project is just to provide information to DOE then I would assume the frequency of meetings is deemed acceptable to DOE. If this project is to have broader industry impact then it wasn't clear what broader stakeholders are targeted and how they are enabled with the models and tools.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Individual tasks are not listed, but each high-level activity appears unique and valuable.

**Reviewer 2:** Score: 6. Comments: The tasks of this project are relatively self-explanatory -- each one contains a component that is required to update the CSP metrics.

**Reviewer 3:** Score: 4. Comments: Experience curves and cost models are useful to focus areas of opportunities.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Some consideration of the "end game" for this effort should be given - model improvements can be done infinitely. However, if the US CSP community continues to dwindle is it still valuable to improve models/update prices when no plants are being built (and how accurate can those prices really be). On the other hand, may be more valuable to pivot to other applications (e.g., process heat) where the overall market is nascent and CSP may have unique advantages over other approaches.

**Reviewer 2:** I think it is important to understand and acknowledge how heterogeneous the CSP industry is. It is just simply smaller than the photovoltaic industry, and fewer components are produced at scale and according to best practices. A plant is likely to have both components that are common and "off the shelf" and components that will have to be built to specification. While data about the former is easily obtainable, the latter is hard to find.

**Reviewer 3:** Getting the models and tools into the hands of industry for them to use would seem to deliver impact. The team refers to "CSP stakeholders use the tools and analysis, such as SAM, annual updates to the Annual Technology Baseline (ATB) and default CSP system costs, to assess the status of CSP technology and to evaluate project feasibility. NREL provides software tools free of charge via NREL's website." Measuring how many people utilize the tools and models would help to quantify impact.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Collaboration appears appropriate.

**Reviewer 2:** It's hard to say. I think greater collaboration from private industry and component manufacturers, but as evidenced from the narrative, this is a relatively small pool and it is hard to get information from them. I'm sure surveying developers and operators of CSP projects would yield an additional source of data and feedback on the design of the modeling tools.

**Reviewer 3:** The team states that the tools are used by govt, researchers and industry analysts but isn't very specific. Are researchers academia or are there corporate researchers using the tools? If there is no corporate researchers using the information than that could be a blind spot.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Measurement of impact appears to be lacking. 2) If US CSP industry continues to be dormant (in terms of electricity application), is it more valuable to pivot this effort to other applications?

**Reviewer 2:** 1) CSP modeling is an important component of the tools available to developers, this project is doing important work in ensuring that these parts of the tools remain important and relevant. 2) CSP is a much smaller industry than PV, and as a result, more consideration to the inputs must be given to how these inputs will change over time as the industry scales. 3) This project appears to have had trouble getting off the ground in year one, but is now on track approaching the second year of study.

**Reviewer 3:** 1) Who is the targeted audience for this piece of work? 2) How is that audience being reached? 3) How is impact being measured?

## Distribution Grid Integration Costs – $2,790,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kelsey Horowitz*

This project, which is a subtask of Solar Technology Cost Modeling and Competitiveness Analysis, provides bottom-up analysis on the distribution system costs associated with integrating distributed photovoltaic technologies while maintaining reliability and power quality. These costs are analyzed as a function of penetration level, and for a variety of circuit types, locations, and integration strategies. This work informs the range and order-of-magnitude that may be expected for distribution grid integration costs at different photovoltaic penetration levels, as well as the primary drivers of integration costs and pathways to reduced integration costs.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 | 6 |
| Implement a high-risk, high-impact approach | 6 | 4 | 6 |
| Match well with the level of DOE funding and planned project duration | 6 | 3 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 4 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Important project focused on the distribution system part of the electricity grid and working to show new lower cost approaches for system upgrades that incorporate distributed solar energy. Using as realistic distribution system data as possible to obtain. Seeking to de-risk these approaches for decision-makers.

**Reviewer 2:** Dynamic hosting capacity methodology is an important opportunity to increase solar penetration while minimizing overall system cost. This project focuses on the distribution system which, while important, is less impactful (in terms of solar MW deployed) than developing a robust dynamic hosting methodology for the transmission system (though perhaps learning from this can be utilized for the transmission system as well). The budget and project time period do seem to be a bit large relative to the proposed outcomes (essentially some data sets and some software built off existing data sets and software).

**Reviewer 3:** Advisory group and objectives look good.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 6 | 5 |
| Collaborates with sufficient stakeholders | 5 | 6 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project includes good collaboration and information sharing; it is meeting or is close to meeting its key milestones after addressing data availability issues.

**Reviewer 2:** The project appears to publish regularly and collaborate with a wide range of stakeholders. Milestones also generally appears to be met on time and budget, with the caveat about size of budget previously noted. There are some good milestones, but there does appear to be quantification lacking. This is especially true related to impact - is the approach seeking to get x% more solar onto a distribution line without additional upgrade/curtailment or reduce upgrade cost by y%? These types of targets would be more meaningful and more clearly define the value of the project as opposed to number of papers published.

**Reviewer 3:** Since this is a techno economic evaluation, I didn't see anything on the poster that shows the economic part or mention of how costs are being obtained or what is in those costs. System costs of integration is what is often contentious as to what it takes to interconnect new DPV. Perhaps this is a later phase but there wasn't anything addressed in here as to what partnerships were needed to get those costs, what the costs would entail... ADMS, integration, DSCADA upgrades, etc. Recognize having an accurate model is key but getting what is in from a cost standpoint is also key and what the costs are can be a challenge since most utilities don't do activity based costing so getting the activity cost not the full burden of the initial software install is important and I am not sure I saw that addressed.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task is necessary to achieve the overall project objectives -- the different tasks being around software techno-economic capabilities and analyses of different feeders and breadth of feeders.

**Reviewer 2:** Score: 4. Comments: A specific list of each task is not provided so simply gave an average score.

**Reviewer 3:** Score: 5. Comments: The framework needs to identify the cost components in order for one to know they are comparing apples to apples when doing the techno cost analysis. The writeup states "We have published a Distribution Unit Cost Database that includes total installed costs per unit for traditional upgrades as well as some emerging solutions." Does that include a portion of any system aka dscada, derms or GIS upgrades or is this just hardware? Does it include communication costs to monitor and sensor to know the state of volt/var ...pf? The team did address their challenges as well as late milestone with a plan to mitigate.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None at this time.

**Reviewer 2:** As noted, the project appears to lack a quantification of the results - it makes it difficult to tell the story of why this work is meaningful, or even convince an outsider as to why it is important that this work be done.

**Reviewer 3:** If this framework is to be translated between utilities it would be good to have a few different utilities on the advisory board...Wires only company, vertically integrated, and one in a competitive market. There wasn't much spelled out in this report on the economic analysis side ... most of the focus was on the technical side.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Good partnerships and plans for information sharing are in place.

**Reviewer 2:** The project partners appear to be sound and the advisory group appears to bring in all the stakeholders one would want on this project.

**Reviewer 3:** The team indicated they have an advisory board of advisory board consisting of DPV developers, PUCs, utilities, and grid vendors. This is good although I note it is important to have different types of utilities as noted in a previous question.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Ensure data sets acquired/used are fairly representative of the broader distribution systems or can be characterized as to how they represent the broader systems.

**Reviewer 2:** 1) Project needs to increase quantification of the benefit of dynamic hosting capacity to convince folks its worth undertaking the effort. 2) Project impact could be increased if results could also be generalized or at least inform bulk system dynamic hosting approach. 3) If primary outcome is an expansion of datasets and some additional analysis capabilities, is the budget appropriate?

**Reviewer 3:** 1) Understanding of the cost elements for the techno economic analysis. 2) Testing the model works in testing somewhere outside PHI.

## Resilient Planning for Distributed Photovoltaics – $1,500,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Benjamin Sigrin*

This project seeks to help grid planners better predict where distributed energy resources like rooftop solar and battery storage will be installed. The team is working with academic partners and all seven of the U.S. Independent System Operators and Regional Transmission Organizations to open-source its Distributed Generation Market Demand tool. The tool, a theory-driven model, is being upgraded with machine learning to make it a data-driven model. Improvements to the tool will provide simulated electricity usage patterns with better resolution, resulting in at least 10 percent greater predictive accuracy compared to historic data on distributed photovoltaic adoption. The tool will be used to predict customer adoption of new technologies, giving grid operators better insights on where more distributed energy resources will be located, helping to improve planning and operation for a more resilient and reliable grid.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 4 |
| Implement a high-risk, high-impact approach | 3 | 3 |
| Match well with the level of DOE funding and planned project duration | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 |
| Advance the U.S. solar industry substantially | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Strengths: Clear scope, building on existing tools. Will provide useful data/tools for utility planners and regulators. Weaknesses: Model limitations, bias, and uncertainty will be challenging to clearly communicate to end-users. Plan to expand user-base beyond ISOs/RTOs is not clear.

**Reviewer 2:** The objective of this project is to improve RNEL tool dGen (tool that simulates customer adoption of distributed energy resources for residential, commercial and industrial entities), with emphasis on methods for forecasting the deployment of distributed PV sources. This aligns with SETO mission. I don't see critical challenges to overcome: the objective is to improve an existing tool in a number of reasonable ways (particularly interfaces). In my view, this is not a high-risk high-return endeavor. The risk is "low" and the outcome an improved tool. Hopefully, this improvement will be highly relevant. The funding seems reasonable to achieve the project objectives. This research endeavor is in line with similar research endeavors elsewhere. This is a hot topic that has attracted the interest of the research community (particularly, behind-the-meter PV production forecasting). An improved dGen tool will be useful for the power industry.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 |
| Disseminates results frequently and actively engages partners | 5 | 3 |
| Collaborates with sufficient stakeholders | 5 | 2 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project performance appears good.

**Reviewer 2:** In my view, the objectives of the project are being achieved as planned. The improvement of the dGen tool will be apparent (if this is the case) at the end of the project. Although result dissemination among ISOs is praiseworthy, no dissemination has taken place so far within the research community: no journal articles and no conference presentations. Although ISOs are very well represented, the "power systems" academic community is not represented: the academic representation pertains to members of a business school.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Yes, each task in the project adds unique and important value.

**Reviewer 2:** Score: 6. Comments: I think the planned tasks make sense of improve RNEL tool dGen.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** OpenEI may not always capture rate structures properly. For example, "Sell" energy rates for energy exported to the grid for some utilities are defined in a separate rate or rider, and this is not clearly reflected in the OpenEI URDB. This could require a lot of manual work to correct, and adoption forecasts could be significantly affected otherwise.

**Reviewer 2:** Disseminate the current developments of the project via engineering conferences (IEEE and the like) and seek input from the power engineering research community.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Seeing a plan to reach out to utility stakeholders beyond ISOs/RTOs would be nice, but their involvement in the project is not critical.

**Reviewer 2:** In addition to the contribution of a business school group, bring to the project the research perspective of a power system group within an engineering school.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** This is useful work. It is good to see that resulting software will be open source.

**Reviewer 2:** 1) Disseminate results within the power system research community (IEEE conferences and the like) and seek feedback. 2) Incorporate the view of the power system academic community, not only that of the business academic community. 3) Make sure that the improved tool is readily available and easy to use by power system researchers across the country.

## Strategic and Programmatic Analysis to Support the Department of Energy – $2,400,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis*

This project provides core support to the Solar Energy Technologies Office through a bottom-up analysis of solar costs. Using inputs and validation from both industry sources and academic papers, the team estimates the current state of solar technologies and system costs, as well as future industry progress toward the cost targets, set by the Solar Energy Technologies Office.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 5 | 4 | 5 |
| Implement a high-risk, high-impact approach | 5 | 3 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 4 | 5 |
| Advance the U.S. solar industry substantially | 5 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is fundamental support for the Program Office, providing a broad array of analysis, technical updates, and technical assistance to places like Puerto Rico.

**Reviewer 2:** I think this is important work for the industry and for SETO to have access to the sort of information generated. However it seems less "timely" than it maybe should be as this is a fast moving market and requires a throughput of work (for example, calls to collaborators) than seems to be achieved.

**Reviewer 3:** This is funding to support strategic market research for SETO. As such, the project is very aligned with SETOs goals, existing to serve the research needs of the organization and provide the office staff with the necessary market data and analysis to allow them to make informed decisions. The program allows SETO to consume a large amount of market data and filter it into a format that can be disseminated in an open manner and in a context that is useful for the DOE. The reason for the lower scores have to do generally with the indirect nature of the project. It is not driving the state of art in solar technology, but it is providing the important context to allow for the creation of projects and initiatives that can.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 3 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 | 6 |
| Collaborates with sufficient stakeholders | 5 | 4 | 6 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project is meeting its milestones for both its routine tasks (quarterlies), and more in-depth studies and getting the more in-depth work out into community journals/networks.

**Reviewer 2:** Performance seems solid against agreed expectations I am just not sure those agreed expectations are sufficient!

Reviewer 3: Generally yes -- the project has only one substantial stakeholder, SETO itself. It is, aligned, by definition, with the office's mission. One reason for the lower score is its indirect nature -- generally with research services it is hard to value or quantify how the results of this project translate to value in other projects or for the office itself. The value tends to be binary -- can SETO do its job, or not?

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task in this general support project provides important value to the program / DOE and its achievement of mission.

**Reviewer 2:** Score: 5. Comments: It is probably true that no-one else can provide this function of sending information to the center of the DOE decision-making system and therefore it is a unique project. The weekly and quarterly meetings should be the scrum sessions for advancing the solar market. As I said before it is also important work - I just would want it to be more current and scaled for similar or less cost.

**Reviewer 3:** Score: 6. Comments: This is correct. The ad hoc nature of the contract implies that the project is only working on topics of value to its primary stakeholder.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Would be good to see a prioritization effort -- top issues -- what could help address -- what to prioritize / plan for each year, which could be refined as things could/would change.

**Reviewer 2:** I appreciate the focus on financing costs in 2018 and think that is useful but think there are other soft costs that need to be more deeply understood and addressed. Please spend more time on this and the non-hardware stuff.

**Reviewer 3:** I would advise an internal review of information sources to ensure that there is adequate churn in the subscription services to get different points of view and sources of information.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Largely in support of DOE program.

**Reviewer 2:** Small contractors and software vendors in the rooftop space may be an example of folk that could be consulted or opportunity zone finance providers in the case of Puerto Rico. It is hard to keep up with all the non-hardware parts of the solar business but they have to be there in the analysis now the module cost is so low.

**Reviewer 3:** Hard to say, the mission of the project is quite broad so the team appears to be able to incorporate new stakeholders and organizations as the project requires.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** How does team ensure quarterlies are most useful to the community? How does team set priorities for what in depth topics to take on?

**Reviewer 2:** Get more done. Work out how to be more efficient with the resources you have (people and time) and increase throughput in a truly timely fashion (data for this year from this year). Take more risks perhaps; work out how to be more agile with the resources at hand.

**Reviewer 3:** 1) Review the data sources from the analysis on a periodic basis to ensure that there is the right mix of inputs. 2) Try to establish some forward-looking research agenda at the beginning of the task period and reduce the uncertainty in topics, this can help with resource allocation. This would also solve some of the challenges with resource allocation and access to expertise. 3) Review and reconcile reports produced by the team so that they are meeting stakeholder needs.

## Techno-Economic Analysis of Solar Energy Technologies – $3,600,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis*

This project directly supports leadership in the Solar Energy Technologies Office with versatile, on-call analysis of the technical and economic performance of solar technologies. To grant the core support required to address market feasibility and other issues related to solar, this project may range from providing quick data or model results to longer-term research leading to published papers.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 | 6 |
| Set critical challenges to overcome | 5 | 5 | 4 |
| Implement a high-risk, high-impact approach | 5 | 4 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 4 | 6 |
| Advance the U.S. solar industry substantially | 6 | 5 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is foundational analysis for the Program Office to support the development of key program directions and to chart progress toward program goals.

**Reviewer 2:** This is essential information for the US solar industry and it is good that SETO is getting it. Working out how to share with more stakeholders would be helpful.

**Reviewer 3:** Strengths: 1) Project helps to inform industry of potential opportunities to focus innovation as a result of the breakdown of the supply chain forecasts. 2) The more years this is done consistently the greater the value becomes as the trend curve can be seen then. 3) Meeting with SETO management for expectation management, alignment, and priorities to address one of their stated challenges. Consideration Areas for improvement: 1) The writeup indicates region specific production costs and policy influences but I am not sure I saw where that is modeled or tied in after seeing the example charts on the ppt. 2) The writeup indicates this information is delivered "to stakeholders via media coverage, interviews, and conference presentations." To have greater impact there should be a more specific spelled out engagement plan of how you will reach the various audiences. Just saying coverage doesn't tell if the media you use reaches the various audiences you mention. 3) The poster example would lead me to believe this is entirely hardware and installation focused. A system typically includes software for management and control and there is no mention of that in any of the cost elements.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 4 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 3 |
| Disseminates results frequently and actively engages partners | 5 | 4 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This is the key modeling effort behind the Program Office strategy which brings in information from many stakeholders and diverse geographies. These efforts provide important benchmarks and offer deep dives to help frame topics such as solar/storage strategies.

**Reviewer 2:** It seems the team has a great network for doing this work. As to whether they meet their milestones well it is hard to tell. And the results are measured in published work but it would be nice to know how else it has impacted SETO decision-making, choices by co's etc.

**Reviewer 3:** The team must interface with manufacturers and installation groups in order to get the breakdown of costs. How often or how frequent is not depicted. With regard to the impact of this excellent work, there really wasn't any metric I saw articulated on how impact is measured.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each foundational task is essential for program development, progress tracking, and understanding the global market.

**Reviewer 2:** Score: 5. Comments: I think the sum of the parts of this is probably greater than the whole so yes.

**Reviewer 3:** Score: 5. Comments: I would not say this project is unique; however, it is important. Breaking down supply chain components and doing cost tracking is something done in many industries. The results of the cost information provides insights into where opportunities still exist to reduce costs that are considered a material component of the cost stack. As such, the information provided is extremely valuable.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** Do not see any at this time.

**Reviewer 2:** Outside of China are we tracking module assembly in all countries (like the Philippines, e.g.)? And is the innovation community contemplated in the assessment - perhaps not till it is impacting real module manufacturing and delivery of batteries and PV but it may be important to see what is coming because the market is moving so quickly.

**Reviewer 3:** I didn't see any costs related to the necessary software components to manage and monitor the solar/PV. These software costs and integration costs are material in an overall project and business case. To have industry impact with this excellent work, there needs to be a more developed engagement plan. Just stating speaking at conferences (what conferences) and using media (what media) is insufficient. Who are the audiences and how do you reach the audience and what channel/venue is the best place to do that? True impact occurs when you have a plan to reach the right audiences.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Has broad engagement.

**Reviewer 2:** Innovation ecosystems that are supporting battery and related business'; fringe PV manufacturing markets to make sure we're seeing all that is going on in this giant global market.

**Reviewer 3:** The writeup doesn't specifically call out the stakeholders...mentions them generically. What manufacturers are involved, what research institutions, what software system vendors, etc. Hard to comment when there weren't any specifics.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Ensure appropriately reflecting changing energy pricing approaches. 2) Ensure reflecting value of distributed resources for the grid -- and potentially value of enhanced resiliency to the customer.

**Reviewer 2:** How do we actually work with China and other countries involved in solar and storage development (UNSW in Australia, the Fraunhofer Institutes in Germany) to ensure this is high fidelity data to advance not only US manufacturing but a global push to bring costs down.

Reviewer 3: The most important feedback I can give is to make sure there is a more spelled out stakeholder engagement plan; otherwise, the penetration of this information could fall short.

## Valuation and Operational Performance of Solar plus Storage Power Plants – $530,946

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Paul Denholm*

As energy storage costs decrease, new opportunities arise to create solar power plants with dispatchable energy, making power available whenever it's needed from both concentrating solar-thermal power and photovoltaic technologies. Understanding the various plant configurations and storage-operation modes can be challenging. For example, photovoltaic and battery developers must consider the relative sizes of module, inverter, and storage power and energy capacities, as well as where in the system to integrate energy storage. This project develops improved methods for evaluating and comparing different solar-plus-storage technologies and configurations to help utilities and system planners develop low-cost, reliable power systems.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 6 |
| Set critical challenges to overcome | 6 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 6 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 |
| Advance the U.S. solar industry substantially | 6 | 6 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is an important project for helping stakeholders understand the capabilities of solar power when linked with storage and where and how it can compete economically. It will also help identify new research needs.

**Reviewer 2:** As utilities push to reach their stated 2050 carbon free goals, this project is relevant and can assist them so is timely. The team states in the project goal that "It will also help ensure many of the reliability benefits of storage technologies are captured." There is a fair amount of differing opinions in industry as to how one defines reliability and what are the components of reliability benefits so I think to avoid confusion it might be a good idea for the purposes of this project for you to define what you mean by this and be clear on what they are and how you will measure them. Articulation of the milestones and status were clear. Perhaps semantics but in milestone 3.1.1 the team states "This analysis will allow us to confirm the hypothesis that under existing dispatch methods, the flexibility of solar plus storage is undervalued, and advanced dispatch strategies." Perhaps consider 'testing' hypothesis versus confirming as that could lead to bias going into the analysis.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 |
| Measures impact appropriately (e.g. quantitative) | 6 | 4 |
| Disseminates results frequently and actively engages partners | 5 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** This project has met and is on track to meet its major milestones and has active engagement with key stakeholders as part of defining/refining the analysis and reporting on results.

**Reviewer 2:** In the project objectives, it states "The audience includes utilities, system planners, regulators and project developers. I see where outreach has occurred to MISO, PJM, SPP, Congressional Staff, and CREPC-WIRAB. I didn't see anything about the plan to reach utilities or system planner, etc. If that is a project objective, it is important to make sure there is a plan.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each analytical question is an important one to pursue to improve stakeholder understanding and/or identify future research needs.

**Reviewer 2:** Score: 5. Comments: In light of the push for carbon free commitments by 2040/2050, understanding the optimal cost effective approach is an important piece of information for planners.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** None at this time.

**Reviewer 2:** The project team states that "This project will develop improved methods for evaluating and comparing different solar plus storage technologies." To have impact, it will be important once the methods are proven out, how to get this institutionalized into existing planning processes in a seamless manner; otherwise, the excellent work may not be as heavily utilized and thus have less impact. This will mean that an understanding of the existing utility planning process would need to mapped and where this step would fit and how it would integrate into the process.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None at this time.

**Reviewer 2:** Utility planners and developers are key.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Strong project for integrating solar and storage for larger solar projects; important metrics development.

**Reviewer 2:** 1) Map out how this will fit into existing planning processes. 2) Clear define reliability for this project.

# Special Projects & Collaborations

## End-of-Life Management Analysis and Stakeholder Engagement – $150,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Garvin Heath*

As the number of photovoltaic installations rises, more modules will age and degrade over time, making it important to learn new ways to safely and properly dispose of photovoltaic modules. This project uses two approaches to investigate current and future state-of-the-art techniques to dispose of modules. First, the team is using lessons learned from abroad by engaging with the environmental health and safety task force of the International Energy Agency's Photovoltaic Power Systems program, where experts are leading a set of projects on photovoltaic module end-of-life management. The team is also analyzing topics relevant to end-of-life management from a U.S. perspective. This analysis helps inform manufacturers and other stakeholders on the value of current recycling requirements for photovoltaic hardware, as well as on the effectiveness of current efforts to design modules and other equipment for ease of reuse along the supply chain.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 6 |
| Set critical challenges to overcome | 6 | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 6 | 6 | 5 |
| Advance the U.S. solar industry substantially | 5 | 6 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** Solar PV panel EOL management is quickly becoming an increasing concern that needs to be addressed to avoid a blackmark on the industry. The project appears to leverage international efforts and therefore appears to punch above its weight in terms of publications and information dissemination relative to the dollars invested.

**Reviewer 2:** The project explanation describes well the strengths of this project: a substantive study (or series of studies) that provides insight into the environmental impact of the expansion of PV generation.  This is the sort of report that is essential to creating pathways to further expansion of photovoltaics and meeting long term development goals, but is rarely supported by private industry because it does not directly contribute to returns of an individual project. A challenge for the project, readily acknowledged by the PI, is the breadth of the study: the number of countries and stakeholders involved, and the fact that the information is being collected on a voluntary basis. It is a testament to the strength of the workgroup that there has only been one delay, and that delay has been resolved.

**Reviewer 3:** This project seems to offer good value for money for SETO in the short- and longer-term. We need to know this information being garnered through the international efforts of Dr Heath. If we act on it, we can preempt significant impact, lost value and create new industries in the capture and recycling of this vast growing waste volume. Thinking on the terawatt timeline is a good thing for DOE.

**2.Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 6 | 5 | 5 |
| Measures impact appropriately (e.g. quantitative) | 4 | 6 | 4 |
| Disseminates results frequently and actively engages partners | 6 | 6 | 5 |
| Collaborates with sufficient stakeholders | 6 | 5 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1**: Project appears to have wide dissemination and broad collaboration. While publishing, and publishing lots, can be important would also be useful to see quantification of impacts beyond publishing - is the data encouraging US recyclers to develop facilities to handle PV modules, are new recycling techniques increasingly being developed, etc.

**Reviewer 2:** The project appears to be off to a really great start, with active participation from all of the members of the workgroup and a demonstration of relevant results and data through a strong series of papers and interim projects during task one. Spending appears to be relatively low and on budget.  On a secondary level, the project honors a DOE commitment to the IEA workgroup, and this collaboration appears to be generating value.

**Reviewer 3:** Well measured reports, appreciated by international collaborators, and the public are useful. All of the work seems on time except as explained. And what I have heard from others is that the work is appreciated globally and contributes to our collective understanding.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Individual tasks not given - in general approach seems appropriate.

**Reviewer 2:** Score: 6. Comments: In short, yes. This project appears to have one main task, to facilitate and support the sustainability component of the IEA workgroup. It is coordinating a massive amount of data from a large number of stakeholders, converting this data into information that will become useful as PV scales further.

**Reviewer 3:** Score: 5. Comments: I think it is unique contribution for the US to still be able to act as an honest broker of this sort of information through a global collaborative approach. It is important because we have to understand the LCA and issues related to this research to advance PV in the long-term.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** As noted above, tracking impact beyond simply publications and downloads would be valuable. Clearly not every new PV recycling activity can be correlated to this work (as one example of an additional metric that could be looked at), but finding a way to measure how this effort is increasing awareness of and efforts to address this problem would be valuable.

**Reviewer 2:** A key blind spot to be aware of is the fact that information is being collected on a voluntary basis from participant countries. Data should be evaluated with this in mind.

**Reviewer 3:** Datasets from developing countries, especially vis Picosolar. If you believe some significant proportion of humanity's electricity flows in 2050 will be served from distributed systems, be they microgrid scale or smaller we need to understand the lifecycle and relevant data for all scales and types of solar. 80% of humans will live in Asia and Africa from 2050 so the modelling needs to start now to serve/sell to them successfully as the US tries to recapture it's lead in this industry.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** None that can think of.

**Reviewer 2:** Unclear from the documents presented, but a broader range of industry participants could be helpful. Broader input from different industries adjacent to the PV manufacturing sector could provide additional color to the results.

**Reviewer 3:** It may be useful to engage with the likes of the Global Offgrid Lighting Association, Power4All or others doing the work at the bottom of the pyramid. Similarly rooftop vendors and those in Alaska and on indigenous land in the USA dealing with small scale systems.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) Important problem that might warrant even further resource. 2) Need to find a way to measure impact beyond publication numbers.

**Reviewer 2:** 1) The project has done a massive amount of work for a relatively limited amount of funding. This work will be important to the future growth of the PV industry. 2) To this end further partnerships with IEA and other international organizations can serve as a "force multiplier" encouraging research on topics of broad, mutual interest. 3) This project could be followed with additional work to look at local US markets in more depth.

**Reviewer 3:** Understanding end-of-life, recyclability, and total costs is critical to the longhaul success of solar so keep it up. Broaden the sense of where the technology will go - from the building fabric of middle America to the bottom of the pyramid in Asia and Africa - and include that in the analysis. Work with China, which is surely grappling with some of these questions too.

## High Penetration Photovoltaic Scenarios – $450,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis*

This project is working to identify challenges and roadblocks to increased deployment of photovoltaics and to find synergies with battery storage that can further support photovoltaic deployment. The analysis focuses on three areas: the potential for photovoltaics and storage to provide grid services during times of extreme weather, the drivers of curtailment under high penetration photovoltaic scenarios with and without storage, and the change in value of a photovoltaics as a grid resource with different storage configurations.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 6 |
| Set critical challenges to overcome | 5 | 5 |
| Implement a high-risk, high-impact approach | 5 | 4 |
| Match well with the level of DOE funding and planned project duration | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 3 |
| Advance the U.S. solar industry substantially | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This project is extending/expanding various modeling capabilities to assess the impact on solar power from extreme events -- critical information as part of maintaining reliability of the power system as PV grows in penetration. This is a substantial modeling and data undertaking that should credibly address some of these key questions for the scenarios analyzed as well as provide new modeling tools to assist in understanding the increasing penetration of solar power.

**Reviewer 2:** In general, this project addresses a key, central challenge of the SETO mission: how can we understand the fundamental challenges to reliability posed by high penetration of renewables and how developments in technology like energy storage can provide a pathway to mitigate those challenges. A disadvantage is that there is already quite a bit of research in both the public and private sector looking at this information, especially in markets like California, so it remains to be seen how this project team approaches the problem differently.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score |
|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 5 | 3 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 5 |
| Collaborates with sufficient stakeholders | 5 | 4 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** The project has completed one extreme event analysis -- hurricanes -- and overcame initial challenges to do that and is working on two more events around extreme summer and winter loads and expects to complete these analyses on time. Further, the developed modeling approaches can be used by energy planners/operators around their own scenarios for greater insights.

**Reviewer 2:** This is a pretty ambitious study, to look at these factors on a macro basis. The challenges of the study are apparent and described -- reconciling the large and heterogeneous data sets associated with large weather events, PV + storage, and resource planning. In terms of performance, the project has just gotten underway, so there is not enough information to see if the task challenges have been met adequately. That noted, the goals are clearly stated and achievable in the time period, to identify the potential challenges of high-penetration PV scenarios.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 5. Comments: Each task tackles an important extreme event to the U.S. and enhancing the modeling capabilities to pursue more scenarios holds large value at the budget levels at play here -- for both DOE and market actors.

**Reviewer 2:** Score: 3. Comments: In general, yes. This is a relatively short project where the current tasks -- assembling a working model -- leads to the final tasks -- delivery of academic papers describing the model output.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** This is a very scenario-focused effort. Need very useful/real scenarios.

**Reviewer 2:** As discussed in previous comments, the key to this study will be to demonstrate how the PI's approach is different from other systems modeling approaches seen at the project or regional level.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Much of the stakeholder outreach is yet to come through industry conferences and through publication of the individual extreme event studies.

**Reviewer 2:** Critically, participation from state agencies and utilities that provide key data about the systems and regions being evaluated is important. A main concern is developing the model and ensuring that they are incorporating the correct programming and computational resources to capture usable and relevant results from such a large and complex dataset.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Important project for understanding vulnerabilities; need robust scenarios of relevance to many stakeholders.

**Reviewer 2:** First and foremost, the team needs to elaborate on the importance of their approach, and how it differs from existing or standard models. Second there needs to be some indication of actionable remedy for the challenges they highlight -- do the technologies exist today, or what will be required for them to be delivered in the future? Finally, be sure to delineate differences across geographies. Markets, in addition to data, are quite different.

## Open-Access ReEDS Model – $300,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Wesley Cole*

This project further develops the Regional Energy Deployment System (ReEDS), which simulates electricity sector investment decisions based on system constraints and demands for energy and ancillary services. This model is unique in its high-spatial resolution and advanced algorithms for representing the cost, value, and technical characteristics of integrating renewable energy technologies. Although it covers a broad geographic and technological scope, ReEDS is designed to reflect the regional attributes of energy production and consumption. The model considers a large suite of generating technologies, including fossil, nuclear, and renewable technologies, as well as transmission and storage expansion options.

### 1. The project's goals, approach, and expected impact:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 5 | 6 |
| Set critical challenges to overcome | 4 | 5 | 4 |
| Implement a high-risk, high-impact approach | 4 | 4 | 3 |
| Match well with the level of DOE funding and planned project duration | 4 | 5 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 6 | 4 |
| Advance the U.S. solar industry substantially | 3 | 5 | 4 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** I am not clear this is not being done better in the private sector especially if we are only public datasets and not leveraging the rich data available to NREL. I have spoken to some modelers outside the DOE who claim to be doing similar or more granular work. Is this the best function of the SETO? Unclear to me this is.

**Reviewer 2:** This project shares NREL modeling capabilities and data with a broad user community to achieve a variety of goals, including engaging more researchers in solar-oriented R&D solutions.

**Reviewer 3:** First Kudos to the team for putting this together and getting it to work on multiple platforms. Various challenges were cited and overcome but I didn't see the challenge of how these models are QA'd with multiple contributors or how this sustains beyond the funding period. In the writeup it says, first users were added to the ReEDS repository on September 30, 2020. I think they mean Sept, 2019.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 5 | 6 |
| Measures impact appropriately (e.g. quantitative) | 5 | 5 | 4 |
| Disseminates results frequently and actively engages partners | 4 | 5 | 4 |
| Collaborates with sufficient stakeholders | 5 | 5 | 3 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Impressed by the number of users in <5 months but wonder whether it is that significant in such a booming industry. Are they students or companies accessing the system? How is it manifesting in improved sales, deployment and design of solar systems?

**Reviewer 2:** This project is really about collaboration and engaging more users in this renewable energy modeling framework, including with providing researchers a way to include new capabilities and/or tailor for their own efforts. Plans include user groups and/or workshops for all interested parties.

**Reviewer 3:** Looks to have made good progress and overcome hurdles with platform, licensing, and gaining some users.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Again not convinced this is unique in the market. Models can be important but not sure with this one.

**Reviewer 2:** Score: 5. Comments: Each task contributes meaningfully.

**Reviewer 3:** Score: 4. Comments: Providing access to a public tool and having a manner for folks to have access appears to be going well.  If this is to be open and leveraged by various entities what I didn't see is how are models QA's or validated so one knows they are reliable.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** I think one of the known unknowns is from the inability to use all the data they know they have at NREL. There's a blind spot baked in.

**Reviewer 2:** None currently.

**Reviewer 3:** Things to consider might be: 1) Tool is described as the 'flagship capacity planning model for the power sector' on the website. It seems to take into account G&T but I didn't see anything about how Distribution connected Generation is handled. As the penetration of connected DERs increases then this could have an impact on capacity planning for G&T.
2) I didn't see how this sustains being maintained beyond the funding period? 3) It would be good to see who the user requests are from.  The project states that it processed more than 250 ReEDS user requests and that requests came from over 170 organizations. Of those, what percent are industry versus Govt/Lab and University requests? Perhaps a suggested impact measurement may be what % of industry uses it or how many regulatory proceedings cite the outputs?

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** Modelling startups that may be doing this better. Two that I have not discussed this with but may be interesting are Kevala and Form.

**Reviewer 2:** Broad stakeholder engagement to date and more is upcoming.

**Reviewer 3:** There has been much great work done but it wasn't clear to me who is going to maintain, QA, and promote this into industry beyond the funding period to ensure the work that has occurred is picked up by industry. Knowing BNEF has work in this area, I wonder if anyone has thought about engaging them. Is there an organization targeted to monetize this to sustain it over the long haul?

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Make sure you know the field in the private sector doing this work and that the DOE efforts are augmenting or besting it. Work out ways to use your own data not just the publicly available stuff. Consider cutting losses and focusing on core competencies.

**Reviewer 2:** Good project for SEO transparency and to let many benefit from the government investment with the overall goal of benefiting solar progress in the US.

**Reviewer 3:** 1) How to sustain beyond the funding period. 2) Understand how much industry is embracing versus Govt/lab and Universities. 3) How are models others contribute QA'd

## Open Energy Data Initiative – $1,060,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Debbie Brodt-Giles*

This project provides the opportunity to change how the energy industry accesses and interacts with data from different energy technologies—including solar, wind, water, and smart grid—by leveraging cloud computing to encourage innovation and build capabilities, solutions, and businesses. The project provides storage repositories with large volumes of widely accessible raw data. The team leverages open data agreements with key cloud-hosting vendors to host free data sets when possible. The team also partners with cloud-computing providers to share DOE data sets with the largest audience yet so potential power users can use them to add value to the solar industry and the energy industry as a whole. This work provides an innovative environment for data access and accelerate analysis capabilities for all consumers of DOE energy data.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 6 | 5 | 5 |
| Set critical challenges to overcome | 2 | 5 | 5 |
| Implement a high-risk, high-impact approach | 4 | 4 | 5 |
| Match well with the level of DOE funding and planned project duration | 3 | 4 | 5 |
| Add significant value to existing research outside DOE-funded efforts | 4 | 5 | 6 |
| Advance the U.S. solar industry substantially | 4 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** In general, open data is a good thing. It appears, however, that one key concern has not yet been addressed - the report notes that a lot of the solar data that would be meaningful is proprietary and, thus far, the performers haven't found a suitable way to anonymize or generalize it so that it can be shared. This does not appear to be a focus of the effort, however. It probably should be. It's also concerning that, thus far, 95%+ of downloaded solar data is from NREL and one other commercial entity. It's unclear if this is due to a lack of industry awareness about the dataset or if others in the industry simply don't need this data/use other sources. If the former, an awareness campaign should also be the focus. If the latter, it raises concerns about the ongoing utility of (presumably paying for) cloud hosting vs. having these two entities simply pay themselves to host the data as they're really the only two groups making significant use of it.

**Reviewer 2:** I think this is great work to do and absolutely necessary to move SETO towards its mission. Providing these data sets to potential users could have significant impact on the industry. I am not sure that the model is that challenging and think it just needs to get done. I do not think it adds to the industry until it is finished and widely used, which is not a fait accompli, so significant concerns remain around the cloud-compute providers and then the marketing of this solution to the industry and adjacent industries to maximize creativity.

**Reviewer 3:** This is a valuable foundational project to increase the value to the country and others of DOE data sets and research results and offer a lower cost means of making foundational related (and other) data available to researchers, the commercial marketplace and others.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 5 | 4 | 5 |
| Disseminates results frequently and actively engages partners | 3 | 3 | 5 |
| Collaborates with sufficient stakeholders | 3 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Collaboration scores are a bit low as, while it appears as the major cloud service providers are being adequately involved, there is some concern that only two entities are responsible for over 95% of downloaded data for the solar dataset.

**Reviewer 2:** I think it has done some good things and is moving in the right direction but needs to move more quickly. If legal is delaying progress break through. Other data hosts than AWS need to be implemented for the good of the project and the SETO mission - please get it done as soon as possible. The identified collaborations sound fine in and of themselves, but I think there may be many more to be had in adjacent industries around energy analytics, computer science, solar production and finance that need to be involved in the OEDI.

**Reviewer 3:** The team is making good progress in making large data sets available in more standardized ways, making interested parties aware of the data sets, and expanding the vendors that can support/host the data sets. The team provides good information on the data sets that have been stood up and the downloads/users of the data so far.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Individual tasks are not provided, so average score given. In general, description of approach to get data onto cloud seems appropriate. As previously noted, there is some concern over outreach to the user community.

**Reviewer 2:** Score: 5. Comments: It is critically important to the success of the industry and SETO's mission that we maximize the voluminous datasets that DOE has - if this is a unique effort to do that then that's a problem for DOE. There needs to be redundant and probably parallel efforts to realize the potential of all this data on performance of the industry. But I agree this has significant value to current and future stakeholders and is the sort of strategic project that SETO needs to continue to support. Such datalakes become enabling platforms for a lot more.

**Reviewer 3:** Score: 5. Comments: This is a unique foundational effort to increase access to large data that DOE wants users to have access to and use. Each task is important to improve the platform, build out the supply of high impact data sets, and build out the awareness and use of the datasets.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** As stated before, if there isn't a wide community that seeks to use this data it's not clear getting it on more platforms is all that valuable (unless the bulk of users are on other platforms, but that seems unlikely given AWS share of the cloud hosting market).

**Reviewer 2:** Blind spots might include the engagement of "outside the box" thinkers in this effort. Similar big data initiatives in other industries have resulted in significant creativity and we should learn from those experiences. I am thinking ICT and telecoms mostly but there may be learnings from other energy analytics arenas closer to DOE like the oil and gas sector here in the USA or the wind turbine industry.

**Reviewer 3:** Prioritizing datasets to add to the system. Seems the easiest is data intended for the public, not subject to an NDA. Given complexities of dealing with NDAs and privacy issues, need to develop an approach for which datasets to pursue to advance the mission. And given interest in collecting datasets outside DOE, again need an approach for establishing priorities.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** As previously stated, engagement/feedback from the broader solar community stating that they want to use/need this data would help justify the effort being undertaken.

**Reviewer 2:** I believe there may be adjacent industries with insights for the fulsome development of this - by which I mean not just solar industry types but folk more broadly gaming energy information flows, financiers, and others in computer science who would love such a big data playground. It may be important to consider getting some unlikely suspects involved in this project or utilizing OEDI once it's up.

**Reviewer 3:** Engage broader research community. Seem like small numbers but perhaps just overwhelmed by commercial users.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Primarily just need some validation that there is a widespread community that wants to use this data. If it's really just kWh Analytics and NREL, seems that the cost of this effort and ongoing maintenance may not be worth it.

**Reviewer 2:** Get it done. Get legal out of the way - this needs to happen now for the fast ramp. Involve unusual suspects in building on the OEDI.

**Reviewer 3:** Balance between solar resources and other resources being pursued, clear, high-impact value proposition for datasets pursued, particularly those that require additional challenges to be addressed. Would be interested in the longer-term plan here as well. What is longer term plan for ongoing updates / maintenance and at what costs?

## Valuing Photovoltaics and Energy Efficiency in Buildings – $1,800,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Monisha Shah*

There is a need to explore and evaluate a new framework that considers photovoltaics, distributed energy resources, and energy efficiency co-optimization and/or co-adoption with new or enhanced existing metrics to determine values to grid operators, developers, energy service providers, homeowners, and communities. The project develops and tests a suite of new and existing metrics to quantify the ability for residential buildings with various energy technology bundles to meet a set of objectives and associated value streams of relevance to different actors (e.g. developers, system operators) in the energy system.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 5 | 4 | 5 |
| Set critical challenges to overcome | 5 | 6 | 4 |
| Implement a high-risk, high-impact approach | 4 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 4 | 6 | 0 |
| Add significant value to existing research outside DOE-funded efforts | 5 | 5 | 4 |
| Advance the U.S. solar industry substantially | 4 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** This is a new project, not yet started, and with budget not fully negotiated. The residential marketplace is a difficult marketplace for meaningful metrics -- those that have value in the marketplace -- other than dollars, and even the energy costs for a particular home are not a meaningful driver at many homes. Critical to define the value streams of greatest value up front -- some of the greatest value in the residential market comes from aggregating what happens across many residences in a community -- and charting an appropriate path around metrics accordingly.

**Reviewer 2:** An interesting study that fits into the template of a study that will generate substantial value for the private sector but is too broad in scope to be undertaken by a profit-driven entity. In general, the strengths of the project are that it creates KPIs and analytic methods for a topic that is anecdotally understood to add value -- the addition of PV and energy efficiency measures to the residential energy envelope. Furthermore, it takes on a nationwide scope -- looking at different climate regions -- that can really only be undertaken by a government agency or national laboratory. The weakness of the project will likely be the limited sample size. The study will likely not yield universal results, but important KPIs to measure larger sets of data.

**Reviewer 3:** I did not rate the fourth criteria, as there is no budget yet so it is impossible to answer that question. The project approach and goals are clear. Having a neutral facilitator for the advisory group is a great thought and will help with not making this a biased approach.

### 2. Based on performance to date, the project team:

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 0 | 5 | 0 |
| Measures impact appropriately (e.g. quantitative) | 0 | 5 | 0 |
| Disseminates results frequently and actively engages partners | 0 | 5 | 0 |
| Collaborates with sufficient stakeholders | 0 | 5 | 0 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** Project not yet started.

**Reviewer 2:** Not enough data to adequately evaluate -- project has not started yet.

**Reviewer 3:** Since the project is a week old it is impossible to comment on their performance.

### 3. Each task in this project adds unique and important value to achieving the overall goals of the project.

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 4. Comments: Premature given project under negotiation.

**Reviewer 2:** Score: 6. Comments: I think it does -- the methodology seems sound in terms of providing a framework to understand how to value a home microgrid. The challenge will be to see if the data can be obtained, cleaned, and evaluated in a consistent manner across regions and climate zones.

**Reviewer 3:** Score: 5. Comments: The metrics and their taxonomy and how they are built up in the calculator will be at the root of success. If not agreed upon and well socialized it can turn into yet another way to coming up with numbers to justify one's position. It is important that this gets well socialized and input from across the stakeholder types identified.

### 4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?

**Reviewer 1:** The project writeup is fairly high level -- about unidentified aspiration metrics and a process to use to define these metrics. Critical to identify the top value streams and what the magnitude of that value is to groups that can possibly capture that value.

**Reviewer 2:** The challenges are important. One issue I would point out is that the survey is being done in conjunction with Sunrun solar. My assumption is that they will be facilitating the data collection from their field of customers. The challenge will be to try to gather universal data from a dataset that will be represented by only one major type of home energy user.

**Reviewer 3:** I would highlight that if there is to be a metric for value to the grid that it behooves you to have utilities in your stakeholder meetings less this become another framework with metrics that has not been well socialized.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** To be addressed later.

**Reviewer 2:** I would work to engage a broader range of home PV customers, ideally from other residential vendors besides Sunrun.

**Reviewer 3:** The stakeholder input on metrics and getting a wide swath of views is important otherwise this work may not have as much impact as it could. Utilities even though they do not operate BTM assets in many states are still a key audience to have in the room as well as some consulting companies.

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** Need clear identification of the value streams.

**Reviewer 2:** 1) This is an interesting study -- I agree that there are value streams and frameworks that are being missed by current valuation methodologies. 2) Focusing on Residential customers is an important category, principally for what the PI mentioned - that the results from this study will have far-reaching applications for developers and policymakers. It will encourage new business models and policy levers to help grow solar penetration in this sector. 3) I would see this as a first step in a broader effort to characterize and understand the residential consumer for DERs and efficiency. It will give an insight into how to value and measure, but more work will require to capture the full breadth of this sector.

**Reviewer 3:** 1) A broad stakeholder advisory group with well socialized input. 2) I would expect more than 50% acceptance of this framework as a definition of success as opposed to 50%... "Concurrence and endorsement of the metrics, analytical frameworks and the common taxonomy by 5 out of the 10 the Technical Advisory Group members." 3) Might want to look at what NEEP(Northeast Energy Efficiency Partnerships) is working on as there are some similarities to this project... they have some similar focus.

## Transitioning Orange Button: Orange Button for Operations & Modeling – $610,000

*National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Debbie Brodt-Giles*

The Orange Button Initiative is an industry collaborative to establish an open, industry driven solar data exchange system to enable a free flow of data between software products that address the solar asset lifecycle. This project extends the use and functionality of the Orange Button data standards by adding system performance monitoring and modeling components. These additions include data structures and elements for electrical current monitoring; weather data records like irradiance, temperature, and precipitation; module characterization; and performance model parameters. In order to encourage adoption, expand use cases, outline steps for users, and demonstrate value to industry, the team is creating an open-source implementation and building a self-sustaining Orange Button community of practice.

**1. The project's goals, approach, and expected impact:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Align well with this topic's goals and support SETO's mission | 3 | 5 | 5 |
| Set critical challenges to overcome | 2 | 5 | 5 |
| Implement a high-risk, high-impact approach | 2 | 5 | 5 |
| Match well with the level of DOE funding and planned project duration | 3 | 4 | 6 |
| Add significant value to existing research outside DOE-funded efforts | 3 | 5 | 5 |
| Advance the U.S. solar industry substantially | 3 | 5 | 5 |

**Using the above criteria, please summarize the strengths and weaknesses of this project in 100-200 words.**

**Reviewer 1:** In general, standards are helpful. It's not clear the standards that are being set by this project though. Three main "applications" are being built by this project. The first, taxonomy, contains an extremely detailed list of data that could be collected - but the list is so extensive that it is unlikely that anyone would actually collect each pieces of data. Further, much of this data is likely considered proprietary and the taxonomy doesn't appear to list a standard unit measurement or methodology for entering the data. The second dataset appears to be the most useful, listing products that meet necessary standards. However, it's not immediately clear if this is just US or international - for example, one company listed in the database appears to be portrayed as meeting standards but believe they are not allowed to sell in the U.S. (Huawei). The third dataset is supposed to support "essential for inventory and parts management, and enable tagging of specification and performance data to provide traceability across stages in an asset's lifecycle". This is basic work that all industries have to perform - it's not clear why the solar industry requires gov't support to do "inventory and parts management".

**Reviewer 2:** The OB system could be a huge boon to reducing costs of real-world PV plants in America. I am not sure the right effort was funded in this case - neither in size of dollars not the time it takes to make something like this stick on the growing solar industry as it goes through its ups and downs. SunSpec will have a heavy lift to make all this sunk cost now become ubiquitous, which is when it will be useful.

**Reviewer 3:** This is a small project in terms of resources currently being expended -- with a completion date of June 2020. The project is meeting its objectives of data standardization with substantial stakeholder input to the standardization process. The key next step will be adoption by different user segments.

**2. Based on performance to date, the project team:**

| | Reviewer 1 Score | Reviewer 2 Score | Reviewer 3 Score |
|---|---|---|---|
| Meets important milestones within reasonable timeframes and budgets | 4 | 3 | 5 |
| Measures impact appropriately (e.g. quantitative) | 1 | 3 | 5 |
| Disseminates results frequently and actively engages partners | 6 | 4 | 4 |
| Collaborates with sufficient stakeholders | 6 | 4 | 5 |

**Using the above criteria, please summarize the performance of this project in 100-200 words.**

**Reviewer 1:** As judged from the wide range of products listed, it appears that broad collaboration is occurring. Measurement of impact seems to be sorely lacking - metrics like talking at conferences and being on podcasts is listed, but no measurement of number of companies adopting the standard is given or appears to have been proposed as a target. This is the only meaningful results of an effort such as this, so should be the focus of discussion when it comes to targeting and/or discussing results.

**Reviewer 2:** The fact it has slipped to mid 2002, which is now going to be a very difficult year, means delivery of the results is impaired. I do not think the budget was commensurate to the task, so am not necessarily blaming the team, but rather that something of this import is not well-resourced and the team thinks a few tweets, webinars or speeches is what makes something like this stick. It's as much a marketing problem as anything.

**Reviewer 3:** Project is completing with regard to its objectives for the data taxonomy and standard. Important progress with the self-sustaining community of practice is necessary; and then uptake of the standard is necessary for overall impact.

**3. Each task in this project adds unique and important value to achieving the overall goals of the project.**

Please explain your score by describing the factors that pulled your score down and what factors pulled your score up. It is important that we understand what is working well and what the most important areas for improvement are.

**Reviewer 1:** Score: 2. Comments: Individual tasks not listed. However, as mentioned above it's not clear that providing methodologies for inventory management (which is well established in the private sector) is helpful in reducing PV soft cost.

**Reviewer 2:** Score: 4. Comments: As mentioned above, I think this is important work. I am not sure it is unique and believe some private sector players may provide a similar but different service however the ideal of an opensource OB model would be better.

**Reviewer 3:** Score: 5. Comments: This small project (at this point) provides a valuable role of data standardization for solar project construction and operations with the promise to contribute to a reduction in soft costs.

**4. What 'blind spots' does the principal investigator have, in this project, that are important to consider?**

**Reviewer 1:** As previously mentioned, there is no discussion of adoption of this methodology as a measurement for success - but if this isn't adopted by solar companies this work doesn't have value. So this should be something that is being closely measured and monitored.

**Reviewer 2:** Marketing takes time and money.

**Reviewer 3:** There may be an issue with sustained engagement/upkeep.

**5. What type of stakeholders, organizations, or collaborations are missing in this project that you consider critical for the project success?**

**Reviewer 1:** It appears that there are indirect routes to work with companies that would have to use the methodologies adopted (speaking at conferences, on podcasts) - but no direct contact methodologies/engagements are listed. The companies that ultimately must adopt this methodology should be more directly involved.

**Reviewer 2:** Nonprofits interested in spreading solutions and supporting the growth of companies in the solar space. Marketing support for SunSpec.

**Reviewer 3:** The taxonomy standard has been shared through industry conferences, etc. The next step is for uptake in use of the standard as part of key transactions -- financing, etc. What is the awareness / ability to engage by these parts of the industry?

**6. What are the three most important pieces of feedback for this project you would like SETO to consider?**

**Reviewer 1:** 1) The engagement approach with companies that must use the results of this effort appears to be indirect rather than direct involvement - this is a recipe for failure.2) Part of this effort is basic blocking/tackling for any private company in any industry (inventory/parts management). I presume the solar industry already has this well-handled generally and if they don't there is more fundamental concerns that need to be addressed.

**Reviewer 2:** When you find an important piece of work like this really think about the shortcomings of the team/institution to get it done - like marketing by NREL and nonprofits. Work out how to get complementary skills to the effort.

**Reviewer 3:** With project coming to completion in June 2020, it is unclear how the self-sustaining community of practice will work. What if any is DOE's longer-term interest/role? Where does DOE want to be in 5 years and what is necessary to get there?

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