SOLAR ENERGY TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF ENERGY

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.

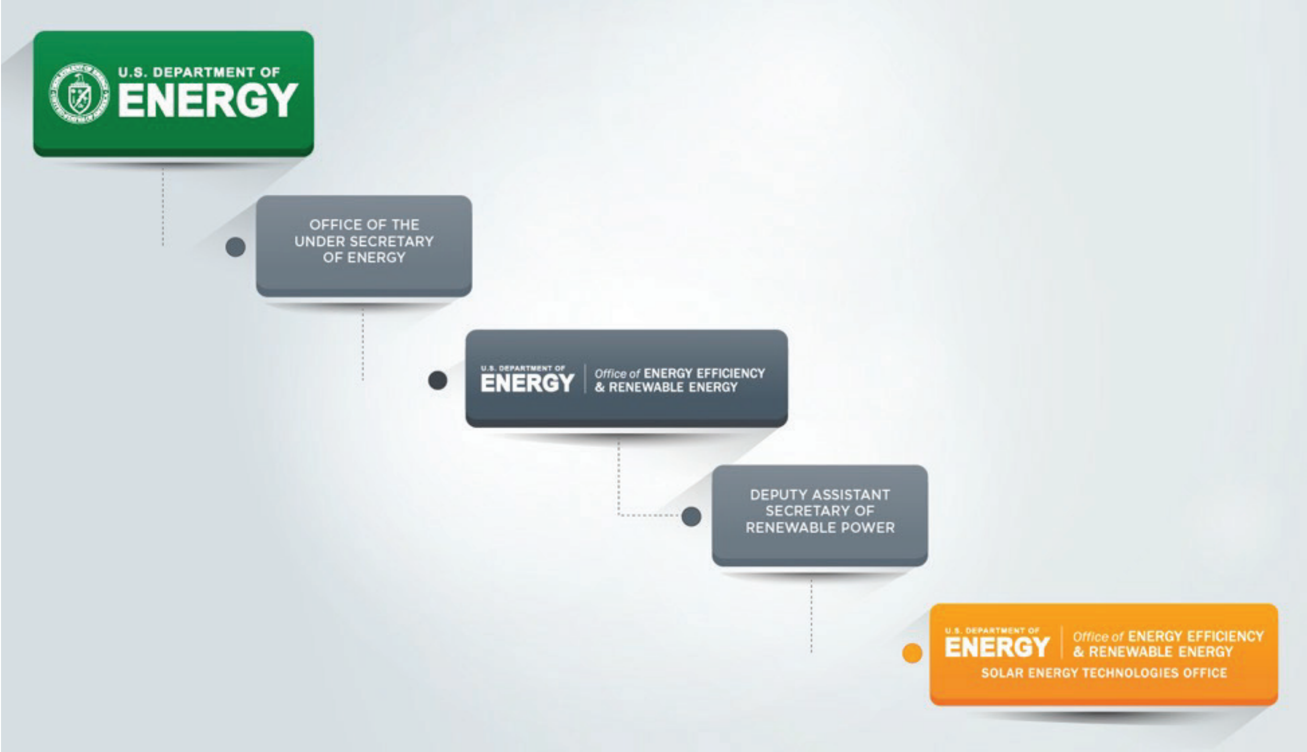
Introduction

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.

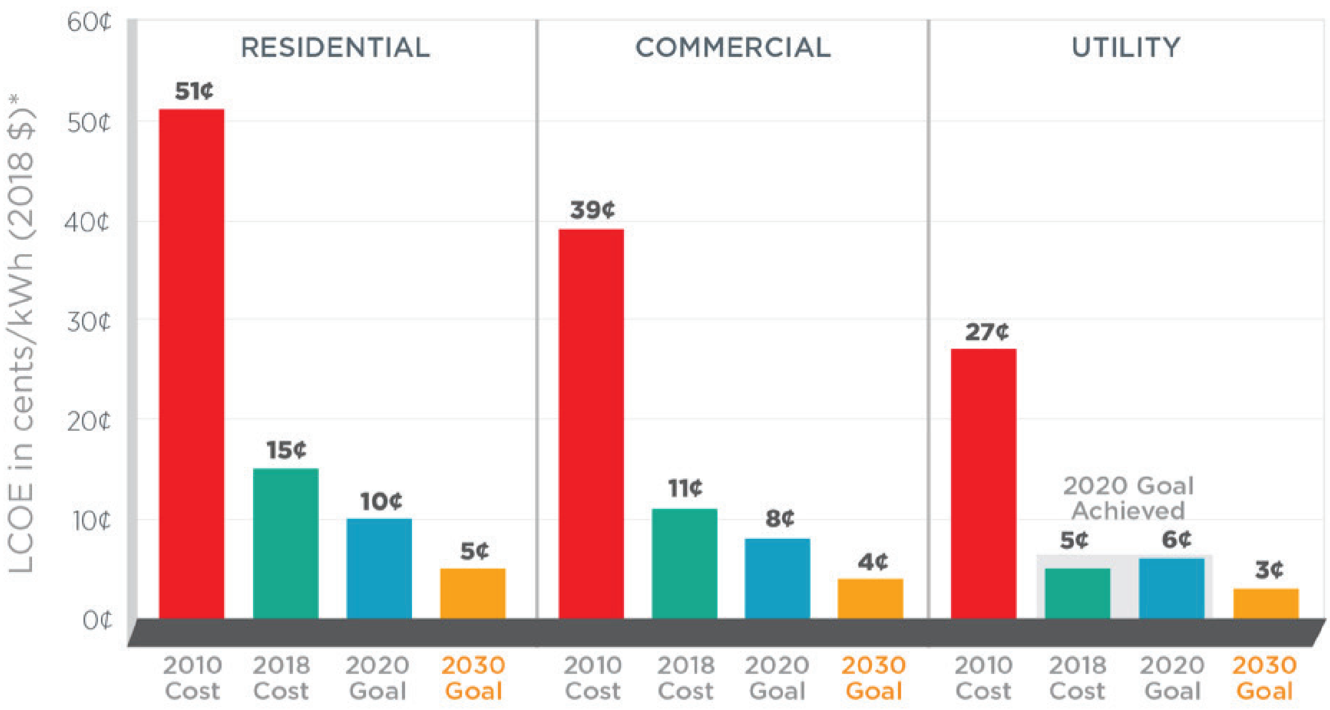
Now, as we start a new decade, solar provides about 3 percent of U.S. electricity,[7] with nearly 80 GW installed and more than 2.4 million solar energy systems.[8] In some states and regions, solar represents over 10 percent of annual electricity generation.[9] Instantaneous solar and wind generation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

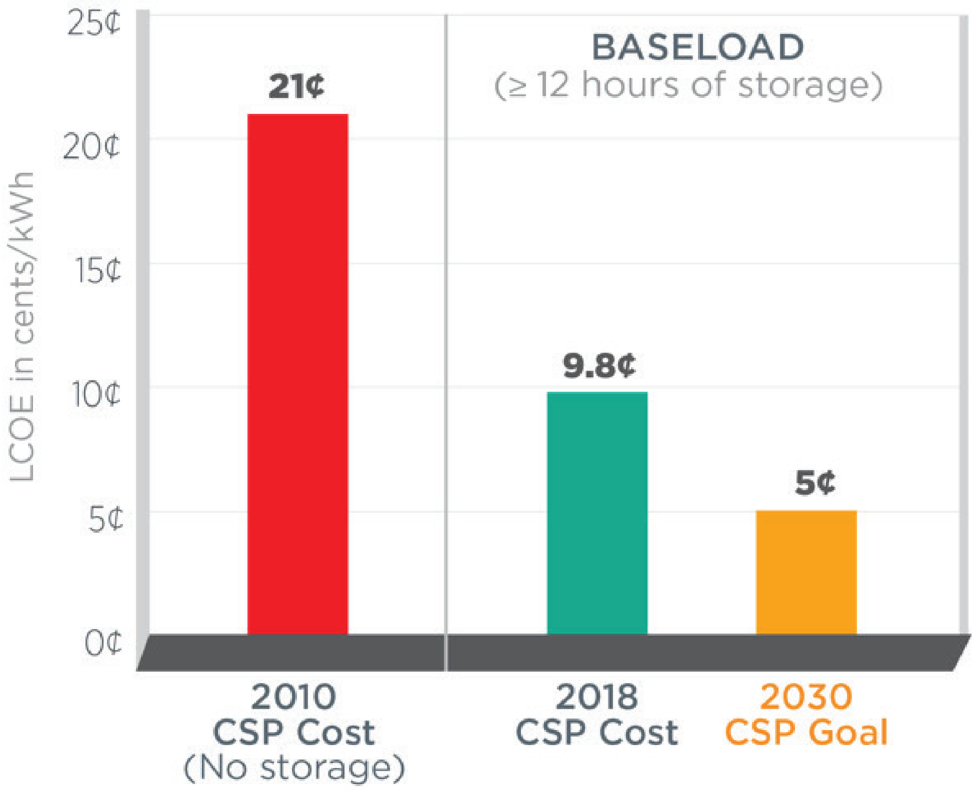


2010 and 2018 costs, with 2020 and 2030 PV LCOE cost targets across the three solar market segments: residential, commercial, and utility-scale. The PV LCOE numbers are calculated based on average U.S. climate and without the Investment Tax Credit. For example, a $0.03 LCOE for utility-scale would translate 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.



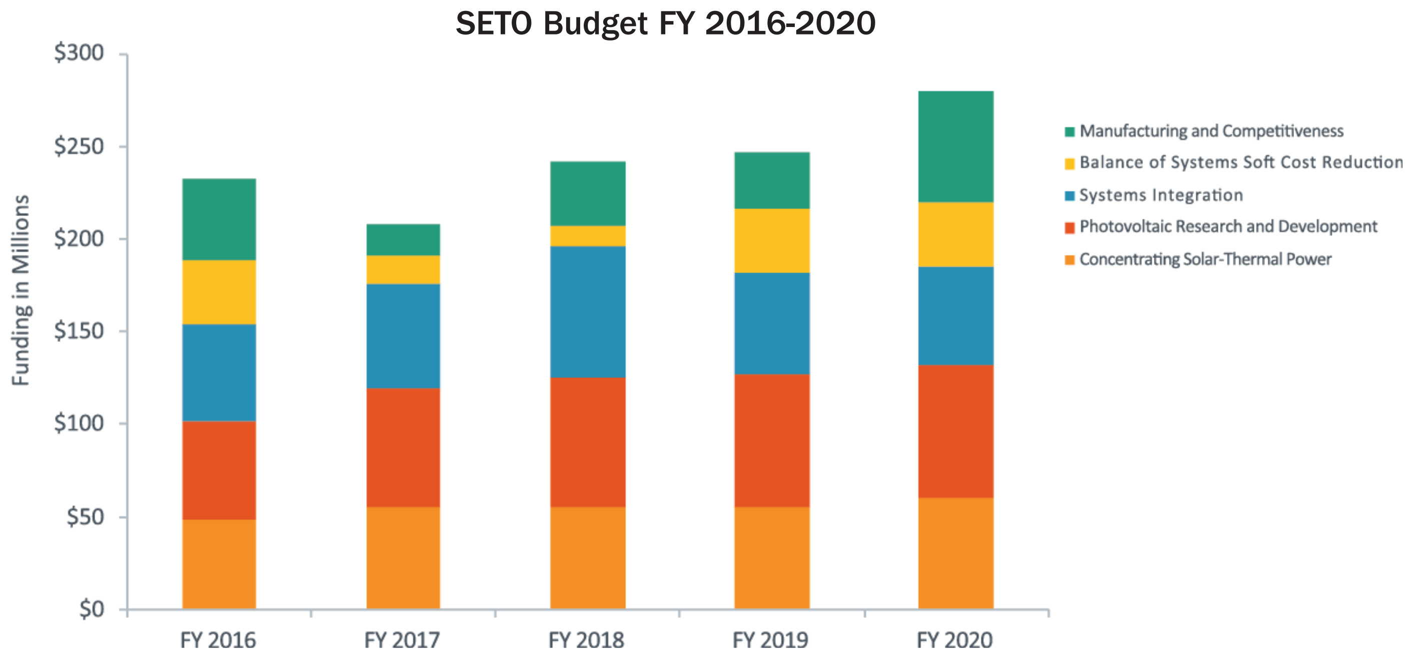
2030 CSP LCOE cost targets for CSP plants with 12 or more hours of storage.

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

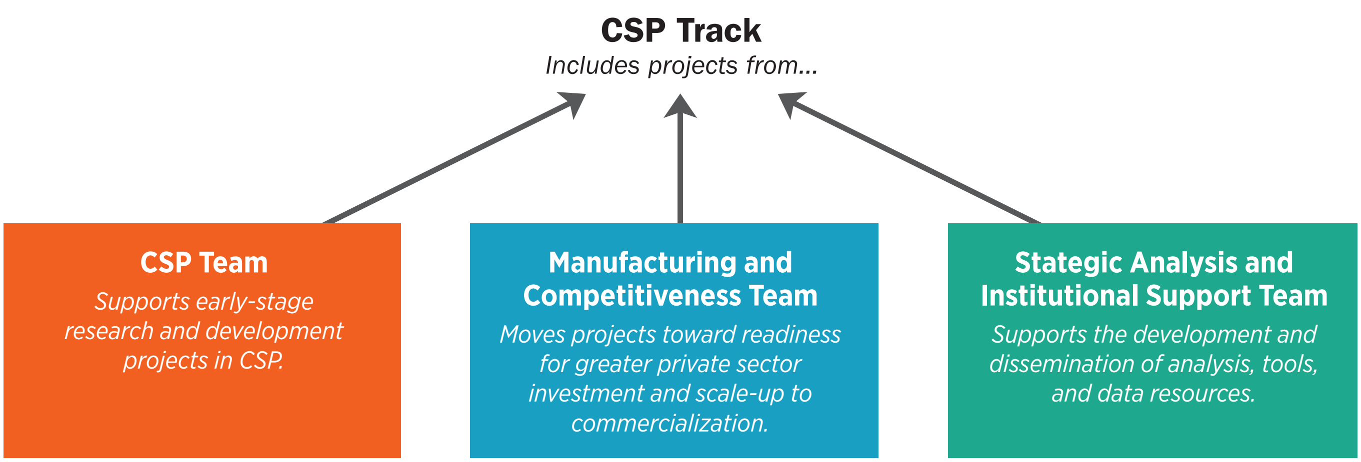
The peer review will evaluate the portfolio in the following tracks:

- **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.



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

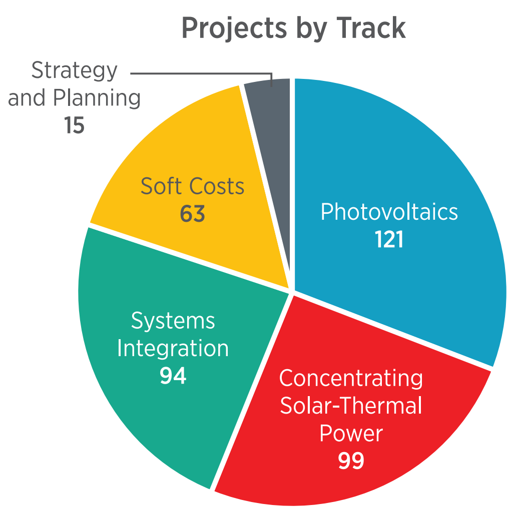
- PV Markets and Regulation
- Solar Energy Access
- Workforce

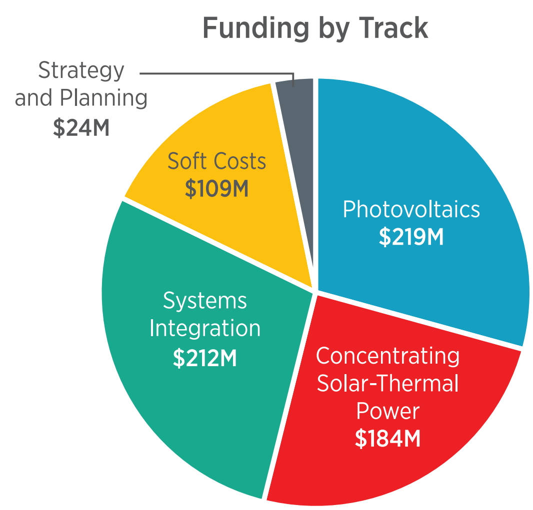
Strategy and Planning

- 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.

Photovoltaics

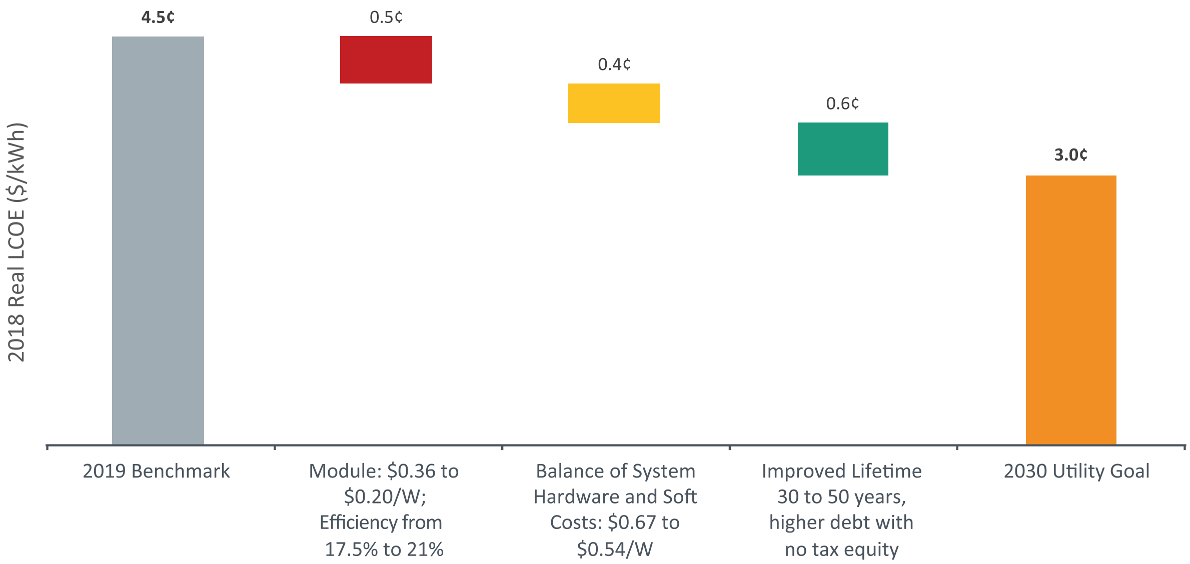
Projects in the Photovoltaics track support research and development of technologies that drive down the costs of solar electricity by improving efficiency and reliability of PV and lowering manufacturing costs. This portfolio of projects spans the Photovoltaics, Manufacturing and Competitiveness, and 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.

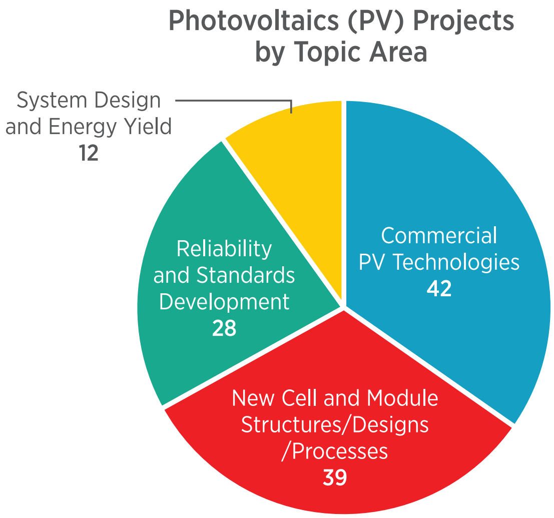
The PV industry has come a long way in the past decade, with the cost of electricity produced by residential solar installations dropping more than 70 percent and the cost of utility-scale installations dropping more than 80 percent.envisions further cost reductions in the coming decade, which motivates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

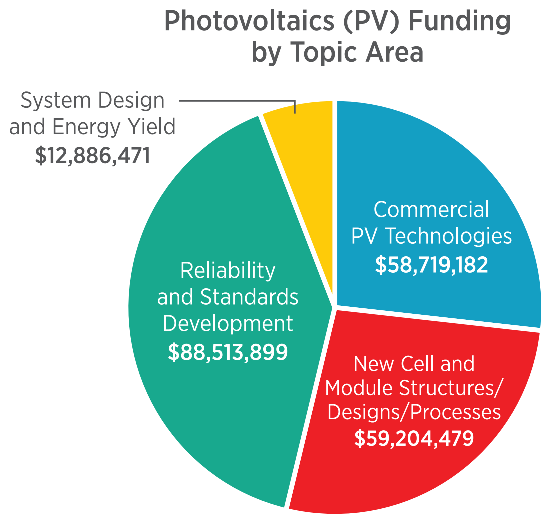


Sample scenario for reducing costs to $0.03 per kWh for utility-scale systems.

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.





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)

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.

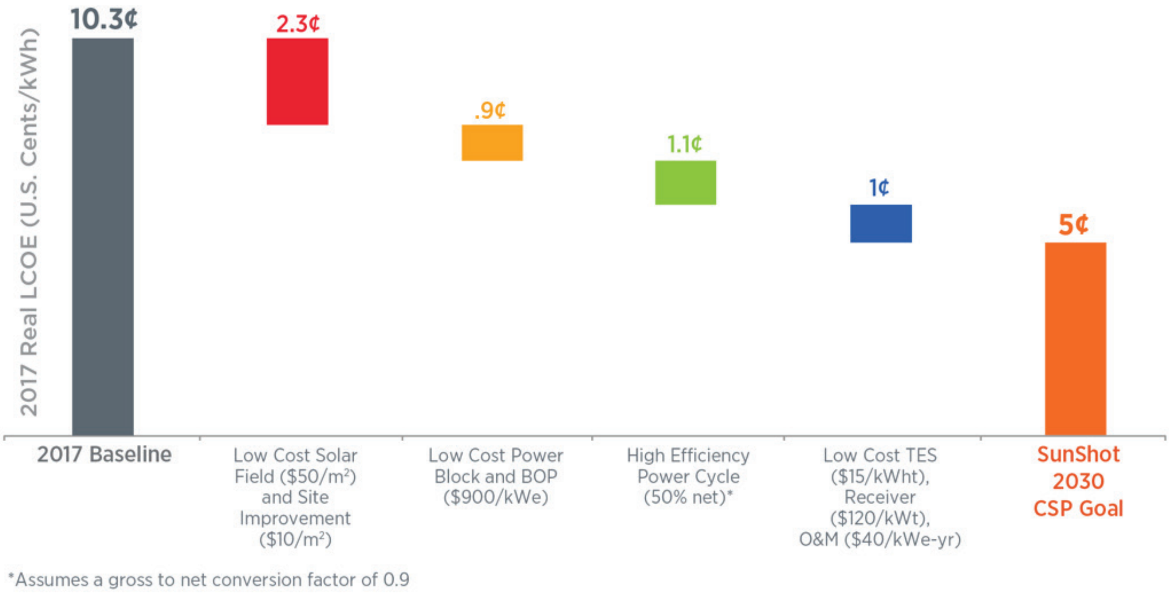
Concentrating Solar-Thermal Power

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

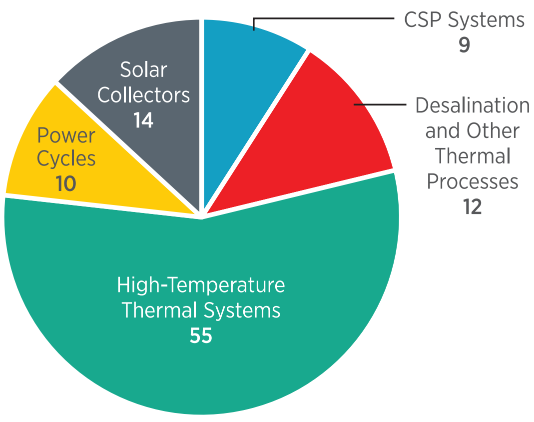


Sample scenario for reducing costs to $0.05 per kWh for Baseload CSP.

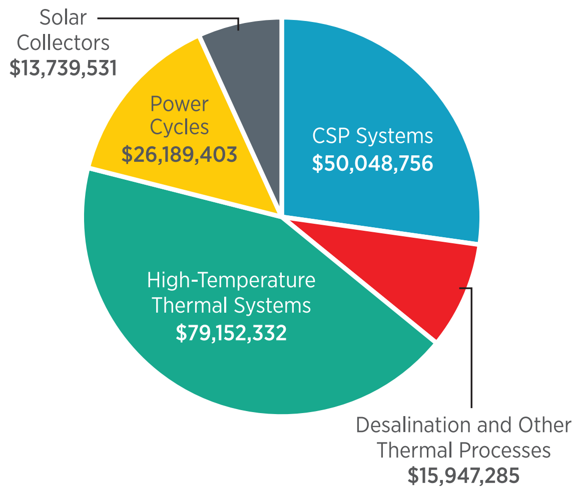
The challenges to achieving these targets require interdisciplinary solutions throughout a variety of fields in science and technology that tackle heat transfer, fluid mechanics, thermodynamics, optical physics, materials science, extreme automation in the solar field, corrosion mitigation, advanced 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)

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 sCO_2 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 sCO_2 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

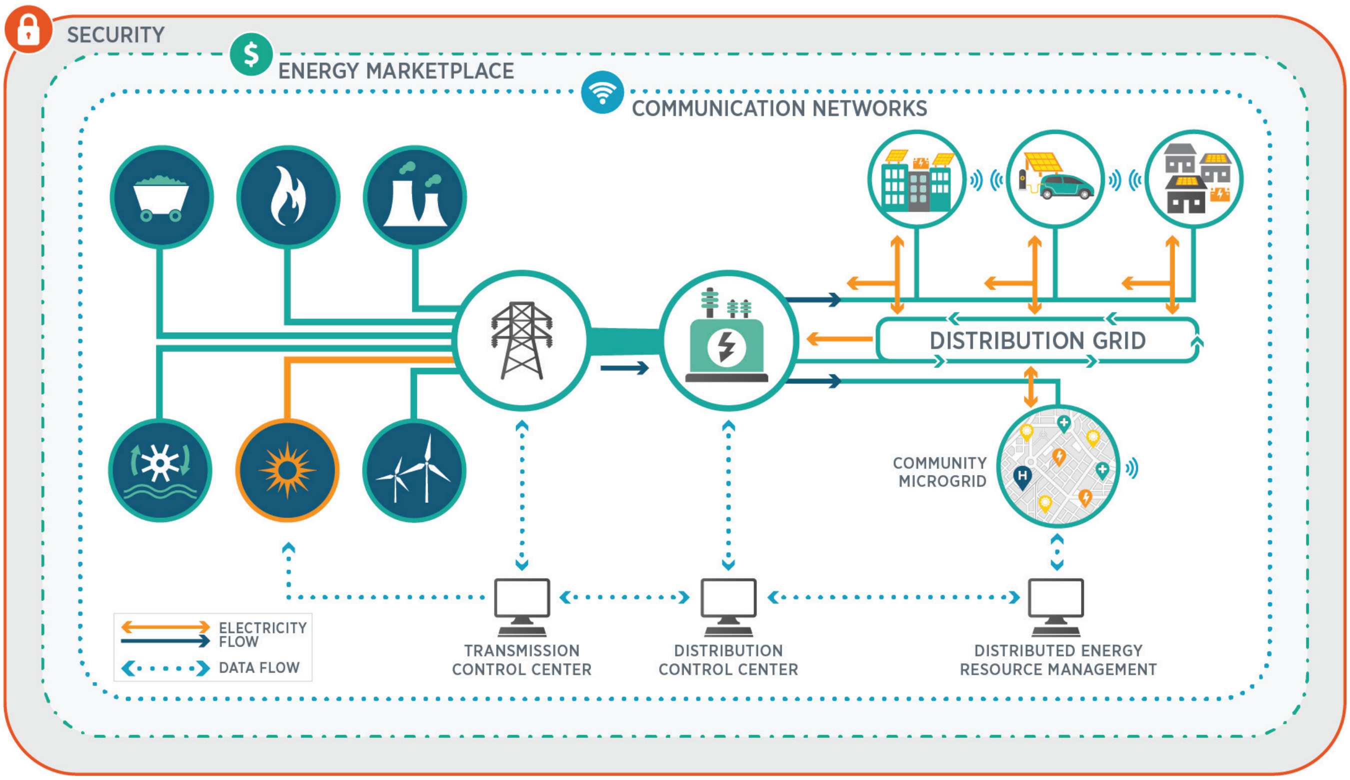
DOE has a long history of funding optical coating research and generating coupon-size optical proofs of concept, but even if those technologies work, they still compete against cheap, durable, highly reflective back-surface mirrors that are widely available. While reviewers understand that SETO wants 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.

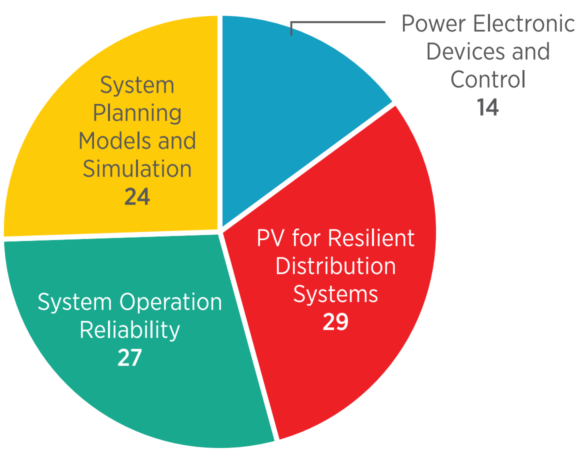


In recent years, solar generation has grown from less than 0.1 percent of the U.S. electricity supply to 2.7 percent per year, according to DOE's Energy Information Administration. In five states, solar electricity represents more than 10 percent of total generation. This rapid solar expansion is occurring 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.

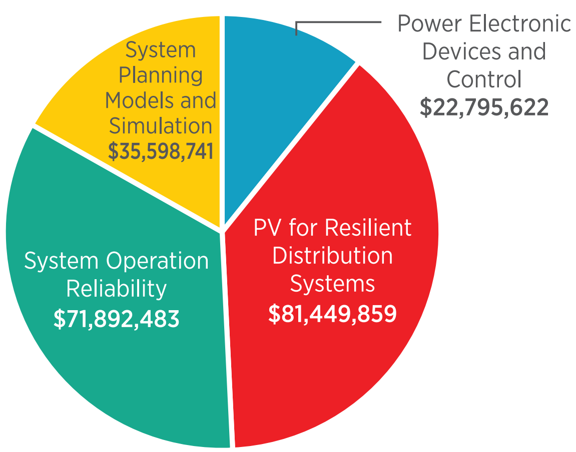
The Systems Integration track incorporates projects that are part of DOE's Grid Modernization Initiative, which is a cross-cutting effort that aligns grid modernization efforts across multiple DOE program offices. A number of these projects are funded under the Grid Modernization Laboratory Consortium (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.

Systems Integration Projects by Topic Area



Systems Integration Funding by Topic Area



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)

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.

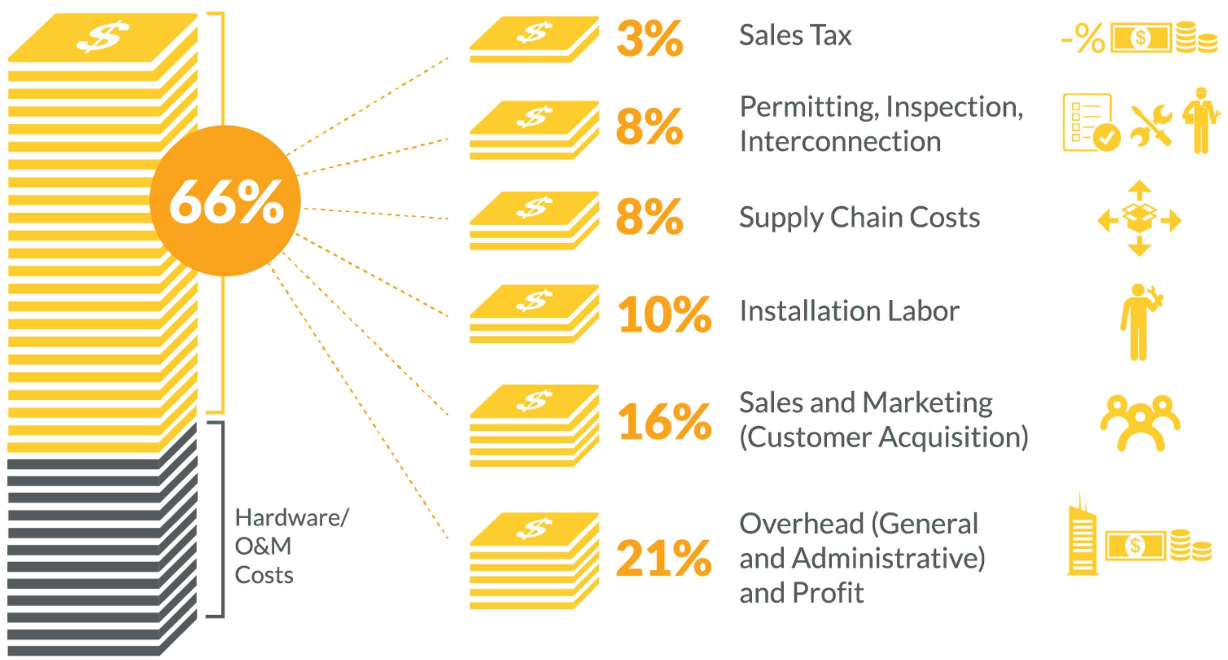
Additionally, upstream supply chain and downstream commercialization are critical factors, and reviewers encourage more focus on how each project fits into a timeline to market (even very-early-stage projects). This was not especially well developed in the presented information.

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

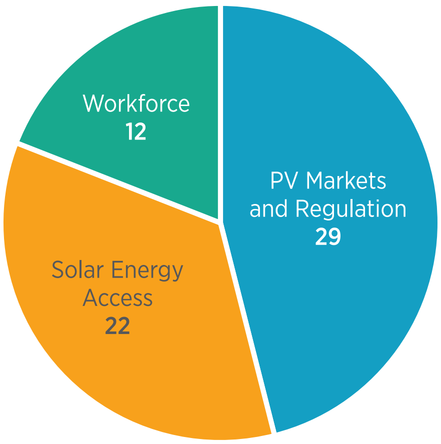
Projects within the soft costs portfolio seek to reduce the "red tape" associated with installing solar energy systems, as regulatory and financing burdens lead to higher costs for both developers and consumers. Across the country, there are more than 18,000 unique Authorities Having Jurisdiction that 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.

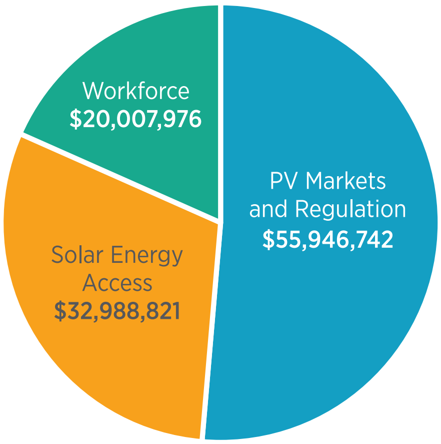
SETO-funded soft costs projects also work to increase solar affordability and expand the market through finance and business model innovations. Several factors limit certain customers from adopting solar, including the high cost and up-front expense of PV systems, a lack of suitable rooftops, a lack 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)

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

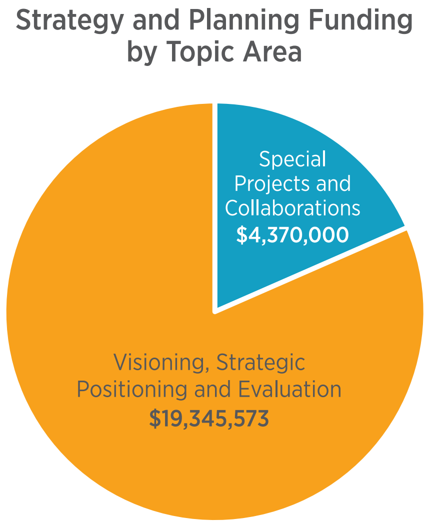
Training programs should be more expansive to include training in longer-term career pathways in clean energy jobs beyond solar installation. A longer-term strategy should be put in place that will determine funding needs for the future workforce.

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.



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

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.

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DOE/EE-2080 – July 2020