SOLAR ENERGY TECHNOLOGIES OFFICE

U.S. Department of Energy

2020 PORTFOLIO

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Letter from the Director

Welcome to the U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) 2020 Peer Review! As we begin a new decade, it is a great time to reflect on the progress over the last decade as well as look forward to our goals for the next decade.

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 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 significant policy incentives, solar deployment has increased significantly over the past decade, with solar power now supplying nearly 3 percent of U.S. electricity with over 70 gigawatts (GW) of installed capacity. For the past seven years, solar has been one of the top three sources of new electric generating capacity added to the grid.

At the same time, we have not yet achieved the goals we set for commercial and residential PV systems or concentrating solar-thermal power (CSP) systems. While costs have fallen significantly, the soft costs, like customer acquisition, supply chain management, and installation labor, of commercial and residential PV systems have decreased much more slowly than hardware costs. For CSP, a lack of scale in deployment and a need for a step change in technology have hindered cost reductions.

So where does that leave us today, in 2020? At SETO, we see continued opportunities for advancements in solar technologies, which remains a priority. The lower we can drive solar costs, the more solar can support greater electricity affordability, as well as balance out the decline in value as solar deployment grows on the grid. As solar deployment reaches over 10 percent in some areas of the country—with moments where solar and wind have generated more than 70 percent of instantaneous power—we will continue to focus on how solar can better support the reliability, resilience, and security of the grid.

We will also focus on new approaches to reduce soft costs for the commercial and residential sectors, while tackling the challenges and opportunities solar faces as a more mature technology. Those include how to enable all Americans to have access to solar energy, how to apply solar in new market segments, how to grow beyond electricity generation—such as desalination, fuel production, and process thermal heat—and how to deal with the waste stream produced when solar technologies reach their end of life.

It is an incredibly exciting time to be working on the acceleration and application of solar energy technologies. While our challenges are different than the prior decade's, they are no less significant, and we continue to need all of your great ideas and hard work to realize solar energy's potential as a power source for the country and the world. We look forward to fruitful discussions and dialogue throughout the Peer Review about how we can most effectively work together over the next decade.

Becca Jones-Albertus
Director, Solar Energy Technologies Office

[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.

Office Overview

The U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) funds early-stage research and development in three technology areas: photovoltaics (PV), concentrating solar-thermal power (CSP), and systems integration with the goal of improving the affordability, performance, and value of solar technologies on the grid. The office works toward these goals in four primary ways:

- Advancing research and development 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.
- Supporting U.S. businesses developing and de-risking innovative solar products.

SETO is the primary funder of solar technologies research within the U.S. Department of Energy (DOE). Within DOE, SETO sits within the 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, non-profits, and state and local governments (currently 25 percent of projects).

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."

Figure 1

Because of this long history, the 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. DOE funding enabled the early development of cadmium telluride (CdTe) thin film solar cells, research that helped to create First Solar, which is now 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 solar office funding to the early demonstration of new technologies that later became commercially successful, and SETO awardees have achieved nearly half of all solar cell efficiency world records.[2]

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 of 2019 and is also the director of DOE's Better Buildings Initiative.

[2]Based on SETO analysis of NREL's efficiency chart.

Figure 2: SETO Management team.

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.

The office's five teams are:

- **Photovoltaics** – The PV team works with industry, academia, national laboratories, and other researchers to the 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 energy available.
- **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 high-heat industrial processes.

- **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 a heavy emphasis on programs that reduce the soft costs of solar like the costs associated with permitting, siting, interconnection, or financing a system, which often are the result of a lack of information needed to do a job or make a decision. These information gaps can slow market growth or prevent market access.
- **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 reduce the soft costs of solar associated with workforce training and institutional capacity. 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 then-ambitious goal: to drive down the cost of solar electricity to be cost-competitive with traditional energy sources by 2020. To accomplish this goal, SETO undertook a broad strategy ranging from research and development of solar generation and integration technologies, solar manufacturing technologies, and better installation, design, and permitting approaches for solar energy systems.

When SETO established the SunShot goals, solar represented a tiny fraction of the country's electricity supply, with about 2.5 gigawatts (GW) of solar capacity.[3] It took five years for solar capacity to grow tenfold, to 25 GW, and approach 1 percent of the country's electricity supply. 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,[4] with nearly 70 GW installed and more than 2 million solar energy systems.[5] In some states and regions, solar represents over 10 percent of annual electricity generation.[6] Instantaneous solar generation can reach a much higher level, nearly 70 percent in some cases.[7]

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, SETO 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.[8] The 2030 targets for the unsubsidized LCOE at the point of grid connection[9] 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
- $0.05 per kWh for CSP with 12 or more hours of thermal energy storage

[3]Wood Mackenzie/SEIA Solar Market Insight Report.
[4]U.S. Energy Information Administration (EIA).
[5]Wood Mackenzie/SEIA Solar Market Insight Report.
[6]U.S. Energy Information Administration (EIA). In California, solar has reached 19 percent.
[7]For example, in March 2018, the California Independent System Operator (CAISO) saw an all-time peak percentage of demand served by solar: 49.95percent. See https://www.greentechmedia.com/articles/read/california-sets-two-new-solar-records.
[8]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/SunShotpercent202030percent20Factpercent20Sheet-12_16.pdf
[9]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

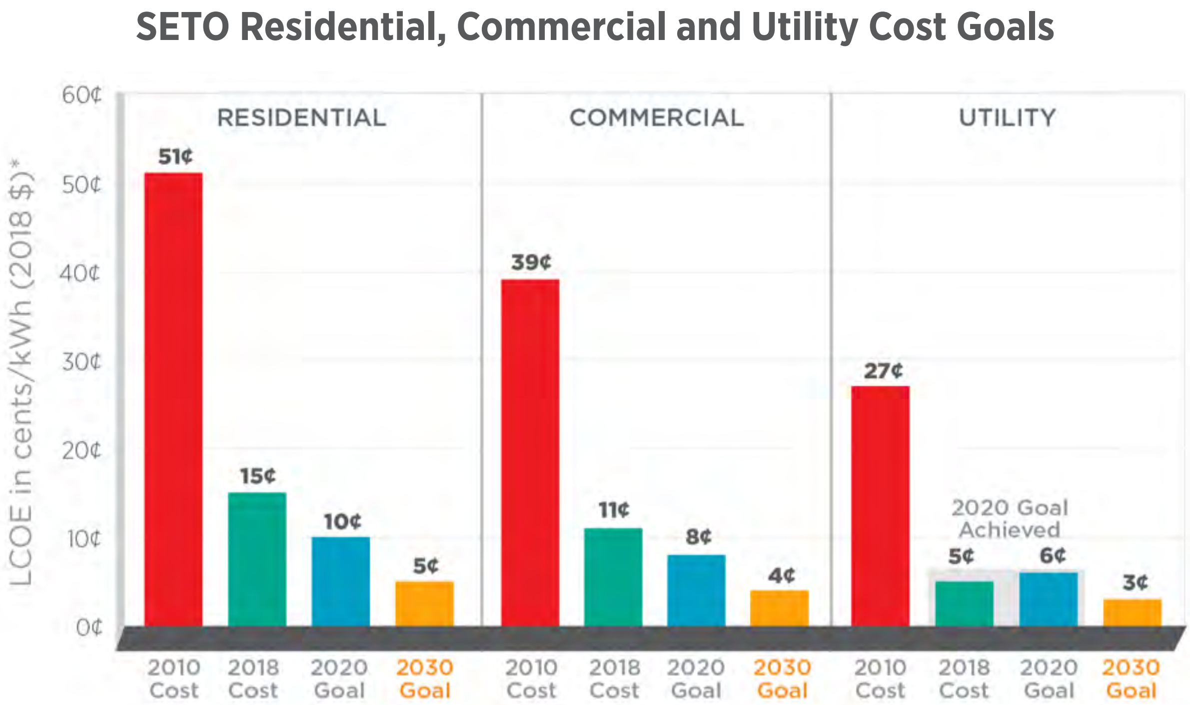

Figure 3: 2010 and 2018 costs, with 2020 and 2030 PV LCOE cost targets across the three solar market segments: residential, commercial, and utility-scale. The PV LCOE numbers are calculated based on average U.S. climate and without the Investment Tax Credit. For example, a $0.03 LCOE for utility-scale 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[10] (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 lower the cost of a CSP system by approximately $0.02 per kWh, which is 40 percent of the way toward the office's 2030 cost goal of $0.05 per kWh for baseload configurations. CSP funding is also addressing other system costs, including those of the heliostat field, operations and maintenance, and advanced power cycles.

[10] 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

SETO CSP Cost Goals

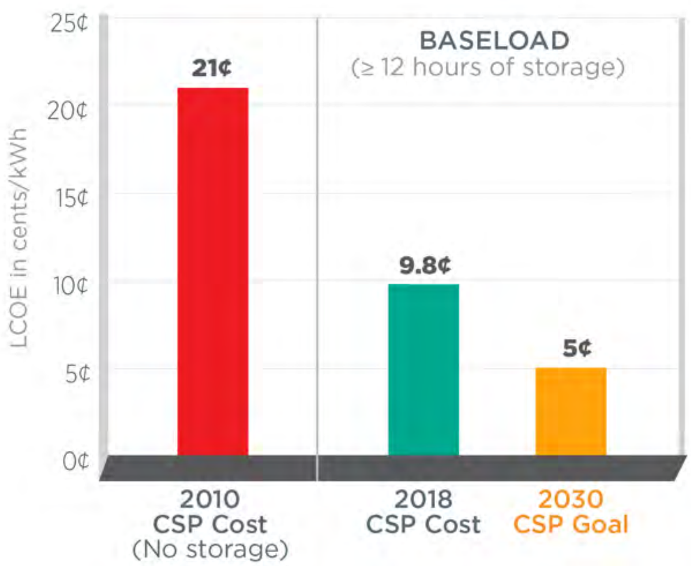

Figure 4: 2030 CSP LCOE cost targets for CSP plants with 12 or more hours of storage.

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, like the integration of solar onto the electric grid and with other energy technologies to support grid reliability and resilience. Today, solar only contributes energy to the grid—it doesn't help grid operators maintain system-wide balance or provide other grid services. The office is also working to harness the capabilities of connected distributed energy resources to improve grid resilience, including restarting power during an outage, improving cybersecurity, minimizing land-use competition, as well as expanding access to solar and energy affordability to all Americans. In addition, there are opportunities to continue to advance technologies to further reduce electricity costs and to build a strong U.S. supply chain and manufacturing industry.

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 totally 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.[11] 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 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 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.

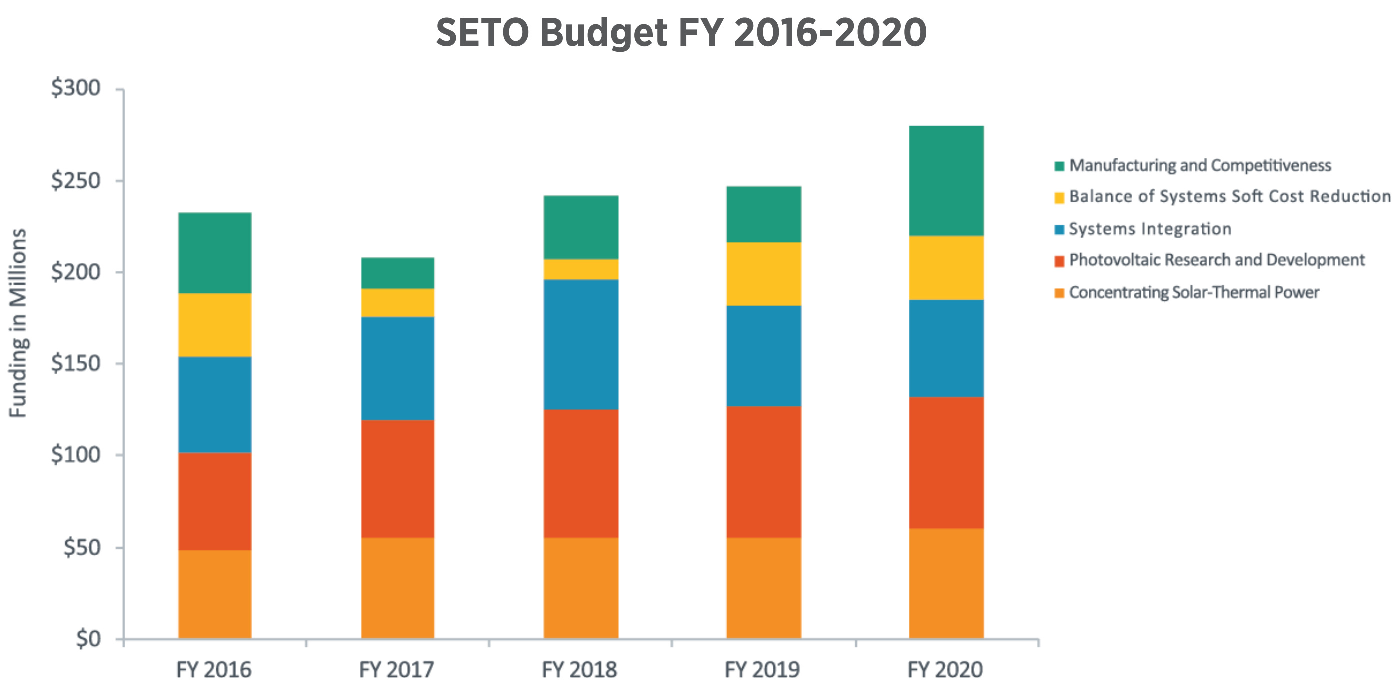

Figure 5: SETO's budget areas are determined by Congress through the annual appropriations process.[12]

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.

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. 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.

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

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

- **Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs** (typically 4 percent of funding): The SBIR/STTR programs are competitive 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, funding opportunity announcements (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 funding opportunity announcements 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.

Frequently Asked Questions about SETO Funding

How does SETO decide what topics it funds in its FOAs?

Prior to the release of a FOA, SETO determines the right problems to address through discussions with stakeholders, research and analysis, and congressional and administrational direction. The office engages with stakeholders through workshops, the Peer Review, conferences and other events, and also can release requests for information (RFIs), which solicit written input from stakeholders. Once the office writes a FOA, it must go through leadership approval within DOE, and may also require review from other DOE offices.

What are SETO's funding restrictions?

There are several limitations to government funding. SETO cannot:

- *Fund the development of policy at a local, state, or federal level;*
- *Fund advocacy work;*
- *Fund passive solar or solar hot water projects;*
- *Purchase solar systems for individuals or other entities;*
- *Provide loans for solar technology demonstrations. Certain projects may receive loans from DOE's Loans Program Office;*
- *Seek out companies to fund.*

Does SETO fund companies outside of FOAs or prize programs?

In almost all cases, SETO only provides funding through FOAs or through prize programs. Although SETO is interested in learning about any idea that has the potential to push the solar energy industry forward, the office has very specific rules that it must follow to administer federal funding for solar energy research, development, and commercialization efforts.

Can SETO speed up the funding process?

SETO makes every effort to streamline the application and selection process. Many aspects of the process are set by federal rules and regulations; these are the primary drivers of the application materials we require and the process timeline. Prizes require less information to apply and in some cases, prize competitors can receive funding faster than other types of SETO funding, but competitors must show results before receiving money.

Why does SETO require so much information when people apply? It's burdensome.

We must comply with federal funding and documentation processes to distribute funds through our FOAs. SETO does its best to limit the amount of information and documentation necessary to administer federal funds at each step of the application process, but ultimately SETO will need all legally required documentation to start an award and reimburse funds. The laws governing FOAs are 2 CFR 200 and 2 CFR 910. Prizes require less information to apply, but competitors must show results to receive funding.

Why doesn't SETO cancel award ?

SETO regularly evaluates projects at pre-negotiated go/no-go decision points. It is at that time SETO and the awardee can assess the ongoing value of a project and have the opportunity to redirect or end awards. For questions on specific project, please reach out to the appropriate program manager.

Can SETO do any proactive teaming for funding opportunities?

SETO cannot direct specific teams to apply to FOAs or compete in prizes. However, in recent FOAs, we have made Teaming Partner Lists, which allows organizations that may wish to apply to the FOA but not as the prime applicant, to express interest to potential partners.

Can SETO ask specific entities to work together?

No. SETO cannot force or encourage specific entities to work together. SETO can only provide an online space so that interested parties may make connections between each other and explore possible synergies.

Does SETO play an active role in the outcomes of projects?

Most of SETO funding is in the form of cooperative agreements, which gives SETO the ability to direct and redirect work conducted under the agreements. This includes negotiation of statements *of work and milestones, approval of redirections of work or project funds, and regular calls with awardees to discuss project results and share our expertise on how projects could be improved.*

Does SETO have any mandates to fund specific geographies?

No. However, SETO does have the ability to select projects to improve the geographic diversity of our overall portfolio.

Is the technical quality of a proposal the only factor that goes into selections?

Technical quality is the primary driver for selections, but SETO also considers factors such as, but not exclusive to, overall award portfolio diversity, if the proposed work is appropriate for government funding, if it furthers the SETO mission, if it is too mature or pre-mature for SETO mission space, the office portfolio's geographic diversity, redundancy with any ongoing work, and more.

Is SETO limited in what it can discuss about funding programs?

When funding programs are open for applications, SETO cannot discuss specifics of the FOA or answer questions about specific potential applications. SETO does want to help applicants understand the funding opportunities and communicate with possible applicants in a fair manner. SETO will answer questions through a public email address and will post all answers publically so that no applicant is given an unfair advantage through private consulting with SETO staff.

Peer Review Overview

The SETO 2020 Peer Review gathers representatives from all of SETO's active projects along with leading solar industry experts to review progress across the portfolio. The review covers the nearly 400 active projects in the office's portfolio, totaling nearly $750 million in federal funding. Reviewers will evaluate the relevance and impact of each individual project and the portfolio as a whole. Further, reviewers will examine 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 will help identify strategies that will shape SETO's work in the future. After a careful review of the projects, the feedback collected from independent, third-party reviewers will be consolidated into a report that will be made available to the public, Congress, and DOE leadership.

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

Figure 6: 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 will be divided between five tracks: Photovoltaics, Concentrating Solar-Thermal Power, Systems Integration, Soft Costs, and Strategy and Planning. The tracks will review 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 are 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 will examine the entire SETO portfolio from a broader perspective.

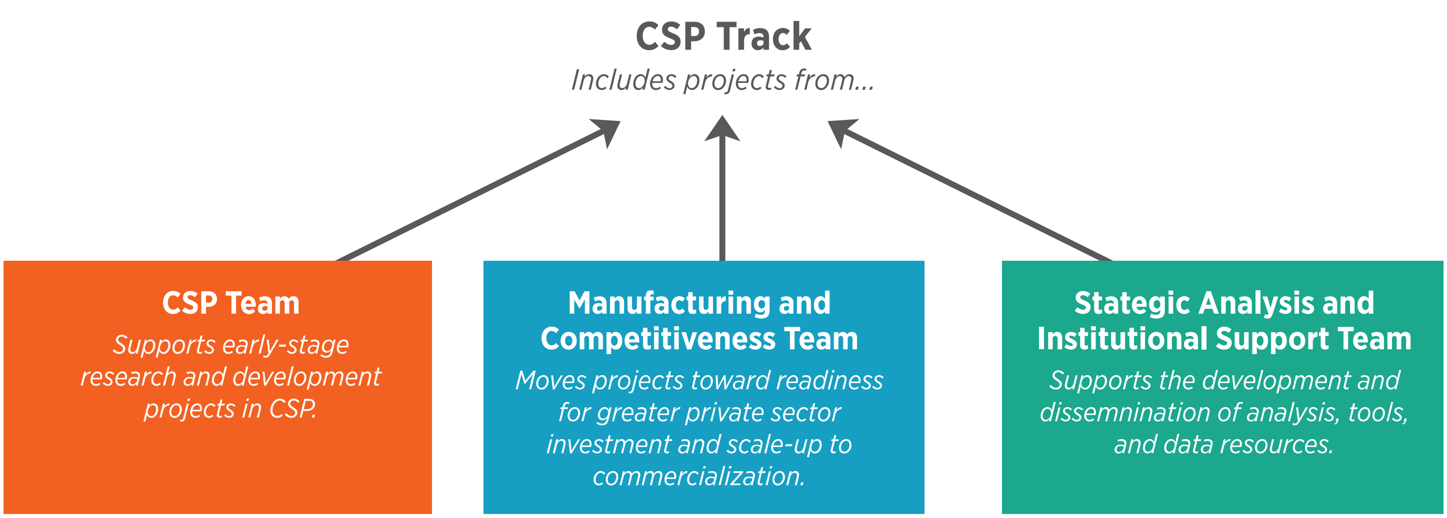


Figure 7: The CSP Peer Review Track includes projects from the CSP team, the Manufacturing and Competitiveness team, and the Strategic Analysis and Institutional Support team.

Across the five tracks, there are 18 topic areas that drive the breakout sessions. During these breakout sessions, SETO staff will provide a broad overview of the office's strategy, funding, and projects in that area and allow for a discussion amongst the reviewers and awardees. These topics will be reviewed based on how the projects in this area help to achieve the office's broader goals, what gaps or barriers remain, and where the office could break new ground. It will also allow reviewers and other attendees to provide feedback on any critical areas that may be falling behind in that topic area, like in 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

- Innovative Ecosystems
- PV Markets and Regulation
- Solar Energy Access
- Workforce

Strategy and Planning

- Technology to Market
- Cross-Cutting
- Portfolio Review

Figure 8: Project in the she SETO Peer Review are divided between five tracks and 18 topic areas.

There are 391 projects being reviewed at various stages of their project cycles—from projects that have just been selected in the last few months and haven't started work, to those that are about to conclude. Projects are not distributed evenly throughout the tracks—roughly 30 percent of the projects and funding will be reviewed in the Photovoltaics track, while the Strategy and Planning track will review four percent of projects and three percent of funding. However, the Strategy and Planning track will also be examining the portfolio as a whole. Insights from each track will inform our overall strategic planning.

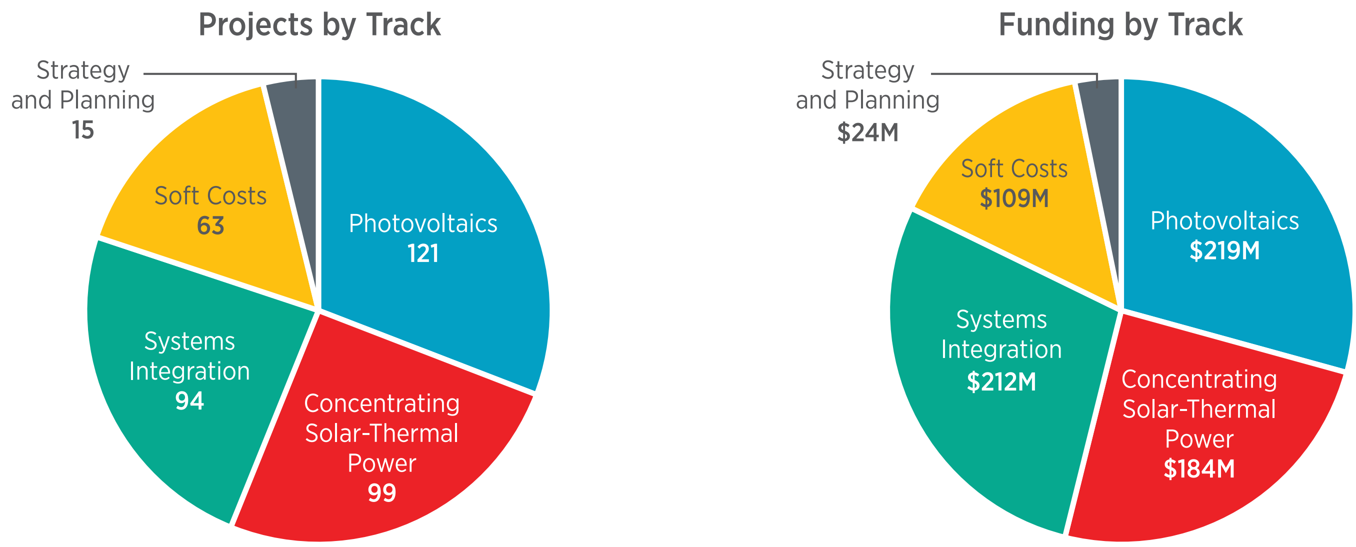


Figure 9: The projects in the peer review are divided by research areas and are not distributed evenly by number or funding amount throughout the tracks.

Final Report

The primary deliverable of the Peer Review is the final report. This report will provide SETO with feedback about the overall goals and strategy of the office, how well the portfolios address these goals, the appropriateness of project selection and funding amounts, and how effective these projects will be in advancing the solar industry as a whole. Reviewers will be assigned up to 20 projects to review. These project-level reviews will inform the review of the topic area, tracks, and portfolio as a whole.

This report will be organized by track and topic area, and will include the responses written by the lead reviewers and chairs, as informed by the project-level reviews. One lead reviewer is assigned to each of the topic areas (with the exception of the Strategy and Planning topics, which are addressed by the full review team). In addition to reviewing up to 20 projects, the lead reviewer also provides in-depth feedback on the topic area as a whole, based on comments from all of the other reviewers in their topic as well as their own project-level reviews. Chairs are assigned to lead each of the five tracks. Chairs are responsible for providing an in-depth response that incorporates the summaries from the lead reviewers of each topic within the track along with their own analyses.

Projects will be reviewed based on their:

- Goals, approach, and expected impact
- Performance to date
- Impact on and importance to the industry
- Stakeholder engagement

Topic areas will be reviewed based on their:

- Alignment with defined goals and strategy
- Appropriateness of the funding level and number of projects
- Uniqueness and value in achieving the strategic goals of this topic and SETO
- Success at advancing the mission of SETO and the U.S. solar industry as a whole

Tracks will be reviewed based on their:

- Alignment with defined goals and strategy
- Appropriateness of the funding level and number of projects
- Uniqueness and value in achieving the strategic goals of this topic and SETO
- Success at advancing the mission of SETO and the U.S. solar industry as a whole

The rest of this book details the tracks, topic areas, and projects that will be reviewed during the Peer Review.

Photovoltaics

The Photovoltaics track supports research and development of technologies that drive down the costs of solar electricity by improving efficiency and reliability of photovoltaics and lowering manufacturing costs. This portfolio of projects spans our 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 dramatic cost reductions.

There are 121 active projects in the Photovoltaics track for a total of more than $219 million in federal funding; nearly one in three SETO projects falls under this category. 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. More than half of the world's solar cell efficiency records, which are tracked by the National Renewable Energy Laboratory, were supported by the U.S. Department of Energy, mostly by the SETO Photovoltaics subprogram and its predecessors. Approximately two percent of U.S. electricity is now generated by photovoltaics, in part thanks to the research and development projects funded by DOE over several decades that contributed to the current low costs of photovoltaic technologies.

The Photovoltaics track includes 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. Projects from the Strategic Analysis and Institutional Support team 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 photovoltaic industry has come a long way in the last 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. The Department of Energy envisions further cost reductions in the coming decade, which motivates the current research and development projects in the photovoltaics track.

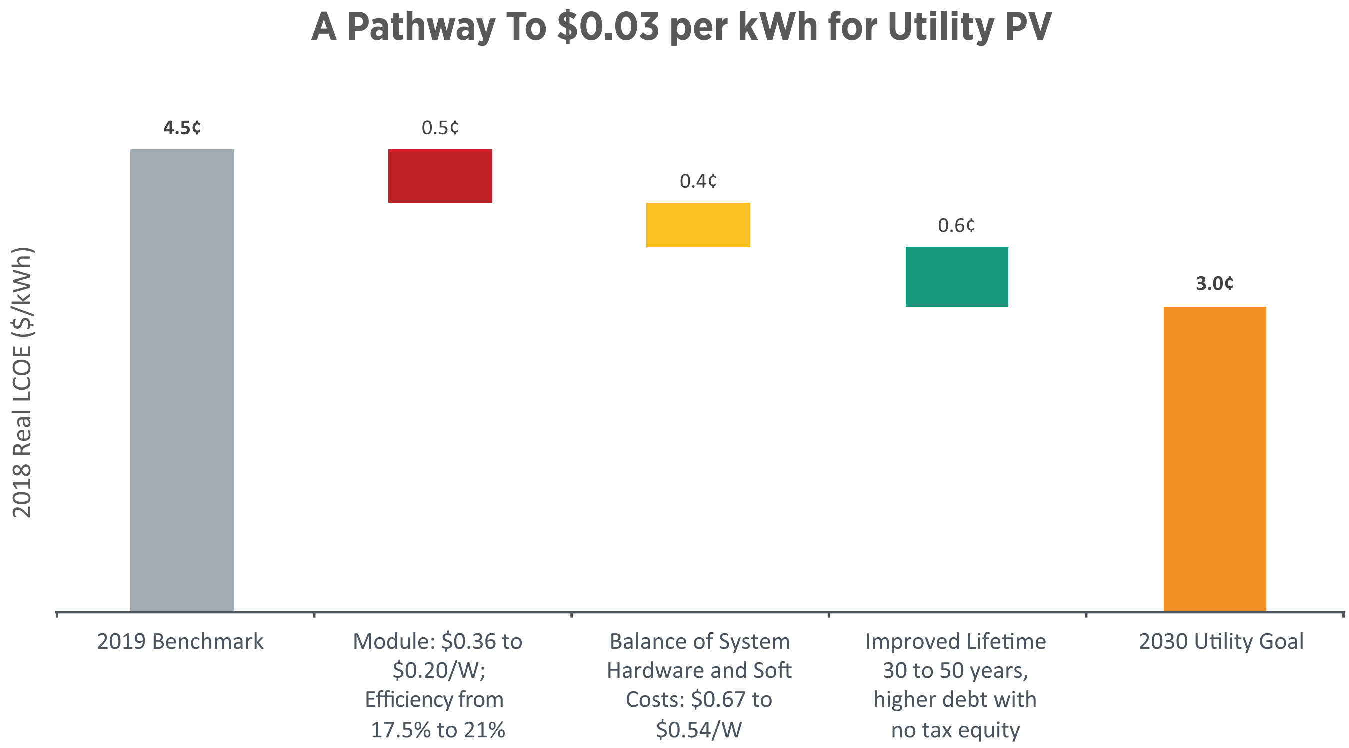
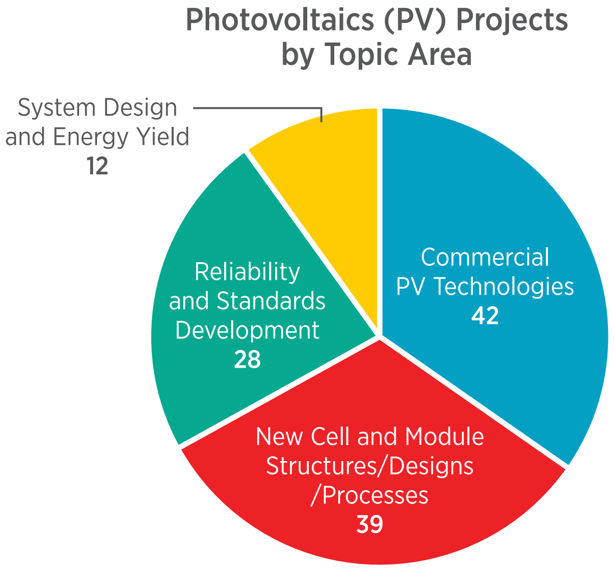
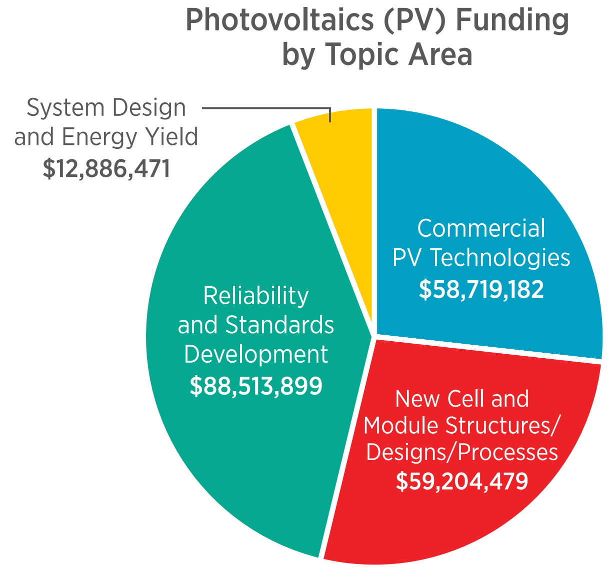


Figure 10: Sample scenario for reducing costs to $0.03 per kWh for utility-scale systems.

As shown in Figure 10, future improvements in the module cost, balance of system 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 reaching a levelized cost of $0.03 per 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 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. A description of each can be found below, along with a detailed list of the projects within it. Projects are alphabetized by the awardee name and represented in the following format:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

Projects managed by the Innovations in Manufacturing and Competitiveness team are identified with a blue diamond (♦) after the project name and amount.

Projects managed by the Strategic Analysis and Institutional Support team are identified with a red spade (♠) after the project name and amount.

Commercial Photovoltaic Technologies

As commercial photovoltaic 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 cadmium telluride and copper indium gallium selenide.

More than a third of the projects in the Photovoltaics track focus on commercial photovoltaic 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 productions costs to reach the goal of $0.03 per kilowatt-hour.

FIELD-EFFECT PASSIVATION BY DESIRED CHARGE INJECTION INTO SILICON NITRIDE PASSIVATION IN CRYSTALLINE-SILICON SOLAR CELLS – $1,118,958

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

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

BRINGING HIGH-EFFICIENCY SILICON SOLAR CELLS WITH HETEROJUNCTION CONTACTS TO MARKET WITH A NEW, VERSATILE DEPOSITION TECHNIQUE – $1,000,000

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

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

DIAGNOSING AND OVERCOMING RECOMBINATION AND RESISTIVE LOSSES IN NON-SILICON SOLAR CELLS USING A SILICON-INSPIRED CHARACTERIZATION PLATFORM – $1,500,000

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

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

IMPACT OF UNDOPED SUBSTRATES ON HIGH PERFORMANCE SILICON SOLAR CELLS – $200,000

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

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

OPERANDO X-RAY NANOCHARACTERIZATION OF POLYCRYSTALLINE THIN FILM MODULES – $1,600,000

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

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

PHOTOVOLTAIC FOUNDRY: INCREASING MANUFACTURING CAPABILITIES IN THE US BY DEVELOPING PASSIVATED CONTACT PHOTOVOLTAIC TECHNOLOGY – $1,750,000

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

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

UNDERSTANDING DEFECT ACTIVATION AND KINETICS IN NEXT GENERATION CADMIUM TELLURIDE ABSORBERS – $510,750

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

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

DIRECT METALLIZATION WITH REACTIVE INKS: ASSESSMENT OF RELIABILITY AND PROCESS SENSITIVITIES - $1,400,000

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

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

NEW APPROACHES TO LOW-COST SCALABLE DOPING FOR INTERDIGITATED BACK CONTACT CRYSTALLINE SILICON SOLAR CELLS – $615,000

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

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

POST-GROWTH RECRYSTALLIZATION BY HALIDES FOR HIGH THROUGHPUT COPPER INDIUM GALLIUM SELENIDE PHOTOVOLTAICS – $900,000

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

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

ADVANCED MODULE ARCHITECTURE FOR REDUCED COSTS, HIGH DURABILITY, AND SIGNIFICANTLY IMPROVED MANUFACTURABILITY – $1,015,000

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

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

BACK-CONTACT INTERFACE ENGINEERING FOR HIGHER EFFICIENCY CADMIUM TELLURIDE PHOTOVOLTAICS – $3,500,000

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

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

DEVICE ARCHITECTURE FOR NEXT-GENERATION CADMIUM TELLURIDE PHOTOVOLTAICS – $899,922

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

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

DOPING CADMIUM TELLURIDE AND CADMIUM SELENIUM TELLURIDE FOR HIGHER EFFICIENCY – $750,000

Colorado State University | Fort Collins, CO | Principal Investigator: Walajabad Sampath

This project is working to significantly enhance the voltage and efficiency of cadmium telluride and cadmium selenium telluride solar cells through p-type doping with group-V atoms. Colorado State University, with help from multiple partners including the National Renewable Energy Laboratory and First Solar, is using arsenic to increase the density of holes in the absorber by two orders of magnitude. The team seeks to increase the cell voltage by 100 millivolts and improve cell efficiency by up to 20 percent. The key to success will be the activation of a major portion of the dopant atoms so that they each contribute a hole to the absorber while minimizing the recombination that commonly results from non-activated dopant atoms. The team will ensure that its cell-fabrication steps are compatible with low-cost, large-scale manufacturing.

TECHNOLOGY DEVELOPMENT FOR 22.5 PERCENT EFFICIENT P-TYPE PASSIVATED EMITTER AND REAR CONTACT SOLAR CELLS – $700,000

Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Ajeet Rohatgi

This project is developing key technologies to achieve commercial-size passivated emitter and rear contact cells with a 23 percent efficiency up from a current efficiency of about 22 percent. The team will integrate multiple technologies to create the solar cell, including spatially controlled doping profiles, passivated rear contacts, advanced annealing treatments, and high-resolution screen printing. Together, these technologies will reduce carrier recombination rates in the junction region, at the back surface field, and at the interfaces within each contact while also minimizing front shading and rear light absorption. To improve solar cell performance, the team is using the same process on n-type silicon to produce rear junction n-type cells with spatially controlled front surface fields.

PUSHING THE EFFICIENCY LIMIT OF LOW-COST, INDUSTRIALLY-RELEVANT SILICON SOLAR CELLS BY ADVANCING CELL STRUCTURES AND TECHNOLOGY INNOVATIONS – $1,425,000

Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Ajeet Rohatgi

This project aims to advance manufacturable silicon cell technologies to above 22 percent efficiency through the use of passivated selective emitter and selective back surface field contact geometries. The improved contact and metallization methods investigated during the course of the project will reduce recombination and improve cell performance by up to two percent absolute efficiency. Multiple fabrication methodologies will be investigated to determine the most cost-effective method for producing the laterally patterned doping profiles needed to realize this high-performance cell technology.

BRITTLE FRACTURE WAFERING OF SILICON INGOTS FOR LOW-COST, HIGH-EFFICIENCY CRYSTALLINE SILICON SOLAR CELLS – $1,073,288

Halo Industries | San Mateo, CA | Principal Investigator: Andrei Iancu

This project is developing and prototyping new solar wafer manufacturing technologies with the goal of significantly reducing the materials cost of all existing crystalline silicon solar cell architectures. The objective is to streamline the solar wafer fabrication process through more efficient and automated production line tools that eliminate silicon waste while reducing both process and operational complexity. Using a proprietary technology, this will reduce silicon solar cell material costs by at least 40 percent as well as drastically improve operational efficiencies for the majority of solar wafer fabrication steps through process simplification and automation.

DEVELOPMENT OF A LOW-COST SINGLE CRYSTAL SILICON SUBSTRATE PROCESS FOR SOLAR CELLS WITH EFFICIENCIES HIGHER THAN 23 PERCENT – $2,500,000

Leading Edge Crystal Technologies | Gloucester, MA | Principal Investigator: Alison Greenlee

This project will improve Leading Edge's floating-silicon method for producing high-quality single crystalline wafers, as opposed to the conventional process of using wire saws to slice the wafers off a block of silicon called an ingot. Sawing creates silicon shavings that waste material, whereas this technology produces continuous thin silicon ribbons. The goal of this work is to remove any contaminating oxygen impurities in the silicon while it changes from liquid to solid, through increased understanding and better-engineered floating silicon furnaces.

REFINEMENT OF THE FLOATING SILICON METHOD: A LOW-COST MONOCRYSTALLINE SILICON WAFER MANUFACTURING PROCESS – $1,500,000

Leading Edge Crystal Technologies | Gloucester, MA | Principal Investigator: Peter Kellerman

This project is developing the first kerfless manufacturing process that continuously produces single-crystal silicon wafers. This process leverages breakthrough developments in heat transfer and crystal growth to yield high quality wafers at unprecedented production rates, underpinning a potential 60 percent cost reduction over existing single-crystal wafer production. As a drop-in substitute in the existing solar supply chain, these wafers have the potential to reduce the all-in solar module manufacturing cost by 25 percent. This project will support the production of sample wafers from an experimental production machine that will be used to both refine the process and demonstrate wafer performance to the industry. These wafers and corresponding cells will generate the market traction needed to initiate further commercialization of the technology.

EXPLOITING FIXED CHARGE AT SELECTIVE CONTACTS FOR SILICON PHOTOVOLTAICS – $200,000

Lehigh University | Bethlehem, PA | Principal Investigator: Nicholas Strandwitz

In a silicon solar cell, thin metal lines are applied to the silicon absorber that serve as electrical contacts in the solar cell. These electrical contacts must efficiently conduct current out of the absorber layer to boost solar cell performance. However, sometimes there are undesirable barriers that form between the two layers that hinder the efficient conduction of current. This team is investigating the use of alumina oxide as a fixed charge layer in the solar cell. They will deposit it between the absorber layer and the front contact of the solar cell to mitigate the effect of these barriers. This project uses atomic layer deposition to grow alumina and the contact layers in the lab and will use a variety of techniques to reveal the structural, chemical, and interfacial electronic properties of the material in order to determine the suitability of this strategy for commercial photovoltaic applications.

HYDROSCANNER - WATER INGRESS EVALUATION TOOL – $250,000

Lawrence Livermore National Laboratory | Livermore, CA | Principal Investigator: Mihail Bora

Water reduces the lifespan of solar panels and accelerates the degradation rate for the module's power efficiency. This project is developing an imaging system to measure how much water gets into photovoltaic modules and related packaging materials, including encapsulants, moisture barriers, and edge seals.

ADVANCED THIN FILM CORE TECHNOLOGY: COPPER INDIUM GALLIUM SELENIDE AND CADMIUM TELLURIDE – $11,841,432

National Renewable Energy Laboratory | Golden, CO | Principal Investigators: Lorelle Mansfield and Wyatt Metzger

This project addresses core photovoltaic cell research to maximize the performance of photovoltaics using advanced thin-film copper indium gallium selenide and cadmium telluride technologies. Solar cells just several microns thick—one-tenth the diameter of a human hair—can be made on inexpensive and abundant glass, plastic, or metal foil very quickly with materials such as cadmium telluride and copper indium gallium selenide. This has reduced market costs for solar energy and cleared paths for novel, flexible, lightweight applications, including integrating solar energy into buildings, aircraft, and military applications. This project will advance the fundamental materials science, physics, and chemistry of thin-film technologies and seeks to improve solar cell efficiency while further reducing costs.

APPLICATION AND DEVELOPMENT OF ADVANCED ELECTRO-OPTICAL CHARACTERIZATION FOR HIGHLY EFFICIENT AND RELIABLE THIN-FILM SOLAR CELLS – $1,800,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Darius Kuciauskas

To determine the sources of power and performance losses in thin-film solar cells, this project works to develop new electro-optical photovoltaic characterization techniques to look at the interfaces between different layers inside thin-film devices. The team will integrate new capabilities with state-of-the-art thin-film characterization at the National Renewable Energy Laboratory in collaboration with national lab, industry, and university researchers. This collaborative research enables the development of more efficient and reliable solar cells, with particular emphasis on cadmium telluride.

INTERDIGITATED BACK CONTACT POLYCRYSTALLINE DEVICE – $240,105

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: David Albin

The basic structure of polycrystalline thin-film devices like cadmium telluride and copper indium gallium selenide have not changed significantly over the past 20 years and consist of at least two discrete active layers to transmit, absorb, and separate photo-generated carriers. Though efforts to optimize layers in these structures have resulted in remarkable improvements, there are new efforts to develop a simpler structure that results in a cheaper and more reliable device. This project is investigating the creation of a device structure that consists of an interdigitated back contact solar cell—a solar cell with two metals—to establish the field necessary to separate electron-hole pairs absorbed by a single, cadmium telluride or selenide absorber that has a long lifetime and doesn't have window or buffer layers.

SILICON PHOTOVOLTAICS CORE CAPABILITY – $10,500,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Paul Stradins

This project is conducting silicon-based photovoltaic cell research and process engineering. The team is working to define, approach, and invent next-generation silicon photovoltaic materials and device concepts, as well as identify and overcome limitations in efficiency and large-scale production. This work will maintain national laboratory core capabilities and expertise in silicon photovoltaics and support workforce training efforts that develop highly qualified research professionals. This project also supports research efforts with academia and industry that advances the knowledge base of fundamental materials science, physics, and chemistry of silicon-based photovoltaic technologies.

IMPROVED SOLAR CELL PERFORMANCE AND RELIABILITY THROUGH ADVANCED DEFECT CHARACTERIZATION AND GROWTH STUDIES - $1,500,000

Ohio State University | Columbus, OH | Principal Investigator: Aaron Arehart

Copper indium gallium selenide photovoltaic solar cells experience defects that reduce efficiency and researchers have been unable to eliminate these defects. If resolved, efficiency could improve from approximately 19 percent to approximately 23 percent. This team is connecting the measured defects to their physical sources using chemical and nano-structural techniques and other photoluminescence-based techniques. Using advanced, physics-based modeling, the team will identify and test copper indium gallium selenide growth conditions of the absorber layer in order to improve cell performance, lower device instabilities, and lower degradation rates, all of which could improve reliability and lower the levelized cost of energy.

TOWARD COMMERCIALIZATION OF LOW-COST, CRACK-TOLERANT, SCREEN-PRINTABLE METALLIZATIONBY FULL-SIZE MODULE TESTING AND FIELD CHARACTERIZATION – $1,000,000 ♦

Osazda Energy | Albuquerque, NM | Principal Investigator: Sang Han

This project is developing a cost-effective metal paste that strengthens the metal connections in solar cells, improving their resistance to fracture, and minimizes cracks that result from degradation and handling. This will increase the long-term durability of the cells. The team will measure and compare crack tolerance with this paste compared with conventional metallization paste, and work with several partners, including a group at Sandia National Laboratories, to test the modules in the field.

DEVELOPING A SINGLE BEAM ION SOURCE TECHNOLOGY FOR EFFICIENT MANUFACTURING OF TRANSPARENT CONDUCTIVE THIN FILMS – $800,000 ♦

Scion Plasma | East Lansing, MI | Principal Investigator: Maheshwar Shrestha

This project is developing a tool that rapidly deposits transparent conductive oxide onto heterojunction silicon with intrinsic thin layer solar cells, improving their performance. These cells are more efficient than other device structures but require a transparent conductive oxide. However, these oxides are costly and difficult to deposit quickly without altering the structure of the cell and lowering its efficiency. This technology will increase the oxide deposition rate, which will increase the manufacturing rate of these cells while reducing the cost, thereby increasing their market value.

FIELD FACTORY FOR COST REDUCTION AND DEPLOYMENT ACCELERATION OF PHOTOVOLTAIC POWER PLANTS – $999,781 ♦

Terabase Energy | Berkeley, CA | Principal Investigator: Dan Cohen

This project is working to create a new field factory facility that delivers photovoltaic power plants and reduces soft costs. The team is designing and field-testing key subsystems of this approach to project construction before conducting an integrated field demonstration. This work will validate the cost, time, and levelized cost of energy targets that underpin the benefits of this facility and prepare the technology for broader commercialization within the industry. The goal is to enable better process control, lower costs, enhanced safety, and faster installation rates.

EXPLORING SILICON HETEROJUNCTION SOLAR CELL DEGRADATION: BULK AND INTERFACE PROCESSES ANALYZED BY SIMULATIONS AND EXPERIMENTS IN ORDER TO DEVELOP MITIGATION STRATEGIES – $200,000

University of California, Davis | Davis, CA | Principal Investigator: Gergely Zimanyi

This project is working to determine whether hydrogen degrades two types of solar cells: heterojunction silicon cells, which consist of thin silicon layers on crystalline silicon wafers, and advanced passivated emitter rear contact cells, which are built to capture more light on the back surface of the cell. The team will identify what causes defects in heterojunction cells and at passivated emitter rear contact interfaces, to develop mitigation strategies and improve stability.

MICRODROPLET ELECTROSPRAY LOCALIZED LASER PRINTING AND SINTERING OF NANOPARTICLES FOR PASSIVATED, CARRIER-SELECTIVE CONTACTS – $200,000

University of Central Florida | Orlando, FL | Principal Investigator: Kristopher Davis

This project is working to enable the printing of silver contacts on silicon solar cells with very little thermal energy use, through a scalable technology called a nanoparticle electrospray laser deposition NELD. This technology will deposit silver microdroplets on the base of a silicon solar cell, then fuse the nanoparticles together with a laser, a process known as sintering. This project will lower costs and improve cell performance.

NOVEL AND EFFECTIVE SURFACE PASSIVATION FOR HIGH EFFICIENCY N- AND P-TYPE SILICON SOLAR CELLS – $800,000

University of Delaware | Newark, DE | Principal Investigator: Ujjwal Das

Passivation of surface defects is key to achieving high-efficiency silicon solar cells. This project aims to achieve superior surface and cell performance in silicon photovoltaics by using sulfur and selenium compounds to passivate the silicon surface and enable high open circuit voltage. The team is analyzing sulfur and selenium surface behavior using advanced X-ray and capacitive characterization methods for advanced cell design applications, such as p-type passivated emitter rear contact and n-type passivated emitter rear totally diffused structures, where voltage has traditionally been a major limiting parameter.

WIDE-BANDGAP POLYCRYSTALLINE III-VS AS TRANSPARENT, CARRIER-SELECTIVE HETEROJUNCTION CONTACTS FOR SILICON PHOTOVOLTAICS – $200,000

University of Illinois at Urbana-Champaign | Champaign, IL | Principal Investigator: Minjoo Lee

This project is testing visibly transparent III-V materials grown at low temperatures for use within the front contact of a silicon solar cell. The cell has heterojunction contacts, which are state-of-the-art contacts that can efficiently extract voltage from silicon solar cells at high rates. The team will then grow heavily doped layers of aluminum gallium phosphide and aluminum indium phosphide on textured silicon solar cells to explore the doping and defects within the cell. Finally, the team will characterize the surface passivation and contact resistance of the most promising layers and make complete photovoltaic cells with the heterojunction contacts.

RESEARCH AND DEVELOPMENT OF ARCHITECTURES FOR PHOTOVOLTAIC CELL-LEVEL POWER BALANCING USING DIFFUSION CHARGE REDISTRIBUTION – $800,000

University of Michigan | Ann Arbor, MI | Principal Investigator: Al-Thaddeus Avestruz

This project is conducting photovoltaic cell-level power balancing using diffusion charge redistribution to increase efficiency, lower manufacturing costs, and improve reliability. This work will examine the use of on-module power electronics to enable cell-level power optimization and transform the often complex current-voltage characteristics a string of solar cells into a well-behaved "super-cell" that eliminates cell power imbalances, mismatches, and partial failures.

IMPROVING ENERGY YIELD IN PHOTOVOLTAIC MODULES WITH PHOTONIC STRUCTURES – $147,163

University of Minnesota | Minneapolis, MN | Principal Investigator: Vivian Ferry

Silicon-based photovoltaic modules operate above ambient temperatures, which both decreases energy yield and reduces the lifetime of the module. One of the major sources of elevated temperature is the parasitic absorption of sub-bandgap radiation. This project is working to create photonic structures on the surface of a crystalline silicon cell that increase energy yield by simultaneously improving anti-reflection of above-bandgap light and reducing module temperature through reflection of infrared light. The structures will be deposited over the existing pyramids on the cell surface, and will be comprised of a small number of layers to be cost-effective. The structures will be created using a combination of opto-electrical-thermal modeling and experimental fabrication.

NOVEL N-TYPE DEVICE ARCHITECTURES TO ACHIEVE 1 VOLT VOLTAGE AT OPEN CIRCUIT IN THIN FILM CADMIUM TELLURIDE CELLS – $645,000

University of South Florida | Tampa, FL | Principal Investigator: Chris Ferekides

Cadmium telluride solar cells are a low cost thin-film technology that has achieved commercial success in the solar market. To expand the opportunities for cadmium telluride technologies, this project is exploring a new cell design which starts with n-type cadmium telluride instead of the p-type that is commercially used today. This new approach could enable higher efficiency levels than those currently being mass produced. The team is using industrially relevant deposition techniques to demonstrate that the fabrication of n-cadmium telluride solar cells is possible at scale with efficiencies approaching 2 percent, an increase of two percent from current world record cadmium telluride solar cells.

INVESTIGATING LOCAL CARRIER DYNAMICS IN PERC PATTERNED CADMIUM TELLURIDE SOLAR CELLS – $214,904

University of Utah | Salt Lake City, UT | Principal Investigator: Heayoung Yoon

This project is developing a cadmium telluride passivated emitter rear contact solar cell that comprises a patterned aluminum oxide layer and small metal contacts defined on individual grains for greater cell efficiency and power output. Passivated emitter rear contact cells are designed to capture more light on the back surface of the cell. The team is using current generated by a concentrated stream of electrons to detect any defects in the passivated emitter rear contact design and quantify changes in physical parameters, such as the components' efficiencies, using 2- and 3-D numerical models.

COPPER INDIUM GALLIUM SELENIDE TECHNOLOGY ADVANCEMENT VIA FUNDAMENTAL MODELING OF DEFECT/IMPURITY INTERACTIONS – $691,014

University of Washington | Seattle, WA | Principal Investigator: Scott Dunham

Copper indium gallium selenide is a promising material for high performance, low-cost thin-film photovoltaics. In order to improve conversion efficiency and lower manufacturing costs, researchers need to better understand interactions between mineral impurities and native defects, as well as how both couple to alloy ordering and phase separation within these cells. This team is using density functional theory calculations to predict distributions of defects and defect complexes, estimate reaction and diffusion rates, and perform simulations to predict alloy, impurity, and defect ordering. The team will test the resulting model and process in order to optimize device performance, reliability, and cost.

DEVELOPING A LOW-COST, HIGH-VOLUME AND SCALABLE MANUFACTURING TECHNOLOGY FOR CADMIUM TELLURIDE FEEDSTOCK MATERIALS – $1,343,301

Washington State University | Pullman, WA | Principal Investigator: Kelvin Lynn

This project is developing low-cost, high-volume, scalable cadmium telluride feedstock production technology, which can be commercialized to deliver high quality feedstocks to industry at a reduced cost with rapid production rate. The material quality of feedstocks is optimized to the needs of high efficiency solar panel production. A novel cadmium telluride synthesis and growth process will be developed and scaled up, and the grown material will be evaluated with respect to defect structure, carrier lifetime, and unintentional impurities.

PREPARATION AND EVALUATION OF N-TYPE CADMIUM SELENIUM TELLURIDE AND CADMIUM TELLURIDE AS AN ABSORBER IN THIN FILM PHOTOVOLTAICS – $188,561

Washington State University | Pullman, WA | Principal Investigator: Kelvin Lynn

The power-conversion efficiency of conventional p-type cadmium telluride absorbers is limited by relatively poor electronic properties, including low carrier lifetime, low doping levels, and challenges with back contact formation. This project aims to produce and evaluate n-type doped cadmium selenium telluride thin films that have the potential to exceed the performance of conventional absorber layers while maintaining the low manufacturing costs inherent to thin-film module architectures. The team will use close-space sublimation and newly developed feedstock materials, followed by heat treatments in the presence of carefully chosen gases to obtain high-quality n-type cadmium selenium telluride with the enhanced electronic properties needed to create high-efficiency thin-film solar cells.

ENVIRONMENTALLY SOUND ONE-STEP LOW-COST SOLAR SILICON FROM NATURAL QUARTZITE – $200,000

Worcester Polytechnic Institute | Worcester, MA | Principal Investigator: Adam Powell

This project aims to produce pure silicon by developing a system that will electrochemically reduce natural quartzite to high-purity silicon in a molten salt bath. This process could significantly lower the cost of silicon.

New Cell and Module Structures/Designs/Processes

While there are many successful photovoltaic 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 levelized cost of energy 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.

QUANTUM ENERGY AND SUSTAINABLE SOLAR TECHNOLOGIES – $8,835,997

Arizona State University | Tempe, AZ | Principal Investigator: Christiana Honsberg

Quantum Energy and Sustainable Solar Technologies (QESST) is an engineering research center sponsored by the National Science Foundation and the Solar Energy Technologies Office. Launched in 2011 and based out of Arizona State University, QESST focuses on advancing photovoltaic science, technology, and education in order to transform the existing electricity generation system. The center's primary research areas are silicon cells and modules, tandem photovoltaic cell architectures on traditional silicon utilizing thin-film or III-V absorbers, and improving the performance of photovoltaics using test beds that can demonstrate manufacturability, integration, and sustainability of solar technologies. In addition to this research, QESST develops solar and photovoltaic education programs for graduate and undergraduate students, K-12 students and teachers, as well as outreach programs for the general public. QESST is designed to set the solar industry on a path to terawatt levels of installed photovoltaic generation in 15 to 20 years.

SONICWAFERING™ OF III-V SUBSTRATES FOR HIGH EFFICIENCY CELLS: A PATH TO LESS THAN $0.50 PER WATT – $2,500,000

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

Creating the base, or substrate, of a solar cell typically requires sawing silicon blocks, but using sound waves instead of a metal saw results in less material waste and improves the lifetime of the substrate. This team is proving the viability of a sonic wafering process that uses low temperatures and intense sound waves to carefully and accurately remove completed gallium arsenide solar cells from the top surface of a thick wafer to reuse III-V substrates, so named for the semiconductor materials in groups III and V of the periodic table. This work aims to significantly reduce the cost of producing high-quality III-V substrates, which is one of the costliest components of this type of solar cell.

SINGLE-SOURCE VAPOR DEPOSITION EQUIPMENT FOR HIGH-THROUGHPUT MANUFACTURING OF THIN FILM PEROVSKITE SOLAR ABSORBERS – $962,740 ♦

BlueDot Photonics | Seattle, WA | Principal Investigator: Daniel Kroupa

This project is developing modular, single-source vapor deposition hardware to enable high-throughput processing and manufacturing of thin-film perovskite solar absorbers. Single-source vapor deposition has the potential to be a rapid, cost-effective technique in which powder is turned directly to vapor and coated onto a substrate, the base of a solar cell. The team is working to design, build, and test a manufacturing platform that will improve the coating's uniformity on the cell, as well as its optical and electronic quality. This work will enable the next generation of solar manufacturing equipment for thin-film solar cell technology.

MULTI-MESSENGER IN SITU TOLERANCE OPTIMIZATION OF MIXED PEROVSKITE PHOTOVOLTAICS – $200,000

Colorado School of Mines | Golden, CO | Principal Investigator: Xerxes Steirer

This project is working to validate solutions to perovskite photovoltaic degradation mechanisms involving water and oxygen, electrical bias, light, and elevated temperature via in situ measurement of chemical reactions, volatile species, and electronic structure. Experiments are being performed on a new environmental X-ray photoelectron spectrometer (EXPS) that has opened up complex new directions in science, including real-time chemical information of interface reactions. State-of-the-art photovoltaic materials will be investigated including high efficiency mixed perovskites which will be provided by colleagues at the National Renewable Energy Laboratory and Hunt Energy Enterprises, LLC. Correlations among variables will be identified using multivariate methods. Mixed water and gas interactions with perovskite layers will be probed directly using EXPS in order to elucidate their surface bonding, activation energies and chemical pathways.

PEROVSKITE SOLAR CELLS: ADDRESSING LOW COST, HIGH EFFICIENCY, AND RELIABILITY THROUGH NOVEL POLYMERIC HOLE TRANSPORT MATERIALS – $200,000

Colorado School of Mines | Golden, CO | Principal Investigator: Alan Sellinger

This project is developing hole transport materials—layers in a solar cell that collect current—using polymers to enable thin-film perovskite tandem solar cells reaching efficiencies greater than 30 percent and lifetimes of more than 25 years. Polymers cost less than materials currently used for this purpose, and they will allow the team to manipulate their material properties to achieve greater compatibility with other layers of the device.

COMPARATIVE LIFE CYCLE ANALYSIS OF SCALABLE SINGLE-JUNCTION – $199,911

Columbia University | New York, NY | Principal Investigator: Vasilis Fthenakis

The project uses a Life Cycle Analysis framework to characterize, quantify, and compare the life cycle health and environmental impacts of the most salient emerging scalable single-junction and tandem perovskite solar cell architectures, which have shown potential for achieving high-level power conversion efficiency, stability at the cell level, and scalable and reproducible processes. The project will produce comparative evaluations of different perovskite designs and production pathways, as well as comparisons with other photovoltaic technologies and conventional power generation technologies that will inform decision makers and stakeholders.

CROSS-CUTTING METROLOGY TOOLS FOR IN OPERANDO CHARACTERIZATION OF CARRIER DYNAMICS IN PHOTOVOLTAIC DEVICES – $200,000

Drexel University | Philadelphia, PA | Principal Investigator: Jason Baxter

This project is developing cross-cutting measurement tools after exposing thin-film solar cells to infrared light with tremendously high terahertz frequencies. These methods enable the observation of how charge carriers move and recombine in the various photovoltaic device layers while the cell is operating. The team will obtain key parameters using noncontact probes and modeling in experiments.

HIGH SPEED, ROLL-TO-ROLL PRODUCTION OF DURABLE, LOW-COST, BIFACIAL PEROVSKITE PHOTOVOLTAIC MODULES – $4,000,000

Energy Materials Corporation | Norcross, GA | Principal Investigator: Thomas Tombs

This project is developing low-cost, high-efficiency, high-stability, bifacial, thin-film solar modules using roll-to-roll printers at the former Kodak manufacturing facility. The team and its partners are creating new methods to deposit layers of material to make the cell, develop a high-speed process using intense pulsed light to fuse the layers, resolve causes of degradation, and produce prototypes. The high-speed manufacturing process could eventually result in gigawatt-scale production.

LOW CAP-EX, HIGH SPEED ROLL-TO-ROLL PEROVSKITE SOLAR MODULE DEVELOPMENT – $2,000,000

Energy Materials Corporation | Norcross, GA | Principal Investigator: Stephan Deluca

This project is developing a process to manufacture perovskite photovoltaic modules at unprecedentedly low cost and capital expense using high speed roll-to-roll printers. Unlike other thin-film technologies, perovskites combine the advantages of low-cost production with efficiencies on par with the dominant crystalline silicon technology. At this stage, the company is developing pilot production tools that will generate prototype modules demonstrating the module efficiency, stability, and cost structure needed to move into full production. Using existing production printers at Kodak, the company expects to produce modules at $0.30 per watt while utilizing U.S. manufacturing.

LOW-COST, HIGH-EFFICIENCY III-V PHOTOVOLTAICS ENABLED BY REMOTE EPITAXY THROUGH GRAPHENE– $977,483

Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Jeehwan Kim

This project is developing low-cost, high-throughput, and high-efficiency multi-junction photovoltaics by leveraging remote epitaxy and a two-dimensional layer transfer process that uses hybrid vapor phase epitaxy. This manufacturing method allows the growth of defect-free single-crystalline films that can be easily separated from the substrate. The substrate, which is expensive, can be reused by copying the crystalline information from the substrate through graphene. To validate the feasibility of this method, tandem photovoltaic cells will be grown and characterized to achieve maximum power conversion efficiency levels. In addition, the hybrid vapor phase epitaxy technique will enable high-throughput epitaxy at low costs, helping to produce photovoltaic cells at manufacturing scale.

CLOSING THE CELL-TO-MODULE STABILITY TESTING GAP – $200,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joseph Berry

This project targets the development of infrastructure to enable outdoor field testing for pre-commercial solar cell technologies. Nascent photovoltaics, such as perovskite solar cells, still have difficulty entering the market due to questions regarding reliability and environmental durability. While outdoor testing can provide valuable information, these tests are often conducted on laboratory demonstration modules with sub-optimal packaging. The lack of consistent packaging and module performance hinders the ability to separately assess the cell and package stability and makes it difficult to ascertain where failures originate. This project targets this problem through the development of a template module package for perovskite solar cells and building out of outdoor testing facilities and equipment. These capabilities will bridge lab scale experiments to module level questions addressing both packaging along with environmental impact to cells. This work will enable real world outdoor test required to de-risk perovskites and other innovations in photovoltaic modules.

FLEXIBLE PEROVSKITE-PEROVSKITE PHOTOVOLTAICS FOR MOBILE POWER APPLICATIONS – $745,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: David Moore

The National Renewable Energy Laboratory and Swift Solar are collaborating to commercialize the lab's novel solar cell device design that enables the manufacturing of lightweight, flexible, and highly efficient multijunction perovskite solar cells.

HALIDE PEROVSKITE SOLAR CELLS – $5,547,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joseph Berry

This core photovoltaic support project examines critical materials, integration, and device issues required to propel the development of halide perovskite solar cell technologies. This project uses a scientific approach to understand the roadblocks and risks associated with commercializing halide perovskite solar cell technologies, including any challenges to fully scalable manufacturing and long lifetime field operation. This project focuses on stability research to better understand mechanisms that cause degradation and failure in halide perovskite solar cells and develop device stability acceleration factors that can be applied across relevant halide perovskite materials for photovoltaics and associated device architectures. This work is device focused but has a materials-driven emphasis in order to overcome the efficiency, stability, and scalability challenges preventing halide perovskite solar cells from reaching $0.03 per kilowatt-hour by 2030.

HIGH-EFFICIENCY, LOW-COST III-V SOLAR CELLS BY DYNAMIC HYDRIDE VAPOR PHASE EPITAXY COUPLED WITH RAPID, POLISHING-FREE WAFER REUSE THROUGH ORIENTATION-OPTIMIZED SPALLING – $200,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kevin Schulte

Low-cost III-V photovoltaics have the potential to lower the levelized cost of energy because III-V cells outperform silicon in terms of efficiency and annual energy harvesting efficiency. In this project, researchers address both the high costs of III-V epitaxy and single crystal substrates. Hydride vapor phase epitaxy is the most promising inexpensive, rapid-growth technique for high efficiency, III-V materials. The continued development of high-throughput hydride vapor phase epitaxy is coupled with novel epitaxial liftoff strategies to enable III-V solar cells that are cost-competitive under one-sun conditions.

HYBRID TANDEM PHOTOVOLTAICS – $955,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Adele Tamboli

Tandem or multijunction solar cells are able to convert sunlight to electricity with greater efficiency than single junction solar cells by splitting the solar spectrum across sub-cells with different bandgaps. Combining well-established photovoltaic technologies into a single tandem architecture holds promise for dramatically increasing total cell efficiency, but substantial development is needed to address the challenges of scaling hybrid tandems from lab "hero cells" to interconnected large modules. This project seeks to demonstrate high efficiency III-V/silicon tandem solar cells, strings, and modules with a primary focus on benchmarking the three-terminal tandem in relation to state-of-the-art two- and four-terminal configurations. This includes robust device and string simulations, experimental cell and string demonstrations, and reliability testing of cells and novel components.

III-V PHOTOVOLTAIC CELL CORE CAPABILITY – $8,100,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Myles Steiner

This project creates a path toward cost-effective III-V solar cells. The materials used to create these cells offer many advantages, including the potential for high solar cell efficiencies, relatively low sensitivity to changing temperatures, environmental stability, and their light weight and flexibility. This project is researching materials and device architectures that can lead to high solar cell efficiencies and develop a low-cost substrate growth technique called hydride vapor-phase epitaxy. The team is also researching substrates, including silicon, that are inexpensive or able to be removed and reused will be investigated to create these low-cost III-V solar cells.

VAPOR-PHASE GROWTH OF LOW-DIMENSIONAL PEROVSKITE INTERFACIAL LAYER FOR STABLE AND EFFICIENT PEROVSKITE SOLAR CELLS – $200,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kai Zhu

Low-dimensional perovskites have shown promise for improving the stability of perovskite solar cells. The challenge has been the lack of control on the structural/chemical/electronic properties of new materials/structures induced by the bulky cations. This project aims to develop a vapor-phase approach to coat a uniform compact low-dimensional perovskite contact layer with improved barrier properties on top of a state-of-the-art three-dimensional perovskite absorber to enhance perovskite solar cell stability. This approach allows control to tailor the low-dimensional perovskite interfacial layer so that one can obtain proper energetics and out-of-plane transport for effective/selective charge extraction for higher perovskite solar cell efficiency and stability. The goal is to establish a new technical approach that can be added to the state-of-the-art technology platform to accelerate the development of stable and efficient perovskite solar cells.

BUILDING WINDOWS WITH TRANSPARENT PHOTOVOLTAICS TO LOWER COSTS – $2,500,000

Next Energy Technologies | Santa Barbara, CA | Principal Investigator: Corey Hoven

Next Energy Technologies Inc. has developed transparent photovoltaic coatings for integration into commercial windows. These low-cost, wet-coated materials selectively absorb and convert light in the infrared and ultraviolet spectrum while allowing significant visible light transmission with colors that are desirable to the window market. This approach uniquely allows the photovoltaic windows to look like conventional windows, but also allows for reduced module and balance of system costs by leveraging existing window costs. This project enables the project team to transition from small-scale 3.5 inch units produced using laboratory processes to larger format devices utilizing manufacturing-relevant processes.

ON-DEVICE LEAD DETENTION FOR PEROVSKITE SOLAR CELLS – $198,112

Northern Illinois University | DeKalb, IL | Principal Investigator: Tao Xu

Perovskite solar cells face major obstacles including toxicity of lead, a key active component, which remains relatively unexplored because of the lack of effective solutions. This project is developing an innovative, simple, low-cost, add-on approach for in-situ on-device sequestration of leaked aqueous lead for severely damaged perovskites. The goal is to capture more than 99.9 percent of lead leakage from perovskites soaked in water by using low-cost, high-efficiency metal ion-exchange resins as lead-trapping layers on both sides of the devices.

INVESTIGATION OF GALLIUM OXIDE AS A NEW TRANSPARENT CONDUCTIVE OXIDE FOR PHOTOVOLTAICS APPLICATIONS – $200,000

Ohio State University | Columbus, OH | Principal Investigator: Tyler Grassman

This project explores the use of a new material, gallium oxide, as a transparent conducting oxide layer for solar cells. Transparent conducting oxides are a layer within a solar cell that conducts electricity on top of the light-absorbing material in the solar cell, such as cadmium telluride. As a result, the conductivity of the transparent conducting oxide and its transparency to the full solar spectrum are critical properties for creating a transparent conducting oxide that's effective. Gallium oxide has a wide bandgap, which enables more light to pass through the transparent conducting oxide and be absorbed by the absorbing layer that converts the photonic energy into electrical potential. To determine the applicability of gallium oxide as a transparent conducting oxide for photovoltaic technologies, this team is studying the deposition of this material in solar cells using tools that are commonly used in the solar industry. The team will then test the resulting optical and electronic properties of the solar cell and analyze the performance of the prototype transparent conducting oxide.

IDENTIFYING IMPACTS OF PROCESS, PRECURSORS AND DEFECTS IN METAL HALIDE PEROVSKITE SOLAR CELLS – $1,500,000

Princeton University | Princeton, NJ | Principal Investigator: Barry Rand

In an effort to improve the energy yield and stability of metal halide perovskite photovoltaic solar cells, this project aims to improve material selection and fabrication techniques for producing these cells. The team is working to identify interactions that can occur in precursor solutions or at solid interfaces that result in defects, either spontaneously or under solar cell-relevant stresses such as light, heat, atmosphere, and voltage. The team will then establish targeted strategies and processes to mitigate perovskite cell degradation by selecting optimal precursor solutions and creating robust absorbers needed to make these high-efficiency solar cells.

ACCELERATED SCALING TO RAPID OPEN-AIR FABRICATION OF DURABLE – $1,496,069

Stanford University | Stanford, CA | Principal Investigator: Reinhold Dauskardt

This project is working to fabricate and encapsulate large-area and durable perovskite solar modules using a scalable open-air processing route that validates the reliability of the cell by using accelerated testing and thin-film metrics. The team's scalable processing of durable perovskite and inorganic transport layers provides a platform to make series-integrated high-voltage perovskite solar modules entirely in open air, eliminating unstable organic transport layers. The work will mitigate barriers to wide-scale deployment of perovskite technology, namely module manufacturing and reliability, and eventually allow photovoltaic-generated electricity to reach costs as low as $0.02 per kilowatt-hour.

PEROVSKITE ON SILICON TANDEM SOLAR CELLS – $1,365,306

Stanford University | Stanford, CA | Principal Investigator: Alberto Salleo

This project is studying newly developed perovskite on silicon tandem modules to determine the best interconnection design and material properties for each module component. The perovskite material will be characterized and modified to produce a top cell with an ideal band gap and few structural and electronic defects. Modeling will be used to predict outdoor panel performance under realistic spectral variations, which affects how well the electrical current is balanced between the two types of cells.

HIGH-THROUGHPUT VAPOR DEPOSITION FOR PEROVSKITE-PEROVSKITE TANDEM MODULES – $660,000

Swift Solar Inc. | Golden, CO | Principal Investigator: Joel Jean

Perovskite-perovskite tandem photovoltaic solar cells offer an opportunity to obtain high efficiency levels while maintaining the low-cost and high-throughput manufacturing potential enabled by thin-film perovskite materials. This team will adapt an already commercially proven vapor deposition technique and test its use with perovskites at industrial scale for the first time. This technique could be an alternative to the widely used solution-based perovskite growth methods. The team aims to validate the vapor deposition method and produce a tandem module with an efficiency that's greater than 25 percent.

INVESTIGATION OF DEFECT PHYSICS FOR EFFICIENT, DURABLE AND UBIQUITOUS PEROVSKITE SOLAR MODULES – $1,000,000

University of California, Los Angeles | Los Angeles, CA | Principal Investigator: Yang Yang

In order to push perovskite solar cells closer to their theoretical limit of efficiency and durability, researchers need to better understand and control defects in the perovskite material and at the surface of the layers in the cell. These defects are the source of losses in the cell's open circuit voltage and can cause degradation in the solar cell over time. This project is developing physical models of defect-induced types of degradation, both on the surface and in the bulk perovskite material. The team will conduct a blend of computational and experimental studies on critical defect types and densities within the perovskite material when there's heat, light, increased voltage, or moisture present. The team will then use in-depth characterization techniques to quantify the chemical and electronic properties of defects in order to improve defect manipulation techniques that could increase perovskite cell efficiency.

MINI-MODULES MADE WITH MONOLITHICALLY INTEGRATED ALL-PEROVSKITE TANDEMS – $1,461,640

University of Colorado Boulder | Boulder, CO | Principal Investigator: Michael McGehee

In collaboration with perovskite researchers at the National Renewable Energy Laboratory, this team aims to make monolithic two-terminal tandem solar cells that have a 27 percent efficiency level and are constructed entirely from thin-film perovskite light absorbers. The project uses scalable deposition methods such as slot-die coating, sputtering, chemical vapor deposition and thermal evaporation to fabricate perovskite solar cells that degrade by less than 10 percent after 1,000 hours of use.

III-V SOLAR CELLS WITH NOVEL EPITAXIAL LIFT-OFF ARCHITECTURES FOR EXTENDED SUBSTRATE REUSE FOR LOW-COST MANUFACTURING – $200,000

University of Houston | Houston, TX | Principal Investigator: Venkat Selvamanickam

The highest solar cell efficiencies have been achieved with costly III-V photovoltaics— so named for the semiconductor materials in groups III and V of the periodic table—but reusing the base of the solar cell, called the substrate, can lower costs. The team is developing an architecture based on novel layers so that polishing the substrate after old layers of material are removed won't be required for reuse.

CONTROLLING THE RECOMBINATION ACTIVITY OF DISLOCATIONS IN III-V SOLAR CELLS – $200,000

University of Illinois at Urbana-Champaign | Champaign, IL | Principal Investigator: Minjoo Lee

Existing III-V manufacturing methods, such as epitaxial liftoff, that attempt to reuse costly III-V and germanium substrates over many growth cycles are too expensive to enable manufacturing at large scale. One way to overcome this issue is to grow the cells on low-cost substrates such as silicon. This team is performing a systematic study of III-V solar cells grown on silicon surfaces decorated with beryllium, carbon, germanium, tellurium, and other impurities in order to identify conditions that will render dislocations and other structural defects less harmful to solar cell performance. Reducing the impact of defects would improve device performance and enable the use of low-cost growth substrates in the fabrication of high-performance III-V cells and modules.

ROLL-TO-ROLL MANUFACTURING OF CONTINUOUS PEROVSKITE MODULES – $849,216

University of Louisville | Louisville, KY | Principal Investigator: Thad Druffel

This project investigates the applicability of low-cost, roll-to-roll manufacturing techniques for perovskite modules. The team employs rapid deposition and annealing techniques, which are the processes used to deposit the absorber layer onto a substrate and then heating and cooling it to toughen the absorber. The team is then studying the performance of the absorber layer and use the same techniques on the remainder of the device layers. The team aims to use these techniques to create a high throughput manufacturing process for perovskite modules in a commercial roll-to-roll facility.

SEMITRANSPARENT, RELIABLE AND EFFICIENT SCALABLE ORGANIC SOLAR CELLS FOR BUILDING INTEGRATED APPLICATIONS – $1,300,000

University of Michigan | Ann Arbor, MI | Principal Investigator: Stephen Forrest

Organic photovoltaics are an ideal solution for semi-transparent building integrated photovoltaics for windows, building facades, and rooftops. This project aims to produce organic solar cells with a 15 percent power conversion efficiency that are 50 percent transparent and have a projected 20-year lifetime for building-integrated photovoltaics. This would nearly double the increase in performance compared to typical power-conversion-efficiency values at similar levels of optical transparency. The team will also use its roll-to-roll film-growth technology to continue to improve manufacturing yields and the scalability of organic photovoltaics.

SCALABLE MANUFACTURING OF EFFICIENT PEROVSKITE/SILICON TANDEM MODULES – $1,350,000

University of North Carolina at Chapel Hill | Chapel Hill, NC | Principal Investigator: Jinsong Huang

This project focuses on increasing solar cell efficiencies by using both perovskite and silicon as the semiconductors in a photovoltaic cell. This team is designing and testing a six-inch by six-inch silicon perovskite tandem cell using an inexpensive high-throughput process capable of producing 5,000 wafers per hour in a solar cell fabrication facility. This process uses a low-cost blade coating process to apply the relevant perovskite layers to make the tandem cells, leading to a lower capital expenditure required to implement this process in existing or new solar cell fabrication facilities. The resulting tandem solar cell could reach an efficiency over 30 percent.

HIGHER THROUGHPUT, LOWER COST PROCESSING OF FLEXIBLE PEROVSKITE SOLAR CELLS BY PHOTONIC CURING – $200,000

University of Texas at Dallas | Dallas, TX | Principal Investigator: Julia Hsu

The University of Texas at Dallas is working closely with NovaCentrix, a company that pioneered the process of photonic curing and has already integrated it in roll-to-roll manufacturing of printed electronics. In this photonic curing approach, short pulses of broadband light quickly raise the temperature of a film high enough to initiate phase transformation, grain growth/coalescence, and chemical reactions, while the substrate remains below its decomposition/deformation temperature, something not possible with conventional methods. The team is applying photonic curing to replace the lengthy thermal annealing steps in perovskite solar cell processing, reducing time and energy cost and enabling flexible substrates. The physical proximity and the complementary expertise of the two teams will facilitate developing this new tool to produce large-area flexible photovoltaic devices with high throughput.

TOWARD LOW-COST, EFFICIENT AND STABLE PEROVSKITE THIN-FILM MODULES – $4,500,000

University of Toledo | Toledo, OH | Principal Investigator: Yanfa Yan

This project is developing high-efficiency perovskite mini modules and investigating deposition techniques that can be scaled up for high-speed manufacturing. The team is working with First Solar, which has world-leading expertise in industrial thin-film photovoltaic manufacturing, degradation testing, and predictive lifetime modeling. To test reliability, the team is developing accelerated stress-testing methods that can detect what degrades perovskite modules outdoors.

ULTRA-HIGH EFFICIENCY AND STABLE ALL-PEROVSKITE TANDEM SOLAR CELLS – $850,001

University of Toledo | Toledo, OH | Principal Investigator: Yanfa Yan

This project is developing processes and strategies to fabricate high efficiency and stable perovskite-perovskite thin-film tandem solar cells. The team aims to develop efficient wide-bandgap perovskite cells with high open circuit voltages for the top layer of the tandem while also developing efficient low-bandgap cells for the bottom layer. The team will then develop efficient interconnecting semiconductor layers with low optical and electrical losses and study potential ways that these perovskite-perovskite tandem cells could degrade over time. The team will use this information to develop approaches to mitigate instability issues in perovskite-perovskite tandem cells in order to increase lifetime and lower costs, with the aim of developing a cell with greater than 25 percent efficiency.

IN-SITU CHARACTERIZATIONS OF MICROSTRUCTURAL DEGRADATION OF PEROVSKITE SOLAR CELLS – $201,015

University of Utah | Salt Lake City, UT | Principal Investigator: Heayoung Yoon

To understand how perovskite solar cells degrade, this project team is developing methods to measure the electronic properties in perovskite absorbers while the device is exposed to high temperature, bright light, and other potential causes of damage. The surface of the perovskite layer as well as the grain bulk and grain interfaces will be monitored to gain insight into how the materials evolve and degrade.

APPROACHING THE RADIATIVE EFFICIENCY LIMIT IN PEROVSKITE SOLAR CELLS WITH SCALABLE DEFECT PASSIVATION AND SELECTIVE CONTACTS – $1,249,997

University of Washington | Seattle, WA | Principal Investigator: David Ginger

This project focuses on using low-cost techniques to develop perovskite solar cells that approach their theoretical efficiency limit in order to reach the maximum possible performance for these cells. In order to achieve this goal, researchers must better understand defects in the perovskite material and invent new ways to passivate, or deactivate, these defects. In order to improve the efficiency and lifetimes of perovskite solar cells, it's important to be able to passivate defects that arise in low-cost manufacturing environments. The team is using novel optical and microscopic probes to provide insight into the defects currently produced during perovskite cell production and then develop scalable layers to add to the solar cell to passivate these defects.

IN-SITU PHOTOPHYSICAL MONITORS AND CORRECTIVE ALGORITHMS FOR PHOTOVOLTAIC FILM DEPOSITION AND RAPID THERMAL PROCESSING IN SCALABLE ROLL-TO-ROLL MANUFACTURING – $199,992

University of Washington | Seattle, WA | Principal Investigator: Devin MacKenzie

Low-cost, high-throughput solution processing could substantially reduce thin-film photovoltaic costs, but it requires new photovoltaic manufacturing lines using roll-to-roll processing. This project is developing gas flow-stabilized slot-die deposition heads and in-situ, real-time optical tools to characterize the roll-to-roll deposition process used to create these cells. The team is using fiber-based optical probes, time-resolved photoluminescence, and light-scattering probes to better understand, for the first time, the critical phase transformations and sintering processes needed to create perovskites with roll-to-roll processing. The team plans to develop real-time corrective algorithms for the deposition process and use these tools to optimize roll-to-roll deposition methods for perovskites and other thin-film photovoltaic materials.

MACHINE LEARNING ASSISTED ENHANCEMENT OF PEROVSKITE STABILITY AND PERFORMANCE – $1,500,000

University of Washington | Seattle, WA | Principal Investigator: Hugh Hillhouse

High photovoltaic power conversion efficiency devices with low year-over-year degradation rates, like hybrid perovskites, have the potential to lower costs if their stability and phase segregation can be improved. In order to better determine the maximum open-circuit voltage and photocurrent a hybrid perovskite solar cell is capable of generating, this team is developing photoluminescence video methods that reveal the role of micron-scale spatial photoluminescence heterogeneity and millisecond-time-scale photoluminescence intensity flickering in material degradation and phase segregation. When combined with large composition libraries and different testing environments, the videos yield enormous data sets. The team plans to mine this data with advanced machine-learning algorithms in order to generate a predictive model of degradation for perovskite solar cells.

QUANTUM-CUTTING LUMINESCENT COATINGS FOR HIGH-EFFICIENCY, LOW-COST SOLAR CELLS – $200,000

University of Washington | Seattle, WA | Principal Investigator: Daniel Gamelin

This project is investigating the use of quantum-cutting down-conversion layers to be placed at the front surfaces of photovoltaic cells in order to remedy a major source of energy loss. The down-converting layer converts high-energy photons, which are normally reflected or inefficiently collected, into multiple lower energy photons. This enables the more efficient conversion of energy by the underlying photovoltaic material, which can double the current generated by the solar cell. This project is developing and optimizing quantum-cutting precursor ink formulations and large-area solution-deposition techniques. Together, these techniques will enable the integration of these high-efficiency, quantum-cutting, down-conversion layers onto the surfaces of commercially available silicon cells to realize low-cost, high-efficiency photovoltaic technologies.

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.

DEFECT KINETICS AND CONTROL FOR MODULE RELIABILITY – $862,000

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

Metal impurities, particularly sodium and potassium originating from the glass used in the solar cell module, have been correlated with the degradation of efficiency over time. This project investigates the thermodynamics and kinetics of impurity atoms within module device layers, including encapsulants, dielectrics, and within the silicon crystal itself and at its interfaces. This includes building physical models to explain the macroscale observations of solar cell degradation by parameterizing the evolution of impurity distribution in the module under operating conditions and the electronic impact of these impurities. With this understanding in hand, the team will develop a platform to predict degradation issues before they arise in emerging materials and architectures and offer design guidelines for new processes to prevent the incorporation of such impurities and/or mitigate their impact in existing wafer to module processes. By advancing the fundamental understanding of degradation mechanisms in low-cost silicon solar cell materials, this project has the potential to help drive down the levelized cost of solar energy.

RELIABILITY EVALUATION OF BIFACIAL AND MONOFACIAL GLASS/GLASS MODULES WITH ETHYLENE VINYL ACETATE AND NON-ETHYLENE VINYL ACETATE ENCAPSULANTS – $1,300,000

Arizona State University | Tempe, AZ | Principal Investigator: Govindasamy Tamizhmani

Photovoltaic modules with glass/glass encapsulation are expected to be more resistant to breakage and degradation than glass/backsheet modules. However, many glass/glass-module architectures continue to use ethylene vinyl acetate as an internal encapsulant, and it has been linked to significant life-limiting reliability issues, including glass cracking, encapsulant delamination, and encapsulant browning. This project assesses the merits and shortcomings of glass/glass modules with and without ethylene vinyl acetate encapsulants by evaluating new and field-aged modules. The team will then evaluate the expected reliability of these modules using indoor and outdoor accelerated tests.

ULTRASONIC CHARACTERIZATION OF EVA CROSSLINKING FOR QUALITY ASSURANCE AND LAMINATION PROCESS CONTROL – $200,000

Arizona State University | Tempe, AZ | Principal Investigator: Rico Meier

Solar modules that are not properly laminated can produce less power over time because of cell breakage, corrosion, and other issues that may occur. This project is developing a method using very high-frequency sound waves to characterize the module lamination process, paying particular attention to specific bonding structures in the ethylene-vinyl acetate encapsulation layer, and quantify the achievable resolution and measurement uncertainties. This work will deliver new insights into how defects and lamination are related and how to optimize the lamination process, ultimately at the industrial scale.

IMPROVING SOLAR PANEL DURABILITY THROUGH NOVEL PANEL DESIGNS, ADVANCED MANUFACTURING EQUIPMENT – $600,000

BrightSpot Automation | Westford, MA | Principal Investigator: Andrew Gabor

This project is conducting a fundamental study on the nature of cracked cells in crystalline silicon solar panels with the goal of improving module materials and designs to make them more resilient against crack initiation, propagation, and degradation over time due to the electrical isolation of cell segments. Key areas of investigation include determining the effects of accelerated lifetime testing on modules in inducing power loss due to cell cracking, and how these effects can be mitigated.

RELIABILITY AND POWER DEGRADATION RATES OF PASSIVATED EMITTER REAR CONTACT MODULES USING DIFFERENTIATED PACKAGING STRATEGIES AND CHARACTERIZATION TOOLS – $1,465,291

Case Western Reserve University | Cleveland, OH | Principal Investigator: Roger French

This project is conducting a systematic study of module degradation pathways in passivated emitter rear contact photovoltaic modules, benchmarking them relative to known degradation mechanisms and pathways of older module designs, such as full-area aluminum back surface field, which have been exposed to real-world and accelerated exposure conditions. Statistical models incorporating outdoor performance and accelerated testing data are being used to understand the dominant physical degradation mechanisms that occur in the field for a variety of encapsulant and backsheet combinations. These models allow for new and previously unmapped material interactions that are present in newly developed module architectures to be modeled, characterized, and ultimately accounted for in future design efforts.

TOWARD 50 YEAR LIFETIME PHOTOVOLTAIC MODULES: DOUBLE GLASS VS. GLASS/BACKSHEET – $1,134,000

Case Western Reserve University | Cleveland, OH | Principal Investigator: Roger French

In order to enable photovoltaic modules to have a 50-year lifetime, researchers are exploring modules with double glass or glass/backsheet designs. To reduce degradation rates and extend the service lifetime of these high efficiency modules, researchers must better understand the operational conditions of solar cells within these modules. This project uses data from stepwise accelerated exposures and real-world photovoltaic systems to quantify the impact of module architecture and packaging materials on the degradation rates of double glass and glass/backsheet modules. Identifying and mitigating the degradation modes related to packaging materials and architectures for double glass and glass/backsheet modules could help to lower degradation rates toward 0.2 percent per year and lower the levelized cost of energy.

UNDERSTANDING THE MECHANISM OF LIGHT AND ELEVATED TEMPERATURE INDUCED DEGRADATION OF P-TYPE SILICON SOLAR CELLS – $200,000

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

The Colorado School of Mines and the National Renewable Energy Laboratory will develop strategies to mitigate degradation in p-type passivated emitter rear contact silicon solar cells, which are built to capture more light on the back surface of the cell, resulting from the interaction of hydrogen with light and high temperatures. This project aims to improve the long-term reliability of passivated emitter rear contact silicon solar cells.

CAPTURING THE FULL BENEFITS OF BIFACIAL MODULES TO APPROACH A LEVELIZED COST OF ENERGY OF $0.03 PER KILOWATT-HOUR THROUGH A REGIONAL OPTIMIZATION OF THE ELECTRICAL ARCHITECTURE – $1,500,000

Cypress Creek Renewables | Santa Monica, CA | Principal Investigator: Jenya Meydbray

Bifacial photovoltaic modules can yield efficiency gains, but the solar industry has been unable to accurately quantify the benefits of these modules at the system level, leading to uncertain cost estimates and lower adoption rates for solar energy systems that need financing. This project seeks to validate existing performance models for bifacial modules and quantify the impacts of system location, tracker height, module technology, and system architecture on bifacial efficiency gains and the projected levelized cost of energy. This project aims to improve investor confidence by providing new data on bifacial system performance gains across the United States and will validate a holistic system architecture that allows system integrators to meet or exceed the levelized cost of energy target of $0.03 per kilowatt-hour by 2030.

DIRECT CURRENT ARC-FLASH SAFETY FOR 1,500 VOLTS: METHODOLOGY, VERIFICATION, AND CODIFYING – $1,010,726

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Michael Bolen

The rapid release of thermal energy, pressure waves, and electromagnetic interference from an arc-flash all pose risks to people and equipment in a photovoltaic plant. However, there is a lack of understanding regarding how to calculate incident energy from direct current arc-flashes. This project is increasing the fundamental understanding of arc-flash mechanics in photovoltaic systems and providing the quantitative foundation and recommendations for adoption by the industry. This is being done by physically testing arc-flashes in a laboratory; developing a detailed physics-based model to confirm underlying methodology and key input variables; and documenting and disseminating results through guidelines submitted to code bodies, journal and conference publications, and an easy-to-use incident energy calculator.

AUTOMATIC REFERENCE FOR EMPIRICAL SOILING – $1,149,848,000 ♦

Fracsun | San Luis Obispo, CA | Principal Investigator: Catlin Mattheis

The accumulation of dirt on solar panels can negatively impact the overall performance of solar arrays. To address this issue, this project is developing and test prototypes of a device that can measure dirt accumulation and calculate the best schedule for cleaning the solar array. This project aims to enable system owners to balance the cost of module cleaning against the loss of solar generation due to soiling and determine the best time to clean the modules, minimizing financial losses, and optimize the frequency of cleaning. As a result, this can lower a photovoltaic system's levelized cost of electricity and improve the system's profitability.

DURABLE MODULE MATERIALS CONSORTIUM (DURAMAT) – $30,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Teresa Barnes

The Durable Module Materials (DuraMat) National Laboratory Consortium is designed to accelerate the development and deployment of durable, high-performance materials for photovoltaic modules to lower the cost of electricity generated by solar power, while increasing field lifetime. DuraMat is one of several consortia under the Energy Materials Network, which aims to solve industry's toughest clean energy materials challenges. DuraMat supports projects that improve module materials in partnership with industry and academia to further optimize reliability and energy harvest of low-cost photovoltaic modules. Sandia National Laboratories, Lawrence Berkeley National Laboratory, and SLAC National Accelerator Laboratory are collaborating in the consortium.

MULTIMODE CHARACTERIZATION APPROACH FOR UNDERSTANDING CELL-LEVEL PHOTOVOLTAIC PERFORMANCE AND DEGRADATION – $3,630,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Glenn Teeter

This project enables the combined use of several complementary measurement techniques to better understand the performance and cell-level reliability of solar photovoltaic technologies. The characterization techniques, which include X-ray and ultraviolet photoelectron spectroscopy, will be augmented to consider how factors like high temperatures and exposure to humid air affect solar modules during operation. The research team will also develop new and advanced characterization techniques, such as near-field transport image in 3-D, making it easier to study different parts of the solar cell. The team will create models to establish clear connections between cell performance and solar cell damage under various operating conditions. The new methodology and device models will speed the improvement of efficiency and durability of thin-film and perovskite photovoltaics.

OPERATION AND MAINTENANCE OF PHOTOVOLTAIC SYSTEMS: DATA SCIENCE, ANALYSIS, AND STANDARDS – $800,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andy Walker

This project is a collaboration between two national labs and private-industry practitioners to advance photovoltaic systems operations and maintenance. Using data from different climates and weather conditions, the team focuses on understanding operational risks, drivers, and cause-and-effect relationships that lead to low performance ratios and high operations and maintenance costs. By conducting foundational analysis, the team aims to create best practices and international standards for the reliability and availability of residential, commercial, and utility-scale photovoltaics.

PHOTOVOLTAIC CELL AND MODULE PERFORMANCE TESTING – $7,800,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Nikos Kopidakis

This core photovoltaic support project maintains the National Renewable Energy Laboratory's Photovoltaic Cell and Module Performance Laboratory and provides access to photovoltaic performance measurements and best practices to universities, national laboratories, and the Solar Energy Technologies Office. Through its primary reference cell calibrations, this laboratory maintains the photovoltaic peak watt rating for the United States. This work assures that consumers, installers, and project developers can have confidence in the power ratings of the modules they purchase, enabling a more robust U.S. photovoltaic industry. This project also provides a world record of photovoltaic performance measurements, which is essential for tracking the progress of photovoltaic research and development.

PHOTOVOLTAIC PROVING GROUNDS – $6,840,000

National Renewable Energy Laboratory ($1,200,000) | Golden, CO | Principal Investigator: Chris Deline
Sandia National Laboratories ($5,640,000) | Albuquerque, NM | Principal Investigator: Bruce King

This joint effort with the National Renewable Energy Laboratory and Sandia National Laboratories conducts short to long-term field research to understand the functionality of photovoltaic systems under real world environmental operating conditions. Short term research focuses on validating technology improvements designed to increase solar energy harvest while long-term research is conducted to assess photovoltaic system reliability and validate computer models for predicting power generation. Researchers design and install photovoltaic systems to meet these goals, often in direct partnership with module manufacturers or equipment providers. U.S. companies benefit from this direct interaction with the National Labs, allowing them access to unique capabilities and expertise in module and system performance assessment. The photovoltaic industry as a whole benefits from the publicly available output performance data. Beyond module manufacturers, beneficiaries of the photovoltaic performance measurement and research include system designers, installers, investment bankers, public utilities and independent third-party test labs.

REDUCING UNCERTAINTY OF FIELDED PHOTOVOLTAIC PERFORMANCE – $5,400,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Chris Deline

This project aims to improve the analysis and reporting of photovoltaic system field performance to increase confidence in system performance among owners and financiers. The team compares the outdoor performance and degradation rates of conventional module technologies with those of new, high-efficiency silicon technologies. To do this, they are studying how exposure to light, water, and other potential sources of degradation affect photovoltaic system components, and then use the results to develop new models and automated analysis techniques to measure system performance and production shortfalls. The team works with industry partners and the Durable Module Materials Consortium's data hub to enable private investors to upload and evaluate photovoltaic production data anonymously.

RELIABILITY CORE: RESEARCH AND DEVELOPMENT TO ENSURE A SCIENTIFIC BASIS FOR QUALIFICATION TESTS AND STANDARDS – $15,115,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Ingrid Repins

This core capability project performs research and development that leads to science-based tests and standards that can better ensure photovoltaic system reliability and quality. The team designs and performs accelerated stress tests on photovoltaic products and then correlates the results with successes and failures of products in the field. Testing focuses on the module package—including the glass and frame, interconnection devices, and solar cells—and the micro-characterization of both failed and healthy modules to help improve test accuracy and predictive ability. The new tests will help photovoltaic system owners better predict long-term safety and energy generation of different products while lowering the cost of photovoltaic electricity by extending the lifetime of photovoltaic modules.

INTERNATIONAL PHOTOVOLTAICS RESEARCH COLLABORATIVE – $100,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Laurie Burnham

The solar industry is undeniably global, from both a manufacturing and deployment perspective, yet access to comparable high-fidelity climatic and photovoltaic data from around the world is lacking. This project addresses that void by creating an international research collaborative dedicated to the generation and sharing of quality data. Members of the collaborative have agreed to share meteorological and solar data, deploy a common set of technologies and technical approaches, and exchange best practices with respect to the monitoring and maintenance of emerging technologies. This international organization furthers the solar community's understanding of the climatic and other local factors that influence solar output and longevity, creates a platform for cross-climate research, and makes available to researchers, manufacturers, developers, investors, and others a global database that is unprecedented in scope.

PHOTOVOLTAIC PERFORMANCE MODELING – $1,725,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Stein

This core capability includes development, implementation, and validation of new performance sub-models in the areas of module thermal behavior, dynamic soiling, and degradation and stakeholder engagement, which is accomplished through the Photovoltaic Performance Modeling Collaborative and International Energy Agency Photovoltaic Power Systems Program Task 13. The project objectives works to reduce uncertainty in photovoltaic performance models by developing and validating new and improved models, creating and managing an open source repository of modeling functions and data, and building and growing the collaborative group. The results of this project will be communicated by workshops, the Photovoltaic Performance Modeling Collaborative's website, open-source software, and reports and conference papers and presentations.

SOLAR PERFORMANCE INSIGHT – $300,000 ♦

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Clifford Hansen

Solar operations and maintenance providers often cannot effectively monitor photovoltaic systems because existing tools often don't meet their needs or are cost-prohibitive. This project is developing a lightweight, affordable, intuitive photovoltaic modeling and analytics platform to calculate performance from real data acquired by multiple data systems. This would improve efficiency among photovoltaic operations and maintenance service providers and solar contractors while lowering soft costs.

PVINSIGHT: A TOOLKIT FOR UNSUPERVISED PHOTOVOLTAIC SYSTEM LOSS FACTOR ANALYSIS – $625,000

SLAC National Accelerator Laboratory | Menlo Park, CA | Principal Investigator: Sila Kiliccote

Evaluating the performance of a photovoltaic system under varying, real-world environmental conditions informs the design of system components and highlights potential causes of degradation. However, detailed and accurate performance analysis is not available for smaller residential and commercial systems. Current performance-analysis tests also require that system data be manually collected or verified. In an effort to streamline these processes, this project is developing an open-source tool kit that uses machine learning to automate power-loss-factor estimations for small and medium-size photovoltaic systems, thereby drastically reducing the manual work typically needed to identify and quantify them.

REDUCING MODULE SOILING WITH SCALABLE AND ROBUST PHOTOCATALYTIC COATINGS – $999,500 ♦

Swift Coat, Inc. | Peoria, AZ | Principal Investigator: Peter Firth

The project is developing and scaling multilayer, anti-reflective and anti-soiling coatings for solar glass to be deposited by a technique that sprays dry nanoparticles. The coatings have the potential to increase annual energy yield by reducing the loss of energy output that results when light gets reflected or when dirt lands on the modules. They are also capable of reducing operation and maintenance costs because the modules won't require as much cleaning. The team plans to perform outdoor testing in collaboration with the National Renewable Energy Laboratory.

MOBILE IN-SITU IMAGING OF PHOTOVOLTAIC MODULES – $1,148,024 ♦

Tau Science | Hillsboro, OR | Principal Investigator: Greg Horner

As photovoltaic solar modules are added to the electric grid in greater numbers, new inspection and qualification techniques are required to maintain reliable electricity generation. This project is developing a non-contact scanner that can operate in solar fields at night and detect various failure and degradation modes of solar modules.

A DATA-DRIVEN APPROACH TO REAL-WORLD DEGRADATION OF BACKSHEETS – $1,500,000

Underwriters Laboratories | Northbrook, IL | Principal Investigator: Ken Boyce

The backsheet of a solar photovoltaic module is the backing of the module. In combination with the front glass sheet, the backsheet helps to seal the module from the outside world. The backsheet is typically made of multiple layers of various types of polymers, a type of plastic, and can degrade over time from climate conditions, making its design an important predictor for how long a solar module can last in the field. However, current accelerated tests for backsheet degradation and the lifetime performance of the module have limitations. This team is working to employ a data-driven approach to analyze backsheet degradation for modules in the field in order to better understand the real-world environmental stresses of airborne pollution, solar irradiance, water, temperature, and abrasion on module performance. The team is using a large sample size to model and quantify the variance in degradation rates and link these to the backsheet materials being studied. This information will help inform a variety of stakeholders in the solar industry and could enable the development of more accurate standards for photovoltaic modules.

UNDERSTANDING AND OVERCOMING WATER-INDUCED INTERFACIAL DEGRADATION IN SILICON MODULES – $588,505

University of California, San Diego | San Diego, CA | Principal Investigator: David Fenning

This project is developing a spatially-resolved characterization methodology to detect the location and amount of water present in photovoltaic modules and to model any predicted acceleration in performance degradation. The project team is examining the physical underpinnings of these effects by combining first-principles atomistic modeling of the segregation, diffusion, and chemical effects of interfacial water with continuum finite element method modeling of water distribution and its effects. Based on the resulting physical model of a module's water exposure over time and predicted changes in material properties and power output, the project team plans to develop statistical response surface models to predict a module's hazard function.

CHARACTERIZATION OF CONTACT DEGRADATION IN CRYSTALLINE SILICON PHOTOVOLTAIC MODULES – $1,581,926

University of Central Florida | Orlando, FL | Principal Investigator: Kristopher Davis

This project is developing a highly-automated metrology solution that can non-destructively extract the series resistance and recombination of individual cells encapsulated within a photovoltaic module with minimal uncertainty for both parameters using calibrated electroluminescence imaging. This metrology can be used in reliability and durability evaluations to accelerate cycles of learning and to help develop new technologies that reduce cell- and module-level power losses and integrate them into high-volume manufacturing. Each of these applications has the ability to reduce the solar costs by minimizing variance in production, reducing the number of failures due to contact and interconnect failure, reducing degradation rates due to contact and interconnect degradation, and accelerating the adoption of new technologies.

LEVELIZED COST OF ENERGY REDUCTION THROUGH PROACTIVE OPERATIONS OF PHOTOVOLTAIC SYSTEMS – $1,189,101

University of Central Florida | Orlando, FL | Principal Investigator: Joseph Walters

This project is developing new methods for characterizing fielded modules in order to provide greater certainty in fielded energy output and degradation rates over their lifetimes. New methods for data analysis and interpretation algorithms are under development in order to maximize fleet performance through a monitoring system that has a higher resolution than state-of-the-art methods currently allow. Additionally, models are being developed to examine the effects that different resolution photovoltaic monitoring systems have on energy yield simulations based on a power plant's design, size, location, environmental considerations, and expected system lifetime.

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.

RACKING SYSTEM FOR COMMERCIAL SOLAR ARRAYS – $1,205,000 ♦

Acme Express | Cleveland, OH | Principal Investigator: Don Scipione

Current solar panel racking systems have several components and require pre-ordering, transporting, inventorying, and labor-intensive deployment. This team is developing an automated racking system that produces the rack from raw material on-demand and on-site during an automated installation process. It is expected to reduce the cost of commercial, flat-roof solar installations by approximately nine percent.

NON-CONTACT SIMULTANEOUS STRING-MODULES I-V TRACER – $709,999

Arizona State University | Tempe, AZ | Principal Investigator: Govindasamy Tamizhmani

This project is developing a non-contact module-level I-V tracer for the rapid and accurate characterization of photovoltaic modules under operating conditions. This tracer aims to enable accurate degradation science and fielded performance monitoring to be conducted on modules under operation.

AUTOMATING DETECTION AND DIAGNOSIS OF FAULTS, FAILURES, AND UNDERPERFORMANCE IN PHOTOVOLTAIC PLANTS – $2,000,000

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Michael Bolen

Using machine learning and developing algorithms, this project team is working to identify reasons for unplanned maintenance events at utility-scale solar photovoltaic plants and differentiate them from power fluctuations due to causes that do not require on-site maintenance, like weather or module degradation. By analyzing the continuous energy-production data stream coming from utility-scale photovoltaic arrays, this technology can eliminate false alarms that are sent to photovoltaic system owners and operations and maintenance firms. This would decrease the labor required to review underperformance, lower the levelized cost of photovoltaic electricity, and increase energy output.

TECHNOECONOMIC ANALYSIS OF NOVEL PHOTOVOLTAIC PLANT DESIGNS FOR EXTREME COST REDUCTIONS – $199,968

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Joe Stekli

This project team is performing a techno-economic evaluation of photovoltaic plant design innovations to reduce costs and enable more dispatchable solar energy. Using machine-learning techniques, they are working gather data about both the plant components and the plants to optimize performance and significantly lower the levelized cost of energy. This will provide the photovoltaic community with a new opportunity to focus resources on technologies and designs that will have the greatest impact on cost reduction.

DECIPHERING DEGRADATION: MACHINE LEARNING ON REAL-WORLD PERFORMANCE DATA – $1,249,978

kWh Analytics | San Francisco, CA | Principal Investigator: Adam Shinn

The study of solar degradation has historically been limited by the unavailability of predictive and accurate analyses based on real-world, time-series photovoltaic plant performance data. This project is working to build a machine learning model on an industry-wide data repository by collecting energy generation data and system metadata on approximately 20 percent of America's operating photovoltaic plants. This will enable the team to statistically quantify degradation rates on an ongoing basis, quantify the impact that various materials and components have on degradation rates, and deliver systemic impact by enabling the world's largest reinsurers to accurately insure and therefore reward reliable solar products.

HIGHLY EFFICIENT STEEL CABLE SOLAR PHOTOVOLTAIC MOUNTING SYSTEM – $1,000,000

P4P Energy | Carbondale, CO | Principal Investigator: Kendra Joseph

This project is developing a unique photovoltaic panel suspension system utilizing tensioned cable design to reduce cost of solar parking structures. The team's strategy is to minimize weight and materials cost, while increasing assembly and construction efficiency to produce a markedly less expensive solar canopy that produces valuable shade as well as electric power. P4P Energy is researching a high volume, high efficiency product that will be both aggressively competitive and aesthetically pleasing.

ENHANCED CONVECTION FOR HIGHER MODULE AND SYSTEM EFFICIENCY – $1,040,000

Portland State University | Portland, OR | Principal Investigator: Raul Cal

This project is developing new solar photovoltaic modules and solar system-scale designs that promote an increase of the convective heat transfer coefficient of at least 40 percent. This reduces the operating temperature of the solar photovoltaic panels and leads to a boost on the annual energy yield and a potentially significant increase in the reliability of modules over time. Extensive modeling and early stage experimentation is being conducted to determine the dynamics of air flow needed to produce vortex generation and flow channeling effects that would lead to lower temperature of the array.

SINGLE MODEL CHARACTERIZATION – $541,504

Power Factors | Larkspur, CA | Principal Investigator: Steve Voss

This project is developing a methodology capable of quantifying and categorizing all losses from nominal energy to energy delivered by photovoltaic systems. This represents a significant streamlining of how photovoltaic experts compare large modeled and measured datasets, and would improve agreement between energy yield models and energy production datasets, which are vital to improving the reliability and bankability of photovoltaic systems. This project enhances the quality and handling of performance data and future modeling efforts.

BIFACIAL PHOTOVOLTAIC MODULE ENERGY MODELING VALIDATION STUDY – $200,000

PVEL, LLC | Berkeley, CA | Principal Investigator: Tara Doyle

Bifacial photovoltaic module suppliers are conducting their own efficiency tests in an effort to demonstrate energy gains to customers, but these tests often lack third-party review. To enable more accurate and bankable solar production forecasts for bifacial modules, this team is working to establish an outdoor test that compares modeled energy from bifacial models to measured energy generation in common types of ground or roof coverings. These tests will account for multiple scenarios for bifacial modules, including placement on painted flat roofs, placement in fields with low-lying vegetation, and soiling from dirt or sand. The team plans to publish the results of this analysis to improve modeling efforts, energy-yield estimates, and bankability for bifacial modules on the market.

OPTIMIZED BIFACIAL MODULES AND SYSTEMS – $1,590,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Stein

Bifacial photovoltaic technologies are developing rapidly and are predicted to play a key role in the future of solar energy. This project aims to develop and validate advanced bifacial performance models capable of simulating a wide range of system designs and perform design optimization studies of a range of bifacial system types utilizing high performance computing resources and tools available at Sandia and the National Renewable Energy Laboratory. Additionally, the team is working to deploy and monitor typical bifacial systems for model validation and work with industry to improve standards and best practices in the areas of module and system rating, capacity testing, site prospecting and safety.

SNOW CHARACTERISTICS AS A FACTOR IN PHOTOVOLTAIC PERFORMANCE AND RELIABILITY – $2,100,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Laurie Burnham

As solar markets expand into northern regions of the United States, the impact of snow on the energy productivity of solar installations is of growing interest. The buildup of snow and ice on solar panels can stifle electrical output, erode reliability, and decrease lifetime performance. To better understand and combat these deleterious effects, this project is working to identify and quantify the factors that contribute to snow-induced energy losses and gains, as well as to validate the efficacy of technological improvements (e.g., advanced coatings) and design configurations that increase annual energy yields. Additionally, the team aims to refine existing predictive models, bringing greater accuracy to levelized-cost-of-energy calculations. This work transcends previous research by being both field- and lab-based, with outdoor experimentation and demonstration supported by high-precision laboratory analysis of snow-module interactions. The knowledge gained will inform product development, improve system designs, and lead to more accurate performance models, thus giving investors, asset owners, insurers, and other stakeholders greater confidence in levelized-cost-of-energy calculations and helping expand solar in northern latitudes.

SPREAD SPECTRUM TIME DOMAIN REFLECTIVITY FOR STRING MONITORING IN PHOTOVOLTAIC POWER PLANTS – $800,000

University of Utah | Salt Lake City, UT | Principal Investigator: Michael Scarpulla

This project is investigating the application of spread spectrum time domain reflectivity to detect faults and their locations in a photovoltaic string in real time without disconnecting the string during the test. For example, the technique can decipher which panel or section of wiring has experienced a physical or operational change. By detecting the fault location in the connected string, this project will enable more efficient repair and maintenance of photovoltaic power plants, maximizing future energy output, and reducing the levelized cost of energy.

Concentrating Solar-Thermal Power

The Concentrating Solar-Thermal Power track supports 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 for a total of more than $180 million in federal funding; approximately one quarter of SETO projects falls under this category.

Concentrating solar-thermal power 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, concentrating solar-thermal technologies can easily supply solar energy on demand, even when the sun isn't shining. Further, concentrating solar-thermal power 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 concentrating solar-thermal power 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 concentrating solar-thermal power even more affordable, with the goal of reaching $0.05 per kilowatt-hour for a baseload plants with at least 12 hours of thermal energy storage.

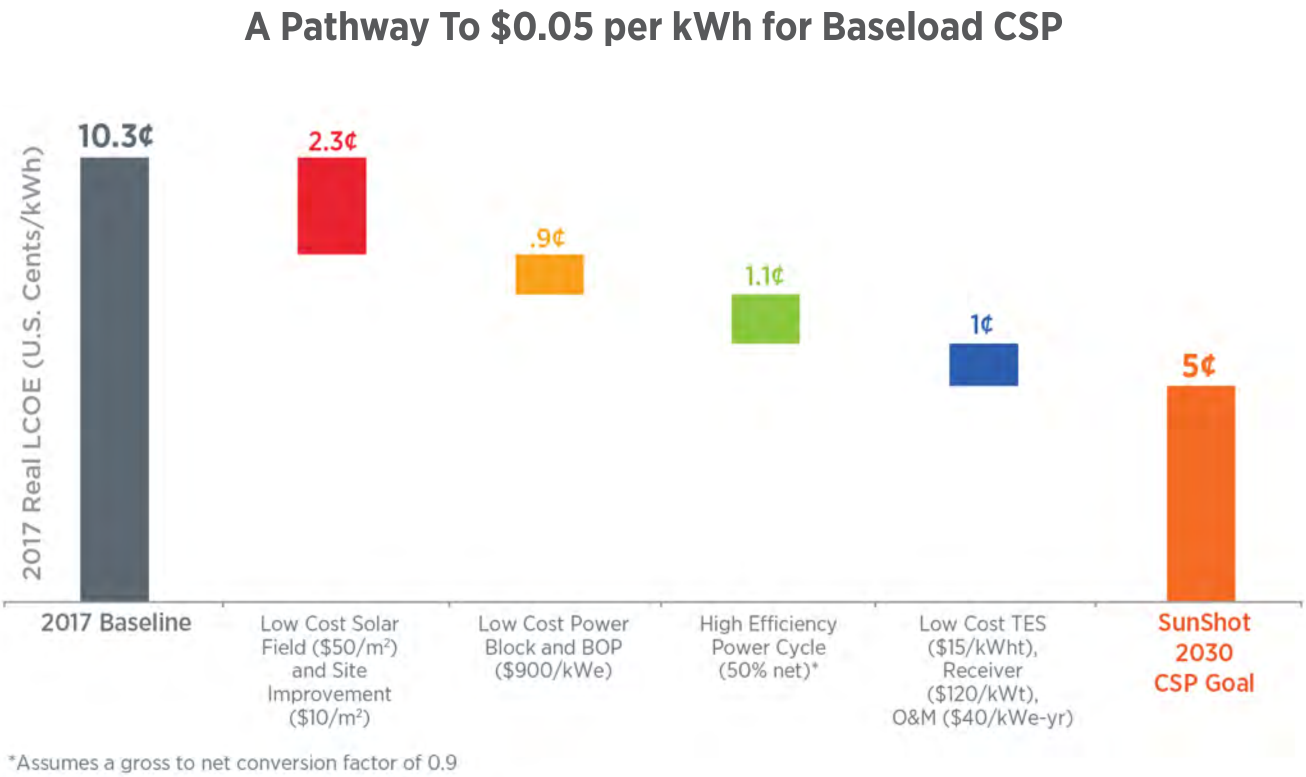
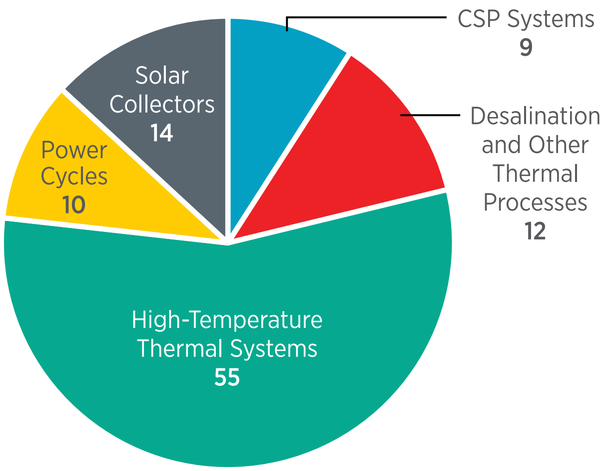


Figure 11: Sample scenario for reducing costs to $0.05 per kWh for Baseload CSP.

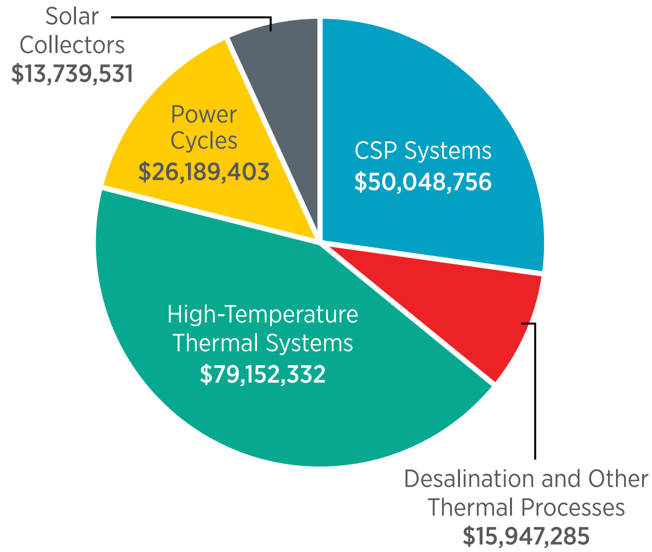
The challenges in achieving these targets require interdisciplinary solutions throughout a variety of fields in science and technology that tackle heat transfer, fluid mechanics, thermodynamics, optical physics, materials science, extreme automation in the solar field, corrosion mitigation, advanced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

The Concentrating Solar-Thermal Power track also includes 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 to build a strong clean energy manufacturing sector and supply chain that produce cost-competitive solar technologies. This track also includes projects in 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 focused its projects in five major categories: High-Temperature Thermal Systems, Desalination and Other Thermal Processes, CSP Systems, Power Cycles, and Solar Collectors. A description of each can be found below, along with a detailed list of the projects within it. Projects are alphabetized by the awardee name and represented in the following format:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

Projects managed by the Innovations in Manufacturing and Competitiveness team are identified with a blue diamond (♦) after the project name and amount.

Projects managed by the Strategic Analysis and Institutional Support team are identified with a red spade (♠) after the project name and amount.

High-Temperature Thermal Systems

In order to lower the cost of concentrating solar-thermal power 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. These projects 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 of the projects in the Concentrating Solar-Thermal Power track are in this topic, representing just under half of the track's total funding.

ROBUST SOLAR RECEIVERS USING MAX PHASE MATERIALS – $360,000

Argonne National Laboratory | Lemont, IL | Principal Investigator: Dileep Singh

As operating temperatures for concentrating solar-thermal power plants continue to increase, current metal-based receivers have structural stability issues that need to be addressed to accommodate higher temperatures. This project is developing receivers using ceramic materials that can operate at temperatures higher than 800 degrees Celsius. The team aims to demonstrate the viability of these new class of materials.

ECONOMIC WEEKLY AND SEASONAL THERMOCHEMICAL AND CHEMICAL ENERGY STORAGE FOR ADVANCED POWER CYCLES – $3,300,000

Arizona State University | Tempe, AZ | Principal Investigator: Ellen Stechel

This project seeks to integrate multiple thermochemical energy storage components into a concentrating solar-thermal power design so that a plant can have multiple storage durations, including daily and long-term. These components will be designed for integration with supercritical carbon dioxide power cycles. The team is conducting techno-economic analyses to improve concentrating solar-thermal power system design and operation for guaranteed year-round energy dispatchability.

INTEGRATED SOLAR RECEIVER WITH THERMAL STORAGE FOR A SUPERCRITICAL CARBON DIOXIDE POWER CYCLE – $2,599,959

Brayton Energy | Hampton, NH | Principal Investigator: Shaun Sullivan

This project integrates a novel solar absorber architecture and metal hydride thermal energy storage in a single close-coupled system. The high energy density of the thermal energy storage allows it to be mounted up-tower alongside the receiver, which further enables up-tower mounting of the entire supercritical carbon dioxide Brayton power block. Mounting the thermal energy storage and power block up-tower eliminates the need for costly piping and fluidic connections between the receiver and a large centralized element, making the system ideal for modular implementation and growth.

INTEGRATED THERMAL ENERGY STORAGE HEAT EXCHANGER FOR CONCENTRATING SOLAR POWER APPLICATIONS – $1,178,556

Brayton Energy | Hampton, NH | Principal Investigator: Jim Nash

This project is developing a heat exchanger that uses a composite phase-changing material to store and release heat from a concentrating solar-thermal power receiver to a supercritical carbon dioxide power-conversion cycle. The team is designing a new heat exchanger and testing the durability of its components by exposing them to high pressures and temperatures, helping to optimize the heat exchanger and create a scalable design for supercritical carbon dioxide concentrating solar-thermal power plants. This project performs component-level research and development for a concentrating solar-thermal power system.

CREEP AND FATIGUE CHARACTERIZATION OF HIGH STRENGTH NICKEL ALLOYS THIN SECTIONS IN ADVANCED CARBON DIOXIDE HEAT EXCHANGERS – $700,000

Brayton Energy | Hampton, NH | Principal Investigator: Jake Boxleitner

Brayton Energy and Oak Ridge National Laboratory are examining creep behavior—the tendency to deform under mechanical stress—in thin-sheet nickel alloys 740H and 282, to see whether they can improve the lifetime of supercritical carbon dioxide heat exchangers in high-temperature concentrating solar-thermal power plants. This will provide information about structural characteristics in metals used to build heat exchangers and determine how thick their components should be.

HIGH TEMPERATURE SILICON CARBIDE COMPOSITE RECEIVER ASSEMBLY FOR LIQUID PATHWAY CONCENTRATING SOLAR POWER OPERATING ABOVE 700 DEGREES CELSIUS – FY19 TBD

Ceramic Tubular Products | Lynchburg, VA | Principal Investigator: Kristen Frey

This project team is developing silicon carbide composite receiver tubes for molten chloride salt and liquid sodium receivers in concentrating solar-thermal power plants. The tubes have thermomechanical properties and corrosion resistance that are superior to metal alloys at high temperatures. As a result, the lifetimes of these tubes could increase, enhancing concentrating solar-thermal power system performance.

NARROW-CHANNEL, FLUIDIZED BEDS FOR EFFECTIVE PARTICLE THERMAL ENERGY TRANSPORT AND STORAGE – $1,177,701

Colorado School of Mines | Golden, CO | Principal Investigator: Gregory Jackson

Using particles to replace the heat transfer fluid in a concentrating solar-thermal power system may be the simplest way to increase the operation temperature and therefore increase the power cycle efficiency of a concentrating solar-thermal power plant. Colorado School of Mines is working with Sandia National Laboratories and Carbo Ceramics to develop and test a narrow-channel, counterflow fluidized bed receiver and heat exchanger designs. These are used to analyze flow conditions and improve heat transfer rates in the receiver and heat exchanger. The team uses these insights to test a modular panel for an indirect particle receiver and/or particle to supercritical carbon dioxide power cycle heat exchanger. The program will deliver detailed multiphase flow modeling tools to assess how receiver and heat exchanger designs can meet receiver cost targets of $150 per kilowatt hours of heat and thermal-energy system targets of $15 per kilowatt hours of heat.

THERMODYNAMICALLY STABLE, PLASMONIC TRANSITION METAL OXIDE NANOPARTICLE SOLAR SELECTIVE ABSORBERS TOWARDS 95 PERCENT OPTICAL-TO-THERMAL CONVERSION EFFICIENCY AT 750 DEGREES CELSIUS – $400,000

Dartmouth College | Hanover, NH | Principal Investigator: Jifeng Liu

This project aims to achieve an optical-to-thermal conversion efficiency of 95 percent for concentrating solar-thermal power receivers using a spray-coated solar selective coating. Specifically, plasmonic metal oxide nanoparticles are thermodynamically stable at 750 degrees Celsius and improve the coupling of incident light with the metal's electrons, thereby improving receiver efficiency. The team is testing whether optimizing the plasmonics response of transition metal components increases the optical-to-thermal conversion efficiency to 95 percent. The project will break through the current efficiency limit of about 89 percent and resolve deterioration issues in high-temperature solar absorbers without increasing the costs.

POWER CYCLE WITH INTEGRATED THERMOCHEMICAL ENERGY STORAGE – $1,000,000

Echogen Power Systems | Akron, OH | Principal Investigator: Timothy Held

Echogen and the Southern Research Institute are designing, modeling, and testing a novel integrated supercritical carbon dioxide power cycle and thermochemical energy storage system for concentrating solar power. The system uses supercritical carbon dioxide both as a power cycle working fluid and as a reactant in the thermochemical energy storage reactor. The team is designing, building, and testing a prototype-scale supercritical carbon dioxide power cycle and reactor to validate the design and performance of the system.

IMPROVING ECONOMICS OF THIRD GENERATION CONCENTRATING SOLAR-THERMAL POWER SYSTEM COMPONENTS THROUGH FABRICATION AND APPLICATION OF HIGH-TEMPERATURE NICKEL-BASED ALLOYS – $1,499,901

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: John Shingledecker

In order to reduce high-temperature concentrating solar-thermal power plant costs, this team is investigating manufacturing methods for alloys that had previously been designed for high-temperature power service in advanced ultra-supercritical steam. They are examining the cost and performance advantages of manufacturing pipes and tubes from flat sheets after further processing, which can lower capital costs. If these alternate manufacturing routes of alloys can produce pipes that are able to maintain operating lifetimes similar to piping produced from other nickel-based alloys, they have the potential to reduce the cost of these components by about 30 percent.

NEAR-NET-SHAPE HOT ISOSTATIC PRESS MANUFACTURING MODALITY FOR SUPERCRITICAL CARBON DIOXIDE CONCENTRATING SOLAR-THERMAL POWER CAPITAL COST REDUCTION – $2,500,000

GE Global Research | Niskayuna, NY | Principal Investigator: Jason Mortzheim

This project is working to fabricate advanced super critical carbon dioxide power cycle structures for concentrating solar-thermal power plants from metal powders by pressing these powders at high temperatures. This process is estimated to reduce the manufacturing cost of these components by at least half and lower equipment costs. This will enable a U.S.-based supply chain and strengthens the nation's role in advanced manufacturing and high-efficiency power generation.

ADVANCED CHARACTERIZATION OF PARTICULATE FLOWS FOR CONCENTRATING SOLAR POWER APPLICATIONS – $1,352,194

Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Peter Loutzenhiser

This project addresses a knowledge gap within the field of particulate flows for concentrating solar-thermal power applications. The team is working to characterize the flow and heat transfer of particulate media over a range of operating conditions, including temperature, particle size, and construction material. Through experimentation and modeling, the team will determine the properties needed for inputs at these high temperatures. These results will provide guidance to the concentrating solar-thermal power industry for ongoing work related to the design and modeling of solar particle heat receivers and reactors.

THERMOPHYSICAL PROPERTY MEASUREMENTS OF HEAT TRANSFER MEDIA AND CONTAINMENT MATERIALS – $1,966,441

Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Shannon Yee

This project researches and analyzes the thermophysical properties supporting third generation integrated thermal systems. This team is investigating thermal conductivity, thermal diffusivity, and specific heat across the range of temperatures and materials of interest to third generation concentrating solar-thermal power systems. The team will perform measurements on molten salt chemistries and containment materials, including alloy, ceramic, and cermet materials. This research will be shared to address the knowledge gap in third generation thermophysical properties.

ADDITIVE MANUFACTURING OF CORROSION RESISTANT ULTRA HIGH TRANSMISSION COATING MATERIALS FOR CHLORIDE SALT TO SUPERCRITICAL CARBON DIOXIDE BRAYTON CYCLE HEAT EXCHANGERS – $250,000

Lawrence Livermore National Laboratory | Livermore, CA | Principal Investigator: James Kelly

This project is developing an ultra-high-temperature ceramic heat exchanger based on Triply Periodic Minimal Surface geometries, which can only be fabricated by additive manufacturing methods. The goal is to develop a heat exchanger that provide up to ten times higher heat transfer coefficients per unit reactor volume, while retaining smooth features and moderate pressure drop, which enables compact design with high efficiency. It is being constructed from materials known to retain their strength at temperatures between 1200 and 2100 degrees Celsius and is expected to be compatible with molten chloride salts and supercritical carbon dioxide.

NOVEL CORROSION AND EROSION PROTECTIVE AMORPHOUS ALLOYS COATINGS – $1,146,108 ♦

LM Group Holdings | Lake Forest, CA | Principal Investigator: Evelina Vogli

This project evaluates and applies amorphous alloy coatings to molten salt system components, such as impellers, sealants, pipes, and tanks, to enable operation at temperatures above 700 degrees Celsius. Amorphous metals combine ultra-high strength, high hardness, and ductility—the ability to stretch—into a single material. In addition, they are more resistant to corrosion compared to conventional metals. The amorphous alloy coatings will be applied to molten salt system components using a high-velocity oxygen fuel coating technique. This novel approach will improve the overall properties of the manufactured components, helping to increase throughput in concentrating solar-thermal power systems.

CERAMIC CASTABLE CEMENT TANKS AND PIPING FOR MOLTEN SALT – $1,768,424

Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Asegun Henry

This team is developing ceramic castable cements to be used for thermal storage tanks and piping, which carry and store high-temperature molten salts at 750 degrees Celsius. This project is also investigating engineered high-temperature cements that can be used to form a self-insulating thermal storage tank. These ceramic castable cements are being chemically engineered to resist corrosion and penetration by the high-temperature salts of interest for the liquid pathway.

HIGH TEMPERATURE PUMPS AND VALVES FOR MOLTEN SALT – $1,892,185

Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Asegun Henry

This project develops high-temperature liquid-phase pumps and valves that use novel ceramic-metal composite materials that are stable at high temperatures, instead of steel or nickel-based alloys, to create components that can reliably operate with molten salts at 750 degrees Celsius. Low-cost novel refractory materials and processes are used to form these materials into the complex shapes needed to form pump and valve components. The team is testing the integration of these components in both liquid pumps and valves and investigate whether any new corrosion mechanisms arise due to salts flowing through the pumps in comparison to stagnant salt. This will enable the scale-up of a liquid pump that can be implemented in a multi-megawatt flowing molten salt loop with high reliability and used in third generation concentrating solar-thermal power plants.

SOLID STATE SOLAR THERMOCHEMICAL FUEL FOR LONG DURATION STORAGE – $2,000,000

Michigan State University | East Lansing, MI | Principal Investigator: James Klausner

This project is developing a low-cost, zero-emission, solid-state fuel that enables energy storage for short or long periods. This environmentally sound fuel can be stored in a bin until it is used to provide low-cost solar energy storage. Since it can be readily scaled up to 100 megawatts, this novel fuel will aim to be economically competitive at long durations and large capacities.

OIL-FREE, HIGH-TEMPERATURE HEAT TRANSFER FLUID CIRCULATOR – $1,678,243

Mohawk Innovative Technology | Albany, NY | Principal Investigator: Hooshang Heshmat

This project is working to develop a maintenance- and oil-free high-temperature heat transfer fluid circulator for gas-based third generation concentrating solar-thermal power systems through research, design, and testing. The heat transfer fluid circulator is designed for system simplicity, maintenance-free operation, high reliability, and reduced capital and operating costs by isolating the drive from the heat transfer fluid and designing foil gas bearings and seals that are able to use the heat transfer fluid as lubricant.

ELECTROCHEMICAL CONTROL FOR CORROSION IN MOLTEN CHLORIDES DURING CONCENTRATING SOLAR-THERMAL POWER PLANT OPERATION – $498,851

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Judith Vidal

Due to their high thermal stability and low cost, molten chloride salts are a promising heat-transfer fluids for concentrating solar-thermal power plants. However, associated corrosion concerns must be addressed. This project focuses on designing electrochemical methods and reactors for controlling and mitigating identified corrosion mechanisms expected during plant operation. Through redox control mechanisms, the team uses electrochemical elimination of corrosive impurities formed by salt hydrolysis in the presence of oxygen or water. If galvanic coupling occurs, the team plans to use cathodic protection of dissimilar alloys. These approaches aim to keep corrosion to less than 20 microns per year.

ENVIRONMENTAL DESIGN OF COST-EFFECTIVE HIGH-TEMPERATURE SENSIBLE THERMAL ENERGY STORAGE USING INDUSTRIAL BYPRODUCTS – $1,700,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Youyang Zhao

This project is designing a cost-effective structure for thermal energy storage tanks using composite concrete instead of metals to help achieve the thermal energy storage cost target of $15 per kilowatt-hour thermal. The team is also working to improve the mechanical strength and thermal stability of the tanks' internal insulation materials by creating a new composite ceramic material with cenospheres—small, lightweight, hollow balls of silica or alumina that are filled with gas—added to prevent salt from seeping in.

MOLTEN CHLORIDE THERMOPHYSICAL PROPERTIES, CHEMICAL OPTIMIZATION, AND PURIFICATION – $1,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Youyang Zhao

This project addresses the thermophysical properties and handling of molten chloride salts that can be used as both the heat-transfer fluid and thermal energy storage material. The team is investigating the purification of commercial salts, optimization of chemical composition, and handling of procedures for concentrating solar-thermal power applications. They also plan to create and publish guidelines and protocols needed for obtaining accurate and reliable thermophysical properties of molten chloride salts.

RE-DESIGNING THE CONCENTRATING SOLAR-THERMAL POWER THERMAL ENERGY STORAGE SYSTEM TO ENABLE HIGHER-TEMPERATURE PERFORMANCE AT REDUCED COST – $1,103,467

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Youyang Zhao

Current commercial concentrating solar-thermal power plants store energy via a heat transfer fluid in large metallic storage tanks that are made of stainless steel. As the operating temperature of heat transfer fluids continues to rise to increase plant efficiency, more expensive alloys will be needed for the storage tanks to handle these higher temperatures. The goal of this project is to develop designs that will eliminate the need for expensive alloys: first, in today's hot tanks operating at 565-580 degrees Celsius, and second, to point the way for similar design approaches to reduce the thermal energy storage costs for tomorrow's much higher operating temperatures.

STRESS CORROSION CRACKING – $700,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Judith Vidal

This project is investigating stress relaxation cracking susceptibility of 347SS, the current alloy employed in commercial hot tanks containing molten nitrate at 565 degrees Celsius, under standard concentrating solar-thermal operational conditions. The goal is to submit a report documenting the findings for which conditions, if any, stress relaxation cracking is a problem. The report aims to communicate findings-to-date, including recommended European and American thermal energy storage tank fabrication protocols along with the negative impacts if such protocols are incorrectly followed.

THERMOMECHANICAL BEHAVIOR OF ADVANCED MANUFACTURED PARTS, SUBCOMPONENTS, AND THEIR WELDMENTS FOR THIRD GENERATION CONCENTRATING SOLAR-THERMAL POWER – $2,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Judith Vidal

This project is developing strategies to prevent corrosion on piping and other metal surfaces that would be in contact with molten chlorides in Generation 3 concentrating solar-thermal power systems. The team is exploring advanced manufacturing techniques for components like heat exchangers as well as cladding for piping materials. This will extend the lifetime of concentrating solar-thermal power components and plants.

CAST COMPONENTS FOR HIGH TEMPERATURE CONCENTRATING SOLAR-THERMAL POWER THERMAL SYSTEMS – $1,000,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Govindarajan Muralidharan

High-temperature concentrating solar-thermal power systems operate at temperatures greater than 700 degrees Celsius, which can be a challenge for components made from conventional metal alloys. While these components are typically hammered into the appropriate shape and then welded, this project explores the feasibility of casting, a simpler and lower-cost manufacturing process in which liquid metal is poured into a mold to create precisely shaped components. Casting is best suited for intricately designed concentrating solar-thermal power components like heat exchangers, tubes, and vessels and could significantly reduce fabrication costs, helping to reduce overall concentrating solar-thermal power capital costs.

DEVELOPMENT OF CAST VALVE BODIES FOR HIGH TEMPERATURE SERVICE – $500,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Govindarajan Muralidharan

This project aims to lower the costs of materials and components in concentrating solar-thermal power systems so capital costs can be minimized while still achieving high operating temperatures. To obtain the lowest cost in castings, there is a significant need to maximize yields in castings by decreasing rejects due to casting defects and to minimize waste in lost material in the gating systems. The scope of the work includes collection of data required for computational design of the casting, design of the rigging system for the casting using computational modeling, development of melting and casting process parameters, casting fabrication, casting integrity evaluation, comparison of experimental evaluation of casting quality with results from modeling, and evaluation of microstructure and tensile properties in a critical location.

ENABLING HIGH-TEMPERATURE MOLTEN SALT CONCENTRATING SOLAR-THERMAL POWER THROUGH THE FACILITY TO ALLEVIATE SALT TECHNOLOGY RISKS – $5,000,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Kevin Robb

This project focuses on the design, construction, and operation of a lab-scale test facility to alleviate salt technology risks. This facility is a versatile, high-temperature molten chloride salt facility designed for temperatures greater than 700 degrees Celsius and for a variety of testing in support of the third generation concentrating solar-thermal power molten salt pathway. The facility and its accompanying research will provide the foundational capabilities necessary to support third generation concentrating solar-thermal power.

INTERFACE EVOLUTION WITH MOLTEN SALTS – $200,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Gabriel Veith

This project aims to understand the surface evolution of high nickel alloy surfaces under molten salt conditions. The team is using a variety of scattering and in situ approaches to follow the interface evolution, with nanometer resolution, as a function of time and temperature. Understanding these interfaces enables the team to identify and evaluate passivation layers and coatings that mitigate materials migration. Understanding changes in the salt chemistry allows for the prediction of additives to stabilize the salt chemistry. Additionally, the atomic scale in situ studies allows for the direct measurement of reaction mechanisms and kinetics aiding in the simulation of lifetime and hardware stability.

HIGH FLUX MICROCHANNEL RECEIVER DEVELOPMENT – $2,000,000

Oregon State University | Corvallis, OR | Principal Investigator: Brian Fronk

This project continues Oregon State University's development of a microchannel solar receiver using supercritical carbon dioxide as the heat transfer fluid. The research is working to resolve key issues associated with the commercial viability of the technology, which allows for a radical reduction in the size of a solar central receiver. The project will culminate in an on-sun test of a commercial scale receiver module with a surface area of approximately one square meter.

SELECTIVE THERMAL EMISSION WITH RADIATION AND ADSORPTION IN ANNULI: AN ADVANCED HEAT EXCHANGER CONCEPT FOR SUPERCRITICAL CARBON DIOXIDE POWER CYCLES – $395,000

Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Peter McGrail

One of the key limitations affecting ability to achieve the efficiency and cost saving advantages of a solar thermal supercritical carbon dioxide power cycle resides with the primary heat exchanger, where costs can exceed 50 percent of the plant capital budget depending on design. This project lays the foundational groundwork for a new type of heat exchanger optimized to take advantage of radiative heat transfer to supercritical carbon dioxide. Using principles from the new field of optical metamaterials, selective thermal emission coatings are being designed to radiate light tuned to the strong infrared absorption band of carbon dioxide. Heat transfer simulations show that an advanced heat exchanger implementing this selective thermal emitter is 25-40 percent smaller than conventional heat exchanger designs.

HIGH-TOUGHNESS CERMETS FOR MOLTEN SALT PUMPS – $1,326,384

Powdermet | Euclid, OH | Principal Investigator: Joseph Hensel

This project is developing high-toughness, ceramic-metal composite materials (cermets), which offer minimal friction in fluids with poor lubrication and are resistant to erosion and wear-and-tear. The team is building a liquid pump and a component test facility that analyzes these materials in a molten chloride salt environment, examines design allowances, and determines the cost-effectiveness of the cermets. This work could enable fabrication of low-maintenance, durable pumps for concentrating solar power systems.

MECHANICALLY-, THERMALLY, AND CHEMICALLY-ROBUST HIGH-TEMPERATURE CERAMIC COMPOSITES – $400,000

Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage

The purpose of this project is to increase the thermal-to-electrical conversion efficiency of concentrating solar power systems by developing new mechanically robust, thermally conductive, and thermally cyclable ceramic composites used to make chloride salt heat exchangers and piping. Currently, no cost-effective solution exists for either of these components at high temperatures. These composites will be stiffer and stronger than nickel-based superalloys at 550-750 degrees Celsius and also resistant to corrosion by supercritical carbon dioxide air, and heat transfer and storage fluids, such as molten chlorides. The team will also test the manufacturability of these robust ceramic composites in complex shapes via scalable, low-cost forming and thermal treatments.

MITIGATION OF MOLTEN SALT CORROSION – $400,000

Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage

When molten chloride salts are used for high-temperature heat transfer and storage, structural metal alloys, and ceramic composites, the materials used to store many tons of molten salt can experience corrosion at high temperatures if the chlorides are contaminated with dissolved oxygen or water vapor. Corrosion is the most likely source of failure for chloride salt heat transfer fluids in a concentrating solar-thermal power system. This project aims to dramatically reduce corrosion for a concentrating solar-thermal power systems by developing novel chemistries of the molten chloride salts, and will show that minimal corrosion can be achieved with appropriate containment materials.

OXIDATION-RESISTANT, THERMOMECHANICALLY-ROBUST CERAMIC COMPOSITE HEAT EXCHANGERS – $3,500,000

Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage

This project team is developing cost-efficient ceramic-composite primary heat exchangers that are highly resistant to corrosion by supercritical carbon dioxide and molten salt and will not deform or fracture at temperatures as high as 800 degrees Celsius. These heat exchangers will last longer than conventional ones and improve the efficiency and lifetime of concentrating solar-thermal power plants.

ROBUST HIGH-TEMPERATURE HEAT EXCHANGERS – $1,960,745

Purdue University | West Lafayette, IN | Principal Investigator: Kenneth Sandhage

This team is developing a high-performance heat exchanger based on a new ceramic-metal composite material (cermet) for transfer of high-temperature molten chlorides, with supercritical carbon dioxide as the working fluid for energy conversion in the power block of a concentrating solar-thermal power system. The higher failure strengths and thermal conductivities at 800 degrees Celsius of these cermets instead of metal alloys will allow the team to design smaller, lower-cost heat exchangers than would otherwise be possible. By tailoring the cermet surface and fluid chemistry, the cermets also have the ability to withstand thermal cycling and thermal shock, as well as resist corrosion from molten salts and fluids based on supercritical carbon dioxide.

DEVELOPMENT OF IN SITU CORROSION KINETICS AND SALT PROPERTY MEASUREMENTS – $1,799,892

Rensselaer Polytechnic Institute | Troy, NY | Principal Investigator: Li Liu

This project is developing in situ experimental techniques and methodologies to gain a fundamental understanding of the mechanisms of molten-salt surface corrosion kinetics and molten-salt properties. Four complementary approaches are under development to achieve these objectives: in situ transmission electron microscopy; neutron reflectometry of molten salt and alloy cells; macroscopic electrochemical studies; and vibrational spectroscopy analysis and modeling. By addressing the knowledge gaps in high-temperature molten-salt properties and corrosion mechanisms, this research can guide the selection of salts and containment materials.

CHARACTERIZATION OF RADIATIVE, CONVECTIVE, AND PARTICLE LOSSES IN HIGH-TEMPERATURE PARTICLE RECEIVERS – $1,031,070

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Clifford Ho

This project is working to reduce particle and heat losses in directly irradiated high-temperature (greater than 700 degrees Celsius) particle receiver systems, using a combination of computer simulations and measurements of particle fluid dynamics and heat transfer pathways. This enables increased receiver thermal efficiencies, reduces receiver costs, and mitigates potential health risks from inhalation of fine particles.

DEVELOPMENT AND DEMONSTRATION OF A 1000 DEGREE CELSIUS SOLID PARTICLE RECEIVER – $750,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Christian

The German Aerospace Center's advanced particle receiver concept, an inclined rotating drum where concentrated sunlight heats particles, is being tested at Sandia's National Solar-Thermal Test Facility at temperatures above 800 degrees Celsius, heat-throughput levels greater than five megawatts, and solar-concentration ratios greater than 1,000 suns.

HIGH-TEMPERATURE FREEZE AND LEAK RESISTANT ADVANCED SALT VALVE – $2,000,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Kenneth Armijo

This project team is developing a robust molten salt valve that can mitigate leaking and freezing in operating temperatures up to 750 degrees Celsius in concentrating solar-thermal power plants. The design uses passive and active heat management strategies suitable to different valve types. This will ensure long-term valve operation at high temperatures, promote a 30-year system lifetime, and reduce operation and management burdens due to freezing and downtime.

HIGH-TEMPERATURE PARTICLE HEAT EXCHANGER FOR SUPERCRITICAL CARBON DIOXIDE POWER CYCLES – $4,586,967

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Clifford Ho

This project is working to design, develop, and test a particle/supercritical carbon dioxide heat exchanger operating at temperatures of 720 degrees Celsius and supercritical carbon dioxide pressures up to 20 megapascals. Industry experience with similar heat exchangers is limited to lower pressures, lower temperatures, or alternative fluids such as steam or water. This project team partners with three experienced heat exchanger manufacturers to develop and down-select several designs for the unit that achieves both high performance and low specific cost to retire risks associated with a solar thermal particle/ supercritical carbon dioxide power system. A prototype unit is being manufactured and tested in a high temperature and pressure supercritical carbon dioxide flow loop to confirm key metrics for performance and cost. Lessons learned and experiences gained will be used to scale-up the design to a multi-megawatt plant with cost estimates and uncertainties.

QUANTIFYING THERMOPHYSICAL PROPERTIES AND DURABILITY OF PARTICLES AND MATERIALS FOR DIRECT AND INDIRECT HEAT TRANSFER MECHANISMS – $445,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Kevin Albrecht

This project seeks to improve the understanding of dense granular flow heat transfer through testing subscale prototype heat exchangers. Currently, data for prototype heat exchangers is limited due to uncertainties in inlet in outlet temperature. Acquiring this data will lead to input parameters for heat exchanger models used in the design process as well as identification of potential methods for improving the performance. The overall objective of this project is to supply other concentrating solar-thermal power projects with sufficient data for the design and optimization of particle-to-fluid heat exchangers.

SOLAR-THERMAL ENERGY AMMONIA PRODUCTION – $2,800,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Andrea Ambrosini

This project enables the use of solar-thermal energy to produce ammonia, a common industrial chemical that requires a lot of energy to produce. First, sunlight will activate solid particles in a concentrating solar-thermal power system to isolate nitrogen from air. Then the nitrogen will be activated to form a metal nitride, which can react with hydrogen to generate ammonia. The project team is developing materials that can be reliably and cost-effectively cycled for both the nitrogen separation and ammonia generation steps in the process.

SUPERCRITICAL CARBON DIOXIDE LOOP IN SUPPORT OF THE THIRD GENERATION CONCENTRATING SOLAR-THERMAL POWER SOLID, LIQUID, AND GAS PATHWAYS – $3,600,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Matt Carlson

To achieve higher efficiencies, concentrating solar-thermal power plants can use the Brayton power cycle, an engine design that uses supercritical carbon dioxide as a fluid to transfer heat. Current concentrating solar-thermal power plants use steam Rankine cycles, in which 35-42 percent of the collected heat is converted to electricity. Brayton power cycles that use supercritical carbon dioxide as the working fluid could increase this efficiency to 50 percent or higher. This project will develop a supercritical carbon dioxide support loop to cool the main heat exchanger in a pilot plant project.

HIGH TEMPERATURE, RAMAN SPECTROSCOPY BASED, INLINE, MOLTEN SALT COMPOSITION MONITORING SYSTEM FOR CONCENTRATING SOLAR POWER SYSTEMS – $1,154,849 ♦

Sporian Microsystems | Lafayette, CO | Principal Investigator: Kevin Harsh

In situ, real-time, and online monitoring of molten salt composition and chemistry could enable the next generation of concentrating solar-thermal power plants to achieve maximum thermal performance and reduce material damage due to corrosion. This project is developing and testing a lab-scale molten salt heat transfer fluid composition and contaminant monitoring system. Additionally, this project is developing and testing a fluid based on Raman spectroscopy, a precise method used to identify contaminants in the molten salt, and able to withstand high temperatures. Altogether, the proposed system will have the potential to improve the efficiency, reliability, and economic viability of concentrating solar-thermal power systems.

SENSING AND ARRESTING METAL CORROSION IN MOLTEN CHLORIDE SALTS AT 800 DEGREES CELSIUS – $800,000

University of Arizona | Tempe, AZ | Principal Investigator: Dominic Gervasio

This project proposes new approaches to mitigating corrosion from molten chloride salts in concentrating solar-thermal power systems. The team is investigating the potential of using metal salt additives to slow the loss of specific metals from piping; zirconium metal structures to remove impurities in the molten salt loop; and novel corrosion warning and controlling devices that can detect corrosion and switch salt flows. If successful, this project will show the feasibility of multiple new methods for sensing and stopping corrosion in advanced molten chloride salts for next-generation concentrated solar-thermal power thermal transport systems.

ADDITIVELY-MANUFACTURED MOLTEN SALT AND SUPERCRITICAL CARBON DIOXIDE HEAT EXCHANGER – $1,812,725

University of California, Davis | Davis, CA | Principal Investigator: Vinod Narayanan

This project seeks to develop an additively manufactured, nickel superalloy primary heat exchanger for advanced molten salt concentrated solar-thermal power systems. The primary heat exchanger will be made using nickel superalloys and laser powder bed 3-D printing, resulting in a compact design that is durable under cyclic operation at high temperatures and pressures in a corrosive salt environment. During the first phase of the project, different alloy powders are fabricated and characterized and then tested, both in conditions representative of Generation 3 concentrating solar-thermal power systems—720 degrees Celsius and supercritical carbon dioxide pressures of 200 bar—and at conditions relevant to current commercial systems—molten nitrate salt at temperatures up to 550 degrees Celsius. The team aims to validate a thermal model that can predict performance in a chloride salt environment and plans to use this model to develop a 20-kilowatt design to test the mechanical integrity of the fabricated primary heat exchanger.

HIGH-ENTROPY CERAMIC COATINGS: TRANSFORMATIVE NEW MATERIALS FOR ENVIRONMENTALLY-COMPATIBLE THIN-FILM INSULATORS AGAINST HIGH-TEMPERATURE MOLTEN SALTS – $400,000

University of California, San Diego | San Diego, CA | Principal Investigator: Jian Luo

This project is developing high-entropy ceramics as a new type of insulating and protective coating material for metal alloys used in high-temperature piping and containment. High-entropy ceramics are a class of materials consisting of several elements in relatively equal proportions, whereas typical ceramics and alloys consist of one or two predominant elements. An effective, low-cost protective coating like high-entropy ceramics could substantially reduce the need for expensive, high-temperature superalloys. In order to develop and select the best material, the team will measure thermal conductivities of high-entropy ceramic compositions and examine their stabilities against molten nitrate, carbonate, and halide salts. This will optimize high-entropy ceramic composition and processing, helping to further reduce their thermal conductivities, which increases performance in high-temperature environments and lowers costs.

NON-CONTACT THERMOPHYSICAL CHARACTERIZATION OF SOLIDS AND FLUIDS FOR CONCENTRATING SOLAR POWER – $1,180,000

University of California, San Diego | San Diego, CA | Principal Investigator: Renkun Chen

This project is developing a non-contact characterization technique called modulated photothermal radiometry. The technique measures the high-temperature thermophysical properties of heat transfer fluids and the associated solids, like tubing and solar absorbing coating, in various components and sub-systems used in concentrating solar-thermal power plants. The modulated photothermal radiometry technology can provide low-cost and fast characterization of heat transfer fluids and solids for third generation concentrating sola thermal power facilities.

ROBUST AND SPECTRALLY-SELECTIVE AEROGELS FOR SOLAR RECEIVERS – $363,999

University of Michigan | Ann Arbor, MI | Principal Investigator: Andrej Lenert

Efficient conversion of sunlight at high temperatures requires both absorption of sunlight and retention of heat from escaping in the form of radiation, convection, and conduction. The team is developing a transparent, thermally insulating aerogel cover that enables a concentrating solar-thermal-power receiver to operate more efficiently at high temperatures. This aerogel cover will be transparent to sunlight and able to absorb thermal radiation. The proposed aerogel would not require selective surfaces or a vacuum for attachment and would enable better thermal resistance at high temperatures. The aerogel cover will be developed and tested in order to minimize thermal losses and improve thermal stability.

EXPERIMENTAL AND NUMERICAL DEVELOPMENT OF THIRD GENERATION CONCENTRATING SOLAR-THERMAL POWER DURABILITY LIFE MODELS – $1,060,000

University of Tulsa | Tulsa, OK | Principal Investigator: Michael Keller

This project is developing a comprehensive particle and substrate durability model that will enable improved understanding of the performance of high-temperature components for the particle-based pathway. The team plans to advance existing research capabilities in erosion, corrosion, fracture mechanics, macro- and micro-scale materials characterization, and thermal and optical property characterization. The results will be used to develop a broad understanding of mechanical durability that can be used to determine component lifetime and performance degradation models.

CARBONIZED MICROVASCULAR COMPOSITES FOR GAS RECEIVERS – $1,277,345

University of Tulsa | Tulsa, OK | Principal Investigator: Michael Keller

This project aims to develop and characterize a novel carbonized microvascular composite intended for use in advanced, gas-phase concentrating solar power receiver. A polymer-fiber composite with directly integrated microchannels will be carbonized to form a light-weight, high-absorptivity material with a microvascular network of channels with an optimized topology that will enhance heat transfer to a supercritical carbon dioxide heat transfer fluid. This system is based on microVasc technology, which enables the formation of defined channels within a composite material through selective depolymerization of polymer fibers. The resulting composite can then be carbonized and coated for oxidative resistance, perhaps in situ, to form a highly adsorptive, mechanically robust carbon-carbon composite with high thermal conductivity.

VOLUMETRICALLY ABSORBING THERMAL INSULATOR FOR MONOLITHIC HIGH-TEMPERATURE MICROCHANNEL RECEIVER MODULES – $400,000

University of Utah | Salt Lake City, UT | Principal Investigator: Sameer Rao

The thermal efficiency of concentrating solar power receivers is limited by optical and thermal losses. This project is developing a novel, low-cost, high-temperature, and chemically stable receiver design based on a porous matrix of refractory ceramics that can absorb concentrated solar light throughout its three-dimensional volume. This design has the potential to substantially reduce optical and thermal losses relative to the two-dimensional surface of the tubes that are currently used as receivers. The team is developing a high-performance receiver that operates at over 720 degrees Celsius, has a thermal efficiency rate above 92 percent, and maintains excellent thermo-mechanical and thermo-chemical stability. The team will validate the design through computations and then experimentally at lab-scale.

DURABLE AND LOW-COST FRACTAL STRUCTURED MULTIFUNCTIONAL COATINGS FOR NEXT GENERATION CONCENTRATING SOLAR-THERMAL POWER – $400,000

Virginia Polytechnic Institute and State University | Blacksburg, VA | Principal Investigator: Ranga Pitchumani

This project team is developing fractal-textured barrier coatings for conventional, low-cost alloys like stainless steel to protect against corrosion from supercritical carbon dioxide, molten chloride, and carbonate salts used in concentrating solar-thermal power plants. Multiscaled, fractal textured surfaces can be fabricated directly on the underlying material using a process called electrodeposition, helping to create a robust and durable coating that preserves the thermal properties of the substrate. The textured surfaces of the coating will prevent wetting of the corrosive fluids with the surface, leading to a lower power requirement to pump fluids, less corrosion and wear, and reduced heat loss. This will help to increase the overall efficiency and lifetime of a concentrating solar-thermal power plant.

FRACTAL NANOSTRUCTURED SOLAR SELECTIVE SURFACES FOR NEXT GENERATION CONCENTRATING SOLAR POWER – $936,326

Virginia Polytechnic Institute and State University | Blacksburg, VA | Principal Investigator: Ranga Pitchumani

This project aims to increase the thermal efficiency of solar receivers by fabricating multiscale fractal nano- and micro-structured, high-temperature coatings that can be applied to the receiver in a concentrating solar-thermal power system. Called a selective solar surface, this multiscale surface has texturing, which could enable the coating to enhance light trapping in the solar receiver, improve energy absorption, and eliminate the need for anti-reflection coatings. The team seeks to develop durable solar selective surfaces that enable absorption efficiency rates greater than 90 percent at temperatures higher than 750 degrees Celsius, and with a degradation rate of less than 0.2 percent per 1,000 hours.

CSP Systems

Concentrating solar-thermal power 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.

THIRD GENERATION GAS-PHASE SYSTEM DEVELOPMENT AND DEMONSTRATION – $8,276,094

Brayton Energy | Hampton, NY | Principal Investigator: Eric Vollnogle

In this project, a commercial-scale gas-phase concentrating solar-thermal power system is being developed in the first two Gen3 phases and, if selected for the third phase, developed into a test facility. The megawatt-scale test system absorbs energy from a heliostat field and delivers it into a thermal energy storage system, storing nine megawatt-hours of heat at a temperature of 750 degrees Celsius for a minimum of ten hours. The energy then moves into a working fluid that could have a round-trip efficiency of 99 percent, creating a concentrating solar-thermal power solution that enables on-demand renewable energy.

CONCENTRATING SOLAR-THERMAL POWER OPTICAL FACILITIES: CORE CAPABILITY – $600,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Judy Netter

This project focuses on the repair and maintenance of concentrating solar-thermal power optical research facilities and equipment at the National Renewable Energy Laboratory. These resources will support ongoing and projected research needs of concentrating solar-thermal power researchers and enable the lab to repair and update its existing concentrating solar-thermal power research equipment that is essential to the optical characterization of concentrating solar-thermal power components. This funding will ensure the continual operation of this equipment and that concentrating solar-thermal power researchers will have the necessary tools to achieve the cost goals of the Solar Energy Technologies Office.

CONCENTRATING SOLAR-THERMAL POWER PLANT CONSTRUCTION, START-UP, AND OPERATIONS AND MAINTENANCE BEST PRACTICES STUDY – $748,192

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Mark Mehos

This project is determining best practices for the engineering, construction, commissioning, operations, and maintenance of concentrating solar-thermal power plants in the United States and abroad. The team is working to obtain and analyze input from operators, owners, developers, financers, and engineering, procurement, and construction contractors of these systems. At the end of the project, a best-practices document will be published to enable future plants to minimize costs and maximize energy production.

LIQUID-PHASE PATHWAY TO SUNSHOT – $8,067,661

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Craig Turchi

This team is testing the next generation of liquid-phase concentrating solar-thermal power technology by advancing the current molten-salt power tower pathway to higher temperatures and efficiencies. The project is designing, developing, and testing a two megawatt thermal system consisting of the solar receiver, thermal energy storage tanks and associated pumps, heat exchangers, piping, valves, sensors, and heat tracing. If selected for the third phase, the system will be validated in a commercial-scale test facility.

REAL TIME OPERATIONS OPTIMIZATION SOFTWARE – $2,900,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Michael Wagner

This project extends prior work on the National Renewable Energy Laboratory's System Advisor Model software for concentration solar-thermal power, focusing on dispatch optimization and solar irradiance forecasting. This software can automate certain decision-making processes at concentrating solar-thermal power facilities to execute real-time, optimal operational strategies in these areas. Automating these processes can simultaneously account for operational factors beyond the knowledge of human operators, generate consistent and improved plant performance, and reduce long-term maintenance costs. Prior work in the System Advisor Model has shown that optimized dispatch could increase a facility's revenue by 5-25 percent, depending on the market.

INTEGRATED HEAT PUMP THERMAL STORAGE AND POWER CYCLE FOR CONCENTRATING SOLAR-THERMAL POWER – $756,466

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joshua McTigue

This project investigates the thermal performance and economic feasibility of a new integrated technology that couples solar power generation and grid-connected storage. By using thermal energy storage, which can be easily incorporated into concentrating solar-thermal power plants, this work explores the effect of storing electricity from the grid by powering a heat pump that can charge a cold storage material. Cold storage could potentially enable very high net power cycle efficiencies. The team is developing techno-economic models to investigate several key variables in this new system design, including potential thermodynamic cycles, working fluids, and cold storage media. A study using California electricity market data will evaluate the economics of the new system and determine which performance metrics may make it economically feasible.

FULL-SCALE HYDROGEN MITIGATION INSTALLATION AND TESTING – $496,352

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Greg Glatzmaier

This project aims to solve efficiency degradation that gradually reduces electricity output over the life of parabolic trough power plants due to hydrogen generation in receiver tubes. The lab and Acciona Energy USA Global will design, implement, and evaluate a full-scale hydrogen mitigation process at the Nevada Solar One power plant.

DEPARTMENT OF ENERGY'S NATIONAL SOLAR-THERMAL TEST FACILITY OPERATIONS AND MAINTENANCE – $3,000,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Christian

The National Solar-Thermal Test Facility, operated by Sandia National Laboratories, is the only large-scale concentrating solar-thermal power research and test facility in the United States. It provides established test platforms and researchers and technologists experienced in the concentrating solar-thermal power field on staff for assistance. This project supports the operations and maintenance needed to provide a safe, fully operational facility with testing capabilities that supports Solar Energy Technology Office awardees as they work to achieve the concentrating solar-thermal power cost goals.

PARTICLE PILOT PLANT: INTEGRATED HIGH-TEMPERATURE PARTICLE SYSTEM FOR CONCENTRATING SOLAR-THERMAL POWER – $9,153,858

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Cliff Ho

This project is designing and testing a multi-megawatt thermal falling particle receiver in a concentrating solar-thermal power system. It has the potential to operate for thousands of hours, provide six hours of energy storage, and heat a working fluid like supercritical carbon dioxide or air to a temperature of at least 700 degrees Celsius. If selected to continue into a third phase, the project team will validate the ability to meet the Solar Energy Technologies Office concentrating solar-thermal power cost and performance goals via a commercial-scale test facility.

Desalination and Other Thermal Processes

Concentrating solar-thermal power 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 reducing 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 overall track and nearly nine percent of the track's budget.

INTEGRATED POWER BLOCK HEAT EXCHANGER AND THERMAL ENERGY STORAGE SYSTEM FOR CONCENTRATING SOLAR-THERMAL POWER PLANTS – $348,000 ♦

Argonne National Laboratory | Lemont, IL | Principal Investigator: Dileep Singh

Working with CFOAM, one of the world's largest carbon and graphite foam manufacturers, Argonne will develop and commercialize a low-cost integrated heat exchanger/thermal energy storage system for concentrating solar-thermal power plants, desalination applications, and waste-heat recovery. By loading up CFOAM's graphite foam with a salt designed to melt or freeze at an industrial process's operating temperature, Argonne hopes to store energy and reduce costs by combining the heat exchanger and the thermal energy storage into a single component.

GEOGRAPHIC INFORMATION SYSTEM-BASED GRAPHICAL USER INTERFACE TOOL FOR ANALYZING SOLAR-THERMAL DESALINATION SYSTEMS AND HIGH-POTENTIAL IMPLEMENTATION REGIONS – $965,198 ♠

Columbia University | New York, NY | Principal Investigator: Vasilis Fthenakis

This project is developing software with state-of-the-art solar-thermal desalination models, verified with data from operating thermal desalination plants and data from solar-thermal desalination pilots at Plataforma Solar de Almeria in Tabernas, Spain. The software also incorporates newly developed geospatial databases of alternative water resources. By integrating desalination techno-economic models and geospatial data layers in one interface, the developed software will assist with the planning and valuation of solar-thermal and hybrid technologies.

SOLAR-DRIVEN DESALINATION BY MEMBRANE DISTILLATION USING CERAMIC MEMBRANES – $873,648

Fraunhofer Center for Energy Innovation | Plymouth, MI | Principal Investigator: Jeffery McCutcheon

This project is developing and testing ceramic membranes for solar-driven membrane distillation systems for desalination. The challenges that ceramic membranes face for membrane distillation applications are mass and heat transfer, wetting, scaling, and fouling. These challenges are being addressed by designing and optimizing membranes at a small scale, and later applying the lessons learned to larger-scale elements that can be used with a solar-thermal test bed.

HIGH-EFFICIENCY, ZERO LIQUID DISCHARGE, MULTIPLE-EFFECT ADSORPTION DISTILLATION – $1,600,000

Greenblu | Hamilton, NJ | Principal Investigator: Howard Yuh

Adsorption distillation, a technology based on using materials that are able to adsorb large volumes of water vapor, is well-suited for zero liquid discharge applications where the incoming brine or waste water must be completely separated to produce only purified water and solid salt. This team is developing a multi-stage adsorption water distiller with the ability to use the same adsorbent beds for both a liquid-only distiller to concentrate brine and a liquid-solid crystallizer to generate solid salt by-products, by only altering only the input mechanics.

DIRECT SOLAR-THERMAL FORWARD OSMOSIS DESALINATION OF PRODUCED WATERS – $800,000

Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Robert Kostecki

This project is developing a new integrated ionic liquid-based forward osmosis water treatment system for produced waters of high salinity that cannot be treated directly by reverse osmosis. This novel desalination system combines advanced forward osmosis membrane technology with the lab's unique ionic liquid forward osmosis draw solute chemistry and direct absorption of solar energy using photonic infrared heaters. The technology is being tested by project partner California Resources Corporation.

SOLAR FOR INDUSTRIAL PROCESS HEAT – $541,594 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis

This project explores the potential role of solar energy technologies, including photovoltaic, solar-thermal, and hybrid approaches that produce electricity and/or heat, to meet a wide range of industrial process heat end uses in the U.S. manufacturing sector. The team is combining detailed information about the spatial-varying and time-varying patterns of industrial process heat demand with the availability of sunlight. They will estimate process parity—the point at which the levelized cost of energy from solar energy is equivalent to that from more traditional combustion sources when used for industrial process heat, based on specific times and geographical locations.

HAWAII SOLAR DESALINATION PROJECT – $1,928,238

Natural Energy Laboratory of Hawaii Authority | Honolulu, HI | Principal Investigator: Alexander Leonard

This project advances the techno-economic viability of solar-powered forward osmosis by reducing the levelized cost of water 40 percent compared to current state-of-the-art technology. The team aims to demonstrate a system that incorporates a concentrating solar-thermal collector array delivering heat to a forward osmosis system. This system utilizes a new generation of membranes whose energy efficiency and durability will be demonstrated in this project. This system will then be installed and operated at an oceanic facility and the results will be used to scale up to a commercial-sized facility that can achieve the low targeted levelized cost of water.

ZERO LIQUID DISCHARGE WATER DESALINATION PROCESS USING HUMIDIFICATION-DEHUMIDIFICATION IN A THERMALLY-ACTUATED TRANSPORT REACTOR – $2,000,000

Oregon State University | Corvallis, OR | Principal Investigator: Bahman Abbasi

This project is developing a hybrid process to treat high-salinity water with zero liquid discharge. The cost and efficiency of energy consumption are targeted to be competitive with large reverse osmosis desalination plants at a fraction of the capital cost. This will be accomplished by using thermally actuated nozzles – components that operate in response to temperature changes – that are heated with low-grade solar heat. These hot air jets are humidified with brine and the solid particles can be separated out. By condensing the water vapor and recouping the heat, this process will target a highly energy efficient cycle.

LOW-COST DESALINATION USING NANOPHOTONICS-ENHANCED DIRECT SOLAR MEMBRANE DISTILLATION – $1,699,988

Rice University | Houston, TX | Principal Investigator: Qilin Li

This project is developing and testing a novel solar-thermal desalination process called Nanophotonics-Enabled Solar Membrane Distillation, which uses a porous, photothermal membrane to simultaneously convert sunlight to heat and desalinate water by membrane distillation with very high thermal efficiency. The Nanophotonics-Enabled Solar Membrane Distillation technology will go through a system-level integration and evaluation at the pilot-scale.

LOW-COST BUFFER STORAGE FOR SOLAR INDUSTRIAL STEAM APPLICATIONS – $2,500,000

Sunvapor, Inc. | Livermore, CA | Principal Investigator: Philip Gleckman

This project aims to demonstrate how using enormous tanks that normally store liquefied petroleum gas can be used to accumulate and store solar-generated steam—and use that steam for manufacturing processes. This technology should be cost-effective due to the low cost of pressurized water and the ability to operate at temperatures above 100 degrees Celsius. In addition, the project team will size the tanks to achieve a low cost of solar-thermal energy storage per gallon, and the solar steam will be able to be used in various industrial applications.

ENERGY WHERE IT MATTERS: DELIVERING HEAT TO THE MEMBRANE/WATER INTERFACE FOR ENHANCED THERMAL DESALINATION – $1,709,744

University of California, Los Angeles | Los Angeles, CA | Principal Investigator: David Jassby

This project modifies a typical membrane distillation system by deploying layers of materials with high thermal and electrical conductivity at the membrane/water interface. These conductive materials will be able to deliver solar-thermal energy directly to where it's needed in the membrane distillation system. By directly coupling the membrane surface to a thermal input, this technology has the potential to be substantially more energy efficient than current membrane distillation systems.

ULTRA-COMPACT AND EFFICIENT HEAT EXCHANGER FOR SOLAR DESALINATION WITH UNPRECEDENTED SCALING RESISTANCE – $980,875

University of Illinois at Urbana-Champaign | Urbana, IL | Principal Investigator: Anthony Jacobi

This project is designing, developing, and testing novel coatings for heat exchanger surfaces in high-temperature thermal desalination applications that aim to increase heat exchanger efficiency by 150 percent or more than current state-of-the-art technology. This will help address challenges like fouling and scaling as well as corrosion resistance that occurs at temperatures above 200 degrees Celsius.

Power Cycles

In concentrating solar-thermal power plants, heat transfer media are able to transport and store the 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 supercritical carbon dioxide 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 supercritical carbon dioxide turbomachinery, thermal energy storage and supercritical carbon dioxide cycle interactions, and primary heat exchanger designs. Projects in this topic represent ten percent of the overall track and 14 percent of the track's budget.

LOW-COST HIGH TEMPERATURE CERAMIC HEAT EXCHANGERS – $2,385,000

Argonne National Laboratory | Lemont, IL | Principal Investigator: Dileep Singh

As concentrating solar-thermal power systems move to power cycles with temperatures greater than 700 degrees Celsius, high-temperature metallic alloys become prone to degradation from corrosion and/or oxidation, which can increase costs. This project uses high-temperature, low-cost ceramic materials with new designs and 3-D printing to develop ceramic heat exchangers. Ceramic system components can potentially reduce corrosion issues created by molten salt heat-transfer fluids and oxidation from gas phases. As a result, high-performance, high-reliability ceramic heat exchangers could provide a cost-effective pathway for operating concentrating solar-thermal power systems at elevated temperatures and enhance overall system efficiency.

740H DIFFUSION BONDED COMPACT HEAT EXCHANGER FOR HIGH TEMPERATURE AND PRESSURE APPLICATIONS – $1,290,834

Comprex | De Pere, WI | Principal Investigator: Zhijun Jia

There is growing demand for high-temperature, high-pressure heat exchangers that can meet the stressful operating requirements of novel supercritical carbon dioxide Brayton cycles systems in a way that's cost-effective at commercial scale. CompRex has developed a heat exchanger design using 740H, a new alloy that can endure significantly higher stress at temperatures over 700 degrees Celsius, making it ideal for use with supercritical carbon dioxide cycles. In collaboration with Special Metals, the University of Wisconsin-Madison, and Advanced Vacuum Systems, CompRex seeks to develop a manufacturing process for producing 740H printed circuit heat exchangers using its proprietary ShimRex® flow path design.

This design addresses the challenges that the material poses in etching and diffusion bonding that prevent the cost-effective manufacturing of 740H heat exchangers.

ADVANCED COMPRESSORS FOR CARBON DIOXIDE-BASED POWER CYCLES AND ENERGY STORAGE SYSTEMS – $4,400,000

Echogen Power Systems | Akron, OH | Principal Investigator: Timothy Held

This project is developing a large-scale, low-cost, single-shaft compressor for supercritical carbon dioxide power cycles and energy storage systems to improve the performance of concentrating solar-thermal power systems. Conventional systems have multiple shafts but lower mechanical efficiency and higher costs. The team plans to build and test a prototype at the University of Notre Dame's test facility.

ADDITIVELY MANUFACTURED SUPERCRITICAL CARBON DIOXIDE POWER CYCLE HEAT EXCHANGERS FOR CONCENTRATING SOLAR-THERMAL POWER – $1,400,142

GE Global Research | Niskayuna, NY | Principal Investigator: Bill Gerstler

This project is developing additive manufacturing processes for the heat exchangers used in supercritical carbon dioxide power cycles in concentrating solar-thermal power plants. To overcome the expensive manufacturing process for heat exchangers, the team is using binder jet printing, a type of additive manufacturing, to significantly lower costs and enable new heat exchanger geometries, such as 3-D channels, and curved features not accessible using traditional fabrication processes. The team will then evaluate the new process and determine if it's capable of producing concentrating solar-thermal power compatible power cycles that cost $900 per kilowatt or less. The team will also perform mechanical tests to ensure that the resulting heat exchangers can withstand the high operating temperatures and pressures of the supercritical carbon dioxide power cycle. Finally, the team will create a risk reduction plan for scaling the heat exchanger design from lab-scale to a full-scale, including, a modular design.

GAS LUBRICATED BEARINGS FOR DRIVETRAIN IN SUPERCRITICAL CARBON DIOXIDE CYCLE – $2,373,442

GE Global Research | Niskayuna, NY | Principal Investigator: Jason Mortzheim

This project is working to de-risk a novel bearing design for the turbines used in concentrating solar-thermal power plants with supercritical carbon dioxide power cycles. The bearing is a critical component that ensures the turbine, which converts heat into mechanical energy, performs reliably and at a high efficiency level. The turbine is the greatest single contributor to the supercritical carbon dioxide cycle's efficiency. These bearings must be durable and able to withstand the high temperatures and pressures associated with next generation supercritical carbon dioxide power cycles. The team will then perform mechanical tests and simulate rotor tests in order to optimize the design for concentrating solar-thermal power plants that provide consistent baseload power or operate as a rapidly-responding peaker plant. The team will perform technoeconomic analysis to determine if the design can achieve a 50 percent efficient power cycle in order to lower costs to $0.05 per kilowatt-hour.

COMPRESSION SYSTEM DESIGN AND TESTING FOR SUPERCRITICAL CARBON DIOXIDE CONCENTRATING SOLAR-THERMAL POWER OPERATION – $3,800,000

GE Global Research | Niskayuna, NY | Principal Investigator: Jason Mortzheim

This project is developing an optimal compression system for a modular supercritical carbon dioxide power block operation in highly transient concentrating solar-thermal power tower applications. The compressor train under development aims to provide high-pressure carbon dioxide compression at state-of-the-art efficiency, required for the operation of a tower-mounted, modular, recompression-type supercritical carbon dioxide power cycle with a wide operating range to be coupled with the turbo-expander being developed for concentrating solar-thermal power tower applications.

VERTICALLY-ALIGNED CARBON NANOTUBE ARRAYS AS NOVEL SELF-LUBRICATING HIGH-EFFICIENCY BRUSH SEAL FOR CONCENTRATING SOLAR-THERMAL POWER TURBOMACHINERY – $1,400,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Jun Qu

In advanced turbines for concentrating solar-thermal power plants that use supercritical carbon dioxide as a working fluid, metal brush seals prevent internal energy leakage. This project is developing a new scalable seal brush on a flexible base that will improve the seal's efficiency and durability. The seal will be made of a vertically aligned carbon nanotube array and use a chemical vapor deposition process without a catalyst. The project aims to improve turbine efficiency and reduce the manufacturing cost by at least half.

DEVELOPMENT OF A HIGH-EFFICIENCY HYBRID DRY COOLER SYSTEM FOR SUPERCRITICAL CARBON DIOXIDE POWER CYCLES IN CONCENTRATING SOLAR-THERMAL POWER APPLICATIONS – $1,790,000

Southwest Research Institute | San Antonio, TX | Principal Investigator: Kelsi Katcher

This project aims to develop a compact dry cooling heat exchanger for supercritical carbon dioxide power cycles in concentrating solar-thermal power plants. Dry cooling drastically reduces the water used by power plants. However, it can reduce the thermal-to-electric conversion efficiency of the power cycle. An efficient heat exchange between supercritical carbon dioxide and ambient air can both conserve water while maintaining peak power cycle performance. The team is working to create and optimize a dry cooling heat exchanger with microchannels on the supercritical carbon dioxide side and a geometry that uses plates and finned chambers on the air side. The team will test the dry cooling system at the megawatt-scale with a supercritical carbon dioxide test loop, in order to determine the reliability of the fabrication method, validate the performance of the heat exchanger geometry, and show that the new dry cooling concept is compatible with an efficient concentrating solar-thermal power plant. These improvements could reduce the cooler cost from $168 per kilowatt to $95 per kilowatt and reduce cooling power consumption in concentrating solar-thermal power plants by 14 percent.

DEVELOPMENT OF AN INTEGRALLY GEARED COMPRESSOR-EXPANDER FOR SUPERCRITICAL CARBON DIOXIDE BRAYTON CYCLE POWER GENERATION APPLICATIONS – $5,350,000

Southwest Research Institute | San Antonio, TX | Principal Investigator: Jason Wilkes

The team of Southwest Research Institute and Samsung Techwin is developing an integrally-geared compressor-expander (compander) and a novel centrifugal compressor impeller design for use in 10 megawatt scale concentrating solar-thermal power applications utilizing a supercritical carbon dioxide cycle. This integrally-geared compander has the potential to improve efficiency, modularity, and process control over other proposed concentrating solar-thermal power turbomachinery configurations utilizing a supercritical carbon dioxide cycle power cycle.

HIGH-TEMPERATURE DRY-GAS SEAL DEVELOPMENT AND TESTING FOR SUPERCRITICAL CARBON DIOXIDE POWER CYCLE TURBOMACHINERY – $1,999,985

Southwest Research Institute | San Antonio, TX | Principal Investigator: Jason Wilkes

Concentrating solar-thermal power plants with supercritical carbon dioxide power cycles require a mechanical seal to prevent working fluid leaks and support efficient operations. The increased temperatures and pressures of the supercritical carbon dioxide power cycle requires a novel seal design to support a target thermal-to-electric power conversion efficiency of 50 percent. This project is developing a high-temperature dry gas seal by replacing the temperature sensitive elements with more durable components, enabling the dry gas seal to reach operating temperatures over 500 degrees Celsius and enable the higher efficiency levels. Because the dry gas seal design would also be significantly smaller in size, it would reduce the complexity of the supercritical carbon dioxide turbine design, helping to increase operation reliability and improve turbine efficiency.

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 concentrating solar-thermal power 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 concentrating solar-thermal power plants. Projects in this topic represent 14 percent of the overall track and seven percent of the track's budget.

LOOP THERMOSYPHON ENHANCED SOLAR COLLECTOR – $1,500,000

Advanced Cooling Technology | Lancaster, PA | Principal Investigator: Nathan Van Velson

This team is developing a loop thermosyphon solar collection system for efficient, low-cost solar-thermal desalination that does not require fluid to be actively pumped throughout the system. The design takes advantage of nanofluids with higher solar absorptivity and a two-phase thermosyphon to improve the system's efficiency and simplify the collection of solar-thermal energy used in desalination processes.

POLARIMETRY-ENHANCED IMAGING TOWARDS AUTONOMOUS SOLAR FIELD AND RECEIVER INSPECTIONS – FY19 TBD

Arizona State University | Tempe, AZ | Principal Investigator: Yu Yao

This project is developing imaging systems using polarimetry, which is the measurement of how light rays are aligned, or polarized. Measuring polarization has the potential to be much more sensitive than conventional optical measurements. The imaging systems are small enough to attach to drones and deploy to evaluate the performance of concentrating solar-thermal power collector systems. They can also be attached to concentrating solar-thermal power plant power towers. Autonomous imaging will reveal damage and soiling on collector mirrors, and reduce errors in mirror alignment, resulting in improved efficiency.

FLAT FOCUSING MIRRORS FOR CONCENTRATING SOLAR POWER – $400,000

Lucent Optics | Sacramento, CA | Principal Investigator: Sergey Vasylyev

To reduce the cost and improve the performance of concentrating solar-thermal power plants, Lucent Optics will investigate the feasibility of making flat focusing mirrors using a thin light-focusing film on a planar reflective substrate. The team will produce a fully functional pilot-prototype of a flat focusing mirror measuring 0.5 meters by 0.5 meters that can be scaled to full-size concentrating solar-thermal power collectors. Planar focusing mirrors that use light-focusing film can replace many types of traditional collectors, providing a new pathway for further concentrating solar-thermal power cost reduction and performance improvement.

DEVELOPMENT AND VALIDATION OF A XENON ARC LAMP ACCELERATED AGING METHOD FOR CONCENTRATING SOLAR-THERMAL POWER MIRRORS – $653,607

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Tirawat

In order to better understand concentrating solar-thermal power mirror degradation and minimize operations and maintenance costs, this project is developing and validating an accelerated aging method for testing solar reflectors using a xenon arc lamp exposure chamber to simulate the effects of sunlight. This evaluation method will ensure that mirror performance testing is standardized and user-friendly. As part of this effort, several databases containing information on the degradation of mirror performance are being updated and consolidated into one platform to help develop the accelerated aging model and the experimental aging method for reflective surfaces.

SOLAR FIELD LAYOUT AND AIMPOINT STRATEGY OPTIMIZATION – $309,616

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Alexander Zolan

Using existing software packages to obtain a layout of the solar collection field of a concentrating solar-thermal power plant without accounting for the aiming strategy may yield solutions with heliostats that cannot be used efficiently without compromising the receiver's designed operating limits. This project develops a model that co-optimizes the layout and aiming strategies of a solar field to maximize the thermal energy generated by the field while operating within the design specifications of the receiver. The team utilizes state-of-the-art tools developed in its previous to characterize the thermal input to the receiver when provided a heliostat location and aiming strategy as input. This data is then used as input to an optimization model to obtain the best strategy within given limits. Advanced optimization techniques allow the model to obtain layouts and aiming strategies for commercial-scale plants.

AERODYNAMIC ANALYSIS AND VALIDATION OF WIND LOADING ON CONCENTRATING SOLAR-THERMAL POWER COLLECTORS USING HIGH-FIDELITY COMPUTATIONAL FLUID DYNAMICS MODELING – $195,412

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Shreyas Ananthan

This project is working to validate high-fidelity computations of wind loading on concentrating solar-thermal power structures using wind-tunnel test data provided by SolarDynamics LLC. The team is addressing the progressively complex issue by validating the loading on a single-parabolic-trough-collector assembly to understand the meshing requirements and simulation best practices, predicting and validating wind loading on waked collectors by simulating multiple rows in different configurations, and simulating wind-loading characteristics of large arrays that are not possible to test in wind tunnels.

DEVELOPMENT OF AN UNMANNED, AERIAL, SYSTEM-DRIVEN, UNIVERSAL FIELD ASSESSMENT, CORRECTION, AND ENHANCEMENT TOOL ADOPTING NON-INTRUSIVE OPTICS – $1,500,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Julius Yellowhair

In collaboration with the National Renewable Energy Laboratory, this project is working to develop a new optical characterization tool for solar collectors. An automated aerial drone carrying a high-resolution camera will survey a large-scale heliostat field to compare the heliostats to their original structural geometry. The images will reveal problematic mirror angles and so that maintenance crews can quickly repair and calibrate underperforming heliostats. This new technology has the potential to reduce operations and maintenance efforts and increase power production, helping to reduce the levelized cost of energy of a concentrating solar-thermal power plant.

LIDAR FOR AUTONOMOUS HELIOSTAT OPTICAL ERROR ASSESSMENT – $320,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Daniel Small

This project seeks to develop new uses for three-dimensional scanning Light Detecting and Ranging (LiDAR) sensors in the automatic/autonomous assessment of the optical errors in large-scale concentrating solar-thermal power heliostat fields. Experiments have demonstrated the ability of a 3D-LiDAR to acquire highly accurate point cloud measurements of facet mirrors across several heliostats at the National Solar-Thermal Test Facility and derive their facet canting angles and errors. The team is writing software for autonomous segmentation and error analysis and conducting in situ testing and evaluation at the National Solar-Thermal Test Facility.

CONCENTRATING OPTICS FOR LOWER LEVELIZED ENERGY COSTS – $2,061,865

Solar Dynamics | Broomfield, CO | Principal Investigator: Kyle Kattke

This project builds on heliostat technology developed under a previous award to develop the DROP C (Drop-in, Ring-Of-Power Heliostat). The new design allows the heliostats to be dropped into a location with drastic reduction of the preparation of the site location, which enables a reduction in costs and improves financing terms. The addition of a wide base and protected drives, which permit heliostats to move and reflect sun at the best angle, allows lower manufacturing costs, reduced costs for the structure's support, and increased protection from high winds. These improvements, coupled with wireless control of the heliostats, support lower cost targets.

DEVELOPMENT OF A FRONT-SURFACE CONCENTRATING SOLAR-THERMAL POWER REFLECTOR USING ULTRA-BARRIER TECHNOLOGY – $323,428

Sundog Solar Technology | Searsport, ME | Principal Investigator: Randy Gee

Sundog Solar Technology and its project partners, Helicon Thin Film Systems, Erickson International, and the National Renewable Energy Laboratory, is developing a high-performance, lower-cost solar reflector for concentrating solar-thermal power systems. The design of this new reflector moves the silver from the back of the glass to the front of it, allowing for more efficient reflection without sacrificing product lifetime. The reflector also has a novel coating that can withstand both ultraviolet radiation from the sun and impact from scrubbing the mirrors clean. High-volume manufacturability is critical to achieving low costs, so this reflector will be constructed using roll-to-roll manufacturing methods. The team is creating laboratory-scale reflector specimens and will then develop the manufacturing techniques for these reflectors.

METROLOGY-ASSISTED ROBOTIC MIRROR ALIGNMENT FOR TROUGHS – $1,150,000 ♦

Sunvapor | Livermore, CA | Principal Investigator: Philip Gleckman

Parabolic trough solar collectors are well-suited to generating industrial steam, but their assembly has significant labor costs. This project is developing a mobile, automated assembly method that is derived from advanced aerospace techniques. This method will lower labor costs, improve safety and quality, and enable the assemblies to be easily transported to new project sites.

SOLAR STEAM ON DEMAND – $1,000,165

Sunvapor | Livermore, CA | Principal Investigator: Philip Gleckman

The most efficient water distillation processes for desalination that use heat recovery require a steam source at a temperature around 180 degrees Celsius. This project is developing and testing a novel solution for generating steam by using solar-thermal energy as the primary source of heat and developing thermal-energy storage using a phase-change material. This solution will be combined with a previously developed low-cost, high-performance solar collector, creating a system that has the potential to operate water distillation equipment and meet the heat requirements of many industrial heating applications day or night.

THE INTERNAL COMPOUND PARABOLIC CONCENTRATOR: A NOVEL LOW COST SOLAR-THERMAL COLLECTION SYSTEM FOR DESALINATION PROCESSES – $1,081,793

University of California, Merced | Merced, CA | Principal Investigator: Roland Winston

This project is designing and building a prototype, then testing a novel, low-cost solar-thermal energy system that can reduce the levelized cost of heat to below 1.5 cents per kilowatt-hour thermal, while also incorporating dispatchability and portability features. The project includes the design and development of a new collector or concentrator, called the Integrated Compound Parabolic Concentrator, as well as the design and development of an accompanying thermal energy storage system.

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 for a total of nearly $212 million in federal funding; approximately one quarter of SETO projects falls under this category.

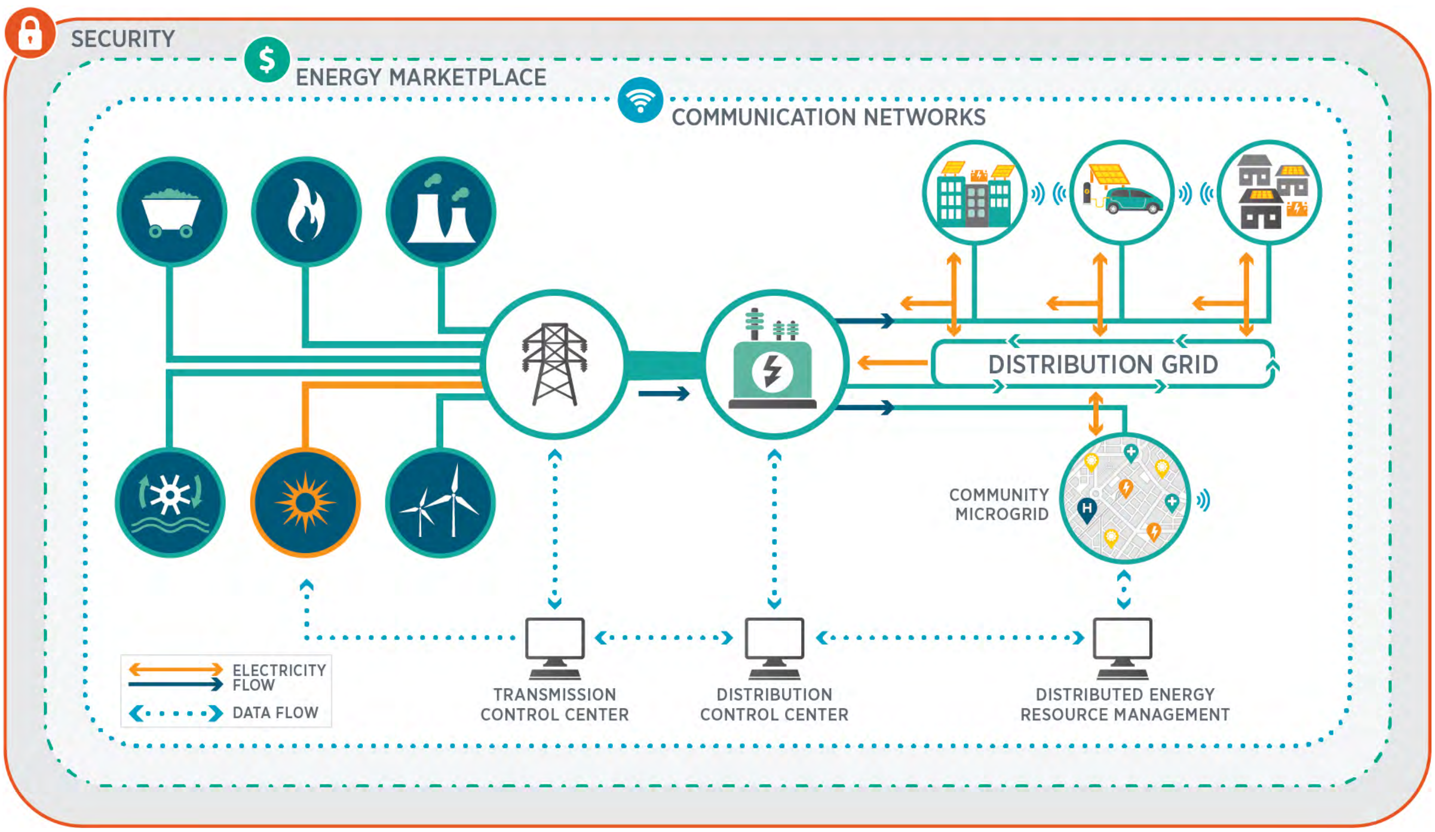


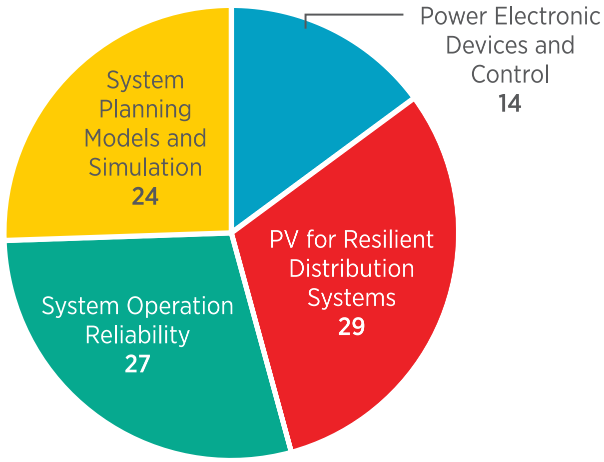
Figure 12

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 last 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.

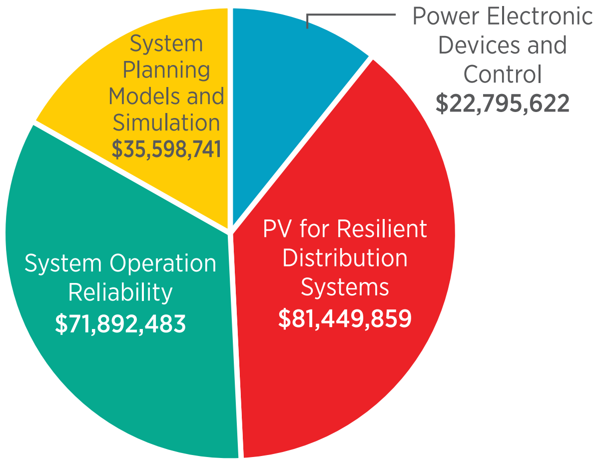
The Systems Integration track incorporates projects that are part of DOE's Grid Modernization Initiative, which is a crosscutting effort that aligns grid modernization efforts across multiple DOE program offices. A number of these projects are funded under the Grid Modernization Laboratory Consortium (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 projects from SETO's Manufacturing and Competitiveness track, which investigates and validates groundbreaking, early-stage solar technology to strengthen concepts and move them toward readiness for greater private sector investment and scale-up to commercialization. These projects help to build a strong clean energy manufacturing sector and supply chain that produce cost-competitive photovoltaic technologies, including those that will enable easier integration of solar energy onto the grid. Projects from the Strategic Analysis and Institutional Support team 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.

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. A description of each area can be found below, along with a detailed list of the projects within it. Projects are alphabetized by the awardee name and represented in the following format:

Project Title – Funding Program, Amount Awarded
Awardee Name | Awardee Location | Principal Investigator
Project Description

Projects managed by the Innovations in Manufacturing and Competitiveness team are identified with a blue diamond (♦) after the project name and amount.

Projects managed by the Strategic Analysis and Institutional Support team are identified with a red spade (♠) after the project name and amount.

Photovoltaics for Resilient Distribution Systems

The rapidly increasing amount of distributed solar photovoltaics and other distributed energy resources 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.

RECONFIGURABLE AND RESILIENT OPERATION OF NETWORK-CONTROLLED BUILDING MICROGRIDS WITH SOLAR INTEGRATION – $2,221,000

Argonne National Laboratory | Lemont, IL | Principal Investigator: Bo Chen

This project is developing a reconfigurable distribution grid framework for reliable and isolated operation through the dynamic integration of neighboring microgrids. This is one of the first steps toward creating a grid of microgrids. Researchers are focused on the load, storage, and solar photovoltaic device level to enable frequency- and voltage-regulating capabilities in buildings that have solar energy storage with grid-forming inverters and controllable loads. The team plans to further develop these technologies and work toward the dynamic integration and separation of neighboring microgrids, which will be tested in the field.

ENHANCING GRID RELIABILITY AND RESILIENCE THROUGH NOVEL DISTRIBUTED ENERGY RESOURCE CONTROL, TOTAL SITUATIONAL AWARENESS, AND INTEGRATED DISTRIBUTION-TRANSMISSION REPRESENTATION – $3,002,085

Arizona State University | Tempe, AZ | Principal Investigator: Raja Ayyanar

This project is building enhanced grid models by integrating transmission and distribution analyses. Using sensors and communications equipment, this tool can enable coordinated distributed resource responses, which can help increase the amount of renewable power operating in the distribution system.

SOLAR CRITICAL INFRASTRUCTURE ENERGIZATION SYSTEM – $5,792,342

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Brian Seal

This project is developing a pre-planning analysis technique, using new communications standards and advanced inverters, to determine how to methodically supply power to critical infrastructure with any resource available on the grid. To validate this technique, the team is working with several partners, including Austin Energy and Pecan Street.

FASTER-THAN-REAL-TIME SIMULATION WITH DEMONSTRATION FOR RESILIENT DISTRIBUTED ENERGY RESOURCE INTEGRATION – $3,115,048

Electrical Distribution Design | Blacksburg, VA | Principal Investigator: Dan Zhu

This project team is developing a technique to speed analysis of power flow using graphic trace analysis, or outputs from a bar graph instead of complex calculations, and then validate it in the field with its project partner, Pepco. The goal is to enable evaluation of the distribution network down to the secondary network and allow for rapid detection of power system abnormalities caused by instability, cyber intrusion, or other factors.

LOW-COST, PLUG-AND-PLAY DATA DIODES FOR SOLAR EQUIPMENT CYBERSECURITY – $1,200,000 ♦

Fend Incorporated | Falls Church, VA | Principal Investigator: Colin Dunn

Solar energy equipment is made by a small number of manufacturers, increasing the risk of economic disruption from a widespread, distributed cyberattack on industrial photovoltaic control systems. This project is developing the “Data Valve,” a low-cost, plug-and-play information transfer device that provides unhackable, physically-enforced security with real-time equipment monitoring. This tool could prevent the large economic disruption that could be caused by a distributed cyberattack on industrial control systems.

INTEGRATING SYSTEM TO EDGE-OF-NETWORK ARCHITECTURE AND MANAGEMENT – $2,400,566

Hawaiian Electric Company | Honolulu, HI | Principal Investigator: Shari Ishikawa

This project is working to validate the system-level benefits of enhanced utility visibility and control of distribution system and edge-of-network electricity resources. This project aims to enable proliferation of a reliable base of solar-plus-storage distributed technologies that offer more plug-and-play customer options for grid participation, and provide cost-effective grid response capabilities to system operators.

GRID MODERNIZATION LAB CONSORTIUM: FIRMWARE COMMAND AND CONTROL – $4,578,500

Idaho National Laboratory, Argonne National Laboratory, Sandia National Laboratories, National Renewable Energy Laboratory | Principal Investigator: Rita Foster

This project creates an agile embedded response capability foundational with baselined firmware and behaviors with bi-directional sharing of threat to upstream energy security operations.

ENABLING CYBER SECURITY, SITUATIONAL AWARENESS AND RESILIENCE IN DISTRIBUTION GRIDS WITH HIGH PENETRATION OF PHOTOVOLTAICS – $2,110,790

Kansas State University | Manhattan, KS | Principal Investigator: Bala Natarajan

This project is developing a compressive sensing method that requires fewer inputs than usual so grid operators can observe quickly-changing grid conditions and determine vulnerabilities in critical infrastructure. The team is developing smart inverter controls to detect cyber intrusions and initiate network defenses.

GRID MODERNIZATION LAB CONSORTIUM: CLEANSTART-DISTRIBUTED ENERGY RESOURCE MANAGEMENT SYSTEM – $2,500,000

Lawrence Livermore National Laboratory | Livermore, CA | Principal Investigator: Emma Stewart

This project is working to validate and demonstrate, at scale, a distributed energy resource-driven mitigation, blackstart, and restoration strategy for distribution feeders. It includes integration of applied robust control, communications, and analytics layers, and a coordinated hierarchical solution.

GRID MODERNIZATION LAB CONSORTIUM: DIGITAL TWIN REINFORCEMENT LEARNING – $511,000

Lawrence Livermore National Laboratory, Idaho National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratories | Principal Investigator: Jovana Helms

The project team is developing new artificial intelligence deep reinforcement learning approaches that use operational technology/distributed energy resources network and targeted physical process data to detect sophisticated, previously unknown threats and deploy appropriate response actions.

GRID MODERNIZATION LAB CONSORTIUM: GRIDSWEEPER: FREQUENCY RESPONSE OF BULK LOW-INERTIA GRIDS – $1,400,000

Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Pacific Northwest National Laboratory | Principal Investigator: Sascha von Meier

The project team is creating a new class of measuring instrument that reveals subtle dynamics of bulk grids. Probes inject a tiny signal and analyzes the response with ultra-high precision, applying novel devices and techniques.

ARTIFICIAL-INTELLIGENCE-DRIVEN SMART COMMUNITY CONTROL FOR ACCELERATING PHOTOVOLTAIC ADOPTION AND ENHANCING GRID RESILIENCE – $2,419,912

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Xin Jin

This project addresses challenges in community-scale coordination of behind-the-meter resources by building on the National Renewable Energy Laboratory's efforts on home energy management, grid hosting capacity, and device characterization for grid services. Using smart meter data, the team is developing artificial intelligence that can learn to identify homeowner preferences and enable day-ahead planning. The project aims to evaluate how to best use solar energy paired with flexible building loads like electric water heating or electric vehicle charging. Since solar energy is intermittent, the algorithms will try to schedule the loads when the sun is out. When there is excess solar energy, the project will determine the smallest battery energy storage system so the community can use that energy later in the day. This analysis will provide insight into cost-effective ways to minimize the need for battery energy storage systems. The team will validate the solution using hardware-in-the-loop laboratory testing, which simulates real-time embedded systems, and field demonstration in a net-zero-energy community.

RAPID, RURAL, AND RESILIENT INTERCONNECT TOOLKIT – $240,000 ♦

National Rural Electric Cooperative Association | Arlington, VA | Principal Investigator: David Pinney

This project is developing simplified interconnection evaluation software to help rural communities and small utilities deploy solar energy systems more easily. Solar applications are on the rise in these areas, and managing the interconnection approval process in a timely, effective manner is challenging. The tool kit will help utilities address interconnection queueing and processing.

PHOTOVOLTAIC ANALYSIS AND RESPONSE SUPPORT PLATFORM FOR SOLAR SITUATIONAL AWARENESS AND RESILIENCY SERVICES – $2,271,130

North Carolina State University | Raleigh, NC | Principal Investigator: Ning Lu

This project is designing a modeling tool to determine the optimal response of renewables on transmission and distribution systems, as well as behind-the-meter response for small-scale solar energy systems. With real-time sensor readings and a cost-benefit analysis, this tool can be used for grid planning and to help restore power during an outage.

CYBERSECURE UTILITY DISTRIBUTED ENERGY RESOURCE NETWORKING WITH INTEGRATED MULTI-PARTY TRUST – $2,600,000

Operant Networks Incorporated | Santa Rosa, CA | Principal Investigator: Randy King

This project team is working with the power company Exelon to develop and deploy communications technology that securely shares information about solar and other distributed energy resources with multiple parties across multiple connections, including the internet. With new capabilities and protections, the technology is able to connect to existing utility software platforms. This allows utilities to comply with new regulations requiring direct communication with distributed energy resources, restrict access to trusted partners, and improve cybersecurity.

GRID MODERNIZATION LAB CONSORTIUM: LAB VALUATION ANALYSIS TEAM – $750,000

Pacific Northwest National Laboratory | Richlands, WA | Principal Investigator: Michael Kintner-Meyer

This project provides consistency and efficiency in performing valuation analysis across the entire Grid Modernization Initiative portfolio of field validation projects using appropriate metrics. Using a cross-cutting approach provides a consistent framework and approach in conducting the benefit/cost analysis, impact analysis, and broader synthesis of results from each project. The research team will facilitate information sharing on the consistent application of metrics and the valuation framework in field validation projects to various audiences.

GRID MODERNIZATION LAB CONSORTIUM - VALIDATION, RESTORATION, AND BLACK START TESTING OF SENSING, CONTROLS, AND DISTRIBUTED ENERGY RESOURCES TECHNOLOGIES AT PLUM ISLAND – $3,000,000

Pacific Northwest National Laboratory, Lawrence Livermore National Laboratory, Idaho National Laboratory | Principal Investigator: Emma Stewart

This project is transforming black start with distributed energy resources and storage, from foundational research based demonstrations, to a viable method for restarting and restoring the bulk power system after critical outages. This will dramatically increasing the toolbox for operators in the face of both physical and cyber incidents.

GRID RESILIENCY WITH A 100 PERCENT RENEWABLE MICROGRID – $4,500,000

San Diego Gas & Electric Company | San Diego, CA | Principal Investigator: Thomas Bialek

This project is working to research and validate microgrid technologies that enable the use of solar and other distributed energy resources with grid-forming photovoltaic and battery inverters. These devices can improve grid stability and resilience by maintaining voltage and frequency during changing conditions, especially microgrid islanding, which independently provides power. The team is developing new controls and software for smart photovoltaic inverters and distributed energy resource management systems that may allow more flexibility for the interconnection and operation of small-scale photovoltaic and other distributed energy resource systems.

GRID MODERNIZATION LAB CONSORTIUM: DESIGNING RESILIENCE COMMUNITY GRID – $4,500,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Robert Jeffers

This project is working to solidify a framework for community resilience planning focused on grid modernization and investment involving key stakeholders including electric utilities. This project is also investigating how a community can be designed to be resilient through coordinated grid investment, and how electric utilities can plan for resilience and benefit from these investments. The project will develop detailed case studies for San Antonio, Texas and Buffalo, New York.

DISTRIBUTED ENERGY RESOURCE CYBER SECURITY STANDARDS DEVELOPMENTS – $1,200,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Jay Johnson

This project is creating cybersecurity standards for distributed energy resources, including solar inverters, for new products entering the market and operating in the field. Specific distributed energy resource cybersecurity requirements will be included in communication protocol standards, interconnection and interoperability standards, and grid operator and aggregator architecture requirements. Sandia National Laboratories and the National Renewable Energy Laboratory are coordinating standards development with stakeholders, leading working groups, and accelerating codes and standards development through in-person and virtual participation. Researchers are also conducting the technical research and development required to validate the test procedures and recommendations within these standards.

SECURING INVERTER COMMUNICATION: PROACTIVE INTRUSION DETECTION SYSTEM SENSOR TO TAP, ANALYZE, AND ACT – $1,930,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Shamina Hossain-Mckenzie

Inverters, which connect solar energy systems to the grid, can improve the hosting capacity of distribution grids, but interoperability, access interfaces, and the proliferation of third-party software applications have made smart inverters more susceptible to cyberattacks. This project is designing a distributed monitoring system to observe a wide range of cyberattack paths, detect various attack methods, predict adversarial movements, and implement controls that mitigate damage to distributed energy resources, like solar energy systems and other devices connected to the grid. The team is also developing and testing a cost-effective, device-level solution called the Proactive Intrusion Detection and Mitigation System in order to effectively protect and defend distributed energy resources.

AURORA: AUTONOMOUS AND RESILIENT OPERATION OF ENERGY SYSTEMS WITH RENEWABLES – $4,999,999

Siemens Corporation | Princeton, NJ | Principal Investigator: Ulrich Muenz

This project is creating a microgrid control system that can coordinate distributed microgrids to work together. The system will include a communications-free method to increase grid resilience and autonomously restore power during a blackout using smart inverters.

GRID MODERNIZATION LAB CONSORTIUM: GRID RESILIENCE AND INTELLIGENCE PROJECT – $3,000,000

SLAC National Accelerator Laboratory | Menlo Park, CA | Principal Investigator: Alyona Ivanova

This project is working to develop and deploy a suite of novel software tools to anticipate, absorb, and recover from grid events by demonstrating predictive analytics capabilities, combining state-of-the-art artificial intelligence and machine learning techniques, and controlling distributed energy resources. The tools will be integrated into an extensible and open platform.

SECURE MONITORING AND CONTROL OF SOLAR PHOTOVOLTAIC SYSTEMS THROUGH DYNAMIC WATERMARKING – $4,400,000

Texas A&M Engineering Experiment Station | College Station, TX | Principal Investigator: Le Xie

This project is working to develop and demonstrate an active defense mechanism of cyber-resilient photovoltaic distribution system operation using a dynamic watermarking technique to monitor cybersecurity. The technique involves injecting a probe signal onto the grid to authenticate grid actions. The approach includes real-time deployment of online computational algorithms in real-world critical locations. The team will test and validate the integrated communication, control, and computational framework using an existing system.

MULTI-LEVEL CYBERSECURITY FOR PHOTOVOLTAIC SYSTEMS – $3,500,000

University of Arkansas | Fayetteville, AR | Principal Investigator: Alan Mantooth

This project addresses cybersecurity at both the inverter and system levels for photovoltaic energy systems. First, the team is developing an inverter to address supply-chain security, real-time intrusion detection methods, vulnerability mitigation, control system security, safety protocols, and other concerns. Then, at the system level, the team will use machine-learning algorithms, a multilayered blockchain platform, and model-based intrusion detection.

OPTIMAL RECONFIGURATION AND RESILIENT CONTROL FRAMEWORK FOR REAL-TIME PHOTOVOLTAIC DISPATCH TO MANAGE CRITICAL INFRASTRUCTURE – $3,699,984

University of North Carolina at Charlotte | Charlotte, NC | Principal Investigator: Sukumar Kamalaasdan

This project is devising a grid management tool that detects cyber and physical threats and can form dynamic clusters to optimally manage photovoltaics and energy storage to improve grid resiliency and support critical infrastructure. This tool has two-level control with reconfigurable grid networks, which allows operators to isolate damaged sections while still powering the rest of the grid.

PROTECTION AND RESTORATION SOLUTIONS TO RELIABLE AND RESILIENT INTEGRATION OF GRID-CONNECTED PHOTOVOLTAIC INSTALLATIONS AND DISTRIBUTED ENERGY RESOURCES: DESIGN, TESTBED, PROOF OF WORK AND IMPACT STUDIES – $4,298,146

University of Oklahoma | Norman, OK | Principal Investigator: John Jiang

This project team is working to build an intelligent sensor network that communicates with the distribution system. The network will autonomously detect and isolate problems while using solar energy to help restore power to the distribution grid after an outage.

MODELING AND CONTROL OF SOLAR PHOTOVOLTAICS FOR LARGE GRID DISTURBANCES AND WEAK GRIDS – $898,060

University of South Florida | Tampa, FL | Principal Investigator: Lingling Fan

This project is designing dynamic models of utility-scale solar plants and their interactions on grids with large penetrations of generation through distributed energy resources like solar-plus-storage systems and wind power. These models will be used to construct a coordination strategy and a stability enhancement module for photovoltaic and storage systems so they can respond to rapidly changing grid conditions.

SOLARSTARTS: SOLAR-ASSISTED STATE-AWARE AND RESILIENT INFRASTRUCTURE SYSTEM – $4,411,297

University of Utah | Salt Lake City, UT | Principal Investigator: Masood Parvania

This project is inventing an automated resilience management system that will use distributed solar photovoltaics, distributed energy resources, sensors, and distribution monitoring and switching equipment to improve the resilience of critical infrastructure and emergency centers. The system includes a cyber detection and outage management tool. PacificCorp is partnering with the University of Utah to validate the system.

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.

ADVANCED SOLAR AND LOAD FORECASTING INCORPORATING HIGH DEFINITION SKY IMAGING: PHASE 2 – $850,000

Brookhaven National Laboratory | Upton, NY | Principal Investigator: Paul Kalb

This project is developing a platform for short-term (0-30 minute) solar forecasting. The team is deploying a network of high-definition total sky imagers and related equipment and developing software to allow for improved cloud and irradiance forecasting at several sites across New York State. That network can stitch together multiple images provided by individual imaging systems, which can expand forecasting capabilities over larger regions and longer time horizons.

MICROGRID-INTEGRATED SOLAR-STORAGE TECHNOLOGY – $4,000,000

Commonwealth Edison Company | Chicago, IL | Principal Investigator: Shay Bahramirad

This project addresses availability and variability issues inherent in the solar photovoltaic technology by utilizing smart inverters for solar photovoltaics combined with battery storage and working synergistically with other components within a microgrid community. This project leverages on the Energy Department-funded microgrid cluster controller and is connected to the existing 12 megawatt Illinois Institute of Technology microgrid.

RISK-INFORMED HIERARCHICAL CONTROL OF BEHIND-THE-METER DISTRIBUTED ENERGY RESOURCES WITH AMI DATA INTEGRATION – $3,000,000

Eaton Corporation | Beachwood, OH | Principal Investigator: Chaitanya Baone

This project is developing a real-time controller of behind-the-meter distributed energy resources, such as solar and battery storage, and loads to ensure that bulk power system operators or distribution utilities get enough power. Integrating data from smart meters and advanced metering infrastructure (AMI) enables optimal provision of grid services to improve grid reliability in distribution systems with high solar penetration. To enable scaling and minimize adoption risk, the team—along with the National Renewable Energy Laboratory, Electric Power Research Institute, Pecan Street, Provo City Power, and Commonwealth Edison—are working with existing utility infrastructure.

ADAPTIVE PROTECTION AND VALIDATED MODELS TO ENABLE DEPLOYMENT OF HIGH PENETRATIONS OF SOLAR PHOTOVOLTAICS – $4,100,000

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Jens Boemer

This project is developing and testing trustworthy models of solar photovoltaic facilities to enable power system engineers to plan, operate, and protect transmission and distribution systems. The models aim to inform system designs so that they can leverage smart inverter capabilities for microgrids and islanded systems, which operate independently of the national grid, to ensure the resilience of critical infrastructure and maintain grid safety and reliability. The team also plans to demonstrate adaptive protection systems that use advanced photovoltaic capabilities.

ADVANCED GRID-FORMING INVERTER CONTROLS, MODELING AND SYSTEM IMPACT STUDY FOR INVERTER DOMINATED GRIDS – $4,200,000

GE Global Research | Niskayuna, NY | Principal Investigator: Maozhong Gong

This project is developing a modeling method and automation tool to analyze the stability of a large energy system with mixed resources, such as inverter-based generation and traditional generators, and see how they interact with each other. The team is also developing controls for individual and clusters of grid-forming photovoltaic inverters to improve grid stability under various conditions. The technology will be implemented in GE's commercial photovoltaic inverter, thereby facilitating its commercialization.

AUTONOMOUS, ADAPTIVE, AND SECURE DISTRIBUTION PROTECTION – $2,600,000

Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Sakis Meliopoulos

This project is developing an autonomous protection system that uses dynamic models to determine the state of the grid based on a physical area that the system protects. It will be able to identify the parameters of the protected area to continuously correct and verify the models. The system will not contain settings or be affected by the direction or level of fault currents. This protection system will be compatible with distribution systems that have very high penetrations of solar and other distributed energy resources.

ROBUST DISTRIBUTED ENERGY RESOURCE MANAGEMENT SYSTEM CONTROL VERIFICATION – $2,500,000

Lawrence Livermore National Laboratory | Livermore, CA | Principal Investigator: Jovana Helms

Implicit trust in the control commands issued by distributed energy resource management systems to solar inverters presents a cybersecurity vulnerability to the power grid. This project addresses this risk by using advanced analytics to verify the commands sent by the management system control center. The team is developing techniques to approximate the state of the grid and distributed energy resource management system control algorithms—independently of the management system—so local controllers can verify that a distributed energy resource management system command is valid based on current conditions. Distributed energy resource components can then operate independently, even if a communication link between the management system and local controllers is down, increasing the resilience of the system.

ACCELERATING SYSTEMS INTEGRATION STANDARDS II – $2,400,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andy Hoke

This project updates standards in interconnection and interoperability of solar photovoltaic and other distributed energy resources at the distribution level. The team is leading an update of conformance testing standards to reflect the industry standard from the Institute of Electrical and Electronics Engineers. To tackle emerging system integration challenges, the team is also developing guidance such as operational best practices for bulk power systems with high levels of photovoltaics and integration of distributed energy storage. Improved practice recommendations and certification standards for end-to-end interoperability of distributed energy resources is also under development.

DISTRIBUTION FUNCTION IN TIME SERIES SIMULATION – $300,000 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andy Walker

This project with HOMER Energy Inc. intends to commercialize a distribution function that replaces the current steady-state assumption in an hourly simulation, to expose phenomenon for grid integration and net-metering, such as balancing, ramp-rates, inverter clipping, sell-back to the utility, and management of all assets on a power distribution system. The goal is to make computer modeling of variable power supply patterns much more accurate and expose new information required for reliability and efficiency of the overall distribution system.

ENHANCED CONTROL, OPTIMIZATION, AND INTEGRATION OF DISTRIBUTED ENERGY APPLICATIONS – $3,920,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Murali Baggu

This project develops, validates, and deploys a unique and innovative data enhanced hierarchical control architecture that enables the efficient, reliable, resilient, and secure operation of future distribution systems with a high penetration of distributed energy resources like solar energy. This architecture enables a hybrid control approach where a centralized control layer will be complemented by distributed control algorithms for solar inverters and autonomous control of grid edge devices. The architecture aims to be fully interoperable and include all the cybersecurity aspects that are necessary for reliable and secure system operation.

GRID OPTIMIZATION WITH SOLAR – $1,591,603

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Yingchen Zhang

This project develops a novel control scheme that provides system-wide monitoring and control using a small fraction of the active devices on the grid. The key innovation of this project's approach is to proactively manage very large distributed energy resource populations using only a few measurement points for input through predictive state estimation and a few carefully selected control nodes identified and dispatched through online multi-objective optimization. The platform gives utilities the capability to seamlessly dispatch legacy devices and distributed energy resources to achieve system-wide performance and reliability targets.

MULTI-TIME-SCALE INTEGRATED DYNAMICS AND SCHEDULING FOR SOLAR – $2,900,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jin Tan

This project is creating and validating advanced grid models by developing simulation models that seamlessly and cost-effectively combine dispatching and dynamic response analysis, where dispatching ranges from a day ahead to minutes, and dynamic response from seconds to sub-seconds. To study the impacts of photovoltaic variability on system reliability at different times, the team is developing a multi-time-scale grid model and an integrated photovoltaic model. These models give operators a more complete understanding of how short-term photovoltaic variability affects transmission-system operations like reserve scheduling and energy deployment. They also help operators accurately assess system reliability when deploying energy and reserve-scheduling under transient instability events, such as the failure of a major generator, and allow them to see how quickly standby generators can ramp up. The team is also studying interactions among all types of essential reliability services provided by photovoltaic power plants.

ROBUST DISTRIBUTED STATE ESTIMATOR FOR INTERCONNECTED TRANSMISSION AND DISTRIBUTION NETWORKS – $633,792

Northeastern University | Boston, MA | Principal Investigator: Ali Abur

This project develops, implements, tests, and validates a comprehensive state estimation algorithm for combined monitoring of transmission and distribution systems. Using this technology allows the computational complexity and solution time to be bounded regardless of the system size and number of measurements. By using a mixed set of measurements under different network configurations, utilities will be able to handle any number of available solar photovoltaic units connected to the distribution system.

OPTIMIZATION OF EXCESS SOLAR AND STORAGE CAPACITY FOR GRID SERVICES – $3,000,000

NV Energy | Las Vegas, NV | Principal Investigator: Michael Brown

This project evaluates using behind-the-meter storage, demand response, and utility “electric storage as a service” to extend the benefits and adoption of behind-the-meter solar through grid services. These services will be enabled by artificial intelligence and blockchain-powered smart contracts that can track and settle transactions leveraging information from smart meters and smart inverters. The team is working to develop artificial intelligence to use excess storage capacity for grid operations and to pay customers for their extra capacity.

SUITE OF ADVANCED MODELS FOR PHOTOVOLTAIC SYSTEMS – $2,000,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Suman Debnath

This project delivers three kinds of models—dynamic, high-fidelity, and advanced—of utility-scale photovoltaic generators, as well as power systems with high penetrations of distributed energy resources in distribution feeders. These models aim to capture the system dynamics under different conditions to better understand how the grid responds to various events. Advanced control functionalities aim to reduce momentary power cessation, increase system stability, and improve grid reliability.

SECURITY CONSTRAINED ECONOMIC OPTIMIZATION OF PHOTOVOLTAICS AND OTHER DISTRIBUTED ASSETS – $3,221,649

Opus One Solutions | Somerville, MA | Principal Investigator: Vivek Somasundaram

This project takes a holistic approach to address critical challenges that prevent high levels of distributed solar penetration in power system networks. The team is coordinating interaction of solar generation units, electric cars, energy storage devices, and demand-side management programs to provide multiple grid services in real-time. This project aims to deploy a general-purpose software platform that will create an optimal dispatch of distributed resources while ensuring secure and normal operations of electric power distribution networks. The project will ultimately enable large scale deployment of the solution to other cooperatives and municipal- and investor-owned utilities.

GRID MODERNIZATION LAB CONSORTIUM: DECENTRALIZED FAULT LOCATION, ISOLATION AND SERVICE RESTORATION – $3,000,000

Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Kevin Schneider

This project accelerates the deployment of resilient and secure distribution concepts, culminating in a field demonstration in South Carolina. It aims to accomplish this through the flexible operation of traditional assets, distributed energy resources, and micogrids using Open Field Message Bus, a reference architecture for security and interoperability.

PROTECTION OF HIGH-PENETRATION DISTRIBUTED PHOTOVOLTAICS – $1,000,000

Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Thomas McDermott

This project is working to define best practices for power system protection—independent controls that isolate faults on the grid—for radial distribution circuits with high photovoltaic penetration. A radial system is a common type of power distribution system. Because high photovoltaic penetration creates bidirectional power flow, and inverters respond differently to faults, traditional protection methods need to be revised. Photovoltaics and battery energy storage inverters produce low-fault currents that don't function properly under traditional overcurrent and distance protection. And with new requirements in new industry standards, like IEEE 1547, devices known as undervoltage relays can't detect faults. This project evaluates potential local solutions—such as high-energy traveling waves, incremental quantities, relays without settings, and focused directional methods on distribution networks—and conducts field tests at two sites. These alternative protections have the potential to overcome costly special protection studies and other grid integration requirements.

KEYSTONE SOLAR ENERGY FUTURE PROJECT – $3,141,920

PPL Corporation | Allentown, PA | Principal Investigator: Yi Li

This project leverages several different grid technologies to deploy a distributed system platform that bridges the gap between existing and future technologies by monitoring, controlling, and optimizing a high penetration of solar generation. The team is also developing a multi-layer device and communications architecture and a 500-customer pilot on at least ten distribution circuits. An extensive one-year, real-world testing will be performed, proving all of the target parameters before deploying it system-wide.

ADAPTIVE PROTECTION AND CONTROL FOR HIGH PENETRATION PHOTOVOLTAICS AND GRID RESILIENCE – $4,900,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Matthew Reno

This project team is designing a scalable adaptive protection platform for distribution systems and microgrids with high penetrations of distributed energy resources, like solar photovoltaics, that improves the selectivity and sensitivity of the protection system. The team is creating communication-free modular units that attach to intelligent protection devices to guarantee the protection system's operation during extreme weather, equipment failures, and other events. This project will transform power system protection from static settings that are not sufficiently reliable for high penetrations of solar to a platform that can adapt to real-time grid conditions.

GRID MODERNIZATION LAB CONSORTIUM: CITADELS – $3,000,000

Sandia National Laboratories, Pacific Northwest National Laboratory, Oak Ridge National Laboratory, Lawrence Livermore National Laboratory | Principal Investigator: Kevin Schneider

This project enables networked microgrids, and their component distributed energy resources, to operate in a distributed manner using collaborative autonomy concepts implemented in an OpenFMB architecture.

ELECTRIC ACCESS SYSTEM ENHANCEMENT – $3,962,113

Southern California Edison | Rosemead, CA | Principal Investigator: Juan Castaneda

This project leverages existing information systems and processes to increase efficient communication exchange between the utility and the customer or resource provider interconnection process by optimizing control of the resource. This complete lifecycle approach defines the necessary data to be exchanged, the grid and device characteristics, and the operating constraints and protocols to enable effective controls and operations. This structured and automated exchange of characteristics and parameters accelerates the interconnection process, establishes common information requirements, and enables effective operational connection of distributed energy resources to the grid.

PHASOR-BASED CONTROL SCALABLE SOLAR PHOTOVOLTAIC INTEGRATION – $1,458,356

University of California, Berkeley | Berkeley, CA | Principal Investigator: Sascha von Meier

This project designs, implements, and validates an innovative framework to enable a distribution grid with solar photovoltaic generation greater than 100 percent. By explicitly controlling voltage phasors at specific network nodes, this framework simultaneously addresses multiple operational challenges, including high resource variability, reverse power flow, grid visibility, and coordination between transmission and distribution systems. The framework solves the problem of complex interdependencies in large networks by creating options for partitioning the grid both physically and computationally.

INTEGRATED DISTRIBUTED ENERGY MANAGEMENT SYSTEM AT RIVERSIDE PUBLIC UTILITY – $2,613,764

University of California, Riverside | Riverside, CA | Principal Investigator: Hamed Mohsenian-Rad

This project is working to design, deploy, and validate at scale a novel distributed energy resource management system. Its main component will be a sophisticated numerical analysis platform that will enable a network management solution for real-time control. The solution provides secure and optimal dispatch of distributed energy resources for power system networks (both transmission and distribution) on feeders with over 50 percent photovoltaic penetration.

SCALABLE/SECURE COOPERATIVE ALGORITHMS AND FRAMEWORK FOR EXTREMELY HIGH-PENETRATION SOLAR INTEGRATION – $1,275,000

University of Central Florida | Orlando, FL | Principal Investigator: Zhihua Qu

This project designs and develops a scalable architecture and a set of algorithms for distributed control and optimization. The platform encompasses automatic fault location isolation and service restoration and Volt/VAR optimization; distribution system state estimation algorithms for both the conventional non-convex task and the convex state estimation task; a three-phase unbalanced power flow model that captures the non-linear behavior of system components and enables rapid computation of sub-transmission network and unbalanced distribution network; a two-stage stochastic security-constrained algorithm for real-time operational planning; and a distribution energy market framework that utilizes both model-based and data-based techniques to provide market-based signals for real and reactive power control of photovoltaic systems.

ROBUST AND RESILIENT COORDINATION OF FEEDERS WITH UNCERTAIN DISTRIBUTED ENERGY RESOURCES: FROM REAL-TIME CONTROL TO LONG-TERM PLANNING – $1,424,285

University of Vermont | Burlington, VT | Principal Investigator: Mads Almassalkhi

This project develops a layered predictive optimization and coordination framework to coordinate the flexible resources available in the distribution grid, as well as the legacy control devices, to ease the fluctuations and variability in solar generation. Solar forecast data is leveraged to schedule the dispatchable flexible resources in a look-ahead fashion, while any mismatch due to solar forecast errors will be solved through real-time coordination of the controllable resources. New estimation methods are leveraging data from smart meters and sensors to estimate the available flexibility in the distribution system, as well as identify the real-time operating conditions, to aid in the informed decision making process. Aggregated models of the flexible resources will be leveraged in a hierarchical fashion to implement autonomous response to contingencies.

A SCALABLE CONTROL ARCHITECTURE FOR 100 PERCENT PHOTOVOLTAIC PENETRATION WITH GRID FORMING INVERTERS – $4,900,000

University of Washington | Seattle, WA | Principal Investigator: Brian Johnson

This project is developing two kinds of grid-forming controls: fast communication-free controls for inverters for solar-plus-storage systems, and slower controls that use a distributed communication architecture for system-wide energy management. These controls aim to be immune to communication outages and be compatible with small solar energy systems as well as the bulk power grid.

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.

A DATA-DRIVEN MULTI-TIMESCALE PREDICTIVE, PROACTIVE, AND RECOVERY OPTIMIZATION FRAMEWORK FOR SOLAR ENERGY INTEGRATED RESILIENT DISTRIBUTION GRID – $900,000

Argonne National Laboratory | Lemont, IL | Principal Investigator: Bo Chen

This project team is developing resiliency planning for microgrids supported by solar photovoltaics. The team is creating a pre-event, proactive energy management optimization model and solution that enables flexible load, storage resources, and distributed solar energy to be strategically prepared for dispatch in the event of a grid disturbance, like extreme weather. They will also develop a post-event, real-time operation optimization model and solution. These microgrid and solar solutions have the potential to improve grid operations and provide microgrid islanding, without power from the electric grid, for up to five days.

ALTERNATING CURRENT AND DIRECT CURRENT HYBRID DISTRIBUTION GRIDS WITH SOLAR INTEGRATION: ARCHITECTURE, STABILIZATION, AND COST ASSESSMENT – $826,000

Argonne National Laboratory | Lemont, IL | Principal Investigator: Dongbo Zhao

This project analyzes the potential of hybrid alternating current and direct current distribution grids. This is a change from the alternating current-only grids currently used that require photovoltaics to be converted to direct current, although direct current could also benefit electric vehicle charging, batteries, light-emitting diode lighting, and other technologies. The concept of direct current nanogrids, microgrids, and medium-voltage distribution grids has drawn increasing attention in both academia and industry. In an effort to maximize the benefits of direct grids in terms of system cost, efficiency, and operation performance amid the challenge of reliable control under high penetration of intermittent solar energy, the team is develop controls for a hybrid grid. They are using a universal impedance-based stabilization approach, with a decentralized and adaptive impedance loop to provide direct current section and alternating current section stabilization, and add interface inverters that interlink the two subgrids.

AN ENERGY INTERNET PLATFORM FOR TRANSACTIVE ENERGY AND DEMAND RESPONSE APPLICATIONS – $1,199,687 ♦

BEM Controls | McLean, VA | Principal Investigator: Jason Lin

This project is developing a blockchain-enabled open architecture platform that allows commercial and industrial buildings to buy and sell excess rooftop photovoltaic energy generation and energy consumption reduction, known as negative watts or negawatts, in a secure and reliable way.

ADVANCING THE WEATHER RESEARCH AND FORECASTING SOLAR MODEL TO IMPROVE SOLAR IRRADIANCE FORECAST IN CLOUDY ENVIRONMENTS – $1,620,000

Brookhaven National Laboratory | Upton, NY | Principal Investigator: Yangang Liu

This project is developing solar-specific improvements to the weather research and forecasting model for improving prediction of solar irradiance in cloudy environments. Specific areas of improvements are cloud microphysics, radiative transfer, and innovative analysis packages.

ADVANCED PEER TO PEER TRANSACTIVE ENERGY PLATFORM WITH PREDICTIVE OPTIMIZATION – $1,199,026 ♦

ecoLong | Albany, NY | Principal Investigator: Nancy Min

The rise in distributed energy resources requires the development of new technologies that enable prosumers—consumers that produce their own energy—to transact directly with other energy users to help meet their energy needs. This project uses new technology to allow consumers, solar owners, and utilities to directly transact with each other in order to maximize economic and technological benefits.

PROBABILISTIC FORECASTS AND OPERATIONAL TOOLS TO IMPROVE SOLAR INTEGRATION – $1,799,826

Electric Power Research Institute | Knoxville, TN | Principal Investigator: Aidan Tuohy

This project is developing improved probabilistic solar and net load forecasts for three separate utility case studies, each with different operating procedures. The team is using advanced tools to research and develop methods for each utility to manage uncertainty in a reliable and economic manner in daily operations. In addition, they hope to validate these methods by integrating forecasts and decision making functions into a scheduling management platform to verify the use of probabilistic forecasts to reduce integration costs.

ENABLE BEHIND-THE-METER DISTRIBUTED ENERGY RESOURCE PROVIDED GRID SERVICES THAT

MAXIMIZE CUSTOMER AND GRID BENEFITS – $3,000,000

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Aminul Huque

This project team is researching, developing, and demonstrating collected data and controls to enable behind-the-meter solar photovoltaics and other distributed energy resources. The goal is to cost-effectively provide grid services in both distribution and bulk power systems while enhancing system reliability. The team is conducting advanced transmission, distribution, and distributed energy resource simulations to validate the merit and performance of distributed energy resource-provided services, and better estimate the potential need for network upgrades. The team will lead an industry collaboration to develop behind-the-meter distributed energy resource grid services guidelines to expand the provision of grid services and address existing regulatory barriers.

COORDINATED RAMPING PRODUCT AND REGULATION RESERVE PROCUREMENTS IN CALIFORNIA INDEPENDENT SYSTEM OPERATOR AND MIDCONTINENT INDEPENDENT SYSTEM OPERATOR USING MULTI-SCALE PROBABILISTIC SOLAR POWER FORECASTS – $1,108,203

Johns Hopkins University | Baltimore, MD | Principal Investigator: Ben Hobbs

This project advances the state-of-the-art in solar forecasting technologies by developing short-term and day-ahead probabilistic solar power prediction capabilities. The proposed technology will be based on the big-data-driven, transformative IBM Watt-Sun platform, which will be driven by parallel computation-based scalable and fast data curation technology and multi-expert machine learning based model blending. The integration of validated probabilistic solar forecasts into the scheduling operations of both the Midcontinent and California Independent System Operators will be tested, via efficient and dynamic procurement of ramp product and regulation. Integration of advanced visualization of ramping events and associated alerts into their energy management systems and control room operations will also be researched and validated.

GRID MODERNIZATION LAB CONSORTIUM: RESILIENCE METRICS FOR DEFENSE CRITICAL INFRASTRUCTURE – $2,775,000

Lawrence Berkeley National Laboratory, Sandia National Laboratories, National Renewable Energy Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory | Principal Investigator: Robert Jeffers

This project is developing models that will calculate time-varying performance of Defense Critical Infrastructure during long-duration bulk power system outages. The project team is vetting the resilience metrics and the models with the Department of Defense and industry stakeholders.

A MACHINE LEARNING APPROACH TO PREDICTING MISSING CLOUD PROPERTIES IN THE NATIONAL

SOLAR RADIATION DATABASE – $250,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Grant Buster

This project is building a data pipeline to facilitate the development of machine learning models. These models will then be used to improve the identification of cloud type and density as part of the input to the National Solar Radiation Database. The team is training, testing, and validating different machine learning approaches to determine which performs best and then integrating a finally selected model into the database workflow.

FOUNDATIONAL OPEN SOURCE SOLAR SYSTEM MODELING – $1,800,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Janine Freeman

This project strives to improve the accuracy and usability of the System Advisor Model as a reliable tool for techno-economic modeling of photovoltaic systems. It also aims to generate a well-documented source code that is available through open-source licensing to the general public and to create an active developer community that can contribute to the evolution of this application.

PROBABILISTIC CLOUD OPTIMIZED DAY-AHEAD FORECASTING SYSTEM BASED ON WEATHER RESEARCH AND FORECASTING SOLAR – $1,720,806

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta

This project develops a publicly available ensemble-based solar capability for the weather research and forecasting model that will serve as a baseline operational solar irradiance forecasting model. The team is using an adjoint analysis technique to adjust the most important variables and calibrate the weather research and forecasting solar system ensemble to provide accurate estimates of forecast uncertainties. This resulting system will increase the accuracies of intra-day and day-ahead probabilistic solar forecasts that can be used in grid operations.

SOLAR RADIATION RESEARCH LABORATORY – $1,200,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta

This project funds the Solar Radiation Research Laboratory to maintain and test solar measurement devices and ensure they are certified for accuracy and precision. The team operates the Baseline Measurement System to provide high-quality, long-term solar and atmospheric measurements. These measurements can be used for instrument comparison and development, standards development, the development of radiative transfer and solar variability models, and validation studies. This project also maintains the national standard for solar measurements and disseminate accurate solar measurement and modeling methods and best practices.

SOLAR UNCERTAINTY MANAGEMENT AND MITIGATION FOR EXCEPTIONAL RELIABILITY IN GRID

OPERATIONS – $1,698,933

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Bri-Mathias Hodge

The project is designing novel algorithms to create probabilistic solar power forecasts and automate their integration into power system operations. Adaptive reserves will dynamically adjust reserve levels conditional on meteorological and power system states. Risk-parity dispatch will be developed to produce optimal dispatch strategies by cost-weighting solar generation scenarios on forecast uncertainty. This project will test the integration of probabilistic solar forecasts into the Electric Reliability Council of Texas' real-time operation environment through automated reserve and dispatch tools that can increase economic efficiency and improve system reliability.

THE NATIONAL SOLAR RADIATION DATABASE – $1,200,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta

This project develops and provides public access to high-quality, long-term solar resource data sets through the National Solar Radiation Database. These data sets encompass studies from the U.S. Department of Energy and solar industry in grid integration, capacity expansion, resource planning and deployment, national energy modeling, production cost modeling, and regional solar deployment. The team is updating the database to provide timely data, incorporate new information from the Geostationary Operational Environmental Satellite system, and improve data set quality through regular research on identified weaknesses.

DEPLOYING INTRA-HOUR UNCERTAINTY ANALYSIS TOOLS TO GRIDVIEW – $500,000 ♦

Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Nader Samaan

This project is focused on the integration of intra-hour uncertainty analysis tools to GridView, a widely used tool to help transmission planners, electricity market modelers, and regulators perform production cost modeling studies. This project aims to add capabilities to GridView that enable users to perform high-fidelity simulations of five-minute markets while considering real-world uncertainties and constraints.

DEVELOPMENT OF THE NEXT WEATHER RESEARCH AND FORECASTING MODEL – $1,214,872

Pacific Northwest National Laboratory | Richlands, WA | Principal Investigator: Larry Berg

This project is developing the next generation of solar resource capabilities integrated into the weather research and forecasting model to include enhancements for intra-day and day-ahead forecasts of solar irradiance. The new or improved treatments include absorptive aerosol, cloud microphysics, subgrid variability in irradiance, and application of uncertainty quantification techniques.

GRID MODERNIZATION LAB CONSORTIUM: HIERARCHICAL ENGINE FOR LARGE-SCALE INFRASTRUCTURE

CO-SIMULATION PLUS: FROM A FACILITATOR TO A HUB – $2,011,600

Pacific Northwest National Laboratory, National Renewable Energy Laboratory, Lawrence Livermore National Laboratory, Argonne National Laboratory, Idaho National Laboratory | Principal Investigator: Jason Fuller

The Grid Modernization Lab Consortium and the energy industry as a whole have been using Hierarchical Engine for Large-Scale Infrastructure Co-Simulation in their projects to comprehensively analyze and assess the increasing interdependency among critical infrastructures. This project addresses gaps in in scalable integration with diverse infrastructures and usability for co-simulation complexity.

P2P TRANSACTIONS WITH DEMAND FLEXIBILITY FOR INCREASING SOLAR UTILIZATION – $1,144,221 ♦

QCoefficient | Chicago, IL | Principal Investigator: Vincent Cushing

As more renewable energy is added to the electric grid, ensuring a reliable and efficient grid becomes more challenging. This project is working to automate smart energy transactions and improve grid operations when more solar energy is connected to the grid.

ENABLING EXTENDED-TERM SIMULATION OF POWER SYSTEMS WITH HIGH PHOTOVOLTAIC PENETRATION – $350,000 ♦

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: David Schoenwald

This project seeks to address the need for more accurate grid simulations that require less computation, time, and costs to produce. The team is developing dynamic grid simulation tools to support analysis of a grid with high levels of solar photovoltaic generation, advancing the power industry's understanding of grid behavior as more renewable energy is added. The project focuses on advancements in the numerical methods used to solve the system of differential and algebraic equations that represent power systems.

PHYSICS-BASED DATA-DRIVEN GRID MODELING TO ACCELERATE ACCURATE PHOTOVOLTAIC INTEGRATION – $2,970,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Matthew Reno

Uncertainty in distribution grid modeling can lead to inaccuracy in decisions regarding photovoltaic integration, limiting the number of photovoltaic systems that can connect to the electric grid. This project is working to increase the precision and accuracy of distribution system models by more efficiently processing grid measurements. The team is developing several physics-based, data-driven, machine-learning algorithms that enables distribution grid models to dynamically adapt to changing grid conditions. This enables usability for all distribution feeders with monitoring. The team will validate the algorithms to improve modeling accuracy and decrease uncertainties in photovoltaic hosting capacity by at least 90 percent.

ADVANCED DISTRIBUTED GRID INFRASTRUCTURE – $1,000,000 ♦

Span.IO, Inc. | San Francisco, CA | Principal Investigator: Chadwick Conway

This project is developing hardware for solar-plus-storage systems that will integrate a hybrid inverter into a novel breaker panel. This aims to reduce the cost and complexity of adopting distributed energy resources like solar by reducing installation time and material costs. This system will be used in newly built homes and retrofitted ones. It will give homeowners the ability to monitor and control both their loads and generation and also improve the interface between homes and grid operators.

OPEN SOURCE EVALUATION FRAMEWORK FOR SOLAR FORECASTING – $794,364

University of Arizona | Tucson, AZ | Principal Investigator: William Holmgren

This project develops an open-source framework that enables evaluations of irradiance, solar power, and net-load forecasts. Team members have previously collaborated on forecasting trials for utilities, developed operational solar and wind forecasts, and led projects using the open-source PVLib simulation and performance tool. The goal is to make the open-source evaluation framework more easily available for forecast providers, utilities, balancing authorities and fleet operators for non-biased forecast model assessment.

HAIMOS ENSEMBLE FORECASTS FOR INTRA-DAY AND DAY-AHEAD GHI, DNI, AND RAMPS – $1,316,203

University of California, San Diego | San Diego, CA | Principal Investigator: Carlos Coimbra

This project is developing the Hybrid Adaptive Input Model Objective Selection (HAIMOS) ensemble model for solar irradiance forecasting. HAIMOS is a physics-based and data-driven model that forecasts both direct normal irradiance (DNI) and global horizontal irradiance (GHI) for horizons up to 72 hours in advance. One of the key gaps in these technologies is the lack of accurate solar forecasts for DNI and inaccurate forecasting of large, sudden changes in irradiance, known as irradiance ramps. This project aims to develop a forecast accuracy that is considerably higher than that of the persistence or baseline forecast, across a wide range of time horizons for both GHI and DNI.

AUTONOMOUS INVERTER CONTROLS FOR RESILIENT AND SECURE GRID OPERATION – $3,000,000

University of Central Florida | Orlando, FL | Principal Investigator: Zhihua Qu

This project aims to provide a unified control design framework to enhance photovoltaic inverter controls and address the technical challenges of keeping the grid secure. It will coordinate grid-forming and grid-following inverters and black-start capability, which enables systems to restart independently after a power outage; ensure scalability and system stability; and protect against cyberattacks. The team will validate the technology using software simulations and lab field tests.

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 electronic 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.

SOLAR POWER ELECTRONICS MODULAR INTEGRATED NODE PLATFORM – $2,296,150

Flex Power Control | Los Angeles, CA | Principal Investigator: Robert Dawsey

This innovative power electronics platform combines solar power with stationary energy storage and electric vehicles to minimize installation costs and to optimize the use of solar energy. The project is developing advanced controls built on system awareness and communications, coupled with cloud-based analytics for optimized energy utilization. The platform leverages silicon carbide-based power electronics to provide high efficiency inverters, in addition to having controllable power flow between the distributed energy resources and the load.

MODULAR HIGH FREQUENCY ISOLATED MEDIUM-VOLTAGE STRING INVERTERS ENABLE A NEW PARADIGM FOR LARGE PHOTOVOLTAIC FARMS – $1,752,973

Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Deepak Divan

This project is developing and validating a new inverter to significantly reduce the balance-of-system costs in larger commercial and utility-scale photovoltaic farms. The inverter realizes higher-value propositions such as dispatchability and dynamic grid support. The project uses a medium-voltage string inverter topology and a soft-switching solid state transformer, which can interconnect direct current from solar panel strings at 600 to 1000 volts to a standard utility distribution voltage of 4.16 kilovolts. The medium-voltage line will be fed from a standard utility substation that derives power from a 69-500 kilovolt transmission source, eliminating a 60 hertz transformer in the power path and resulting in both cost and efficiency savings.

ADVANCED SILICON CARBIDE WAFER MANUFACTURING FOR LOW COST, HIGH EFFICIENCY POWER ELECTRONICS IN SOLAR APPLICATIONS – $1,000,000 ♦

Halo Industries, Inc. | Palo Alto, CA | Principal Investigator: Andrei Iancu

This project is developing a technology that mechanically fractures wafers off blocks of silicon carbide without wasting material. These wafers can be processed into power electronics devices that can be used in solar applications. Conventionally, the wafers are sawed off the blocks, which is a slow process in which the sawing wastes some material. This new technology could be faster and, if so, could reduce the cost of wafers due to higher throughput and reduced material loss.

ENABLING INTEROPERABILITY FOR PHOTOVOLTAIC INVERTER CONTROLLERS – $149,995 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kumaraguru Prabakar

Protection systems in the power grid are necessary to ensure that there are minimal disruptions to customers when a fault occurs. Protection schemes are designed to identify faults as quickly as possible and isolate those parts of the system while maintaining electrical service to as many customers as possible. As the grid continues to incorporate higher levels of inverter-based photovoltaics, existing protection systems need to change due to the much lower levels of fault current produced by inverters. This project is developing Travelling Wave based protection schemes as an innovative method to overcome these challenges and allow for wide-spread deployment of inverter-based photovoltaics. These protection schemes can be implemented at both the transmission and distribution system to simultaneously ensure stability of the distribution system and reliability of the bulk system, while enabling significant penetration of distributed PV and other distributed energy resources.

PHOTOVOLTAIC INVERTER SYSTEMS ENABLED BY MONOLITHICALLY INTEGRATED SILICON CARBIDE-BASED FOUR QUADRANT POWER SWITCH – $1,517,146

North Carolina State University | Raleigh, NC | Principal Investigator: Subhashish Battacharya

This project creates an ultra-high-density, low-cost power conversion device using a newly developed single die silicon carbide-based power semiconductor switch that can block voltage and carry current in all polarities or quadrants of the power switch. The proposed scalable power conversion device can enable single-stage power conversion and then be used as a building block for photovoltaic inverters to meet and exceed efficiency, reliability, and power density targets when compared to conventional two-stage cascaded solutions.

MULTIPORT AUTONOMOUS RECONFIGURABLE SOLAR POWER PLANT – $2,500,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Suman Debnath

This project is developing an integrated system of modular power electronics devices that connect utility-scale solar power plants and energy storage with the high voltage direct current and alternating current distribution and transmission grid. This system, referred to as a multiport autonomous reconfigurable solar power plant, introduces greater grid stability and enable continued operation under grid disturbances through advanced controls. It also includes a cyber-physical security layer for the controller that uses a combination of data-based and physics-based integrity checks to determine intrusions.

POWER ELECTRONICS RELIABILITY STANDARDS – $1,200,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Jack Flicker

This project assesses photovoltaic converter and inverter reliability, since reliability and failure mechanisms of photovoltaic power electronics are key cost drivers. The team is conducting tests to quantify the difference in reliability attributed to nonstandard operating conditions, compare the effects of potting and component layout to reliability temperature gradients, and evaluate the equivalency of different reliability tests. This data will directly impact the standards-making process for photovoltaic power electronics devices and will conclude with the publication of a testing and qualification standard for photovoltaic power electronics.

AUTONOMOUS GRID-FORMING INVERTERS ENABLED BY ALWAYS-ON UNIVERSAL DROOP CONTROL WITHOUT EXTERNAL COMMUNICATION OR PHASE-LOCKED LOOPS – $600,000 ♦

Syndem LLC | Chicago, IL | Principal Investigator: Qingchang Zhong

This project is developing a hacker-proof, grid-forming inverter that doesn't rely on a communication network, can avoid cascading blackouts even when there are grid faults, and can start up the grid without the help of a traditional generator in what's known as black start. The inverter will be able to autonomously resynchronize with the grid while supplying local loads, including during a black start. The project addresses a major challenge of high penetration of solar and other distributed energy resources and offer guidelines for distributed energy resource integration to improve grid stability, resiliency, security, and reliability.

A RELIABLE, COST-EFFECTIVE TRANSFORMERLESS MEDIUM-VOLTAGE INVERTER FOR GRID INTEGRATION OF COMBINED SOLAR AND ENERGY STORAGE – $2,735,138

University of Arkansas | Fayetteville, AR | Principal Investigator: Yue Zhao

This project aims to enhance photovoltaic plant reliability with significantly reduced lifetime costs for a high-density 300 kilowatt central inverter. It converts 1.5 kilovolt direct current output of the photovoltaic systems to 4.16 kilovolt alternating current without the use of bulky 60 hertz transformers. The proposed technology lowers the lifetime costs of silicon carbide inverters through the simultaneous electro-thermal design of the subsystem and the components of the inverter. This project establishes a basis for new innovations by addressing the challenge of multi-objective optimization while accounting for inverter cost and reliability constraints.

COMPACT AND LOW-COST MICROINVERTER FOR RESIDENTIAL SYSTEMS – $1,872,818

University of Maryland | College Park, MD | Principal Investigator: Alireza Khaligh

This project aims to create a holistic design of microinverters using the emerging gallium nitride semiconductors combined with a novel circuit with reduced components and filters. The project models thermal stresses and their effect on reliability by using a multi-physics-based approach resulting in an improved assembly design. It is anticipated that the microinverter will yield more than 250,000 hours of operation with no failures under consumer rooftop and commercial installation use conditions, while simultaneously achieving lower costs.

MODULAR, MULTIFUNCTION, MULTIPORT, AND MEDIUM-VOLTAGE UTILITY SCALE SILICON CARBIDE PHOTOVOLTAIC INVERTER – $2,887,025

University of Texas at Austin | Austin, TX | Principal Investigator: Alex Huang

This project is developing the next-generation utility-scale photovoltaic inverter referred to as a modular, multi-function, multiport, and medium-voltage utility-scale silicon carbide solar inverter. Called the M4 Inverter, it directly converts the direct current output of solar panels to medium-voltage alternating current, eliminating the bulky and costly low-frequency transformer. The inverter also has a direct current port to interface with an additional energy storage device. The device has multiple functionalities and can be used for reactive power support, fast frequency regulation, and peak power reduction, and enables synthetic inertia to be integrated into the inverter for grid support. Taken together, these advances will enable the inverter to drastically reduce the levelized cost of energy.

MODULAR WIDE-BANDGAP STRING INVERTERS FOR LOW-COST MEDIUM-VOLTAGE TRANSFORMERLESS PHOTOVOLTAIC SYSTEMS – $2,253,060

University of Washington | Seattle, WA | Principal Investigator: Brian Johnson

This project is developing a string inverter that uses integrated circuit control blocks, each comprised of a wide-bandgap-based power converter and local controller that can be assembled in a modular fashion to produce ultra-low-cost medium-voltage transformerless photovoltaic inverters. Each circuit control block will be fabricated on high-voltage printed circuit boards with planar magnetics, such that automated manufacturing processes can be leveraged for maximum cost savings and throughput. This eliminates costly passive components and low-frequency transformers, substantially reducing electrical balance-of-system costs.

ULTRA-COMPACT ELECTROLYTE-FREE MICROINVERTER WITH MEGAHERTZ SWITCHING – $1,031,317

Virginia Polytechnic Institute and State University | Blacksburg, VA | Principal Investigator: Jason Lai

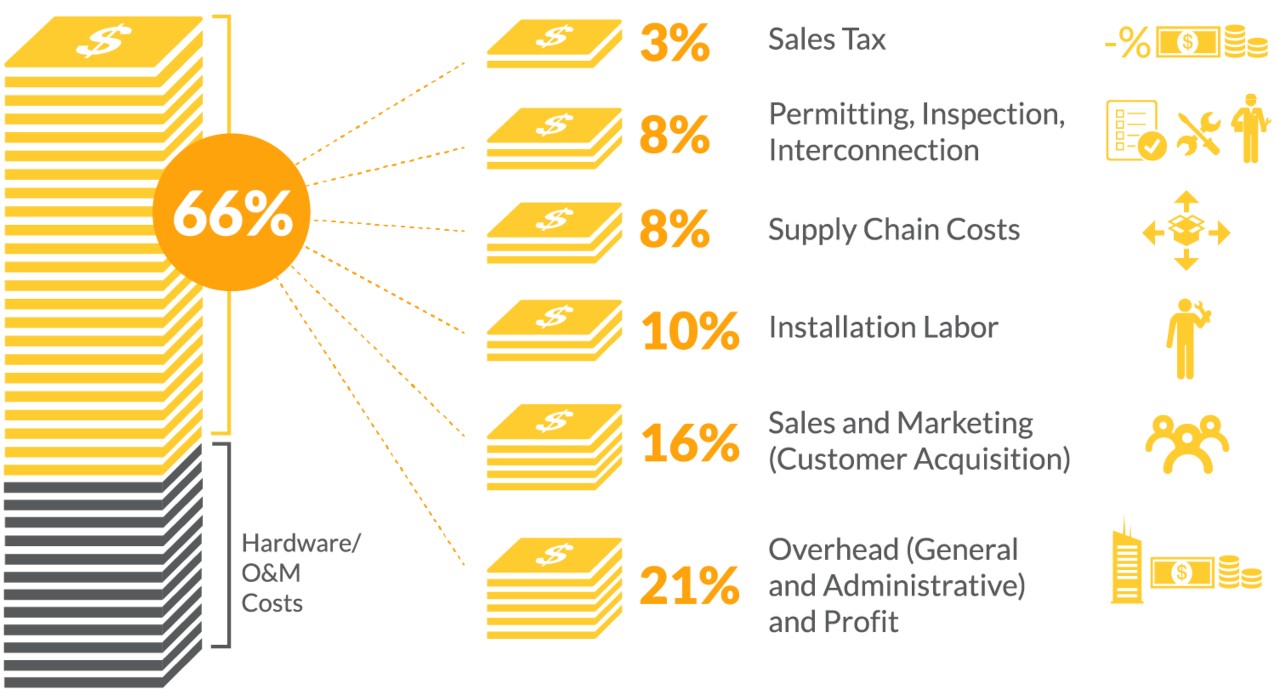
This project is working to develop a cost-effective photovoltaic microinverter that fully utilizes the potential of wide-bandgap semiconductor devices, like gallium-nitride devices, which have shown potential of switching at megahertz frequencies. By operating the microinverter at such high frequencies, passive component size can be drastically reduced while still maintaining ultra-high efficiency of the microinverter. With the tallest component in the entire package measuring less than 0.2 inch, the potting compound material can be reduced by 80 percent as compared to typical designs with a one inch tall package, further reducing the cost of the product.

Soft Costs

The Soft Costs track addresses 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 total nearly than $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.

Soft Costs Breakdown



Source: National Renewable Energy Laboratory (unpublished) "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2019."

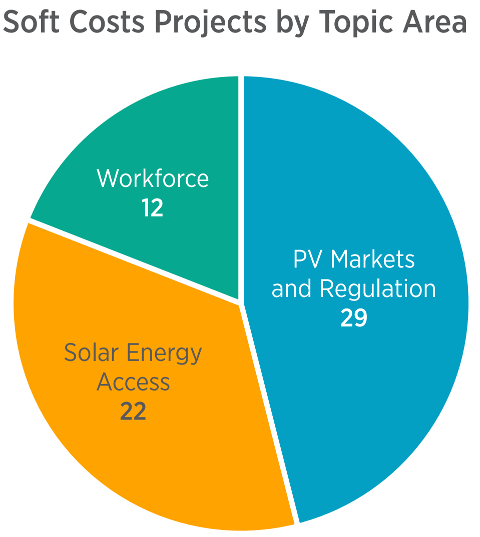
Figure 13

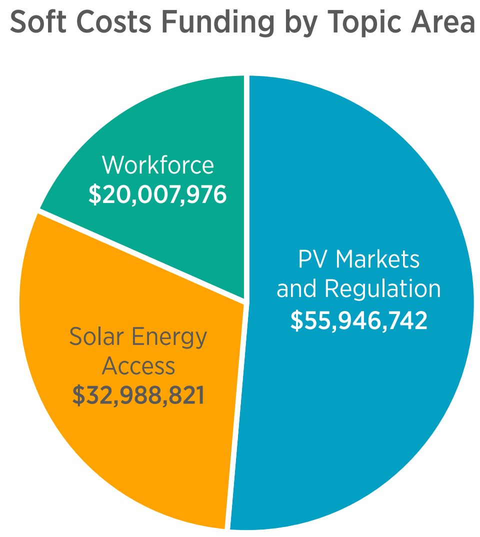
Projects within the soft costs portfolio seek to reduce the “red tape” associated with installing solar energy systems, as regulatory and financing burdens lead to higher costs for both developers and consumers. Across the country, there are more than 18,000 unique Authorities Having Jurisdiction that 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 across the country, with the largest year-over year growth occurring in states with developing markets like Utah, Minnesota, and Tennessee. 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, there are many professions across the country that are impacted by the growth of solar, like 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, to prepare those in the utility industry to manage a modern grid, as well as to 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 photovoltaic systems, the lack of competitive interest rates, low credit scores and/or income below traditionally acceptable underwriting criteria, and the 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-moderate income customers, within their communities.

Projects in the Soft Costs track conduct fundamental research and analysis, identify and replicate best practices, 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.





The Soft Costs track has focused its projects in three major categories: Solar Energy Access, Photovoltaic Markets and Regulation, and Workforce. A description of each can be found below, along with a detailed list of the projects within it. Projects are alphabetized by the awardee name and represented in the following format:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

Projects managed by the Innovations in Manufacturing and Competitiveness team are identified with a blue diamond (♦) after the project name and amount.

Projects managed by the Strategic Analysis and Institutional Support team are identified with a red spade (♠) after the project name and amount.

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 low- and moderate-income communities. Projects in this topic represent more than a third of the Soft Costs track and 31 percent of the track's budget.

DEVELOPING SOCIALLY AND ECONOMICALLY GENERATIVE, RESILIENT PHOTOVOLTAIC ENERGY SYSTEMS FOR LOW- AND MODERATE-INCOME COMMUNITIES: APPLICATIONS TO PUERTO RICO – $1,215,891 ♦

Arizona State University | Tempe, AZ | Principal Investigator: Clark Miller

The project team is developing innovative approaches and models to enable Puerto Rico's low- and moderate-income communities to better understand how they can use solar energy to improve resilience and energy affordability. The team is analyzing and modeling different approaches for expanding solar energy access, including household, business, community, and utility-based solar solutions. Researchers are mapping the solar opportunity for low- and moderate-income communities in Puerto Rico and conducting deeper analysis of specific representative communities.

BRINGING LOW- AND MODERATE-INCOME SOLAR FINANCING MODELS TO SCALE – $1,103,239 ♦

Clean Energy States Alliance | Montpelier, VT | Principal Investigator: Warren Leon

There have been several pilot and small-scale efforts to tackle the challenges of financing low- and moderate-income solar energy projects, but there hasn't been a multi-state or regional initiative. This project researches three new solar program designs and associated financing models to expand and scale solar access to low- and moderate-income single family homes, mobile homes, and multifamily homes. The project focuses on analyzing the outcomes of these newly piloted business models and, when appropriate, assessing how they could be scaled to multiple states. Specifically, the team is analyzing: the Connecticut Green Bank model to serve low- and moderate-income single family homeowners; the New Mexico state model to develop "Photovoltaics on a pole" prototypes that can be inexpensively manufactured and installed widely at mobile homes; and the Clean Energy Group model to work with affordable housing organizations to use non-government funded loan guarantees and other strategies to finance solar and solar plus battery storage for multifamily affordable housing buildings.

STATE STRATEGIES TO BRING SOLAR TO LOW- AND MODERATE-INCOME COMMUNITIES – $1,730,000 ♦

Clean Energy States Alliance | Montpelier, VT | Principal Investigator: Warren Leon

This project works with the state governments of Connecticut, Minnesota, New Mexico, Oregon, Rhode Island, and the District of Columbia to provide technical assistance necessary to develop and implement strategies for expanding the amount of solar available to low- and moderate-income residents and communities. Each participating state is developing goals and plans of action that match its programmatic needs, demographic profile, solar potential, and financial resources.

AN ONLINE MARKETPLACE THAT ALLOWS CONSUMERS TO COMPARISON SHOP FOR SOLAR EQUIPMENT, FINANCING, AND LABOR, INDEPENDENTLY – $1,599,839 ♦

EnergySage | Boston, MA | Principal Investigator: Vikram Aggarwal

This project applies best practices from online shopping in other industries to the solar shopping process to lower customer acquisition costs and the installed price of solar photovoltaic systems. The approach focuses on scalable online tools that facilitate consumer decision making, while streamlining the sales process for suppliers. By adopting best practices from other industries, this project aims to better align the consumer experience with consumer expectations, reduce customer acquisition costs, and increase solar deployment.

REVOLVING PROGRAM RELATED INVESTMENTS ENERGY SAVINGS FUND – $999,470 ♦

Grid Alternatives | Washington, DC | Principal Investigator: Jacob Bobrow

This project is designing, building, testing, and scaling an innovative financing and project-development model that could expand photovoltaic access to low- and moderate-income Americans. The model, which incorporates new sources of capital, aims to lower solar electricity costs and reduce creditworthiness as a barrier of entry, particularly in the development of multifamily rooftop and ground-mounted community solar projects that are 50-500 kilowatts.

ACCELERATING LOW-INCOME FINANCING AND TRANSACTIONS FOR SOLAR ACCESS EVERYWHERE – $1,499,988 ♦

Groundswell | Washington, DC | Principal Investigator: Michelle Moore

This project assesses the replicability and scalability of a variety of solar financing models that could enable greater solar access, including: a private finance option similar to a utility credit structure; a “pay as you save” structure that pays for solar with shared savings; and a credit enhancement model that leverages alternative financing like loss reserves offered through foundations, municipal authorities, or public-private partnerships. The team will analyze adoption rates and performance data from ongoing projects, with an eye toward optimizing the models for scale.

ACTIVATING OPPORTUNITY ZONES FOR RAPID SOLAR PLUS STORAGE DEPLOYMENT IN LOW-AND MODERATE-INCOME COMMUNITIES – $500,00 ♦

Houston Advanced Research Center | Spring, TX | Principal Investigator: Gavin Dillingham

This project is developing a cost-effective solar financing program in low- to moderate-income opportunity zones in the underserved Texas deregulated power market to accelerate solar deployment. The project plans to research and develop new ownership and financing structures, leveraging opportunity zones, to increase the accessibility to solar energy among low-income communities.

DEVELOPING AND PILOTING SOLAR FINANCING MODELS TO EXPAND PHOTOVOLTAIC ACCESS TO LOW- AND MODERATE-INCOME AMERICANS – $999,935 ♦

International Center for Appropriate and Sustainable Technology | Denver, CO | Principal Investigator: Ravi Malhora

This project partners with utilities, multifamily affordable housing projects, and private investors to create and validate an aggregated shared solar financing model. This financing model aims to reduce project costs and risks, which has prevented multifamily affordable housing projects solar development.

NATIONAL COMMUNITY SOLAR PARTNERSHIP – $10,000,000 ♦

Multiple Awardees | United States of America

The National Community Solar Partnership is a coalition of community solar stakeholders working to expand access to affordable community solar to every American household by 2025. This partnership is developing multi-stakeholder teams to convene around specific goals, provide technical assistance for unique local challenges, and develop an online community platform to support information exchange.

INCLUSIVE SHARED SOLAR INITIATIVE – $1,000,000 ♦

National Association of State Energy Officials | Arlington, VA | Principal Investigator: Sandy Fazeli

In partnership with the National Energy Assistance Directors Association and the Energy Programs Consortium, this project team brings together state agencies, utilities, solar providers, and financial institutions to pilot low-income community solar programs. This project, inspired by the New York State Solar for All program, leverages the federal Low Income Home Energy Assistance Program, state and local incentives, and other capital funding sources to promote the development of community solar for low- to moderate-income customers.

RESEARCH AND DEVELOPMENT OF FLEXIBLE FINANCIAL CREDIT AGREEMENTS – $600,000 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Paul Schwabe

This project team is working to reduce barriers to solar access through innovative financing programs that serve low- to moderate-income communities. The team is researching, designing, and implementing flexible financial credit agreements to increase low- to moderate-income customer choice and solar affordability, addressing barriers to solar adoption such as long-term contracting requirements, nontransferable solar subscriptions, low credit, and seasonal income fluctuations.

SHARING THE SUN: COMMUNITY SOLAR COST, DESIGN, AND DEPLOYMENT – $579,669 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jenny Heeter

This project collects and analyzes data on existing community solar programs, benchmarks community solar costs compared to other solar options, and identifies pathways for new community solar program designs, such as community solar paired with storage. Working with experts in the solar industry, academia, and other relevant entities, the project team is developing a streamlined data-reporting process that could help to lower the cost of community solar projects, as well as next-generation community solar programs that can provide enhanced grid reliability.

UNLOCKING WIDESPREAD SOLAR ADOPTION: UNDERSTANDING PREFERENCES OF LOW- TO MODERATE-INCOME HOUSEHOLDS TO CREATE SCALABLE, SUSTAINABLE MODELS – $1,350,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Benjamin Sigrin

This project focuses on identifying novel, data-driven, and evidence-based strategies that could dramatically scale up solar adoption rates in low- and moderate-income communities. The goal is to develop pathways for reaching parity in solar penetration rates across socioeconomic groups. This project serves a core need for developing objective tools and datasets for policymakers and identifying the barriers that have previously limited deployment. The primary focus of this project is to rate the technical solar potential of buildings in low- and moderate-income communities across the country, develop predictive models to understand previous deployment, and then work with a national nonprofit solar installation group to determine how communication about solar energy usage occurs within these communities.

COOPERATIVES ACHIEVING RURAL EQUITY IN SOLAR – $1,000,000 ♦

National Rural Electric Cooperative Association | Arlington, VA | Principal Investigator: Deb Roepke

This project provides models, best practices, and other materials for cooperative utilities, solar developers, and community and regional financial institutions to expand solar affordability in low- to moderate-income communities. The team is investigating solutions that will streamline customer access to solar, enable small-scale solar projects to more easily obtain the economic benefits available to larger-scale projects, and use financial mechanisms that leverage opportunity zone benefits, among other challenges. The project incorporates participation from rural electric cooperatives, community and regional financial institutions, nonprofits, foundations, solar developers, economic development agencies, and current and potential customers.

COMMUNITY SOLAR FOR THE SOUTHEAST – $1,000,000 ♦

North Carolina Clean Energy Technology Center | Raleigh, NC | Principal Investigator: David Sarkisian

This project makes solar more affordable and accessible through shared solar projects developed by cooperative and municipal utilities across the Southeast. The North Carolina Clean Energy Technology Center leads a stakeholder process with rural cooperative and municipal electric utilities, which can influence many states within the Southeast region. The project is expected to result in a dramatic increase of shared and community solar projects in the region.

DATA-DRIVEN UNDERSTANDING OF LOW-TO MODERATE-INCOME CUSTOMERS' ADOPTION AND FINANCIAL QUALIFICATION IN COMMUNITY SOLAR – $816,092 ♠

Solstice Initiative | Cambridge, MA | Principal Investigator: Stephanie Speirs

This project gathers customer data to assess the assumption that metrics other than a traditional FICO score can and should be used to qualify customers for community solar. Using customer data on income, FICO score, and utility, rent, and cell phone repayment history, the project tests whether new qualifying metrics open up the community solar market to additional households. This new model is then tested by enrolling customers in community solar and comparing actual payment. This project identifies and tests better ways to finance and perform due diligence on solar purchases for nontraditional adopters.

PRODUCT INNOVATION TO INCREASE LOW- TO MODERATE-INCOME CUSTOMERS' ADOPTION OF COMMUNITY SOLAR PHOTOVOLTAICS – $1,235,634 ♦

Solstice Initiative | Cambridge, MA | Principal Investigator: Stephanie Speirs

Approximately 77 percent of U.S. households cannot access rooftop solar and 40 percent of homes earning less than $40,000 per year only make up less than five percent of U.S. solar installations. Low- and moderate-income households are often excluded from community solar because of information asymmetries, prohibitively high credit score requirements, and restrictive contract terms. This project aims to expand photovoltaic solar access to households by evaluating the use of an alternate credit score, previously developed by Solstice Initiative, and performing tests to understand the most suitable contract terms for different low- and moderate-income customer segments. The project explores ways to deploy alternative capital in partnership with foundations, community development financial institutions, and others to produce and pilot a suite of community and shared solar contracts that can meet the needs of low- and moderate-income households. The team will then perform rigorous data analysis concerning the factors that affect the financial viability of low- and moderate-income-inclusive projects. This will help to expand the solar market, lower customer acquisition costs, and increase solar affordability.

ADVANCING SOLAR INNOVATION FOR LOW- AND MODERATE-INCOME HOUSEHOLDS – $733,104 ♠

University of Georgia | Athens, GA | Principal Investigator: Jacqueline Hettel Tidwell

This project identifies key socioeconomic factors and social values that enable and constrain solar adoption in low- and moderate-income communities. The team is developing an accessible and easy-to-understand database of social drivers for solar adoption and non-adoption in low- and moderate-income communities. By closely studying the areas that represent a large portion of the state's population, this project provides insights regarding low- and moderate-income adoption patterns that will not be observed in larger-scale national studies.

DEVELOPING SHARED CAPITALIZATION PLATFORMS FOR LOW-INCOME SOLAR FINANCE – $1,200,000 ♦

University of New Hampshire | Durham, NH | Principal Investigator: Eric Hangen

This project team works with community finance institutions to create training programs and shared capitalization platforms that enable credit unions, community banks, and community development financial institutions to expand their engagement in solar finance in low-income communities. Completion of these web-based trainings on the tools and techniques of solar finance will yield a certificate from the University of New Hampshire. The team strives to have at least 300 staff at community finance institutions participate in the trainings during the project period.

KNOWLEDGE SPILLOVERS AND COST REDUCTIONS IN SOLAR SOFT COSTS – $1,250,000 ♠

University of Texas at Austin | Austin, TX | Principal Investigator: Varun Rai

This project studies the size and mechanism of knowledge spillovers in the solar industry, specifically how best practices related to solar soft cost issues are transferred. These best practices include installation processes, permitting processes, customer acquisition, and overhead costs. The project examines how important knowledge spillovers are, what types of knowledge are most likely to spill over, and how policies can be designed to address them.

COUPLED SOCIAL AND INFRASTRUCTURE APPROACHES FOR ENHANCING SOLAR ENERGY ADOPTION – $1,225,960 ♠

University of Virginia | Charlottesville, VA | Principal Investigator: Achla Marathe

This project identifies social and behavioral factors that influence the adoption of solar in rural areas and incorporates that information into diffusion models using agent-based modeling technology and synthetic information systems. These diffusion models will integrate social, behavioral, financial, and demographic data. The project's primary data collection area is in the state of Virginia, but the results are anticipated to inform rural communities throughout the country.

USING BEHAVIORAL SCIENCE TO TARGET LOW- AND MODERATE-INCOME AND HIGH-VALUE SOLAR INSTALLATIONS – $1,350,000 ♠

Yale University | New Haven, CT | Principal Investigator: Kenneth Gillingham

This project is testing new messaging, financing, and shared solar approaches for enhancing the diffusion of solar energy in low- and moderate-income populations. The project also quantifies the benefits to the electricity grid from programs that expedite and increase deployment of solar energy in areas where solar provides additional value to the grid. In addition, pilot projects within three states test the models developed under this work in the field with the intent to use lessons learned from messaging studies to encourage more populations to go solar, particularly in areas of high grid congestion.

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 a half of the Soft Costs track and slightly over a half of the track's budget.

DEVELOPING A DEEP LEARNING-COMPUTER VISION FRAMEWORK TO MONITOR AVIAN INTERACTIONS WITH SOLAR ENERGY FACILITY INFRASTRUCTURE – $1,300,000 ♦

Argonne National Laboratory | Lemont, IL | Principal Investigator: Yuki Hamada

This project uses deep learning and networks of high-definition cameras for automated detection of avian-solar interaction, specifically fly-through, perching, and collisions. The team is training the deep learning models using data from video of birds and deploy the trained models at solar facilities to validate their performance. This project could improve the efficiency and effectiveness of detecting avian collisions around solar facilities, inform mitigation strategies, and reduce monitoring costs.

UNMANNED AIRCRAFT SYSTEMS AND LIGHT DETECTION AND RANGING/CAMERA TECHNOLOGIES TO DETECT AVIAN EVENTS AND OTHER ENVIRONMENTAL MEASURES AT UTILITY-SCALE POWER PLANTS – $1,400,000 ♦

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Christian Newman

This project develops machine-learning models for monitoring birds at solar facilities using two complementary remote sensing technologies: drones and three-dimensional imaging. The drones are used to detect bird carcasses and nests while simultaneously performing other site inspection tasks, and the 3-D imaging is used to detect avian collisions. The team is developing and testing both technologies in the field to compare them and validate their effectiveness and cost.

APPLICATION OF MANUFACTURING QUALITY MANAGEMENT PRINCIPLES TO PHOTOVOLTAIC SYSTEM INSTALLATIONS – $1,489,675 ♦

Institute for Building Technology and Safety | Ashburn, VA | Principal Investigator: Rudolph Saporite

This project develops an independent quality management system for photovoltaic installations that is low-cost and accessible to local and regional photovoltaic installers. Third-party inspections for systems can be costly and inconsistent across the industry. This team is working to standardize quality control processes, enable remote review of photovoltaic systems through photos and documents, and implement an industry-recognized quality scoring system for participating installers. The team is working with a broad group of industry stakeholders to define and test the software's functionality. Through use of the product, installers will increase the quality of their projects, which will in turn increase the overall value of photovoltaic systems across their lifetimes and improve investor confidence in the solar asset class over time.

SOLAR AT SCALE: IMPROVING THE LOCAL RULES OF THE GAME FOR LARGE SCALE SOLAR – $1,000,000♦

International City/County Management Association | Washington, DC | Principal Investigator: Scott Annis

This project team brings together public- and private-sector stakeholders to identify best practices for local governments, special districts, and other authorities that have jurisdiction to install large-scale solar projects. They are developing tools and resources for procedures, analysis, and communications related to permitting, zoning, regulations, and planning for these installations, especially on public and municipal lands, brownfields, and in rural areas. The team will disseminate this information through workshops, trainings, and other programming.

DEFINING SAFE AND EFFICIENT INTERCONNECTION POLICIES FOR ENERGY STORAGE AND SOLAR PLUS STORAGE TO IMPROVE INTEGRATION AND REDUCE COSTS – $1,300,000 ♦

Interstate Renewable Energy Council | Latham, NY | Principal Investigator: Sara Baldwin

This project identifies and addresses interconnection barriers to solar and energy storage by developing best practices and technical solutions. The team is creating a tool kit to inform the development and updating of state standards and utility tariffs and will use it to educate and train regulators and utilities in at least 35 states. This project helps states and utilities reduce the costs and time it takes to process applications and interconnect energy storage and solar-plus-storage systems safely, while maintaining grid reliability.

DEVELOP CONSENSUS RECOMMENDATIONS TO ADDRESS CHALLENGES WITH SOLAR AND SOLAR PLUS STORAGE CODE ENFORCEMENT AND PERMITTING APPROVALS – $1,500,000 ♦

Interstate Renewable Energy Council | Latham, NY | Principal Investigator: Larry Sherwood

This project addresses challenges to efficient permitting approvals by focusing on filling knowledge gaps. The team surveys stakeholders to learn what complicates code enforcement and creates a regular web conference call forum for interested stakeholders to discuss issues. This project team will develop consensus recommendations that advance adoption of data-driven permitting and inspection best practices, ultimately leading to growth in new markets and cutting red tape for safe solar and solar-plus-storage projects.

INTEROPERABLE ENERGY INFORMATION DATABASE FOR REAL ESTATE – $450,000 ♠

Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Ben Hoen

Solar is growing rapidly, but data about the accurate valuation of homes with photovoltaic solar is lacking, as is information-sharing between solar data sources and real estate multiple listing services. Building on past work, this project combines previous ad hoc efforts to auto-populate photovoltaic data in multiple listing service databases. This database holds energy-efficiency data and software infrastructure from the Home Energy Labeling Information Exchange repository, and this project would result in a solar-data-enhanced version of the HELIX package. Guided by an industry advisory team, the team will partner with the HELIX project leader and software developers to enable HELIX to accept solar data and disseminate information about it.

SOLAR PHOTOVOLTAICS AND REAL ESTATE: HARNESSING BIG DATA TO DRIVE DEMAND, INCREASE TRANSPARENCY, AND LOWER BALANCE OF SYSTEM COSTS – $1,771,229 ♠

Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Ben Hoen

This project analyzes the extent to which photovoltaics can add value to real estate properties. Past analyses have shown that solar adds value to host-owned residential properties, but there is a lack of information for residential properties with third-party owned systems and commercial properties. This project analyzes the impact of these systems on home values and other factors, which allows for increased growth of the solar market by providing real estate professionals and potential adopters with accurate valuations.

GRID MODERNIZATION LAB CONSORTIUM: FUTURE ELECTRIC UTILITY REGULATION – $930,000 ♠

Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory | Principal Investigator: Andy Satchwell

This project provides decision-makers with access to high-quality and impartial analyses, case studies, and decision-support tools to enlist utilities and customers as partners in grid modernization and consider alternative regulatory approaches.

THE ENERGIZER BUNNY: DUAL-USE PHOTOVOLTAIC AND PASTURE-RAISED RABBIT FARMS – $200,000 ♦

Michigan Technological University | Houghton, MI | Principal Investigator: Joshua Pearce

This project evaluates the technical, economic, environmental, and social feasibility of raising rabbits on land with a photovoltaic solar energy system. Solar installations provide shade and protection from aerial predators, which may lead to increased reproduction and higher profits. The team aims to produce a free, publicly accessible, comprehensive manual that includes data about solar with rabbit farms and their effects on economics, market size, and operations.

MINNESOTA SOLAR PATHWAYS: ILLUMINATING PATHWAYS TO 10 PERCENT SOLAR – $1,999,964 ♦

Minnesota Department of Commerce | St. Paul, MN | Principal Investigator: Michelle Gransee

This project uses a scenario-based tool to examine the potential for key technologies and management approaches—such as demand management strategies, storage, and synergy with wind—to overcome grid integration challenges with increased solar penetration. This project identifies barriers to deployment while laying a technical foundation to understand how much solar capacity potential exists across Minnesota. In addition, it tackles grid management approaches to overcoming solar integration challenges.

ENABLING SOLAR CYBERSECURITY SOLUTIONS THROUGH STATE ENERGY OFFICE AND PUBLIC UTILITY COMMISSION ENGAGEMENT WITH PRIVATE SECTOR PARTNERS – $500,000 ♦

National Association of State Energy Officials | Arlington, VA | Principal Investigator: Sandy Fazeli

This project team, which includes the National Association of Regulatory Utility Commissioners, is creating a solar cybersecurity working group to improve the ability to respond to cybersecurity threats related to solar energy and other distributed energy resources. The group includes state energy officials, public utility commissioners, solar industry stakeholders, cybersecurity experts, utility representatives, and others. The project team is working to develop an online cybersecurity tool kit to help solar industry decision-makers, regulators, utilities, and state and local governments pursue policies, plans, and partnerships for cyber-secure solar infrastructure in their jurisdictions.

ADDRESSING REGULATORY BARRIERS TO TRIBAL ADOPTION OF SOLAR PHOTOVOLTAICS – $1,400,000 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Sherry Stout

This project works with Native American tribes to help address nationwide interconnection challenges and other barriers to solar photovoltaic and solar-plus-storage systems on tribal lands. The team plans to discuss the challenges with stakeholders and then conduct analysis and workshops to design regulatory solutions and find opportunities for solar energy on tribal lands. The team aims to provide technical assistance to identify ways for tribes to develop favorable contract terms and conditions, and create a guidebook with a list of options for Native American tribes across the country.

ANALYSIS OF MUNICIPAL FRANCHISE AGREEMENTS IN CITIES THAT HAVE INCORPORATED ENERGYOBJECTIVES – $150,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jeff Cook

Municipalities can use franchise agreements to let public utilities run electricity distribution lines in public rights-of-way, like transportation routes. Solar energy can be incorporated into these agreements, but it is unclear how many municipalities have done so and what the outcomes were. This project assesses historical franchise agreements between public utilities and municipalities within their service territories, as well as ways in which municipalities have successfully integrated their energy goals.

DATA ANALYTICS FOR RESIDENTIAL PHOTOVOLTAICS FROM PERMIT TO INTERCONNECT – $500,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jeff Cook

This project aims to provide novel insights into the effects of personally identifiable information processes on photovoltaic system installations, in particular the relationship between these processes, timelines, and customer cancellations. The team plans to use these analyses to clarify the potential effect of certain process changes on reducing personally identifiable information timelines, customer cancellation rates, and related costs nationwide.

IMPROVING SOLAR AND SOLAR PLUS STORAGE SCREENING TECHNIQUES TO REDUCE UTILITY INTERCONNECTION TIME AND COSTS – $1,000,000 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Julieta Giraldez

The laboratory team is developing a new method for mapping secondary low-voltage circuits, which aims to help utilities speed up their interconnection processes for approving solar connections onto the grid. These tools should enable grid operators to improve resilience and assess their capacity for new interconnections more rapidly. The team is also forming an advisory board to engage with stakeholders throughout the project and disseminate the findings nationwide.

INSPIRE 2.0: FACILITATING LOW-IMPACT SOLAR DEVELOPMENT THROUGH DATA AND ANALYSIS FOR ENVIRONMENTAL RESILIENCY AND COMPATIBILITY – $1,889,928 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jordan Macknick

This project conducts field-based research to address data gaps relative to expanding solar in agricultural areas. Specifically, there is a lack of data about how solar projects on agricultural land affect revenues, which solar configurations best meet agricultural needs, and how solar and agriculture co-location results differ regionally. In addition, the project is conducting three analysis and modeling studies to augment field research, including an analysis of land-management practices at existing solar facilities, an economic assessment of low-impact operations and maintenance practices at solar facilities, and a quantification of ecological services, such as pollinator services and erosion control, provided by solar-agriculture co-location. The team will develop a Wiki-style data portal with user-input capabilities for co-location research data.

PHOTOVOLTAIC STORM WATER MANAGEMENT RESEARCH AND TESTING – $800,000 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Megan Day

This project is working to identify the co-benefits of solar facilities, specifically regarding storm water management and water quality. The team is conducting field research on storm water infiltration and runoff at solar installation sites; validating a model to understand, predict, and manage water resources; identifying best practices for storm water management; and engaging with local jurisdictions. This project will reduce soft costs and break down regulatory barriers to solar projects.

SOLARAPP – $695,000 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jeff Cook

This project builds on the lab's existing software capabilities to commercialize the Solar Automated Permit Processing software platform known as SolarAPP. This tool provides installers with a standard portal for entering permit information for residential solar systems across all authorities having jurisdiction who adopt this tool, providing a streamlined form, transparency into permitting timelines, and required specifications. Authorities having jurisdiction will then be able to approve those permits without overburdening personnel, with confidence that the permitted systems meet code requirements.

SOLAR ENERGY INNOVATION NETWORK – $10,000,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Eric Lockhart

This project brings together teams of stakeholders from across the United States—including utilities, state and local governments, nonprofits, innovative companies, and electric system operators. With the support of technical experts from national laboratories and other research institutions, these teams work to implement innovative applications of solar and distributed energy resources in their unique locations and contexts. The solutions developed by the teams are demonstrated and validated in real-world contexts, making them ready for replication and scale.

FLORIDA ALLIANCE FOR ACCELERATING SOLAR AND STORAGE TECHNOLOGY READINESS – $1,750,000 ♠

Nhu Energy | Tallahassee, FL | Principal Investigator: Rick Meeker

This project conducts analysis and planning activities in Florida to increase solar deployment and maximize the benefits of solar, including combining solar with other distributed energy resources like energy storage and demand response. This project lays the foundation to enable Florida municipal and cooperative utilities to reach 10 percent of solar in their electricity capacity in less than 10 years.

GRID MODERNIZATION LAB CONSORTIUM: TECHNICAL ASSISTANCE FOR PUBLIC UTILITY COMMISSIONS – $1,802,500 ♠

Pacific Northwest National Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, National Renewable Energy Laboratory, Argonne National Laboratory | Principal Investigator: Peter Cappers

The project team aims to deliver in-depth technical assistance to 10-20 state public utility commissions for one to two year durations on any topic that can meaningfully and substantively support their grid modernization or energy infrastructure initiatives using a proactive-annual solicitation process.

SOLAR POWERING AMERICA BY RECOGNIZING COMMUNITIES SOLSMART DESIGNATION PROGRAM – $3,398,450 ♦

The International City/County Management Association | Washington, DC | Principal Investigator: Scott Annis

This project creates a national program to recognize local governments across the country for their efforts to build stronger local solar markets. With guidance from a panel of industry experts, the project team has crafted a fresh and accessible designation program signaling that participating communities are prepared to build local workforces and economies through solar market growth. To spur innovation and friendly competition among communities, the team provides annual awards for achievements in various categories. The awards and other competitions will celebrate communities and other stakeholders that break new ground and make remarkable progress.

SPARC SOLSMART TECHNICAL ASSISTANCE – $11,599,996 ♦

The Solar Foundation | Washington, DC | Principal Investigator: Theresa Perry

This project provides technical assistance support to communities pursuing SolSmart designation, enabling more than 300 communities and counting across the U.S. to qualify via a three-pronged approach to delivering technical assistance: one-on-one technical assistance delivery to communities from a team of experienced national experts; the use of SolSmart Corps Fellows to help select communities identify and reduce soft cost barriers; and peer mentorship and learning.

BUILDING A FRAMEWORK TO GENETICALLY CHARACTERIZE “FEATHER SPOTS” AND UNDERSTAND DEMOGRAPHIC IMPACTS OF SOLAR ENERGY SITES ON MIGRATORY BIRD POPULATIONS – $1,600,000 ♠

University of California, Los Angeles | Los Angeles, CA | Principal Investigator: Ryan Harrigan

This project plans to improve data on bird mortality at solar facilities by applying new genetic-based methodologies to characterize feathers recovered from solar energy facilities by species, population of origin, and individual. The resulting data will be used to develop models to evaluate the risk of solar energy facilities to specific bird populations. The results of this project can be used to develop cost-effective bird monitoring and mitigation strategies at solar facilities.

QUANTIFYING AND VALUING FUNDAMENTAL CHARACTERISTICS AND BENEFITS OF FLOATING PHOTOVOLTAIC SYSTEMS – $850,000 ♠

University of Central Florida | Orlando, FL | Principal Investigator: John Sherwin

This project undertakes a systematic and comprehensive collection of floating photovoltaic-related techno-ecological data at four sites in Florida, Colorado, and California. The data will be used to examine floating photovoltaic performance, assess potential environmental risks and benefits, and provide data that can aid in the development of research protocols to more fully understand the impacts of floating photovoltaics.

SOLAR PLUS STRATEGIES FOR OREGON AND WASHINGTON – $2,050,000 ♦

Washington Department of Commerce | Olympia, WA | Principal Investigator: Linda Irvine

This project manages a regional effort to plan and implement state strategies in Oregon and Washington to achieve the full technical, social, and economic benefits of solar. With state-level plans that leverage the added social and economic benefits of solar, the project works to accelerate market growth in the Pacific Northwest and triple solar capacity over three years, reduce installed costs for rooftop solar by almost half, and add 5,000 solar jobs, which would double the solar-related employment in the region. This will be done, in large part, through community solar projects.

ENHANCED DISTRIBUTED SOLAR PHOTOVOLTAIC DEPLOYMENT VIA BARRIER MITIGATION OR REMOVAL IN THE WESTERN INTERCONNECTION – $2,020,000 ♠

Western Interstate Energy Board | Denver, CO | Principal Investigator: Maury Galbraith

This project with the Western Interstate Energy Board, an organization of 11 western states that provides the instruments and framework for cooperative state efforts on energy, focuses on removing or reducing the impact of barriers to distributed solar photovoltaic deployment in the Western Interconnection. If successful, the project will result in greater deployment of distributed solar photovoltaics in the Western Interconnection than is currently predicted.

ADDRESSING REGULATORY BURDENS TO ACCESSING SOLAR AMONG MUNICIPAL, COMMERCIAL AND INSTITUTIONAL CUSTOMERS – $600,000 ♦

World Resources Institute | Washington, DC | Principal Investigator: Lori Bird

This project helps cities and towns evaluate opportunities for solar energy by training them to effectively engage in the wholesale market and utility planning processes. The team is developing educational materials for stakeholders on how wholesale markets and utility planning and accounting affect solar energy procurement, as well as convene stakeholders to potential solutions. This work aims to foster collaborative partnerships and enable stakeholders to share findings to break down regulatory or institutional barriers more rapidly.

Solar Workforce

Solar jobs have risen rapidly in the last 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.

MULTI-SECTOR SOLAR CAREER TRAINING INITIATIVE FOR NATIVE AMERICANS AND VETERANS – $599,999 ♦

Blue Lake Rancheria | Blue Lake, CA | Principal Investigator: Stephen Kullmann

This project provides integrated solar-career training for Native Americans, veterans, and Native American veterans. Blue Lake Rancheria offers workshops, training, and hands-on learning experiences for a variety of solar-related skill sets. The training emphasizes cross-sector skill building as well as the needs and experiences of veterans and Native Americans. Trainings are tailored to areas of likely growth in the solar industry as well as the skills of the program participants.

GRID-READY ENERGY ANALYTICS TRAINING WITH DATA – $6,532,977 ♦

Electric Power Research Institute | Knoxville, TN | Principal Investigator: Thomas Reddoch

This initiative enhances workforce readiness in the electric utility industry by focusing on the intersection of power systems and digital systems. The project is working to develop and deliver open-source professional training and university course content in data science, cybersecurity, integration of solar photovoltaic and other distributed energy resources, and information and communication technology for power systems workers in transmission and distribution. Through collaboration with utility and university partners, this project will result in certifications, credentials, qualifications, and standards for the training and education needed in the electric utility workplace to help transform the grid of the future.

EXPANDING THE SOLAR WORKFORCE THROUGH THE ILLINOIS COMMUNITY COLLEGE SYSTEM – $1,250,000 ♦

Lewis and Clark Community College | Godfrey, IL | Principal Investigator: Katie Davis

This project expands the solar workforce through a statewide program that strengthens the connections between education and training providers, job seekers, industry, and local communities. The team is building upon current solar-related courses and programs available at Illinois community colleges and making improvements through credentialing, instructional design, and new industry partnerships to better align with employer needs. The program also ensures that licensure is embedded within the program and leverage all potential talent pools, including veterans.

SOLAR READY WISCONSIN – $800,000 ♦

Midwest Renewable Energy Association | Custer, WI | Principal Investigator: Nick Hylla

This project supports the development of a statewide network of industry stakeholders, training providers, and nonprofit organizations working to develop solar workforce capacity in Wisconsin and the surrounding region. In collaboration with a network of local community colleges, the team is creating a program called the Wisconsin Solar Corps to provide job training and facilitate job placement for qualified candidates in the solar industry. The goal is to make Solar Ready Wisconsin a replicable program that has the potential to be used across the Midwest.

COLLEGIATE SOLAR INNOVATION CHALLENGE: SOLAR DISTRICT CUP – $1,550,000 ♦

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joe Simon

The Solar District Cup is a multidisciplinary collegiate competition that challenges student teams to design and model distributed solar energy systems for multiple buildings on a local electrical distribution network. These systems integrate solar, storage, and other distributed technologies and capabilities across mixed-use districts, or groups of buildings served by a common electrical distribution feeder, such as a campus, a development, or an urban area. The competition engages students across the engineering, urban planning, finance, and business disciplines to re-imagine how energy is generated, managed, and used in a district.

HANDS-ON PHOTOVOLTAIC EXPERIENCE CORE CAPABILITY – $225,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Adele Tamboli

This program, also known as HOPE, is a one-week summer school program held at the National Renewable Energy Laboratory each year to train graduate student researchers in photovoltaic fundamentals, as well as specific cell technologies and techniques in measurement and characterization. The program brings in students from across the United States and their faculty advisors for an in-depth, intensive program that includes hands-on lab experiences in solar cell fabrication and testing. This program aims to train future photovoltaic researchers and increase collaboration among the students, faculty, and staff at the lab. HOPE is a selective program with a competitive application process and is limited to approximately 12-15 students each year.

STAKEHOLDER TRAINING FOR IEEE 1547-2018 – $750,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: David Narang

The revised IEEE 1547 standard for interconnection and interoperability of distributed energy resources at the distribution level was published in April 2018. The updated standard is significantly different, with new concepts and new technical requirements, and requires educational material on the application of these changes. The National Renewable Energy Laboratory had a principal role in accelerating the revision process though its chairmanship of the IEEE 1547 working group to revise the standard and through technical support provided to the working group. Under this project, the team is compiling and developing education materials for IEEE 1547-2018 and make them publicly available. This includes the formation of a Technical Education Committee of stakeholders; the development of a series of educational modules; the publishing of educational materials online; the development of a guide for adoption of IEEE 1547-2018 to aid state regulators; and providing technical assistance to stakeholders. Coordination of education and dissemination with other entities will be completed to avoid duplication of efforts.

FELLOWSHIPS AND RESEARCH OPPORTUNITIES ♦

Oak Ridge Institute for Science and Education | Oak Ridge, TN | Principal Investigator: Rachel Hill

SETO sponsors multiple fellowship and research opportunities for recent graduates and mid-career experts. The Solar Energy Innovators Program enables selected applicants to conduct practical research on-site at a host institution (electric utility, electric public utility commission, or energy service provider). Postdoctoral Awards support the next generation of scientific leaders in energy efficiency and renewable energy. And, the Science and Technology Policy Opportunity supports fellows working within SETO.

BRIGHT SOLAR FUTURES – $1,250,000 ♦

Philadelphia Energy Authority | Philadelphia, PA | Principal Investigator: Laura Rigell

This project expands existing efforts in Philadelphia to develop a new, replicable workforce training program for the region's growing solar industry. The curriculum includes solar installation, construction safety, an introduction to solar sales and design, and other job-readiness programs. Successful program graduates will be placed in internships with local employers and get ongoing support from the program to increase the likelihood of job retention.

SAFER'S SOLAR ENERGY DEMAND SKILLS TRAINING PROGRAM – $800,000 ♦

Safer Foundation | Chicago, IL | Principal Investigator: Marketer Ash

The Safer Foundation, which focuses on workforce development and programming for people in the criminal justice system, is advancing its Solar Energy Demand Skills Training program to fill the growing workforce needs of the solar industry. The Safer Foundation and its partners across the state of Illinois are providing participants with a comprehensive program based on interests and aptitudes. Experienced solar industry trainers, employers, and supervisors will combine classroom training, hands-on experience in the lab, and real-world installations to enable participants to better understand the sales, design, and installation fields.

CYBERGUARDIANS AND STEM WARRIORS – $1,250,000 ♦

SunSpec Alliance | San Jose, CA | Principal Investigator: Tom Tansy

Veterans with information technology skills and the ability to use advanced digital tools can lead efforts to modernize the electricity grid and improve the integration of distributed energy resources. This project supports veterans with cybersecurity and information technology training to further develop these skills through new online training modules, accredited curricula, and hybrid training programs in distributed energy resource system designs, grid operations, data analytics, cyber security, and investment decision support. The program recruits veterans and transitioning military personnel from military bases and through existing veterans programs and facilitate job placement with utilities, grid operators, and other companies in the distributed energy resource industry. This helps to increase the pool of veterans to help fill positions critical to the security of the U.S. electrical grid.

NATIONAL SOLAR JOBS ACCELERATOR – $2,000,000 ♦

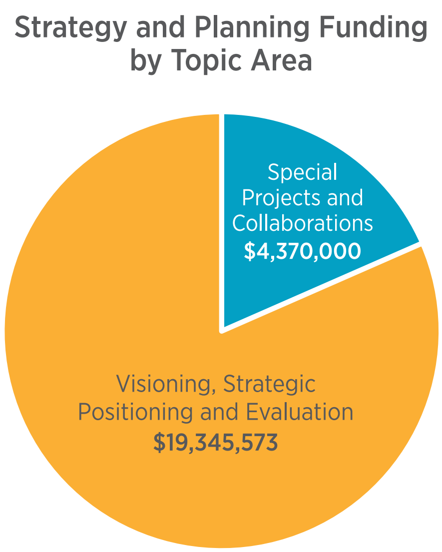
The Solar Foundation | Washington, DC | Principal Investigator: Richard Lawrence

Building off of the Solar Ready Vets pilot program, the National Solar Jobs Accelerator program works to increase the pipeline of transitioning service members and veterans into the U.S. solar industry via two complementary efforts. The team offers a work-based learning "fellowship" model for transitioning service members and a matchmaking system that will channel veterans into appropriate training or employment opportunities. The Accelerator also undertakes high-impact capacity-building activities that enhance and streamline veterans' options for pursuing solar training and employment opportunities and incent employers' participation over the long-term.

Strategy and Planning

The Strategy and Planning track will both review individual projects that are selected for their potential to impact SETO's strategic direction while also taking a broader look at SETO as a whole. The 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. The broader portfolio-level review will consider the office's near- and long-term strategy, technology targets, and organizational effectiveness, while sampling the office's portfolio of nearly 400 projects.

There are 15 projects in the Strategy and Planning track out of 391 total projects in the SETO portfolio, totaling about $24,000,000 in federal funding, or three percent of the overall portfolio. The projects in this track are a small subset of the projects managed by the Manufacturing and Competitiveness team and the Strategic Analysis and Institutional Support team. Most of the projects managed by those teams are reviewed as part of the other four tracks. This track will look at 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.



The Strategy and Planning projects are organized into two topics: Visioning, Strategic Positioning, and Evaluation; and Special Projects and Collaborations. Projects are alphabetized by the awardee name and represented in the following format:

Project Title – Funding Program, Amount Awarded
Awardee Name | Awardee Location | Principal Investigator
Project Description

Projects managed by the Strategic Analysis and Institutional Support team are identified with a red spade (♠) after the project name and amount.

Visioning, Strategic Positioning, and Evaluation

Projects in this topic collect, analyze, and disseminate big picture data across multiple solar energy technologies. This work informs SETO's R&D direction, allows for researchers to better understand the potential impact of their approaches, and provides high-level information to a variety of stakeholders working with solar energy. Half of the projects in the Strategy and Planning track are in this topic, representing approximately 80 percent of the track's budget.

ALIGNING UTILITY AND SOLAR INTERESTS: UTILITY REGULATION AND PLANNING FOR A SUNSHOT FUTURE – $1,450,000 ♠

Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Galen Barbose

This project assesses emerging and innovative options for aligning high solar deployment with utility shareholder and ratepayer interests. The team is evaluating the potential for bankable demand charge savings and identifying best practices for incorporating solar into resource planning studies. Through this combination of targeted analyses and stakeholder engagement, the project empowers key decision-makers to alleviate market barriers in order to increase deployment and lower business risks and market inefficiencies that inflate soft costs.

SOLAR MARKET DATA TRACKING AND ANALYSIS – $4,000,000 ♠

Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Ryan Wiser

This project expands the availability of high-quality data and information on solar energy through extensive data collection, curation of shared databases, and timely analysis. The team is tracking and analyzing solar technology, cost, performance, access, and market trends through foundational annual reports, publicly available data sets, and objective new analyses. Covering utility-scale and distributed solar, this work supports the Department of Energy and the energy industry more broadly by harnessing big data to track progress toward DOE goals. It also facilitates market transparency, affordability, and consumer choice and protection by reducing information barriers.

SOLAR-TO-GRID (S2G): ANALYTIC SUPPORT TO INFORM RELIABILITY, MARKET VALUE, AND AFFORDABILITY – $825,000 ♠

Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Andrew Mills

Along with the cost of a photovoltaic solar system, the competitiveness of solar energy depends on its market value and how solar interacts with other technologies in electricity markets. This project aims to better understand the location-specific market value of solar, the contribution of solar to grid reliability, and the impact of solar on the power system. The project team combines historical production and performance data from solar energy systems across the United States with electricity market data to identify trends in the historical value of solar and its contribution to grid reliability. To assess the impact of solar on the power system, the team relies on market data to observe trends in wholesale prices and the resulting incentives to invest in flexible resources, like combined-cycle gas turbines and storage. The geographically specific results will be communicated through three annual reports, each building on and updating data from the previous year, to help inform stakeholders on planning, procurement, market design, and grid operations.

CONCENTRATING SOLAR-THERMAL POWER ANALYSIS – $2,249,627

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Chad Augustine

This project addresses upgrades to the System Advisor Model (SAM) related to concentrating solar-thermal power, including the development of new modules within SAM to expand the types of CSP systems that can be simulated and new tools for evaluating CSP subsystem performance or optimizing CSP system layouts; for example, SolarPILOT and SolTrace. The project evaluates the potential cost and performance of new CSP-relevant technologies and generally includes assessment of CSP technologies.

DISTRIBUTION GRID INTEGRATION COSTS – $2,790,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kelsey Horowitz

This project, which is a subtask of Solar Technology Cost Modeling and Competitiveness Analysis, provides bottom-up analysis on the distribution system costs associated with integrating distributed photovoltaic technologies while maintaining reliability and power quality. These costs are analyzed as a function of penetration level, and for a variety of circuit types, locations, and integration strategies. This work informs the range and order-of-magnitude that may be expected for distribution grid integration costs at different photovoltaic penetration levels, as well as the primary drivers of integration costs and pathways to reduced integration costs.

RESILIENT PLANNING FOR DISTRIBUTED PHOTOVOLTAICS – $1,500,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Benjamin Sigrin

This project seeks to help grid planners better predict where distributed energy resources like rooftop solar and battery storage will be installed. The team is working with academic partners and all seven of the U.S. Independent System Operators and Regional Transmission Organizations to open-source its Distributed Generation Market Demand tool. The tool, a theory-driven model, is being upgraded with machine learning to make it a data-driven model. Improvements to the tool will provide simulated electricity usage patterns with better resolution, resulting in at least 10 percent greater predictive accuracy compared to historic data on distributed photovoltaic adoption. The tool will be used to predict customer adoption of new technologies, giving grid operators better insights on where more distributed energy resources will be located, helping to improve planning and operation for a more resilient and reliable grid.

STRATEGIC AND PROGRAMMATIC ANALYSIS TO SUPPORT THE DEPARTMENT OF ENERGY – $2,400,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis

This project provides core support to the Solar Energy Technologies Office through a bottom-up analysis of solar costs. Using inputs and validation from both industry sources and academic papers, the team estimates the current state of solar technologies and system costs, as well as future industry progress toward the cost targets, set by the Solar Energy Technologies Office.

TECHNO-ECONOMIC ANALYSIS OF SOLAR ENERGY TECHNOLOGIES – $3,600,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis

This project directly supports leadership in the Solar Energy Technologies Office with versatile, on-call analysis of the technical and economic performance of solar technologies. To grant the core support required to address market feasibility and other issues related to solar, this project may range from providing quick data or model results to longer-term research leading to published papers.

VALUATION AND OPERATIONAL PERFORMANCE OF SOLAR PLUS STORAGE POWER PLANTS – $530,946 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Paul Denholm

As energy storage costs decrease, new opportunities arise to create solar power plants with dispatchable energy, making power available whenever it's needed from both concentrating solar-thermal power and photovoltaic technologies. Understanding the various plant configurations and storage-operation modes can be challenging. For example, photovoltaic and battery developers must consider the relative sizes of module, inverter, and storage power and energy capacities, as well as where in the system to integrate energy storage. This project develops improved methods for evaluating and comparing different solar-plus-storage technologies and configurations to help utilities and system planners develop low-cost, reliable power systems.

Special Projects & Collaborations

In addition to the traditional research project structure in SETO, there are several projects that taken on different approaches. These include stakeholder engagement initiatives and projects that look at high-level analysis related to how solar technologies best integrate with other technologies. This topic includes a sampling of these projects from SETO's portfolio; related projects in other tracks are listed below the projects from this track. Half of the projects in the Strategy and Planning track are in this topic, representing approximately 20 percent of the track's budget.

END-OF-LIFE MANAGEMENT ANALYSIS AND STAKEHOLDER ENGAGEMENT – $150,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Garvin Heath

As the number of photovoltaic installations rises, more modules will age and degrade over time, making it important to learn new ways to safely and properly dispose of photovoltaic modules. This project uses two approaches to investigate current and future state-of-the-art techniques to dispose of modules. First, the team is using lessons learned from abroad by engaging with the environmental health and safety task force of the International Energy Agency's Photovoltaic Power Systems program, where experts are leading a set of projects on photovoltaic module end-of-life management. The team is also analyzing topics relevant to end-of-life management from a U.S. perspective. This analysis helps inform manufacturers and other stakeholders on the value of current recycling requirements for photovoltaic hardware, as well as on the effectiveness of current efforts to design modules and other equipment for ease of reuse along the supply chain.

HIGH PENETRATION PHOTOVOLTAIC SCENARIOS – $450,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Robert Margolis

This project is working to identify challenges and roadblocks to increased deployment of photovoltaics and to find synergies with battery storage that can further support photovoltaic deployment. The analysis focuses on three areas: the potential for photovoltaics and storage to provide grid services during times of extreme weather, the drivers of curtailment under high penetration photovoltaic scenarios with and without storage, and the change in value of a photovoltaics as a grid resource with different storage configurations.

OPEN-ACCESS REEDS MODEL – $300,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Wesley Cole

This project further develops the Regional Energy Deployment System (ReEDS), which simulates electricity sector investment decisions based on system constraints and demands for energy and ancillary services. This model is unique in its high-spatial resolution and advanced algorithms for representing the cost, value, and technical characteristics of integrating renewable energy technologies. Although it covers a broad geographic and technological scope, ReEDS is designed to reflect the regional attributes of energy production and consumption. The model considers a large suite of generating technologies, including fossil, nuclear, and renewable technologies, as well as transmission and storage expansion options.

DEPARTMENT OF ENERGY OPEN ENERGY DATA INITIATIVE – $1,060,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Debbie Brodt-Giles

This project provides the opportunity to change how the energy industry accesses and interacts with data from different energy technologies—including solar, wind, water, and smart grid—by leveraging cloud computing to encourage innovation and build capabilities, solutions, and businesses. The project provides storage repositories with large volumes of widely accessible raw data. The team leverages open data agreements with key cloud-hosting vendors to host free data sets when possible. The team also partners with cloud-computing providers to share DOE data sets with the largest audience yet so potential power users can use them to add value to the solar industry and the energy industry as a whole. This work provides an innovative environment for data access and accelerate analysis capabilities for all consumers of DOE energy data.

VALUING PHOTOVOLTAICS AND ENERGY EFFICIENCY IN BUILDINGS – $1,800,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Monisha Shah

There is a need to explore and evaluate a new framework that considers photovoltaics, distributed energy resources, and energy efficiency co-optimization and/or co-adoption with new or enhanced existing metrics to determine values to grid operators, developers, energy service providers, homeowners, and communities. The project develops and tests a suite of new and existing metrics to quantify the ability for residential buildings with various energy technology bundles to meet a set of objectives and associated value streams of relevance to different actors (e.g. developers, system operators) in the energy system.

TRANSITIONING ORANGE BUTTON: ORANGE BUTTON FOR OPERATIONS & MODELING – $610,000 ♠

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Debbie Brodt-Giles

The Orange Button Initiative is an industry collaborative to establish an open, industry driven solar data exchange system to enable a free flow of data between software products that address the solar asset lifecycle. This project extends the use and functionality of the Orange Button data standards by adding system performance monitoring and modeling components. These additions include data structures and elements for electrical current monitoring; weather data records like irradiance, temperature, and precipitation; module characterization; and performance model parameters. In order to encourage adoption, expand use cases, outline steps for users, and demonstrate value to industry, the team is creating an open-source implementation and building a self-sustaining Orange Button community of practice.

RELATED PROJECT LED BY OTHER DOE OFFICES

In addition to its own portfolio, SETO contributes funding to some projects that are led by other offices within the Department that include a solar energy component. These projects are outlined below with the funding amounts provided by SETO:

HYDROGEN SYSTEMS: DEMONSTRATION OF INTEGRATED HYDROGEN PRODUCTION AND CONSUMPTION FOR IMPROVED UTILITY OPERATIONS (FUEL CELL TECHNOLOGIES OFFICE) – $250,000

Giner ELX, Inc. | Newton, MA | Principal Investigator: Monjid Hamdan

This project will develop an integrated hydrogen system including electrolysis for hydrogen (H2) production and storage, electricity generation with stationary fuel cells, and H2-fuel for refueling of fuel-cell-electric-vehicles, with dispatch decisions based on grid-level optimization controls. Project will include feasibility studies and analysis identifying the technical, operational, and safety requirements of the integrated system, analysis of energy efficiencies, and a detailed analysis of the process economics for the proposed technology plan.

BEHIND THE METER STORAGE SCENARIO ANALYSIS (BUILDING TECHNOLOGIES OFFICE AND VEHICLE TECHNOLOGIES OFFICE) – $500,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Tony Burrell

This project is investigating the value of integrated Behind the Meter Storage, for solar, thermal energy storage, electrochemical storage (batteries), flexible loads, energy-efficient systems, and electric vehicle (EV) extreme fast charging. This project will include model development and refinement as well as scenario evaluation for optimal system design and operation under varying parameters such as building type, climate zones and irradiance, solar and storage technology integration, fast charging capabilities and utility rate structures.

ENERGY STORAGE AND FLEXIBILITY FUTURES STUDY (STRATEGIC PRIORITIES AND IMPACT ANALYSIS AND OTHERS) – $1,425,000 TOTAL; $250,000 SETO

National Renewable Energy Laboratory | Golden, CO | Nate Blair

This study will comprehensively examine the potential role of storage in the power sector, including batteries, compressed air, pumped-hydro, and seasonal storage, across a range of potential future cost and performance scenarios out to 2050. Scenarios including a range of possible storage characteristics and cost projections and a range of renewable energy levels using utility-scale electric sector modeling (capacity expansion and production cost modeling) in conjunction with distributed storage deployment modeling will be considered. Through this scenario analysis, this study will identify how storage might be effectively deployed, how storage compares to other flexibility options and how storage affects the integration of variable renewable energy and system costs.

GRID STORAGE FOR EXTREME EVENTS (STRATEGIC PRIORITIES AND IMPACT ANALYSIS AND OTHERS) – $850,000 TOTAL; $100,000 SETO

National Renewable Energy Laboratory | Golden, CO | Paul Denholm

This study will conduct a detailed evaluation and analysis of the various long-term storage options to understand and quantify the scale of the long-term storage challenge and the costs and tradeoffs faced by candidate technologies to serve this role. This study will consider storage requirements longer than typical diurnal storage and up to and including storage to meet requirements during cold winter polar vortexes and hot summer doldrums.

IMPROVING THE REPRESENTATION OF STORAGE IN THE REEDS LONG-TERM PLANNING MODEL (STRATEGIC PRIORITIES AND IMPACT ANALYSIS) – $235,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Welsey Cole

This project improves the capabilities of the Regional Energy Deployment System (ReEDS) to include energy storage technologies in capacity expansion modeling. This effort focuses primarily on diurnal storage technologies with varying operational durations and considers system capacity value and dispatch characteristics. The enhanced modeling capabilities will be utilized by multiple other projects considering issues around solar generation and energy storage deployment.

OPEN-ACCESS REEDS MODEL (STRATEGIC PRIORITIES AND IMPACT ANALYSIS) – $300,000

National Renewable Energy Laboratory | Golden, CO | Welsey Cole

This project improves access and transparency for the Regional Energy Deployment System (ReEDS). ReEDs is the flagship capacity planning model for the North American electricity system. It simulates the evolution of the bulk power system—generation and transmission—from present day through 2050 or later. This project is focused on improving public availability and accessibility of the model to facilitate user communities outside of the National Renewable Energy Laboratory.

Manufacturing and Competitiveness

The Manufacturing and Competitiveness team funds projects that are developing pathways to commercialization for disruptive innovation in the solar industry. As the projects managed by this team are spread across the tracks for the Peer Review, this section serves as a repository for all Manufacturing and Competitiveness projects. They are listed below sorted alphabetically first by awardee name and second by project name, followed by the page number where you can find the full description. These projects are listed here to help to inform this track's review of how effective SETO is in moving technology to market and in supporting U.S. manufacturing.

Strategic Analysis and Institutional Support

The Strategic Analysis and Institutional Support team uses data, models, and analytical frameworks to explore, shape, and inspire new possibilities for affordable and reliable integration of solar technologies into the U.S. energy ecosystem. As the projects managed by this team are spread across the tracks for the Peer Review, this section serves as a repository for all Strategic Analysis and Institutional Support projects. They are listed below sorted alphabetically first by awardee name and second by project name, followed by the page number where you can find the full description.

Acronyms

OFFICES & PROGRAMS

EERE Energy Efficiency and Renewable Energy

SETO Solar Energy Technologies Office

POSITIONS & TITLES

PM Program Manager

SETA Science and Engineering Technical Adviser

TM Technology Manager

TPO Technical Project Officer

SETO PROJECTS & PROGRAMS

CSP Concentrating Solar-Thermal Power

GMI Grid Modernization Initiative

GMLC Grid Modernization Laboratory Consortium

SBIR Small Business Innovation Research

STTR Small Business Technology Transfer

PROGRAMMATIC/AWARD/PROJECT/FINANCIAL – SYSTEMS & DOCUMENTS

FOA Funding Opportunity Announcement

RFI Request for Information

NATIONAL LABORATORIES

ANL Argonne National Laboratory

BNL Brookhaven National Laboratory

LANL Los Alamos National Laboratory

LBNL Lawrence Berkeley National Laboratory

LLNL Lawrence Livermore National Laboratory

NETL National Energy Technology Laboratory

NREL National Renewable Energy Laboratory

ORNL Oak Ridge National Laboratory

PNNL Pacific Northwest National Laboratory

SNL Sandia National Laboratories

List of Funding Opportunities Since 2013

FOA	Team	Date Announced	Federal Amount Announced (in millions)	Number of Awards
The Physics of Reliability: Evaluating Design Insights for Component Technologies in Solar (PREDICTS) funding program took a physics- and chemistry-based approach to identifying failure modes for solar products.	PV, SI, CSP	October 2013	$8	5
The Concentrating Solar Power: Efficiently Leveraging Equilibrium Mechanisms for Engineering New Thermochemical Storage (CSP: ELEMENTS) funding program supported the development of thermochemical energy storage systems that could validate a cost of less than or equal to $15 per kilowatt-hour-thermal and operate at temperatures greater than or equal to 650° Celsius.	CSP	May 2014	$10	6
The Next Generation Photovoltaics 3 funding program supported projects that investigated transformational PV technologies that could meet office's cost targets.	PV	October 2014	$14	10
The Solar Manufacturing Technology 2 funding program focused on lowering the cost of manufacturing and implementing efficiency-increasing technology in manufacturing processes.	CSP, T2M	October 2014	$16	10
The Solar Market Pathways funding program supported projects that worked to advance solar deployment across the United States.	BOS	January 2015	$6	6
For systems integration, the SunShot National Laboratory Multiyear Partnership (SuNLaMP) funding program enabled U.S. national laboratories to conduct research and development that will enable hundreds of gigawatts of solar energy to be integrated reliably and cost-effectively onto the U.S. electric power grid.	SI	July 2015	$59	16
For concentrating solar-thermal power, the SunShot National Laboratory Multiyear Partnership (SuNLaMP) funding program enabled U.S. national laboratories to develop novel technologies for concentrating solar power that will reduce the levelized cost of energy for electricity it generates to six center per kilowatt-hour.	CSP	July 2015	$29	9
For photovoltaics, the SunShot National Laboratory Multiyear Partnership (SuNLaMP) funding program enabled U.S. national laboratories to address the most impactful barriers to the advancement of photovoltaic technologies.	PV	July 2015	$110	30
For balance of systems soft costs, the SunShot National Laboratory Multiyear Partnership (SuNLaMP) funding program enabled U.S. national laboratories to support soft cost reductions, expand access to solar energy, and accelerate solar deployment.	BOS	July 2015	$24	15

FOA	Team	Date Announced	Federal Amount Announced (in millions)	Number of Awards
For technology-to-market, the SunShot National Laboratory Multiyear Partnership (SuNLaMP) funding program enabled U.S. national laboratories to support commercialization, market readiness, and domestic manufacturing across the solar value chain through strategic cost and competitiveness analysis.	T2M	July 2015	$2	1
The SunShot Physics of Reliability: Evaluating Design Insights for Component Technologies in Solar 2 (PREDICTS 2) program funded research in physics, chemistry, and advanced data analysis to gain a better understanding of how and why solar PV modules degrade.	PV	September 2015	$8	7
The Concentrating Solar Power: Advanced Projects Offering Low LCOE Opportunities (CSP: APOLLO) funding program furthered CSP system technologies through transformative projects that target all components of a CSP plant.	CSP	September 2015	$29	14
The Solar Powering America by Recognizing Communities program, now called SolSmart, established a national recognition and technical assistance program for local governments, driving greater solar deployment and making it possible for more American homes and businesses to access affordable solar energy.	BOS	September 2015	$15	2
The Technology to Market funding program brought highly impactful solar energy technologies and solutions to the marketplace through technology research, development, and demonstration that overcame technical, institutional, and market challenges.	T2M	November 2015	$23	33
The Grid Modernization Laboratory Consortium (GMLC) advanced predictive modeling capabilities for solar generation to enable utilities to better manage the variability and uncertainty of solar power and improve grid reliability.	SI	January 2016	$12	9
The Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES) funding program developed and demonstrated integrated photovoltaic and energy storage solutions that are scalable, secure, reliable, and cost-effective.	SI	January 2016	$18	6
The Orange Button funding program sought to reduce soft costs by streamlining the collection, security, management, exchange, and monetizing of solar data sets across the solar value chain.	BOS	April 2016	$9	4
The Solar Training and Education for Professionals (STEP) funding program tackled soft costs by addressing gaps in solar training and energy education, within the solar workforce and in professions that play a key role in solar deployment.	BOS	May 2016	$12	11

FOA	Team	Date Announced	Federal Amount Announced (in millions)	Number of Awards
The Concentrating Solar Power: Concentrating Optics for Lower Levelized Energy Costs (CSP: COLLECTS) funding program supported research and development projects that would dramatically improve and reduce the costs of CSP collectors, also known as reflectors.	CSP	July 2016	$7	5
The Photovoltaic Research and Development funding program pushed the limits of power conversion efficiency, fielded energy output, service lifetime, and manufacturability of commercial and emerging PV technologies.	PV	September 2016	$32	21
The Technology to Market 2 funding program supported the development of tools, technologies, and services that would significantly reduce the costs for solar energy systems across all technology areas.	T2M	September 2016	$23	31
The Solar Energy Evolution and Diffusion Studies 2 – State Energy Strategies funding program sought to reduce the soft costs of solar deployment by increasing foundational understanding of technology evolution, soft costs, and barriers to deployment, and tackling market challenges at the state and regional levels.	BOS	October 2016	$21	17
The Solar in Your Community Challenge prize competition was designed to incentivize the development of new approaches to increase the affordability of electricity while expanding solar adoption across America.	BOS	November 2016	$3	1
The Small Business Innovation Research and Small Business Technology Transfer programs are competitive 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.	T2M	2016	$2	
The Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE) funding program develops distribution planning and operation solutions to enable dynamic, automated, and cost-effective management of solar and other distributed and variable generation sources onto the grid.	SI	January 2017	$26	13
The Photovoltaics Research and Development 2: Modules and Systems funding program sought to develop technologies with the potential to lead to new classes of commercial PV products that improve module performance, reliability, and manufacturability.	PV	July 2017	$18	28
The Technology to Market 3 funding program supported projects that sought to develop products to leverage new and emerging technologies, increase system values while reducing hardware costs, improve business operational efficiency, expand the investor pool for project development, and increase consumer access to solar.	T2M	July 2017	$22	18

FOA	Team	Date Announced	Federal Amount Announced (in millions)	Number of Awards
The Innovative Pathways funding program supports projects that develop and test new ways to integrate emerging technologies into the energy industry and unlock private sector resources to support energy innovation.	T2M	August 2017	$4	4
The Resilient Distribution Systems lab call via the Grid Modernization Laboratory Consortium seeks to develop and validate innovative approaches to enhance the resilience of distribution systems, including microgrids, with high penetration of distributed energy resources.	SI	September 2017	$12	9
The Solar Energy Innovation Network supports multi-stakeholder teams that research and share solutions to reduce barriers to solar energy adoption using real-world data.	BOS	October 2017	$11	2
The Solar Forecasting 2 funding program builds on the Improving Solar Forecasting Accuracy funding program to support projects that generate tools and knowledge to enable grid operators to better forecast how much solar energy will be added to the grid.	SI	December 2017	$12	9
The Small Business Innovation Research and Small Business Technology Transfer programs are competitive 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.	T2M	2017	$7	
The Solar Energy Technologies Office Fiscal Year 2018 funding program supports concentrating solar-thermal power (CSP) projects that work toward achieving a 50percent cost reduction by 2030 and focus on advancing components found in CSP subsystems, while pursuing new methods for introducing innovation to CSP research.	CSP	April 2018	$12	15
The Solar Energy Technologies Office Fiscal Year 2018 funding program supports early-stage PV research projects that increase performance, reduce materials and processing costs, and improve reliability of PV cells, modules, and systems to enable the industry to achieve its 2030 cost goals.	PV	April 2018	$28	31
The Solar Energy Technologies Office Fiscal Year 2018 funding program supports workforce projects that seek to prepare the solar industry for a digital future and modern grid while increasing the number of veterans and other participants in the solar industry.	BOS	April 2018	$13	7
The Advanced Power Electronics Design for Solar Applications (Power Electronics) funding program will help the industry develop new technology to improve the devices that serve as the critical link between solar photovoltaic arrays and the electric grid.	SI	April 2018	$20	9

List of Funding Opportunities Since 2013

FOA	Team	Date Announced	Federal Amount Announced (in millions)	Number of Awards
The Generation 3 Concentrating Solar Power Systems funding program supports projects that seek to de-risk CSP technologies by advancing high-temperature components and developing integrated assembly designs with thermal energy storage that can reach high operating temperatures.	CSP	May 2018	$72	7
The American-Made Solar Prize Round 1 prize competition is designed to revitalize solar manufacturing in the United States by supporting entrepreneurs as they develop transformative technology ideas into concepts and then into early-stage prototypes ready for industry testing.	T2M	June 2018	$3	20
The Solar Desalination funding program explores novel technologies that use solar-thermal energy to help create fresh water from otherwise unusable waters like seawater, brackish water, and contaminated water.	CSP	June 2018	$21	14
The Advanced Systems Integration for Solar Technologies (ASSIST): Situational Awareness and Resilient Solutions for Critical Infrastructure funding program will improve situational awareness of solar energy systems, especially at critical infrastructure sites, increase resilience to cyber and physical threats, and strengthen solar integration on the grid.	SI	October 2018	$36	10
The Small Business Innovation Research and Small Business Technology Transfer programs are competitive 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.	T2M	2018	$9	16
The American-Made Solar Prize Round 2 prize competition is designed to revitalize solar manufacturing in the United States by supporting entrepreneurs as they develop transformative technology ideas into concepts and then into early-stage prototypes ready for industry testing.	T2M	March 2019	$3	20
The American-Made Solar Prize Round 3 prize competition is designed to revitalize solar manufacturing in the United States by supporting entrepreneurs as they develop transformative technology ideas into concepts and then into early-stage prototypes ready for industry testing.	T2M	September 2019	$3	20
The SETO FY2019-21 Lab Call supports core capabilities at the national labs as well as research and development projects that facilitate a more resilient, reliable, and affordable electric grid.	All	June 2019	$158	71
The Solar Energy Technologies Office Fiscal Year 2019 funding program supports several applied research collaborations to tackle key challenges in commercially available technologies and invest in new materials that can lower the cost of PV-generated electricity.	PV	November 2019	$24	21

FOA	Team	Date Announced	Federal Amount Announced (in millions)	Number of Awards
The Solar Energy Technologies Office Fiscal Year 2019 funding program supports the development of new thermal storage technologies that will make solar energy available on demand, as well as the development of advanced manufacturing and autonomous operational technologies to reduce the cost of CSP.	CSP	November 2019	$30	13
The Solar Energy Technologies Office Fiscal Year 2019 funding program aims to increase solar energy affordability and expand the U.S. solar market by addressing regulatory burdens, improving data collection, developing new solar financing tools and mechanisms, and supporting rapid solar software development.	BOS	November 2019	$18	19
The Solar Energy Technologies Office Fiscal Year 2019 funding program supports for-profit companies developing early-stage product ideas that have both a clear pathway to reducing solar electricity costs and the potential for rapid commercialization.	T2M	November 2019	$7	7
The Solar Energy Technologies Office Fiscal Year 2019 funding program supports the creation of technologies that ease the integration of solar energy onto the U.S. grid, especially in areas where solar could supply a high percentage of electricity.	SI	November 2019	$50	15
The Small Business Innovation Research and Small Business Technology Transfer programs are competitive 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.	T2M	2019	$9	
The Solar Energy Technologies Office Fiscal Year 2020 funding program will support projects across all the office's research areas, as well as siting solar and agriculture and developing artificial intelligence applications for solar.	All	February 2020	$125.5	

U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

For more information, visit:
energy.gov/eere/solar

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