SOLAR ENERGY TECHNOLOGIES OFFICE

U.S. Department of Energy



2018 PORTFOLIO

Message from the Director

Just over forty years ago, the idea that solar power could make the leap from powering satellites in space to powering the planet was the vision of only a few people, brought together by the shock of the first oil embargo. Today, solar power is everywhere.

This Multi-Year Program Plan (MYPP) describes the path forward to tomorrow's continuum of opportunities produced by the transformative power of solar energy. The exponential increase in applications powered by solar is directly tied to the predictable cost reduction experienced through economies of scale and continuous technology performance improvements. The MYPP delivers insights, goals, and objectives that are both inspirational and quantitatively framed by thoroughly documenting many of the pathways for achieving scale that have been built upon foundations of science and experience proven over decades.

The MYPP describes the quantification and range of considerations appropriate to every dimension of the solar value chain: how feedstocks are prepared, how modeling informs the panorama of possibilities, how factories consistently operate, how manufacturing environment, health, and safety is planned and audited, how life cycle benefits are quantified, and how to best use resources – all while ensuring that business prospers. Through the orchestration of these elements of opportunity, it is possible to have development that is economically sustainable.

The combination of information technology and low-cost solar technology has established the foundation for irreversible growth connecting the dots between the supply of cost competitive electricity and the need for power everywhere. The MYPP is a roadmap to understanding the cornerstones upon which an industry has been framed so that ideas for fully optimizing that early vision can be explored and accelerated to meet real world needs.

Here is our guidebook to a bright energy future.

Charles F. Gay

Dr. Charles Gay
Director, Solar Energy Technologies Office
U.S. Department of Energy

TABLE OF CONTENTS

TABLE OF CONTENTS

1 Executive Summary

In 2016, solar power surpassed 1% of annual electricity supply in the United States and for the world as a whole, and the Energy Information Administration projects that solar will grow to 5% of U.S. electricity by 2030.[1] Further, if the price of solar electricity and/or energy storage declines more rapidly than projected, that percentage could be even higher.[2]

The costs of utility-scale solar power have declined rapidly over the past decade. But while solar is becoming more affordable, technological challenges remain. If these challenges are addressed, solar holds the potential to improve grid reliability and resilience, as well as increase employment growth,[3] business opportunities, energy diversity, and environmental benefits.

The dramatic cost reductions to date in solar technology provide an opportunity to increase SETO's focus on the longer-term challenge of grid integration. While lower prices have helped drive new capacity installations, more work is needed to make solar a reliable, on-demand energy resource. In addition, there is an opportunity for further cost reductions to support greater energy affordability through low cost solar power.

The mission of the Solar Energy Technologies Office (SETO) is to support early-stage research and development to improve the affordability, reliability, and performance of solar technologies. The office invests in innovative research efforts to securely integrate more solar energy into the grid, enhance the use and storage of solar energy, and lower solar electricity costs.

SETO focuses on two different solar energy technologies: photovoltaic (PV) technologies that directly convert sunlight into electricity, typically via a semiconductor, and concentrating solar thermal power (CSP) technologies that convert sunlight to heat, which can be stored until needed, and then used to generate electricity.

Advancements in solar technology combined with evolving low-cost energy storage could enhance the performance and reliability of solar power, improving its ability to integrate into the electric grid. If the technology continues to improve, solar energy could potentially supply larger amounts of our nation's electricity demand.

1. U.S. Department of Energy, Energy Information Administration, International Energy Outlook 2017, DOE/EIA-0484 (2017).
2. P.A. Basore and W.J. Cole, "Comparing supply and demand models for future photovoltaic power generation in the USA," submitted to *Progress in Photovoltaics: Research and Applications*, 2017.
3. The Solar Foundation, *National Solar Jobs Census*, 2010 – 2016.

Solar installations have grown over the past decade, but adding large amounts of solar to the grid presents reliability challenges. Because sunshine varies with the time of day, location, and season, solar power systems must be paired with adaptive loads, other sources of power, or energy storage to deliver electricity whenever it's needed. This dependency reduces the value of solar power systems once solar starts to supply a significant fraction of the electricity within a given region and highlights the need for a focus on addressing reliability and integration challenges with the energy system.

Continuing to reduce the cost of solar electricity will also enable greater deployment. SETO has set 2030 goals to further reduce the cost of solar electricity across all market sectors.[4] The targets for the unsubsidized cost of electricity at the point of grid connection in a location with average U.S. solar resource are 3¢ per kilowatt-hour (kWh) for utility-scale photovoltaics, 4¢ per kWh for commercial rooftop photovoltaics, 5¢ per kWh for residential rooftop photovoltaics, and 5¢ per kWh for concentrating solar power with thermal energy storage.

By effectively executing the Multi-Year Program Plan (MYPP), SETO can spark innovation and enable technology combinations that advance affordable and reliable solar power while securely integrating it into the nation's energy system.

This is a draft version of the MYPP. The MYPP will be updated based on feedback in February 2018.

2 Office Overview

SETO is a solar technology-focused organization established within the Office of Energy Efficiency and Renewable Energy (EERE) of the U.S. Department of Energy (DOE). SETO, in partnership with other offices at DOE, set a goal in 2011 for solar electricity to become price-competitive with conventional utility sources by 2020.[5] The 2020 goal for utility-scale PV was achieved in 2017, three years ahead of schedule. With continued effort, it is likely to be achieved for all solar applications.

As a result of this tremendous progress and in response to the growing deployment of solar in the United States, SETO is increasing its focus on a more significant long-term challenge: dispatchability. Specifically, SETO will focus on addressing the challenges related to integrating high penetrations of solar energy onto the nation's electricity system. Additionally, SETO set 2030 goals to further reduce the cost of solar electricity across all market sectors, which would make solar one of the most affordable sources of electricity and enable solar to supply a larger fraction of U.S. electricity demand.

The MYPP describes how SETO can help the solar power sector achieve its full potential. SETO intends to implement this plan in cooperation with related offices within DOE, including the Building Technologies Office (related to solar integration for efficient building energy systems), the Office of Electricity (related to solar integration for enhanced grid interoperability, reliability, and resilience), the Offices of Fossil Energy and Nuclear Energy (related to the development of supercritical CO_2

4. U.S. Dept. of Energy, *The SunShot Initiative's 2030 Goal: 3¢ per Kilowatt Hour for Solar Electricity*, 2016.
5. *SunShot Vision Study*, NREL Technical Report DOE/GO-102012-3037, 2012.

power systems), the Advanced Manufacturing Office (related to the solar domestic supply chain), the Vehicle Technologies Office (related to integration of solar with affordable energy storage), and the Advanced Research Projects Agency – Energy and the Office of Science (related to emerging solar technologies).

2.1 SETO'S MISSION

> *Accelerate the development and application of technology to enable low cost, reliable solar power in the United States*

SETO's mission is executed primarily by funding early-stage research and development projects that address electric system integration challenges and pathways to cost reduction that are too high-risk or not otherwise amenable to private sector support. As explained in an August 17, 2017 joint memorandum from the Office of Management and Budget and the Office of Science and Technology Policy titled "FY 2019 Administration Research and Development Budget Priorities," SETO's priority is to "invest in early-stage, innovative technologies." In addition, "federally-funded energy R&D should continue to reflect an increased reliance on the private sector to fund later-stage research, development, and commercialization of energy technologies."

Partners in this endeavor include national laboratories, universities, businesses, and other government agencies. Staff members regularly interact with the community of these solar stakeholders to ensure the relevancy of SETO's programs. The outcome of a strategy development workshop in 2016, which was particularly relevant to the formulation of this MYPP, is described in section 3.1 *Stakeholder Input*.

The office's projects that support the further development of photovoltaic technologies contribute to SETO's mission by shaping system reliability, annual energy yield, novel PV devices, and new materials. These efforts, described in section 3.2 *Photovoltaics*, directly contribute to increasing PV affordability through continuous improvements in PV efficiency and durability. SETO's work ensures that a pipeline of innovation continues to reduce system cost, increase power conversion efficiency, and reduce supply-chain capital expense.

SETO projects that focus on the seamless integration of high penetrations of solar energy into the nation's electricity system are described in section 3.3 *System Integration*. These projects advance the prediction, monitoring, and control of solar power production, the capabilities of solar power electronics and the integration of solar energy with synergistic technologies. SETO projects that support codes and standards, industry best practices, and workforce development are described in section 3.4 *Market Acceptance*. These projects directly address affordability and access of solar energy.

SETO projects that support solar technologies that focus sunlight to generate and store high-temperature heat for electricity generation and other end uses are described in section 3.5 *Concentrating Solar Thermal*. These projects contribute to increasing solar power adoption and grid reliability often through combined power and storage.

SETO's funding supports U.S. leadership in solar technology R&D by funding the next generation of innovative technologies and by developing domestic research talent and capabilities.

2.2 PROJECT FUNDING

SETO funds projects at national laboratories, universities, businesses (non-profit 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 providing access to unique facilities for testing and measurement or strategic analysis is focused at national laboratories. Funding aimed at developing leading-edge, 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.

Among those projects that address SETO's mission, funding decisions favor those that offer the greatest prospect for addressing the following national needs:

- Economic Growth Across the Full Value Chain
- Job Creation
- Grid Reliability and Resilience
- Infrastructure Renewal
- U.S. Leadership in Innovation
- Diversity of Affordable Electricity Supplies

SETO supports collaborations for the research and development phases of technology innovation that have not historically been well-serviced by venture capital or traditional financing mechanisms. Without these programs, many innovations capable of improving the reliability, resilience, and affordability of PV systems would be unable to reach the level of technical maturity that is required for market adoption.

Fostering Positive Stakeholder Relations

- **We ensure fairness and seek to minimize bias in our decisions.**
- **We proactively recognize the organizations, teams, and individuals where credit is due.**
- **We actively share information to the maximum extent appropriate.**
- **We strive for efficiency in all facets of operation and interaction.**

2.3 OFFICE FUNCTIONS

The SETO staff develops budget plans, leads the design and promotion of funding opportunities, leads the review and selection of proposals, and provides technical and fiscal oversight of awarded projects in compliance with EERE, DOE, and federal government policy.

SETO's funding opportunities, reports, and accomplishments are communicated within DOE and to stakeholders, the scientific community, and the general public through the convening of workshops and symposia, and through integrated strategies that utilize all DOE-approved traditional and digital media channels.

2.4 NATIONAL LABORATORIES

DOE is responsible for a suite of national laboratories distributed nationwide, and EERE is specifically responsible for the National Renewable Energy Laboratory (NREL) in Golden, Colorado. The national laboratories complement research and development performed at universities and businesses by combining academic expertise with long-term research execution to provide continuity for meeting national needs. SETO promotes an effective partnership with DOE's national laboratories by carefully and cooperatively defining roles, responsibilities, and goals consistent with EERE's National Laboratory Guiding Principles.[6] The key elements of this relationship:

- SETO strives to maintain funding for an agreed-upon suite of core capabilities at the national laboratories, especially those related to specialized diagnostic and analytic tools, and independent evaluation of technology performance, reliability, and safety;
- Labs may compete for certain additional SETO funding opportunities on an equitable basis; and
- The parties continuously seek to optimize the efficiency of all facets of operation and reporting, while maximizing opportunities for academic and entrepreneurial cooperation.

6. EERE 700, *National Laboratory Guiding Principles*, 2016.

3 Research and Development Plan

3.1 STAKEHOLDER INPUT

SETO sponsors a series of topical workshops to solicit stakeholder input on a range of strategic issues. A workshop sponsored by SETO in June 2016 collected input from a broad cross-section of the U.S. solar community on which issues should be addressed by SETO from 2020-2030. The two primary messages conveyed from the workshop were that:

- Cost reduction alone is no longer sufficient to ensure widespread adoption of solar power. Other barriers to deployment are of significant importance.
- As a federal office, SETO should target its efforts well beyond business-as-usual, to accelerate inspired innovation and motivate stakeholders.

The opportunity for low-cost energy storage was highlighted as a major consideration, and the need to better integrate energy storage with PV systems was flagged as appropriate for SETO's attention.

Additional discussion centered around concentrating solar-thermal approaches to low-cost power, with an emphasis on how the ease of incorporating thermal storage can allow such solutions to power turbine generators or industrial processes any time of day or night.

Attendees also expressed a longer-term vision for emerging photovoltaic technologies enabling U.S. supply-chain manufacturing that would scale with deployment to expand and repatriate employment in PV manufacturing.

3.2 PHOTOVOLTAICS

Future improvements in the efficiency, cost, reliability, and lifetime of PV technologies have the potential to substantially reduce the cost of solar power and contribute to greater energy affordability. Figure 1 illustrates one possible path for realizing a factor of two reduction in the levelized cost of electricity (LCOE) for utility-scale PV (UPV).[7] The values shown in Figure 1 are for a U.S. location with average solar resource and without incentives. PV systems located elsewhere in the 48 contiguous states have annual solar

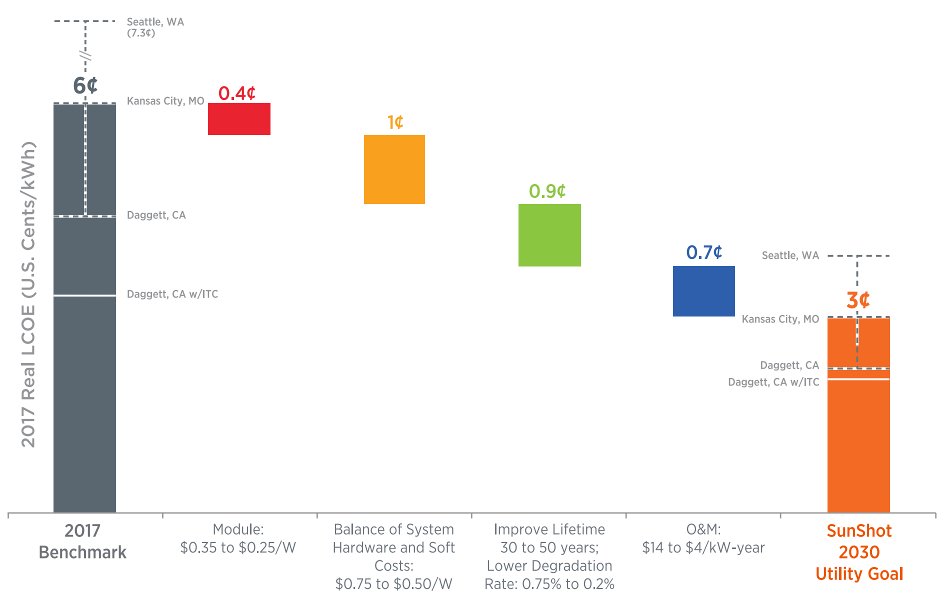


Figure 1. Waterfall chart showing one possible path to achieving an unsubsidized LCOE of 3¢/kWh for standard UPV project conditions in the U.S.

7. Single-axis tracking, 21% capacity factor (AC), 7% nominal weighted average annual cost of capital, 2.5% annual inflation, operation/maintenance (O&M) of $4/kWdc-yr escalating 2% faster than inflation, 5-yr depreciation, 37% effective tax rate. No investment tax credit or financial incentives beyond MACRS are included in the calculation.

exposure that can be as much as 30% higher or 30% lower than the national average, with a corresponding variation in the cost of solar electricity for those locations.

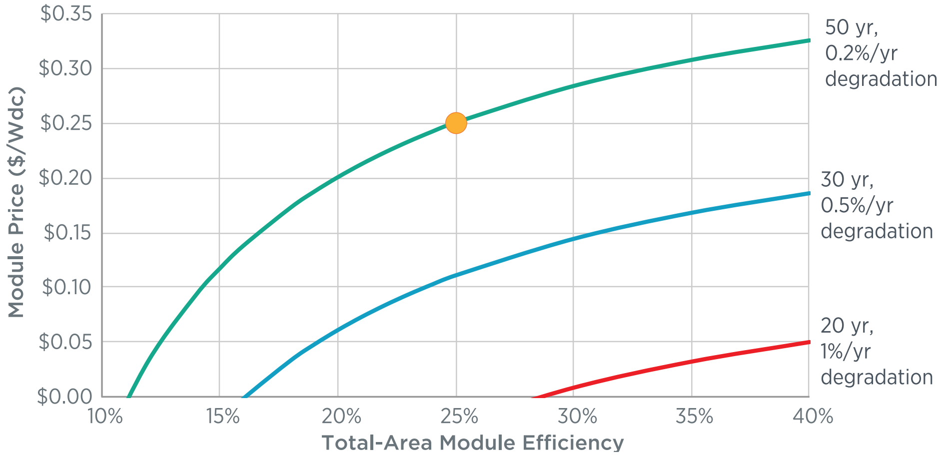


Figure 2. PV technology pathways to reach 3¢/kWh in a U.S. location with average solar resource, specifically illustrating the trade-offs between module price, efficiency and reliability. All points on all lines are combinations of metrics that reach 3¢/kWh. The orange dot identifies the combination of module price and efficiency used to generate Figure 1.

The path for achieving 3¢ per kWh for UPV illustrated in Figure 1 assumes a PV module efficiency of 25% and a module price of 25¢ per watt, but other combinations of module cost and performance can deliver the same LCOE. Figure 2 illustrates various combinations of module efficiency, module price, and system lifetime that all represent LCOE of 3¢ per kWh under standard UPV project conditions.[8] The module price needs to be high enough to support a sustainable module supply chain, yet low enough to help drive growth in market demand.[2]

Further improvements in annual energy yield, reducing project development and construction time, and reducing the cost of capital for project financing are likely required in order to achieve SETO's LCOE targets for 2030. Cost of capital can be reduced by collecting data that increases the confidence that investors and financiers have in the long-term performance and reliability of installed systems, and by expanding the pool of capital sources. Reducing the annual cost of capital by one percentage point (from 7 to 6%) would reduce LCOE by 10 to 15%.

Distributed PV (DPV) systems on rooftops have a higher LCOE on average due to diverse roof orientations and construction materials, higher installation and customer acquisition costs, and service lifetimes unique to individual installations.[8] SETO's 2030 LCOE goals for unsubsidized DPV systems in a location with average U.S. solar resource are 4¢ per kWh for commercial rooftops and 5¢ per kWh for residential rooftops. The higher LCOE of DPV compared to UPV may be partially compensated by the higher value of electricity supplied directly to a retail consumer, rather than to a wholesale electric utility network. Over the past several years, the installed capacity in the United States for UPV and DPV systems has been of similar magnitude (roughly one-third DPV and two-thirds UPV), and this general parity in deployment is expected to continue. SETO therefore anticipates supporting advances in both UPV and DPV systems.

Technical innovation for PV technologies encompasses more than just PV cells and modules. In order to achieve the office's 2030 goals, innovation must span the production, installation, and operation of all PV system components. In addition to reducing component costs, other innovations can decrease the LCOE of PV systems, such as increased module efficiency (more watts per module), more durable module materials (longer life for more kWh per module), and module and racking form factors to ease installation (reduced installation labor).

U.S. government support for photovoltaic technology innovation dates back to the Solar Energy Research, Development, and

8. Fixed-tilt, 17% ac/dc capacity factor, 30-year life, 0.5%/yr degradation.

Demonstration Act of 1974. Early DOE programs to develop silicon solar cells at the Jet Propulsion Lab and Sandia National Laboratories contributed to today's market-leading silicon-based PV technology. In parallel, NREL (previously the Solar Energy Research Institute) has been the principal laboratory for DOE programs aimed at developing alternatives to silicon technology. Two novel device technologies that DOE supported at NREL over the past four decades, cadmium telluride (CdTe) and copper-indium-gallium-selenide (CIGS), became commercially successful and now play a significant role in PV. Additionally, the knowledge gained from the development of amorphous-silicon PV device technology is now proving to be valuable for commercial crystalline silicon PV technologies, in cell structures that utilize doped amorphous or microcrystalline silicon for carrier-selective contacts and heterojunction designs.

The U.S. government has provided funding for the research and development of all components of the photovoltaic systems deployed today, with a focus on driving increases in solar cell and module conversion efficiency, reducing the cost of silicon-wafer and thin-film solar cells, developing more durable materials for module packaging, designing less-costly and easier-to-use module racking and sun-pointing trackers, and developing lower-cost and more durable power electronics.

SETO continues to support PV module technologies that have the greatest promise of being manufactured domestically while offering a competitive advantage over commercial technologies. These initiatives support both novel devices and novel materials. Novel devices include advanced versions of silicon cells, thin-films, III-V compounds, and tandem concepts combining two different PV materials. Novel materials include advanced module packaging, new photovoltaic absorbers, and innovative methods of making electrical contact.

Table 1 lists SETO's plans for FY 2018-2022 to spur technology innovation to help the solar industry lower the cost PV, along with challenges that those plans must address and specific goals that can be used to track progress. These barriers were developed considering both the impact of each on achieving low cost PV and the ability of SETO to help overcome that barrier.

All of the plans for technology innovation listed in Table 1 would benefit from the development of new, complementary financing instruments to attract more capital investment to the commercialization of these innovations. SETO can work with innovation hubs at the national laboratories to identify new financing arrangements that enable patient investors and specialized funds to transition these innovations to the private sector and expand the domestic market share throughout the PV value chain.

PV technologies based on novel devices have the potential to supply a significant portion of the national electricity demand if they can out-perform the moving target presented by commodity PV technologies. It is not sufficient for an emerging PV technology to excel at just cost, efficiency, or reliability; addressing all three attributes is necessary to become relevant for gigawatt-scale power.

The development of novel PV devices depends fundamentally on understanding semiconductor science and how materials and processes impact device performance. This understanding relies heavily on advanced metrology to accurately characterize all optical and electrical aspects of device performance. While it is occasionally necessary to develop entirely new measurement techniques, SETO's primary focus is to ensure that existing measurement techniques from other disciplines are effectively adapted and applied to PV.

Specialized materials determine the performance and reliability of PV modules. From the semiconductor material that absorbs sunlight and converts it to electricity, to the contacts that collect and transport that electricity, to the packaging materials that protect the module from being damaged or degraded, opportunities are plentiful for identifying and developing new materials that better perform these functions at reduced cost.

The development of novel materials requires detailed understanding that can only be gained using advanced analytic techniques. These techniques measure mechanical, optical, thermal, chemical, and electrical properties of individual materials, and the interactions between materials, at scales ranging from subatomic to macroscopic. Many of the tools for performing these measurements are costly and require highly trained operators, so they are most often located at major research universities and at national laboratories.

Table 1: Plans for innovation in photovoltaic technologies

Long-term system reliability is unclear	**Plans:** Ensure new materials developed to improve module performance or lower cost are thoroughly tested through field observation and accelerated testing. Improve methods for accelerated testing and field monitoring of modules, tracking hardware, and other active system components to anticipate and rapidly detect failures. Identify principal degradation mechanisms that limit the long-term field performance of PV technologies and develop mitigation strategies based on deep understanding of their macroscopic and microscopic mechanisms. Identify operations and management (O&M) servicing procedures that optimize the cost-benefit trade-off. Make reliability data widely available to promote best practice.
	Challenges: It is difficult to collect enough field data to accurately quantify the impact of new module technologies on long-term field performance. An alternative is to develop improved accelerated testing methods, but those require extensive validation.
	Goal: The median warranty on system lifetime in the United States for customers complying with the recommend O&M schedule is at least 30 years for DPV and 50 years for UPV.
Supply-chain capital expense is too high for rapid growth	**Plans:** Develop new manufacturing methods that utilize lower capital-expense (capex) production tools, while ensuring that new, cheaper methods of manufacture do not sacrifice product quality.
	Challenges: The capex-to-income ratio for new PV supply-chain production capacity is higher than for many other industries competing for investment. Approaches that reduce capex intensity through higher throughput often introduce more variability in product quality.
	Goal: The capital investment required to grow the entire global PV-specific module manufacturing supply chain is less than $500M for each gigawatt of annual production capacity.
Annual energy production doesn't deliver to its potential	**Plans:** Develop module technologies and mounting configurations that maximize annual energy yield, minimize the impact of non-ideal operating conditions, reduce performance degradation, and reduce system-level losses. Develop new methods of performance monitoring that identify degradation early, before it significantly impacts energy yield.
	Challenges: Changes in the design of PV systems that increase annual energy production typically incur additional costs. There is a lack of standardization for characterizing and valuing energy yield benefits, which limits their bankability and adoption.
	Goal: The average annual capacity factor for new UPV systems with single-axis tracking in a location with average solar resource exceeds 21% (kWh$_{ac}$ per year per kW$_{dc}$ installed module rating) and the median degradation in capacity factor over time for PV systems in the U.S. that comply with recommended O&M schedules is less than 0.2%/yr.

PV cells and modules need to increase efficiency while reducing cost	**Plans:** Increase cell efficiencies through stable, high-performance contacts and reduced bulk and interfacial defects. Realize reliable, low-cost thin film absorbers and device architectures. Reduce cell-to-module efficiency losses and develop low-cost conductive adhesives and printable conductive inks or pastes. Develop new characterization methods that improve data feedback to researchers. Develop techniques to increase materials utilization, use less costly precursors, and rapidly produce high performance PV materials and devices.	
	Challenges: Many PV module efficiencies are approaching the theoretical maximum limit, and further improvement typically incurs additional costs, which often outweigh the benefit of efficiency gains. Lower-quality materials and faster production processes typically have an adverse impact on efficiency and reliability.	
	Goal: PV modules that can be sustainably sold for less than 30¢/W have a power rating at standard test conditions that gives a total-area efficiency of at least 25% (or 20% at 25¢/W).	
PV systems could better leverage existing infrastructure to reduce cost	**Plans:** Develop PV technology concepts that leverage existing physical support structures and labor to dramatically reduce installation costs.	
	Challenge: Combining functionalities adds project risk and can hinder utilization if there is not a clear value proposition.	
	Goal: Cost of the integrated PV application does not exceed the cost of a combination of PV plus the baseline support structure(s).	

3.3 SYSTEM INTEGRATION

SETO is a key partner in the Department of Energy's Grid Modernization Initiative (GMI), working closely with DOE's Office of Electricity Delivery and Energy Reliability and other EERE technology offices to enable increasing amounts of solar energy to be integrated into a modernizing national electricity grid while meeting safety, reliability, resiliency, and cybersecurity requirements. Because solar is a variable resource–dependent on location, time of day, season, and weather–there are significant challenges to the planning and operation of the electricity grid as solar becomes an important part of the generation mix. Grid integration challenges for solar arise at both the transmission and distribution levels, as well as the interfaces between them.

Integration issues that arise at the transmission level with high variable power generation include:

- Increased cycling, rapid ramping, and curtailment of conventional generators;
- Increased demand for operating reserves, generation flexibility, and transmission capacity;
- Reduction in system inertia, which impacts frequency response;
- Inadequate planning and operation tools and lack of experience managing high PV penetration; and
- Incompatibility between network reliability standards set by the North American Electric Reliability Corporation and distributed generation standards set by the Institute of Electrical and Electronics Engineers.

In addition, high generation levels that exceed supply needs can lead to curtailment of the PV power, which impacts PV economics. An example where renewable power generation within a transmission-balancing region becomes a substantial fraction of the total generation capacity is illustrated in Figure 3. In this hypothetical case, some PV generators that could have sold power to the grid were curtailed around mid-day. PV curtailment would be substantially reduced if this region had more increased energy storage or more dispatchable loads.

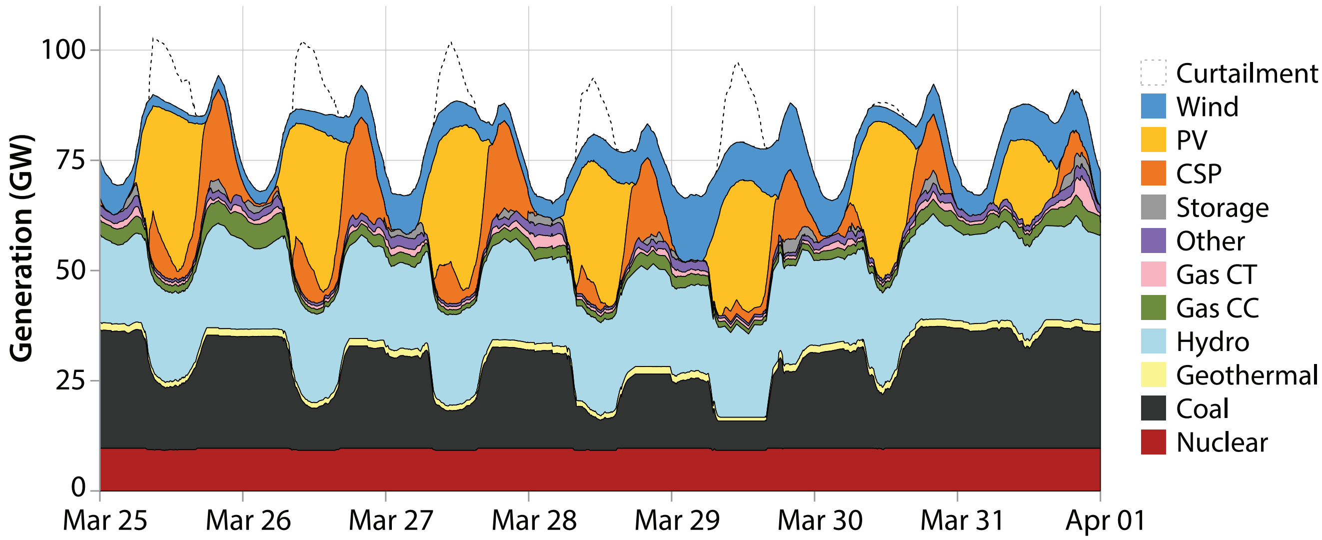


Figure 3. Potential scenario where solar power (yellow and orange) supplies a substantial fraction of electricity generation. Source: www.nrel.gov/docs/fy13osti/55588.pdf

Integration issues that arise at the distribution level with high renewable power generation include:

- More frequent voltage excursions outside the ranges specified by industry standards;
- Increased wear on transformer tap-changing equipment;
- Safety hazards for line crews and the public due to unexpectedly energized lines;
- Potential for power quality issues such as voltage flicker and harmonic distortion;
- Additional fault current patterns impeding the ability of protection devices to isolate the fault;
- Inability to visualize and effectively manage two-way power flows on the distribution network; and
- Inadequate planning and operation tools and lack of experience managing high PV penetration.

While many challenges exist for solar grid integration, there are also abundant opportunities for solar to contribute to improved grid reliability and resilience. For example, during a large scale disaster event that causes wide-spread power outages, distributed PV and energy storage have the potential to bring power back faster to customers, as compared to using the traditional manual black start process. In another example, it has been demonstrated that a large utility-scale photovoltaic (PV) power plant–including its advanced power electronics and generation controls–has the ability to provide essential ancillary services to the electric grid and therefore contribute to system-wide reliability.[9]

9. *"Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant"*, Technical Report, NREL/TP-5D00-67799, March 2017

Table 2 lists SETO's plans for FY 2018-2022 to help the solar industry and utilities overcome the challenges related to grid integration of solar-generated electricity, along with challenges that those plans must address and specific goals that can be used to track progress.

Table 2. Plans for system integration of photovoltaics.

Impacts on grid reliability or power quality	**Plans:** Develop improved modeling, simulation, and testing tools for power system planning and operations with high solar penetration, and improve the scalability, speed and accuracy of these tools using computing environment and hardware-in-the-loop capabilities.
	Challenges: The electric power grid has been designed for power flow in one direction—from central generators to individual consumer loads. As solar penetration increases, local generation can exceed local consumption, creating power flows in the reverse direction and voltage issues for which existing grid devices, protection, controls, models, and simulation tools were not designed.
	Goal: No reportable failures of grid reliability or power quality intrinsically caused by solar power operating in compliance with industry standards.
Best practices for integrating solar with energy storage and synergistic technologies	**Plans:** Develop foundational platforms upon which to create a menu of options representing best practices for integrating PV with energy storage, energy efficiency and dispatchable loads to enable a more flexible grid with higher distributed energy resource (DER) penetration and to provide operators more control options to balance electricity generation and demand.
	Challenges: Effective utilization and evaluation of flexible loads and energy storage when paired with solar is not yet well understood. A wide variety of flexible end use load and energy storage characteristics exist and energy storage can be either centralized or distributed. They can be used for capacity, energy shifting, or ancillary services. Energy storage can be expensive, so it must be introduced optimally. Energy efficiency and load flexibility can be inexpensive, but are even more complex to deploy and operate optimally from a grid plus built environment perspective. Additionally, markets that allow for the monetization of the multiple DER value streams must be better understood.
	Goal: Increased system flexibility and reduced generation reserve requirement to allow dynamic generation and load balancing at high solar penetration levels.
Variability of solar generation	**Plans:** Develop accurate and high-resolution (spatial and temporal) models to predict solar power generation. These models are used by utilities and grid operators to improve system planning and control and as a result lower costs for meeting consumer electricity demands on a day-to-day and hour-by-hour basis.
	Challenges: A high penetration of utility-scale and distributed solar generation creates fast-changing grid dynamics due to the variability of cloud movement and weather, which pose challenge to grid operation. Coarse prediction resolution or accuracy limits the range of options for system control and adds operational costs.
	Goal: High-resolution and accurate prediction models reduce the cost for utilities to host higher level of solar generation on their systems.

Converter-based power flow control	**Plans:** Develop converter-based power flow control technologies, with a focus on advanced PV inverters and grid supporting functions, to accommodate a high penetration of solar power and energy storage. Improve sensing devices and edge analytics that anticipate and manage two-way power flow.
	Challenges: PV inverters today disconnect rather than support the grid during disturbances. Distribution systems are currently operated almost independently of each other, with sensing and control systems not designed to accommodate reverse power flow across distribution system networks, as well as to the transmission system.
	Goal: Multiple power electronic converter technologies that provide voltage control, black start, ramp rate control, frequency response, frequency and voltage ride-through, synthetic inertia control, and automatic generator control; and can perform these grid services in clusters of multiple converter units.
Standardization of interconnection, interoperability, and cybersecurity for PV and other DER systems	**Plans:** Develop codes and standards that establish a uniform, transparent, and secure basis for grid integration, including interconnection requirements, communication protocols, and multi-scale testing.
	Challenge: The requirement for interconnection and communications to enable all elements of the grid to work together depends on the network topology, which is evolving rapidly. Cybersecurity is more complicated as the grid becomes more dependent on information technology infrastructure.
	Goal: National interface standards for PV system interconnection to the grid are adopted by all transmission and distribution operators having significant PV generation capacity.
Enhancing situational awareness of solar energy at the grid edge	**Plans:** Build situation awareness algorithms and visualization that leverage recent improvements on sensor technologies and data fusion techniques to provide visibility into real-time solar generation throughout the distribution system.
	Challenges: As distributed PV and distributed energy resource (DER) penetration continues to increase, the power flow patterns in the distribution system become much more complex and will pose challenges for state estimation, particularly given the lack of real time observability into the distributed generation within the network. This observability is crucial for switch operations, voltage control and power quality management within the distribution system.
	Goal: Solar generation across the distribution system is estimated or observed.

All of the plans for system integration listed in Table 2 would benefit from the development of new business models and markets for the utility sector that are adaptable to the rapidly evolving relationships between the grid's multiple stakeholders. SETO can help identify new business models that could allow utilities and associated grid service providers to profitably integrate information exchange, power flow, power quality, energy storage, and cybersecurity into new product offerings that are capable of handling high penetrations of PV while providing enhanced grid resiliency.

3.4 MARKET ACCEPTANCE

The United States has experienced unprecedented growth in solar installations and associated jobs in recent years due to the emergence of successful business and deployment models, rapid cost reductions, and policy incentives and targets, but this growth has been disproportionately concentrated in a handful of states. Addressing barriers to increased market acceptance presents a significant opportunity to support strong growth in the solar industry and associated jobs throughout the country in the coming years.

Key market barriers for PV include permitting, inspection, and interconnection; customer acquisition; installation labor; and financing.[10] These challenges are layered into an energy market landscape with differing policies and regulations from state to state, many of which are dated and unable to accommodate expectations for resilience, reliability, consumer choice, digital and communications functions, and increased coordination and competition among technologies. In addition, consumers are sensitive to peer influences, which analysis has shown can radically accelerate adoption rates in specific locations.[11]

Business models that can adequately support the integration of PV technology, fairly assign value, and allocate the full range of costs and benefits are still being developed and refined. Supporting the transformation of the U.S. energy sector requires approaches that make effective use of data and information assets, create new management instruments, and cultivate a broader set of skills for those innovating in this space.

SETO has focused efforts to address market barriers primarily in the following activity areas:

- Harnessing big data analysis, technical solutions, and interoperable databases to support the many stakeholders involved in solar deployment;
- Training an innovative solar workforce to enable the solar industry to meet growing demand; and
- Innovating and developing solutions to expand access to validated information.

Underlying these efforts are extensive analyses that characterize the barriers. Work at the national laboratories, as well as insightful tools and analyses from project partners in the non-profit and the private sectors, have helped shed light on these barriers and the potential pathways to reduce them. These programs develop datasets, standards, and guides that serve solar consumers across the country.

Table 3 lists SETO's plans for FY 2018-2022 to help the solar industry overcome the barriers related to market acceptance, along with challenges that those plans must address and specific goals that can be used to track progress.

10. K. Ardani, D. Seif, R. Margolis, J. Morris, C. Davidson, S. Truitt, and R. Torbert, *"Non-Hardware ("Soft") Cost-Reduction Roadmap for Residential and Small Commercial Solar Photovoltaics, 2013-2020,"* NREL Technical Report, 2013.

11. K. Gillingham and B. Bollinger, *"Solarize Your Community: An Evidenced-Based Guide for Accelerating the Adoption of Residential Solar."* 2017.

Table 3. Plans to address market barriers for photovoltaics.

Limited and inaccessible data	**Plans:** Expand the availability of high-quality data and information to the solar industry by supporting the development of software, information management tools, and interoperable databases. Establish
	Challenges: Data is of varying quality and availability is often limited due to proprietary concerns and because of difficulties converting between data formats. To be effective, automated tools must be able to rapidly access and process relevant data.
	Goal: Fewer than 10% of surveyed U.S. project developers report that projects were delayed in the past year due to limited access to data.
Lack of experience and expertise hinders effective execution	**Plans:** Create consistent, high-quality workforce training and skills-credentialing that support the U.S. solar industry. Develop tools and trainings that assist solar and other professionals and that help veterans fill the growing workforce needs.
	Challenges: New resources are needed to cultivate a broader set of training skills. There is a need to leverage, attract, and retain more talent from adjacent fields.
	Goal: Less than half of surveyed U.S. electric utilities, project developers, and system installers report difficulty recruiting and retaining adequately trained staff.
Market potential for solar energy is poorly understood	**Plans:** Explore innovative solutions that improve affordability and increase the value of solar energy to consumers and other stakeholders. Support research on the drivers of solar technology innovation and diffusion.
	Challenges: Because the widespread uptake of distributed energy is a recent phenomenon, the solar industry has high transaction costs.
	Goal: The number of consumers whose total energy costs have decreased due to solar energy grows yearly at an accelerating rate.
Burdensome regulatory processes	**Plans:** Reduce barriers to solar access resulting from burdensome and outdated regulations. Empower institutional players through timely, easy-to-use data and analytical support. Build networks that can support the development and diffusion of proven and effective programs for emerging markets.
	Challenges: Outdated energy regulations are not easily adapted to accommodate the competition, coordination, and aggregation challenges associated with distributed generation.
	Goal: In at least 25 states, solar generates more than 3% of the annual electricity consumed.

Inequitable distribution of benefits across society	**Plans:** Support the analysis needed to ensure that states and local communities have the information they need to design programs that empower low-income customers and spread impacts, costs, and benefits equitably across society.
	Challenge: Low- and moderate-income customers are less likely to own homes and less likely to have access to capital to make solar investments. Policies that fairly assign value and allocate the full range of costs and benefits among market actors are complex and often contentious.
	Goal: The number of low and middle income customers whose total energy costs have decreased due to solar energy grows yearly at an accelerating rate.

3.5 CONCENTRATING SOLAR THERMAL

Concentrating solar thermal (CST) technologies use mirrors to focus sunlight to generate high-temperature heat. A key advantage of CST technology is that the heat can be stored until it is needed, even well after the sun sets. A key disadvantage is that mirrors are effective at focusing sunlight only when the sky in the vicinity of the sun is completely clear, which limits the geographic range for this approach.

Two applications of CST that are of particular interest to SETO are concentrating solar power and solar industrial process heat. The status and plans related to each of these two applications are discussed in the following sections.

3.5.1 CONCENTRATING SOLAR POWER

Concentrating solar power (CSP) is the application of concentrating solar thermal technology to drive a conventional turbine generator. The key components of a CSP plant in a "power tower" configuration using molten salt as a heat transfer fluid (HTF) are illustrated in Figure 4.

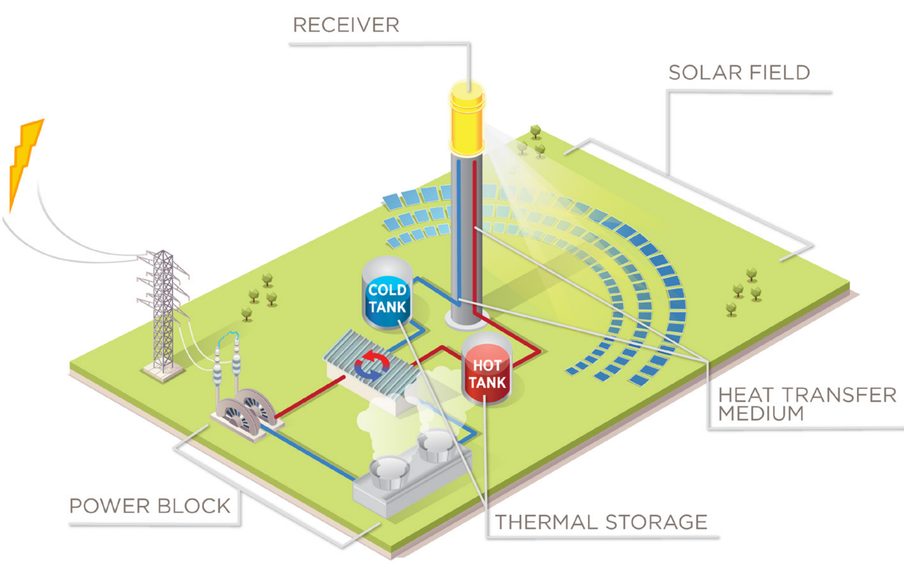


Figure 4. Major components of a power-tower CSP plant with thermal energy storage.

Due to the relative ease of incorporating thermal energy storage into the design of CSP plants, CSP technology represents a dispatchable solar energy resource. That dispatchability means that CSP plants can be designed to provide generation during periods of highest demand to help stabilize the grid. Depending on market conditions, the highest-net-value CSP configuration may lie anywhere along a spectrum of applications ranging from baseload power to peaker power (next page).

	Baseload	Peaker
Capacity Factor	High	Low
Collector Field	Large	Small
Energy Storage	≥ 12 hours	≤ 6 hours

Today's most advanced CSP systems have tower receivers with molten-salt thermal energy storage (TES). This design has lowered the cost of CSP electricity by half compared to the prior generation of parabolic trough systems. Further improvements are needed to cut the cost by half again to enable CSP to be cost competitive. This requires reducing the cost of the field of mirrors and improving energy conversion efficiency by raising the operating temperature of the receiver and turbine generator. Three main pathways have been identified for a high temperature (>700°C) system, according to the phase of matter of the primary heat transfer fluid: solid, liquid, or gas:

- The solid pathway involves solid inert media that absorbs solar radiation and stores that energy as heat. When electric power is needed, the turbine working fluid is heated by the solid media.
- The liquid pathway looks much like today's molten salt two-tank tower configuration (Figure 4), but using a suitably high-temperature and cost-effective HTF/TES.
- The gaseous pathway uses an inert gas flowing through a receiver to absorb the solar energy and then transfer the thermal energy to a storage system and/or the turbine working fluid. The distinctive characteristic of inert gas systems is that the thermal energy is stored in a media that is not the fluid flowing in the receiver.

To understand the specific challenges in developing an integrated system that can meet the requirements of delivering heat to a high-temperature power cycle, EERE commissioned a technical report describing the most promising pathways and key technical gaps remaining, based on the body of CSP R&D that has been performed both domestically and globally. The results of this study are published in the *Concentrating Solar Power Gen3 Demonstration Roadmap*.[12] The roadmap was organized into three system concepts based on the phases of matter: solid, liquid, and gas. The identified specific

COLLECTOR FIELD	RECEIVER	THERMAL TRANSPORT	THERMAL STORAGE	HEAT TRANSFER MEDIA	HEAT EXCHANGE	POWER CYCLE
SOLID MEDIA	• **Thermal efficiency** • Particle loss • Flow velocity control and monitoring	• Reliability • Mechanical and thermal efficiency • Scalability • Insulation	• Charging and discharging • Particle loss, efficiency, scalability	• Particle attrition • Optimized performance character	• Low cycle fatigue • Particle mass flow control • Ramp rates & transients	
MOLTEN SALT	• Thermal conductivity • Thermal stability • Tube strength and durability	• **Pipe material compatibility** • Freeze recovery • Pumps, valves and seals • Leak detect	• **Corrosion behavior** • **Chemistry monitoring and control** • Tank cost	• Characterize material properties • Cost/supply chain	• **Material compatibility w/ salt & CO_2** • Freeze protection • Thermal ramp rates	
GAS	• High pressure fatigue • Absorptivity control and thermal loss management	• Recirculator cost & operating power • Large pipes, high cost	• **Storage concept not determined**	• Low thermal conductivity • Low heat capacity	• Requires high area • Multiple heat exchangers • Cascading temperature	

Figure 5. Pathways for cost-effective, reliable CSP technology. The technical gaps and risks identified by the roadmap document are overlaid on the pathways. (The most significant technical, economic, or reliability barriers are indicated in red.)

12. M. Mehos, C Turchi, J. Vidal, M. Wagner, Z. Ma, C Ho, W. Kolb, C. Andraka, and A. Kruizenga, *Concentrating Solar Power Gen3 Demonstration Roadmap,* NREL Technical Report, NREL/TP-5500-67464, 2017.

technical gaps and research topics are overlaid on the three media pathways in Figure 5.

The solar collector field–comprising arrays of mirrors that focus sunlight onto a solar receiver–typically makes up a large percentage of the capital cost of the CSP plant. In 2011, the baseline cost of heliostat solar collectors used with tower receivers was estimated at approximately $200/m^2.[13] As the CSP industry has gained experience and made gradual improvements in plant construction, the collector field cost has decreased dramatically. In 2016, a capital cost of $93/m^2 was estimated for near-term heliostats that could be deployed in new construction.[14]

In addition to next-generation, high-temperature tower configurations, CSP systems based on parabolic trough collectors present a lower-cost, but lower-efficiency alternative. The high receiver surface area in trough systems limits the operating temperature to lower values than tower configurations, which reduces the total system efficiency. However, the relative maturity of commercial trough designs, and the associated supply chain, raises the possibility that rapid cost reductions may be realized in a shorter time frame than for heliostat/tower systems.

Due to the added value of stored, dispatchable energy, CSP is competitive at a higher LCOE than PV. The 2012 SunShot Vision Study[5] showed that an LCOE of 6¢ per kWh for a baseload CSP configuration (> 60% capacity factor) would lead to significant U.S. CSP deployment. Preliminary results from recent NREL analysis suggest that this LCOE target enables ≥10% CSP penetration in the western United States, but a lower LCOE target of 5¢ per kWh for baseload power enables CSP to double its contribution to national electricity generation. One possible path to achieving that LCOE goal by 2030 is illustrated in Figure 6. DOE support for CSP development has a substantial history, going back to the 1970s and the construction of the National Solar Thermal Test Facility, a research tower and heliostat field at Sandia National Laboratories in Albuquerque, New Mexico. SETO subsequently supported the first two pilot-scale demonstrations of CSP tower technology: Solar One, a steam generating tower in the 1980s; and Solar Two, the first molten-salt-based tower in the 1990s. Over the years, SETO has also supported R&D on other configurations of CSP technology, including parabolic troughs, parabolic dishes, and linear Fresnel reflectors.

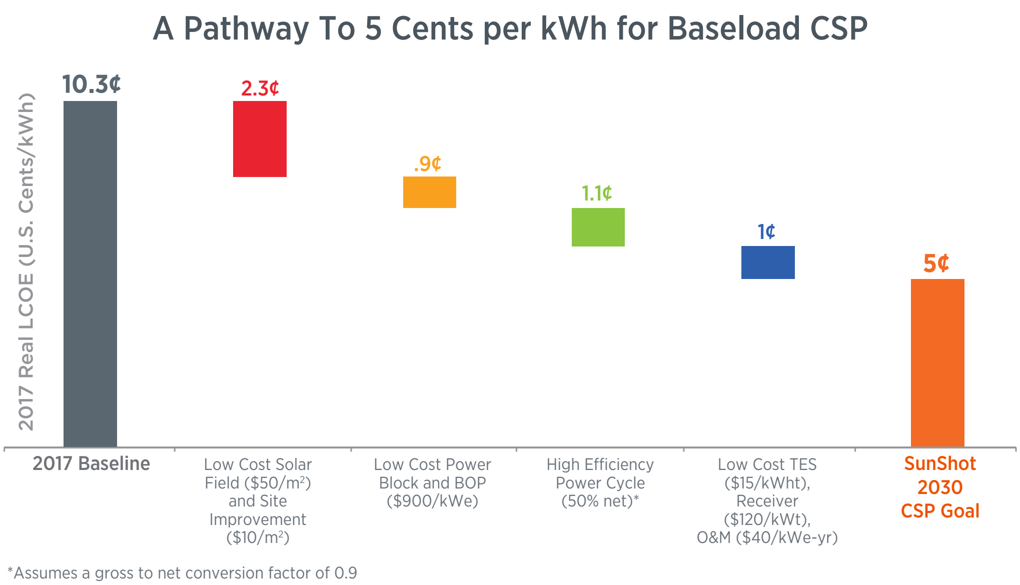


Figure 6. Waterfall chart showing one possible path to achieving an unsubsidized LCOE of 5¢/kWh for a concentrating solar power tower plant in the southwestern United States (BOP = Balance of Plant).

13. G. Kolb, C. Ho, T. Mancini, and J.A. Gary, *Power Tower Technology Roadmap and Cost Reduction Plan,* Sandia Technical Report, *SAND2011-2419*, 2011.

14. M. Mehos, C. Turchi, J. Jorgenson, P. Denholm, C. Ho, and K. Armijo, *On the Path to SunShot: Advancing Concentrating Solar Power Technology, Performance, and Dispatchability,* NREL Technical Report, NREL/TP-5500-65688, 2016.

More recently, SETO has funded a diverse CSP research portfolio, primarily focused on specific plant components that are compatible with a higher operating temperature than current commercial systems. SETO has also funded the development of advanced solar collectors, which are largely compatible with any of the heat transfer media pathways.

SETO is additionally active in a cross-cutting initiative between EERE and the DOE offices of Nuclear Energy and Fossil Energy that is focused on developing a power cycle based on supercritical carbon dioxide (sCO_2), which offers a higher thermal- to-electric power conversion efficiency. Increased efficiency in the power cycle reduces the cost per watt for every component of the CSP plant, not just for the power block. In addition to increased efficiency, sCO_2 power cycles can be economical at much smaller scale. This reduces the capital investment required for each plant, thereby accelerating the cycle of innovation.

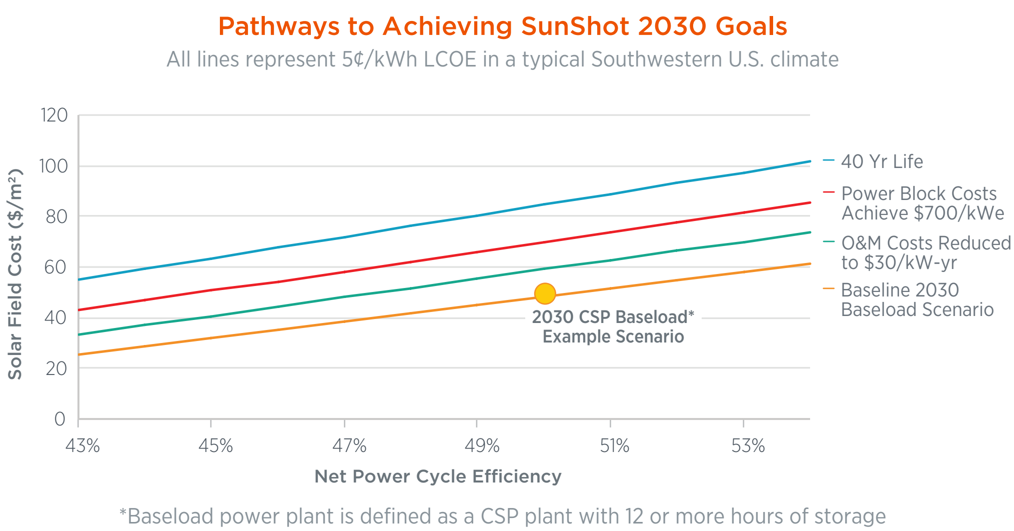


Figure 7. The area below each curve encompasses a solution space compatible with the baseload target of 5¢/kWh.

Table 4 lists SETO's plans for FY 2018-2022 to help the solar industry overcome key barriers to technology innovation in concentrating solar power, along with challenges that those plans must address and specific goals that can be used to track progress.

Table 4. Plans for concentrating solar power.

Higher operating temperature	**Plans:** Develop the three media pathways identified in the Gen3 Roadmap, each of which require heat transfer fluid temperature of at least 700°C.
	Challenges: The operating temperature of current CSP plants is limited by the stability of nitrate-based molten salt HTF at 565°C. Operation at higher temperatures requires new materials that are thermally and chemically compatible.
	Goal: The efficiency of converting direct-normal solar illumination into AC power for a dry-cooled CSP plant is over 30%.

Smaller power plant scale	**Plans:** Develop sCO_2 power cycles for CSP plants, with a particular focus on the primary heat exchanger. Ensure compatibility with high ramp rates and dry cooling.
	Challenges: The closed Brayton cycle using sCO_2 that is being pursued as a high efficiency cycle for a diverse set of technology areas has not yet been demonstrated in a commercial application.
	Goal: A 10 MW_{ac} sCO_2 power cycle converts thermal energy of the working fluid into alternating current (AC) power with at least 50% efficiency.
Reduced collector field cost	**Plans:** Minimize optical losses, tracking error, weight, and material costs for the collector field. Utilize extreme automation for manufacturing, assembly, and installation to reduce solar field installation time and cost.
	Challenges: Design changes that reduce the amount of material used in the collector field, or that use less expensive materials, typically have an adverse impact on tracking accuracy and thus reduce solar conversion efficiency.
	Goal: Collector fields with optical efficiency and O&M cost at least as good as 2017 benchmarks are installed for less than $50/m².
Minimize operations and maintenance costs	**Plans:** Develop improved O&M procedures by applying lessons from currently deployed heliostat and parabolic trough CSP systems.
	Challenges: Collector O&M procedures must balance many competing issues, including cleaning effectiveness, mirror degradation, plant availability, soiling, and mirror alignment. O&M associated with the high-temperature thermal transport and power blocks depends on the embodiment of those systems, which are rapidly evolving.
	Goal: Annual CSP plant fixed and variable O&M costs are less than $40/kWac and $3/MWh.

3.5.2 SOLAR INDUSTRIAL PROCESS HEAT

While SETO's focus on solar thermal energy has primarily been CSP for electricity generation, there is significant technical overlap with technology development for other solar thermal applications. Much of the design of solar thermal energy harvesting is the same whether that thermal energy is ultimately delivered to the working fluid of a turbine or to an industrial process driven by heat. Solar industrial process heat can be implemented using either a tower configuration or a parabolic trough configuration. Even parabolic dish configurations, which have not yet been proven cost-competitive for electric power generation, may find application for solar thermochemical processes.

The technology development challenges for solar industrial process heat depend on the temperature regime being targeted. Previous analysis has identified a substantial market in California for process heat between 120 and 220°C (e.g. food processing plants, paper mills, enhanced oil recovery).[15] In contrast, thermochemical applications (e.g. production of ammonia, hydrogen, energy-dense chemicals, primary metal refining) typically demand higher temperatures (600°C or higher). The first SETO funding for solar industrial process heat is a low-temperature application, with a $15M funding initiative in 2017 that focuses on applying low-cost solar collector technology for water desalination.

Table 5 lists SETO's plans for FY 2018-2022 to help the solar industry overcome barriers to the commercial success of solar industrial process heat, along with challenges that those plans must address and specific goals that can be used to track progress.

Table 5. Plans for solar industrial process heat.

Low-temperature applications (120 – 220°C)	**Plans:** Develop ultra-low-cost solar collectors with an initial emphasis on desalination. Support early-stage research on concentrating optics and thermal management.
	Challenges: Low-temperature applications require reliable, low-cost solar collector systems that can be financed for the relatively short planning horizons (5-10 years) of many industrial heat consumers. Due to the continuous nature of most industrial processes, innovation is needed in low-cost, long-term thermal energy storage to maintain uninterrupted operation.
	Goal: The cost of low-temperature solar process heat is less than 2¢/kWh_t, including sufficient energy storage to maintain continuous operation.
High-temperature applications (>600°C)	**Plans:** Analyze the quantifiable benefits of integrating solar thermal energy with thermochemical processes. Informed by those results, develop thermochemical applications with an emphasis on energy-dense chemicals. Seek to involve researchers not currently engaged in CST R&D.
	Challenges: Integration of solar thermal energy for industrial processes at high temperatures must compete on cost without the opportunity to use low-cost materials that are only compatible with lower temperatures.
	Goal: The cost of high-temperature solar process heat is less than 2¢/kWh_t, including sufficient energy storage to mitigate the impact of daily and seasonal solar variation.

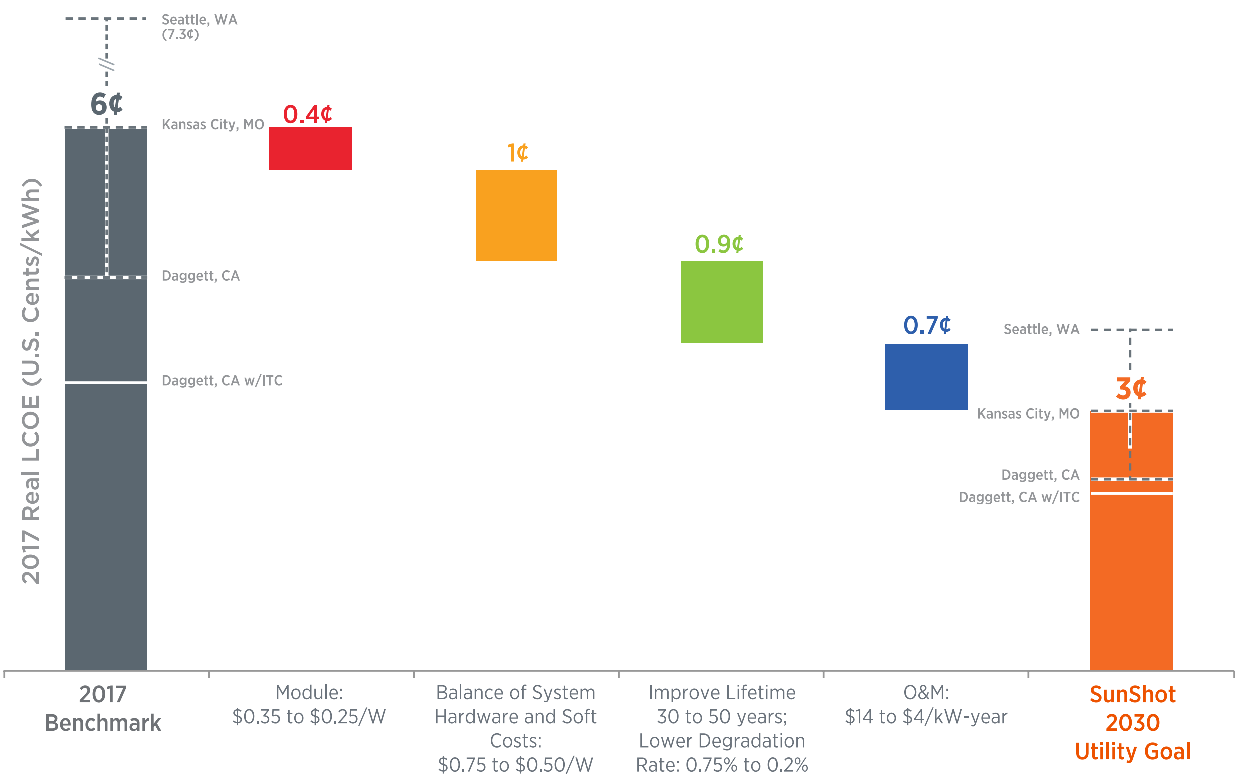
15. P. Kurup and C. Turchi, *Initial Investigation into the Potential of CSP Industrial Process Heat for the Southwest United States,* NREL Technical Report, NREL/TP-6A20-64709, 2015.

Photovoltaics

The Solar Energy Technologies Office's Photovoltaics subprogram supports the early-stage research and development of technologies to drive down the cost of solar electricity and contribute to greater energy affordability by improving efficiency and reliability and lowering manufacturing costs. The project portfolio funds innovative concepts and experimental designs across a range of technology approaches that show promise to achieve dramatic cost reductions. The scope of the projects goes beyond the industry, focusing on non-proprietary innovations that have the potential to achieve commercial success in 10-20 years. This creates an innovation ecosystem in the United States, supporting the long-term growth of the solar industry.

A Pathway to 3 Cents per KWh Utility Systems

100 $MW_{(DC)}$ One-Axis Tracking Systems With 1,860 $kWh_{(AC)}/kW_{(DC)}$ First-Year Performance. Includes 5 Year MACRS. ITC Lines Indicate Low, Median, and High U.S. Solar Resources.



The Photovoltaics subprogram maintains 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, most through the Photovoltaics suprogram and its predecessors.

Projects in the portfolio target three main areas of improvement:

INCREASING EFFICIENCY AND ENERGY YIELD: In order to make solar energy more affordable, projects are investigating the use of materials that will allow photovoltaic systems to produce more electricity from the same amount of sunlight. Current projects include the improvement of crystalline silicon cells, the most common type of solar cell on the market, by pioneering ultra-thin crystalline silicon absorber layers, passivated selective contacts, and developing module technologies that are more shade tolerant. Projects also target cadmium telluride cells, the second-most common type, by increasing the crystal quality, improving doping control, and increasing the minority carrier lifetime. Additionally, projects explore the use of tandem structures that combine two different types of solar cells into one, enabling record efficiencies.

REDUCING MATERIAL AND PROCESS COSTS: Lowering the costs of solar panels through less expensive materials and more efficient processes enables savings for consumers. Projects include working to improve ultra-thin perovskite-based solar cells, a relatively new material in the solar industry that can be deposited inexpensively from solution while attaining high efficiencies. Other projects are working to accelerate and reduce the costs of the materials growth processes that are used to manufacture solar cells of all types, including techniques to use flexible substrates and hydride vapor phase epitaxy.

UNDERSTANDING RELIABILITY AND MITIGATING DEGRADATION: Increasing the lifetimes of solar panels is a significant lever to reduce solar electricity costs. The Solar Energy Technologies Office (SETO) works on several initiatives that focus on improving panel reliability and lowering degradation rates. The Durable Module Materials (DuraMat) consortium brings together the national lab and university research infrastructure with the photovoltaic and supply-chain industries to develop and de-risk new materials with longer lifetimes. To provide better knowledge about real-life photovoltaic performance, SETO supports the Regional Test Centers across the country to test panel performance in a multitude of climates. SETO also supports national lab leadership in the Photovoltaic Module Quality Assurance Task Force, which develops international test standards necessary to validate the quality of PV modules and determine service lifetimes, as well as smaller projects aiming to better understand degradation and develop better predictive testing.

Photovoltaics projects have recently been selected through an annual Photovoltaic Research and Development (PVRD) funding program. PVRD focuses on both current and emerging technologies aimed at improving power conversion efficiency and energy output, while also enhancing service lifetime and decreasing hardware costs. In addition to traditional three-year projects, PVRD includes small, single-year projects focused on novel and/or emerging areas of photovoltaic research.

Photovoltaics

See a list of active funding programs below, followed by a description of all active Photovoltaics projects.

Funding Program	Year Announced	Amount Awarded
Photovoltaic Research and Development 2: Modules and Systems (PVRD2)	2017	$20M
Photovoltaic Research and Development (PVRD)	2016	$17M
Photovoltaic Research and Development: Small Innovative Projects in Solar (PVRD-SIPS)	2016	$2M
Physics of Reliability: Evaluating Design Insights for Component Technologies in Solar 2 (PREDICTS 2)	2015	$7M
SunShot National Laboratory Multiyear Partnership (SuNLaMP)	2015	$110M
Next Generation Photovoltaics 3 (NextGen3)	2014	$14M
Bridging Research Interactions through Collaborative Development Grants in Energy (BRIDGE)	2012	$8M

Each project is displayed as follows:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

ACTIVE COMPETITIVE AWARDS

Increasing Efficiency and Energy Yield

FAULT-TOLERANT, SHADE-TOLERANT HIGH-VOLTAGE PHOTOVOLTAIC MODULES – PVRD2-SIPS, $180,000

Arizona State University | Tempe, AZ | Principal Investigator: Stuart Bowden

This project is developing a solar cell architecture called the M-CELL, which enables higher voltage and lower current than conventional modules. The M-CELL architecture results in a single silicon wafer on which multiple cells are monolithically integrated and interconnected in series. This project is researching the series connection configuration, current-voltage characteristics, shadowing reduction, and impact of higher voltage on power losses of this early-stage technology.

FIFTEEN PERCENT EFFICIENT (MAGNESIUM, ZINC) CADMIUM TELLURIDE SOLAR CELLS WITH 1.7 EV BANDGAP FOR TANDEM APPLICATIONS – PVRD, $400,000

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

This project aims to demonstrate solar cells based on wide bandgap cadmium telluride alloys that will eventually enable the fabrication of highly efficient tandem photovoltaic cells in combination with a silicon bottom cell. The photovoltaic market is dominated by silicon and cadmium telluride technologies, which have become low-cost and reliable in the last decade but are nearing their individual efficiency limits. This project works to boost the eventual efficiency of photovoltaic systems by beginning the process of allowing cadmium telluride and silicon to function together to efficiently harvest the solar spectrum, potentially enabling a 20 percent decrease in the cost of installed systems.

NON-CONTACT SIMULTANEOUS STRING-MODULES I-V TRACER – PVRD2, $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 will enable accurate degradation science and fielded performance monitoring to be conducted on modules under operation.

PLANT AND MODULE DESIGNS FOR UNIFORM AND REDUCED OPERATING TEMPERATURE – PVRD, $899,316

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

This project intends to identify and evaluate thermally conductive and radiative but electrically insulating backsheets, which can be used by module manufacturers to reduce future solar levelized cost of energy values. Based on the typical temperature coefficients of standard multicrystalline modules, it is possible for conventional rooftop crystalline silicon modules to lose as much as 30 percent of power and the open rack crystalline silicon modules to lose as much as 20 percent power on hot summer days in sunny and/or desert locations. This project intends to reduce the levelized cost of solar energy by lowering module operating temperatures, reducing reliability failures, and reducing degradation rates to improve system lifetimes.

PUSHING THE LIMITS OF SILICON HETEROJUNCTION SOLAR CELLS: DEMONSTRATION OF 26 PERCENT EFFICIENCY AND IMPROVING ELECTRICAL YIELD – PVRD, $837,044

Arizona State University | Tempe, AZ | Principal Investigator: Stuart Bowden

This project examines the manufacturability of n-type industrial silicon heterojunction cells and develops methods to improve energy yield and increase the appeal of this type of cell to manufacturers. The research performed will help to improve cell efficiency by two percent and reduce the cost of the cells by improving electrical yield based on a range of new processing improvements. The project also aims to demonstrate the feasibility of using thinner cells to increase the lifetime of the wafer and achieve a 26 percent record efficiency. The knowledge gleaned from this research is expected to help improve the manufacturing of silicon heterojunction cells in the next five years.

DEVICE ARCHITECTURE FOR NEXT-GENERATION CADMIUM TELLURIDE PHOTOVOLTAICS – PVRD, $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 thin-film polycrystalline 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.

PUSHING THE EFFICIENCY LIMIT OF LOW-COST, INDUSTRIALLY-RELEVANT SILICON SOLAR CELLS BY ADVANCING CELL STRUCTURES AND TECHNOLOGY INNOVATIONS – PVRD, $1,125,000

Georgia Tech Research Corporation | 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.

TUNNELING BACK-CONTACTED SILICON PHOTOVOLTAICS – PVRD2-SIPS, $117,291

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

This project is investigating the introduction of atomic layer deposited tunnel barriers that simultaneously allow carrier flow and passivate the silicon surface for silicon-based solar cells. The tunnel barrier is combined with metal oxide materials that selectively transport electrons or holes. This work employs and atomic layer for the deposition of these thin film layers, which is a potentially scalable technique capable of uniform sub-nanometer control of film thickness, even on non-planar substrates. This work quantifies the electronic behavior of these contacts, which may establish some of the most efficient electrical contacts to silicon photovoltaics to date.

SELECTIVE AREA GROWTH OF III-V MATERIALS ON SILICON PATTERNED WITH NANOIMPRINT LITHOGRAPHY – NEXTGEN3, $1,500,000

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

This project mitigates the issues surrounding the integration of III-V and silicon into solar modules by incorporating a nano-patterned buffer layer that results in a low-cost method for selective area growth of lattice mismatched triple junction solar cells. This will help to reduce defect density in the top cell and on the silicon interface, preserve silicon interface passivation, and provide a platform to integrate nano-photonic light management for enhanced cell performance. The nano-patterning and growth techniques developed by this project will be compatible with industrial photovoltaic manufacturing.

ULTRA HIGH-EFFICIENCY AND LOW-COST POLYCRYSTALLINE HALIDE PEROVSKITE THIN-FILM SOLAR CELLS – NEXTGEN3, $1,360,000

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

This project is developing high-efficiency single-junction perovskite solar cells, helping to gain an understanding of basic material and device properties related to halide perovskites, which will lead to the demonstration of ultra-high efficiency tandem thin-film devices. Researchers are using two complementary methods: solution processing and co-evaporation deposition. Theoretical modeling is being conducted to understand doping/defect physics for perovskites, while information learned on doping physics, defect chemistry, and device modeling will be made available to the photovoltaic community and will support solar manufacturers and start-ups looking for their next-generation photovoltaic products.

OPTIMIZED, LOW-COST, HIGHER THAN 30 PERCENT EFFICIENT INDIUM GALLIUM ARSENIDE PHOSPHIDE AND SILICON TANDEM SOLAR CELLS – NEXTGEN3, $1,500,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Aaron Ptak

This project is developing indium gallium arsenide phosphide and silicon tandem photovoltaic technology that leverages extremely high efficiency devices and low-cost, high-throughput methods to meet and exceed cost targets. Researchers are conducting controlled liftoff of III-V devices grown on germanium substrates with attention toward device quality, substrate reuse, and manufacturability, while also developing a low-cost, high-throughput growth of highly efficient III-V solar cells with the optimal bandgap, which will achieve the maximum efficiency from a two-junction structure. In addition, this project is attempting a proof-of-concept integration to illustrate that the technology is capable of achieving a conversion efficiency of more than 30 percent.

TANDEM SOLAR CELLS: PATHWAY TO LOW-COST, HIGH-EFFICIENCY PHOTOVOLTAICS – PVRD, $1,124,999

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

This project is developing a monolithic tandem solar cell with gallium arsenide phosphide on silicon wafer substrates aimed at an efficiency of at least 30 percent. The cell will be produced using scalable and manufacturable processes, which will be accomplished through optimization of the current prototype cell, including the demonstration of structures that are ideally suited for maximized silicon-based tandem manufacturing. A mature tandem cell could then be manufactured at scale via existing silicon and III-V tooling and infrastructure, greatly reducing capital expenditures and revitalizing existing manufacturing industries.

ENHANCED CONVECTION FOR HIGHER MODULE AND SYSTEM EFFICIENCY – PVRD2, $800,000

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 – PVRD2, $551,644

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.

PEROVSKITE ON SILICON TANDEM SOLAR CELLS – PVRD2, $1,365,306

Stanford University | Stanford, CA | Principal Investigator: Michael McGehee

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.

CROSSCUTTING RECOMBINATION METROLOGY FOR EXPEDITING OPEN-CIRCUIT VOLTAGE ENGINEERING – PVRD, $1,025,000

Texas State University | San Marcos, TX | Principal Investigator: Jian Li

This project is developing a comprehensive characterization methodology for extracting recombination rates in thin-film solar cells as a function of depth into the device. The advanced metrology methods developed as part of this project will ideally allow researchers and manufacturers to identify problem areas in their materials to a depth resolution of a few dozen nanometers and correct their procedures accordingly. The proposed methodology will also allow for the viability of certain interfaces and contact structures to be examined at a greater level of detail than has previously been available based on existing optoelectronic methods.

ENABLING EFFICIENCIES GREATER THAN 22.5 PERCENT WITH METAL OXIDE PASSIVATED CONTACTS USING LOW-COST, IN-LINE, ATMOSPHERIC PRESSURE CHEMICAL VAPOR DEPOSITION – PVRD, $1,125,000

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

This project aims to increase module efficiency and reduce manufacturing costs by transferring lab-scale heterojunction passivated contact technology into the high-volume manufacturing of industrial-scale crystalline silicon cells. The target efficiency for these cells is 22.5 percent, which will create a lower cost alternative to cells currently on the market by reducing the wafer-to-cell conversion cost by 13 percent compared to current manufacturing methods.

LEVELIZED COST OF ENERGY REDUCTION THROUGH PROACTIVE OPERATIONS OF PHOTOVOLTAIC SYSTEMS – PVRD2, $1,599,821

University of Central Florida | Cocoa, 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.

RESEARCH AND DEVELOPMENT OF ARCHITECTURES FOR PHOTOVOLTAIC CELL-LEVEL POWER BALANCING USING DIFFUSION CHARGE REDISTRIBUTION – PVRD, $807,817

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 J-V characteristics a string of solar cells into a well-behaved "super-cell" that eliminates cell power imbalances, mismatches, and partial failures.

DEVELOPING EFFICIENT PEROVSKITE AND SILICON TANDEM DEVICES – NEXTGEN3, $1,211,075

University of Nebraska | Lincoln, NE | Principal Investigator: Jinsong Huang

This project is developing tandem junction solar cells with organo-lead trihalide perovskites, using high-efficiency perovskite cells as the top cell and crystalline silicon cells as the bottom cell. Project investigators are creating a novel top cell system that is compatible to the bottom high-efficiency crystalline silicon solar cell. The original design will boost the power conversion efficiency of silicon solar cells with minimal cost increases.

COLLABORATIVE ATOMIC-SCALE DESIGN, ANALYSIS, AND NANOFABRICATION FOR RECORD BREAKING, SINGLE-CRYSTAL CELLS – BRIDGE, $895,908

University of Texas at El Paso | El Paso, TX | Principal Investigator: David Zubia

This project allows researchers to use Los Alamos National Laboratory's Center for Integrated Nanotechnologies facility to create a molecular dynamics simulation capability to address fundamental barriers to achieving high open-circuit voltages in cadmium telluride or cadmium sulfide solar cells.

SPREAD SPECTRUM TIME DOMAIN REFLECTIVITY FOR STRING MONITORING IN PHOTOVOLTAIC POWER PLANTS – PVRD2, $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.

RAPID DEVELOPMENT OF HYBRID PEROVSKITES AND NOVEL TANDEM ARCHITECTURES – NEXTGEN3, $1,500,000

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

This project is developing high-bandgap hybrid perovskite materials and a novel two-terminal monolithic tandem device architecture that are capable of reaching power conversion efficiencies of higher than 25 percent. Researchers are rapidly discovering compositions and processing conditions that yield high-optoelectronic-quality hybrid perovskite films with the ideal bandgap to pair with record efficiency copper indium gallium selenide and copper zinc tin sulfide selenide absorbers. In addition, the team is engineering stable and efficient electron transport materials, hole transport materials, and interfaces to achieve better band alignment and passive interfaces for the hybrid perovskite top cell, as well as developing alternative structures and recombination layers to facilitate the fabrication of a tandem structure.

Reducing Material and Process Costs

DIRECT METALLIZATION WITH REACTIVE INKS: ASSESSMENT OF RELIABILITY AND PROCESS SENSITIVITIES – PVRD2, $1,400,000

Arizona State University | Tempe, AZ | 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.

ELECTROPLATED ALUMINUM - AN ALTERNATIVE TO COPPER OR SILVER ELECTRODE IN SILICON SOLAR CELLS – PVRD2-SIPS, $225,000

Arizona State University | Tempe, AZ | Principal Investigator: Meng Tao

This project is developing a simple, two-layer aluminum electrode to substitute the silver electrode in silicon solar cells. This includes the examination of electroplating to significantly reduce processing costs, improve module reliability and lifetime, and maintain high cell efficiency.

MONOLITHIC SILICON MODULE MANUFACTURING AT UNDER $0.40 PER WATT – PVRD, $800,000

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

This project aims to lower the cost of photovoltaic (PV) electricity generation in fewer than five years to $0.04 per kilowatt hour through the development of a photovoltaic module that is based on back-contact silicon solar cells, which have interdigitated metal fingers on their rear sides and no metal on their front sides. The cells in this project will not have any metal; instead, they will be interconnected with a "flex-circuit" consisting of two layers of aluminum foil separated by an insulating spacer layer. This design reduces the amount of silver or copper used in modules and eliminates solder points that are prone to failure. Researchers will focus on cell interconnection, module assembly, module reliability testing, and techno-economic analysis.

SOUND ASSISTED LOW TEMPERATURE (SALT) SPALLING: UPSCALING AND THROUGHPUT – PVRD2-SIPS, $222,519

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

Exfoliating a wafer from a silicon block, known as spalling, has been shown to be a promising kerfless, or waste-saving, technique in wafer production. This project is researching an early-stage, novel spalling process called sound-assisted low-temperature spalling to address defects, wafer thickness, and surface planarity through the use of acoustic waves to sharpen and facilitate crack formation during the spalling process.

NEW APPROACHES TO LOW-COST SCALABLE DOPING FOR INTERDIGITATED BACK CONTACT CRYSTALLINE SILICON SOLAR CELLS – PVRD, $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 achieve 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 will develop a photo-assisted, area-selective patterning method that produces high-quality devices and is highly scalable for large-area manufacturing at reduced cost.

PEROVSKITE SOLAR CELLS: ADDRESSING LOW-COST, HIGH-EFFICIENCY, AND RELIABILITY THROUGH NOVEL HOLE TRANSPORT MATERIALS – PVRD2-SIPS, $192,529

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

A very important component of a perovskite solar cell is the hole transport layer, which is generally an expensive and a relatively unstable component of this early-stage technology. Currently, the state-of-the-art hole transport layer is based on a lithium salt doped aromatic amine that is very difficult to prepare and has no paths to becoming cost-effective at high volume. This project is researching new hole transport layer materials for perovskite solar cells to address the current bottlenecks, such as cost, tunable conductivity and energy levels, hydrophobicity, lithium-free dopants, and stability.

HIGH LIFETIME AND MOBILITY CADMIUM TELLURIDE ALLOYS BY CO-SUBLIMATION – PVRD2-SIPS, $162,702

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

Researchers are investigating the composition and grading of cadmium selenium telluride material to understand how it changes the performance and material properties of absorber layers. The effects of novel surface passivation techniques on carrier lifetime and other device properties will also be investigated. Material and device characterization will provide insight to the unique properties of these new materials and architectures. The project aims to produce record carrier lifetimes for cadmium telluride based devices.

HIGH-PERFORMANCE PEROVSKITE-BASED SOLAR CELLS – NEXTGEN3, $1,300,002

Duke University | Durham NC | Principal Investigator: David Mitzi

This project supports the development of lead-halide-based perovskites in order to make these devices more suitable for commercialization. Researchers are optimizing the device efficiency at the cell level in order for the promise of an ultra-low-cost technology to be realized, pursuing a lead replacement, and improving the stability of the materials and devices towards moisture, air, and temperature.

ADHESIVE MOUNTING OF CONVENTIONAL PHOTOVOLTAIC MODULES FOR RESIDENTIAL SOLAR – PVRD2, $800,000

Fraunhofer USA Inc., Center for Sustainable Energy Systems | Boston, MA | Principal Investigator: Christian Honeker

This project aims to reduce the installation cost of photovoltaic systems by researching a non-penetrating adhesive mounting interface for securing conventionally framed and glass-glass modules to asphalt shingles. Key areas of investigation include characterizing and understanding the direction and balance of forces between the proposed adhesive chemistry and the target surface, and the physical changes that take place in the mounting materials over time. Eliminating penetrating adhesives has the potential to mitigate the risk of expensive roof leaks, speed module mounting, and reduce the training requirements of the installer.

LOW-COST TOOL DESIGN FOR CELL AND MODULE FABRICATION WITH THIN, FREE-STANDING SILICON WAFERS – PVRD, $1,125,003

Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Tonio Buonassisi

This project aims to reduce the barriers to inexpensive photovoltaic module manufacturing by de-risking key technology elements necessary to enable manufacturing with lower capital costs. The project team is focusing its efforts on crack detection and metallization techniques to enable high yield wafer, cell, and module fabrication with thin, free-standing silicon wafers. Thin wafers dramatically reduce the amount of polysilicon required and increase growth-system productivity, thereby reducing the capital expenditures associated with silicon refining and wafer fabrication, which together are more than half of the total capital costs of silicon module manufacturing.

TWO-DIMENSIONAL MATERIAL-BASED LAYER TRANSFER FOR LOW-COST, HIGH-THROUGHPUT, HIGH-EFFICIENCY SOLAR CELLS – PVRD2-SIPS, $225,000

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

This project is developing an innovative method to reduce or eliminate the cost of expensive substrate materials, which are generally used to grow high-efficiency solar cells. The research team is using a single crystal substrate coated with a single layer of graphene to achieve the required cost reduction that helps to make III-V solar cells a realistic option for commercial use. Once the concept is realized, a substrate containing graphene will provide releasable high-efficiency, single-crystalline, gallium arsenide solar cells and a reusable wafer substrate.

CONTINUOUS SILICON REDUCTION AND CONSOLIDATION – PVRD, $900,000

SRI International | Menlo Park, CA | Principal Investigator: Marc Hornbostel

This project investigates a continuous silicon reduction and consolidation process to reduce the capital, material, and energy costs associated with producing high-purity polysilicon. The new method will use low-cost precursors and has the capability to recycle silicon fines, which are a common waste product of fluidized bed reactors and wafer sawing. This technology has the capability of reducing module costs by up to 10 percent based on reducing the cost of the polysilicon feedstock used to grow silicon bricks and ingots.

ALIGNED WIRE METALLIZATION AND STRINGING FOR BACK CONTACT SOLAR CELLS – PVRD2, $1,200,000

SunPower Corporation | San Jose, CA | Principal Investigator: Richard Sewell

Solar modules based on interdigitated back contact solar cells provide the highest efficiency and reliability currently available in the market. Despite the fundamental advantages of these modules, they are costly due to the complexity of the cell manufacturing process. This project aims to use newly conceived surface bonding procedures to completely change the approach to cell metallization and interconnection that is used to produce interdigitated back contact modules, which has the potential to reduce the number of relevant process steps by more than 50 percent and significantly reduce the cost of module fabrication.

INDUSTRIALLY FEASIBLE, DOPANT-FREE ASYMMETRIC HETEROCONTACT SILICON SOLAR CELLS – PVRD2-SIPS, $225,000

University of California, Berkeley | Berkeley, CA | Principal Investigator: Ali Javey

This project is investigating novel dopant-free, asymmetric heterocontact solar cells to understand the heterocontact material properties needed for compatible metallization and encapsulation processes. Early stage materials research is being performed to optimize cell architectures and materials in order to increase stability. The end goal of this project is to demonstrate a reliable cell with no significant drop in performance after back-end processing and 1,000 hours at 85° Celsius and 85 percent relative humidity damp heat testing.

ISOVALENT ALLOYING AND HETEROVALENT SUBSTITUTION FOR SUPER-EFFICIENT HALIDE PEROVSKITE PHOTOVOLTAIC SOLAR CELLS – PVRD2-SIPS, $225,000

University of Colorado | Boulder, CO | Principal Investigator: Alex Zunger

The primary goal of this early-stage research is to build upon solid state and semiconductor knowledge to improve understanding, design, optimization, and validation of isovalent perovskite alloys. The research team is applying theoretical and computational methods to examine next-generation double perovskites, which replace element pairs with heterovalent pairs, and to collaborate with experimentalists to study the most promising candidates for photovoltaic absorber materials based on their stability and electronic structure. The theory of alloys, defects, novel materials, and materials-by-design will be used to overcome limitations in absorber stability in the application of isovalent alloys and heterovalent-substituted halide perovskites for photovoltaic applications.

HIGH-EFFICIENCY, INEXPENSIVE THIN FILM III-V PHOTOVOLTAICS USING SINGLE-CRYSTALLINE-LIKE, FLEXIBLE SUBSTRATES – NEXTGEN3, $1,499,994

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

This project is working to achieve a drastic reduction in the cost of III-V solar cells through a combination of high efficiency and low manufacturing costs. Researchers are depositing III-V thin films on flexible metal substrates that have been textured via ion beam assisted deposition using roll-to-roll processing.

RELIABLE AND LARGE ORGANIC SOLAR CELLS ON FLEXIBLE FOIL SUBSTRATES – NEXTGEN3, $1,350,000

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

This project is advancing the practical viability of organic photovoltaics by demonstrating reliable, large area, and high-efficiency organic multi-junction cells based on small molecule materials systems. The project aims to demonstrate multi-junction organic solar cells with efficiencies of higher than 18 percent, extrapolated cell lifetimes exceeding 20 years, ultra-rapid organic film deposition on continuous rolls of foil substrates, and roll-to-roll application of package encapsulation.

DEVELOPING A LOW-COST, HIGH-VOLUME AND SCALABLE MANUFACTURING TECHNOLOGY FOR CADMIUM TELLURIDE FEEDSTOCK MATERIALS – PVRD, $1,124,992

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 will be 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.

Understanding Reliability and Mitigating Degradation

CORRELATION OF QUALIFICATION TESTING WITH FIELD DEGRADATION – PREDICTS 2, $798,934

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

This project aims to obtain the correlation for the degradation modes typically observed in hot-dry, hot-humid, and cold-dry climates. The major degradation modes in these climates include: encapsulant discoloration, delamination at interfaces, metallization, solder bond and interconnect fatigue, cracks and corrosion. In the qualification testing, the primary environmental accelerated tests, which are related to the above climates and degradation modes, are: thermal cycling, damp heat, and humidity freeze. Therefore, the correlative study focuses only on these three environmental tests of the qualification testing programs. The potential impact of the proposed project is to obtain climate-specific and construction-specific acceleration factors for the current accelerate qualification tests.

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

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

This project is improving photovoltaic module reliability by developing a model to predict silicon module degradation. Once finalized, the modeling tool will evaluate the effects of sodium-induced degradation on materials in different operating conditions. The model will be able to evaluate the impact of a variety of contaminants, including potassium, though sodium is widely known to be responsible for major potential-induced degradation losses. The goal is to assist the selection and engineering of better encapsulation materials, dielectrics, contacting schemes, and device architectures based on the reliable performance of the device.

OPERANDO X-RAY NANOCHARACTERIZATION OF POLYCRYSTALLINE THIN FILM MODULES – PVRD2, $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 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.

QUANTUM ENERGY AND SUSTAINABLE SOLAR TECHNOLOGIES (QESST) - $17,487,800

Arizona State University | Tempe, AZ | Principal Investigator:

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 PV cell architectures on traditional silicon utilizing thin-film or III-V absorbers, and improving the performance of PV using test beds that can demonstrate manufacturability, integration, and sustainability of solar technologies. In addition to this research, QESST develops solar and PV 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 PV generation in 15 to 20 years.

SOLUTION FOR PREDICTIVE PHYSICAL MODELING IN CADMIUM TELLURIDE AND OTHER THIN-FILM PHOTOVOLTAIC TECHNOLOGIES – PVRD, $812,998

Arizona State University | Tempe, AZ | Principal Investigator: Dragica Vasileska

This project aims to develop a software tool to enable a more accurate interpretation of thin-film photovoltaic device performance and material properties, with the goal of enabling predictive device design. The software includes a modeling tool that connects atomic diffusion and drift to device performance. This model will allow researchers to simulate recombination losses over time in II-VI absorber materials, such as cadmium telluride, using different doping profiles, process and stress conditions, and grain boundary or interface geometries.

IMPROVING SOLAR PANEL DURABILITY THROUGH NOVEL PANEL DESIGNS AND ADVANCED MANUFACTURING EQUIPMENT – PVRD2, $600,000

BrightSpot Automation LLC | 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.

MODULE-LEVEL EXPOSURE AND EVALUATION TEST FOR OUTDOOR AND INDOOR PHOTOVOLTAIC MODULES – PREDICTS 2, $1,350,000

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

This project is correlating photovoltaic module degradation from accelerated tests and fielded module data to develop models with chemical and physical mechanistic detail in order to improve prediction of photovoltaic lifetime performance. Understanding and quantifying degradation can reduce the final cost of the system by reducing financing costs and uncertainty.

RELIABILITY AND POWER DEGRADATION RATES OF PASSIVATED EMITTER REAR CONTACT MODULES USING DIFFERENTIATED PACKAGING STRATEGIES AND CHARACTERIZATION TOOLS – PVRD2, $1,465,291

Case Western Reserve University | Cleveland, OH | Principal Investigator: Roger H. 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 will be used to understand the dominant physical degradation mechanisms that occur in the field for a variety of encapsulant and backsheet combinations. These models will 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.

REVEALING THE MECHANISM OF LIGHT INDUCED DEGRADATION AND REGENERATION OF P-TYPE CZOCHRALSKI SILICON – PVRD2-SIPS, $225,000

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

This project employs advanced spectroscopic tools to explore boron-oxygen related defects in p-type Czochralski monocrystalline silicon that informs processing strategies to permanently suppress these defects and improve cell efficiency. Early-stage materials research is improving understanding of the hydrogenation and dehydrogenation of boron-oxygen complexes, and light-stimulated electron spin resonance methods is clarifying their bonding configurations and evolution during intense illumination.

ADVANCED MODULE ARCHITECTURE FOR REDUCED COSTS, HIGH DURABILITY, AND SIGNIFICANTLY IMPROVED MANUFACTURABILITY – PVRD2, $1,125,000

Colorado State University | Fort Collins, CO | Principal Investigator: Kurth 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 will provide 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 accelerating testing.

GENERALIZABLE MECHANISTIC UNDERSTANDING OF MODULE-LEVEL LIGHT-, HEAT- AND HUMIDITY-INDUCED INSTABILITY – PREDICTS 2, $1,349,998

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

This project is working to eliminate detrimental changes in copper indium gallium selenide solar modules and better characterize the expected performance of a given product by studying degradation processes.

DIRECT CURRENT ARC-FLASH SAFETY FOR 1,500 VOLTS: METHODOLOGY, VERIFICATION, AND CODIFYING – PVRD2, $1,010,726

Electric Power Research Institute | Charlotte, NC | 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.

NOVEL ACCELERATED AGING PROTOCOLS FOR PHOTOVOLTAIC MODULES – PREDICTS 2, $1,042,496

Electric Power Research Institute | Palo Alto, CA | Principal Investigator: Cara Libby

This project is advancing the state of the art of module certification and degradation certainty. The project is also advancing the knowledge base of on-site plant monitoring and proactive maintenance in order to maximize energy production and profitability of photovoltaic power plants.

NON-DESTRUCTIVE EVALUATION OF WATER INGRESS IN PHOTOVOLTAIC MODULES – PREDICTS 2, $570,000

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

A better understanding of the water diffusion process substantiated by experimental data analysis from deployed modules has the potential to improve both reliability and performance of photovoltaic modules. This project is developing a non-invasive optical detection technique based on hyperspectral near infrared imaging of modules.

LOW-COST SCAFFOLD-REINFORCED PEROVSKITE SOLAR MODULES WITH INTEGRATED LIGHT MANAGEMENT – PVRD2-SIPS, $225,000

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

Novel hybrid perovskites hold great promise for early-stage, next-generation solar cells. However, the mechanical fragility, chemical instability, and moisture sensitivity of the current organometal trihalide perovskites will need to be addressed to ensure a competitive advantage. This project focuses on researching a revolutionary new compound solar cell module design based on a recent breakthrough in Stanford's lab—using an innovative patterned hexagonal reinforcing scaffold filled with perovskite—that mitigates the chemical, thermal, and mechanical degradation of planar perovskite solar cells.

PREDICTIVE MODELS AND NOVEL ACCELERATED TESTS FOR THE RELIABILITY OF CELL METALLIZATION AND SOLDER JOINT FAILURES – PREDICTS 2, $1,350,000

SunPower Corporation | San Jose, CA | Principal Investigator: Staffan Westerberg

This project examines two key failure modes of metallization interconnect reliability: metallization corrosion and solder joint failures. The key outcomes will be predictive models for metallization corrosion and solder joint failures to aid in the design of reliable interconnects and predictive and faster accelerated tests useful for qualification, certification, and ongoing reliability.

BACKSHEETS: CORRELATION OF LONG-TERM FIELD RELIABILITY WITH ACCELERATED LABORATORY TESTING – PREDICTS 2, $1,349,746

Underwriters Laboratories | San Jose, CA | Principal Investigator: Ken Boyce

This project is advancing the mechanistic understanding of photovoltaic module backsheet degradation in fielded modules and developing improved laboratory weathering exposures with results correlated to field performance.

UNDERSTANDING AND OVERCOMING WATER-INDUCED INTERFACIAL DEGRADATION IN SILICON MODULES – PVRD2, $750,000

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 connect the presence of water to acceleration in performance degradation. The quantitative understanding of water ingress and its effect on module performance will enable mitigation strategies extending lifetime of photovoltaic modules and thereby lowering solar costs.

CHARACTERIZATION OF CONTACT DEGRADATION IN CRYSTALLINE SILICON PHOTOVOLTAIC MODULES – PVRD2, $1,581,442

University of Central Florida | Cocoa, 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.

IMPROVING RELIABILITY AND REDUCING COST IN CADMIUM TELLURIDE PHOTOVOLTAICS VIA GRAIN BOUNDARY ENGINEERING – PVRD, $959,400

University of Chicago | Chicago, IL | Principal Investigator: Robert Klie

This project is developing an innovative approach to understand and eliminate the detrimental effects of grain boundaries in poly-crystalline thin-film cadmium telluride solar cells. The project team will examine how grain boundaries play a role in limiting the open circuit voltage, performance, and reliability and leverage insight from fundamental atomic and electronic studies.

IMPROVED PERFORMANCE AND RELIABILITY OF PHOTOVOLTAIC MODULES USING THE REACTION OF METAL PRECURSORS – PVRD, $800,000

University of Delaware | Newark, DE | Principal Investigator: William Shafarman

This project is working to improve the performance and reliability of thin-film copper indium gallium sulfide selenide cells. The team is developing innovative approaches to improve the deposition and device fabrication to provide a pathway to significant reduction in solar costs. By focusing on processes and materials with low manufacturing cost and that are already used in commercial production, the project expects to directly impact the market and advance copper indium gallium sulfide selenide technology toward a levelized cost of energy of $0.06 per kilowatt-hour.

RAPID PATTERNING AND ADVANCED DEVICE STRUCTURES FOR LOW-COST MANUFACTURABLE CRYSTALLINE SILICON INTERDIGITATED BACK CONTACT CELLS – PVRD, $1,124,491

University of Delaware | Newark, DE | Principal Investigator: Steven Hegedus

This project is developing a new method for the manufacturing of interdigitated back contact solar cells with metal contacts on the backside of the wafer, which allows for greater light harvesting on the front surface due to the absence of grid shadowing. The new process will use direct laser patterning of the metal electrodes to isolate the positive and negative contacts, as well as laser firing of dopants to create localized contacts regions between the metal and the silicon wafer. The result will be a lower-cost silicon manufacturing process and device structure that will lead to an interdigitated back contact solar cell with 25 percent efficiency.

METASTABILITY, POTENTIAL INDUCED DEGRADATION, DAMP HEAT DEGRADATION AND RECOVERY IN COPPER INDIUM GALLIUM SELENIDE DEVICES: EFFECT OF ALKALI – PVRD, $900,403

University of Nevada, Las Vegas | Las Vegas, NV | Principal Investigator: Shubhra Bansal

This project is working to understand degradation that occurs in copper indium gallium selenide solar cells. These devices can suffer from degradation due to high temperatures, damp heat, or high system voltage. Developing a further understanding of why degradation occurs in these environments will allow scientists and engineers to develop copper indium gallium selenide products that are able to withstand these elements and have lower degradation rates, leading to a lower cost of solar energy.

ACTIVE LAB AWARDS

Increasing Efficiency and Energy Yield

ADVANCED THERMAL MANAGEMENT FOR HIGHER MODULE POWER OUTPUT – SUNLAMP, $2,816,911

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Tim Silverman

This project enables lower operating temperatures for modules resulting in higher module power output and lower levelized cost of electricity. This will be accomplished by developing a thermal model for photovoltaic modules and modified passive cooling packaging to lower the module temperature when overheated.

CELL AND MODULE PERFORMANCE CHARACTERIZATION – SUNLAMP, $9,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Dean Levi

This project supports the cell and module measurement lab, which provides the only recognized, accredited efficiency measurements in the United States for the photovoltaics industry, and provides direct support to all SETO programs through independent efficiency measurements and reference cell calibrations.

CORRELATIVE ELECTRONIC SPECTROSCOPIES FOR INCREASING PHOTOVOLTAIC EFFICIENCY – SUNLAMP, $2,000,000

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

The project is developing fast, no-contact optical metrology methods to detect optically active defects in thin-film materials and map recombination velocities at shallow interfaces. These techniques will speed up the diagnostics and optimization of thin-film absorber materials and interfaces.

DEFINING THE DEFECT CHEMISTRY AND STRUCTURAL PROPERTIES REQUIRED FOR 24 PERCENT EFFICIENT CADMIUM TELLURIDE DEVICES – SUNLAMP, $6,900,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Wyatt Metzger

This project is improving the defect chemistry and structural properties of polycrystalline cadmium telluride necessary to overcome photovoltage barriers and enable 24 percent efficiency. This project will advance the use of doping in polycrystalline cadmium telluride and improve the way that the community passivates and characterizes grain boundaries. New dopants, new post-processing methods, and new characterization tools and models will be developed and novel device architectures will be explored.

ENABLING HIGH-CONCENTRATION PHOTOVOLTAICS WITH 50 PERCENT EFFICIENT SOLAR CELLS – SUNLAMP, $8,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: John Geisz

This project is pushing the limits of high-concentration III-V multi-junction solar cell technology by designing and building five- and six-junction solar cells that can exceed 50 percent efficiency under concentrator standard testing conditions. The project aims to develop new physical understanding and break the worldwide photovoltaic efficiency records.

INTERFACE SCIENCE AND ENGINEERING FOR RELIABLE, HIGH-EFFICIENCY CADMIUM TELLURIDE – SUNLAMP, $4,900,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Wyatt Metzger

Surface and interface recombination become more detrimental to cadmium telluride device performance as lifetime increases. This project is developing effective surface passivation and carrier selective contacts for higher efficiency, improved reproducibility, and increased stability.

MECHANICALLY STACKED HYBRID PHOTOVOLTAIC TANDEMS – SUNLAMP, $999,999

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kirstin Alberi

This project is developing a gallium indium phosphide on silicon mechanically stacked voltage-matched tandem, aiming at low cost and high efficiency. The project will result in one of the first published demonstrations of voltage-matched modules, an assessment of the advantages and disadvantages of the new architecture, and its promise for module design.

OVERCOMING BOTTLENECKS TO LOW-COST, HIGH-EFFICIENCY SILICON PHOTOVOLTAIC AND INDUSTRIALLY-RELEVANT, ION-IMPLANTED, INTERDIGITATED BACK-PASSIVATED-CONTACT CELL DEVELOPMENT – SUNLAMP, $9,999,235

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

This project is working to enable high-throughput, lower-cost, higher-efficiency silicon photovoltaics by advancing interdigitated back-contact n-type Czochralski silicon cells, targeting 23 percent efficient cells. This includes the development of non-proprietary high-efficiency silicon technology, which would reduce the barriers for companies to have high-efficiency silicon cells.

SILICON-BASED TANDEM SOLAR CELLS – SUNLAMP, $1,500,000

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

This project is working to demonstrate bonded gallium indium phosphide on silicon tandem cells, evaluate the advantages and disadvantages of this method of forming higher-efficiency tandem cells, and compare two- and three-terminal device configurations.

UTILIZING EMERGENT MATERIAL PROPERTIES AND NOVEL DEVICE ARCHITECTURES FOR ADVANCING ORGANIC PHOTOVOLTAICS – SUNLAMP, $2,000,000

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

This project is designing and developing efficient, stable, and inexpensive organic photovoltaics. It will also make the lab's organic photovoltaic database available to the public online at organicelectronics.nrel.gov.

PERFORMANCE MODELS AND STANDARDS FOR BIFACIAL PHOTOVOLTAIC MODULE TECHNOLOGIES – SUNLAMP, $3,000,000

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

Bifacial photovoltaic technology is available today, but due to its more complex light collecting dynamics, its performance advantages have not been fully exploited and commonly available tools do not allow it to be considered for major projects beyond current niche applications. Unpublished field data indicates that this technology has the potential to increase system outputs by 10-30 percent. This project provides the data, standard test methods, and validated models to allow developers to fairly evaluate the potential benefits bifacial photovoltaic technologies for specific projects.

HIGH-RESOLUTION INVESTIGATIONS OF TRANSPORT LIMITING DEFECTS AND INTERFACES IN THIN-FILM PHOTOVOLTAIC DEVICES – SUNLAMP, $1,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Helio Moutinho

This project is developing a capability of high-resolution transport imaging in photovoltaic devices, which is useful for improving polycrystalline thin-film photovoltaic materials.

Reducing Material and Process Costs

2D MATERIALS FOR LOW COST EPITAXIAL GROWTH OF SINGLE SUN GALLIUM ARSENIDE PHOTOVOLTAICS – SUNLAMP, $125,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andrew Norman

The project is developing low-cost two-dimensional material substrates to template the growth of gallium arsenide.

HIGH-EFFICIENCY, LOW-COST, ONE-SUN, III-V PHOTOVOLTAICS – SUNLAMP, $4,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Aaron Ptak

This project continues development of hydride vapor phase epitaxy growth coupled with novel epitaxial liftoff strategies toward low-cost multi-junction III-V photovoltaics.

HYBRID PEROVSKITE SOLAR CELLS – SUNLAMP, $4,000,000

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

This project is working to demonstrate efficient, stabile, and scalable hybrid perovskite solar cells, rapidly transforming these new materials into an industry-relevant technology. The team will advance this technology by improving the stability, efficiency, and scalability of perovskites.

METAL NANO-GRIDS FOR NEXT-GENERATION TRANSPARENT CONDUCTION IN SOLAR CELLS AND MODULES – SUNLAMP, $125,000

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

This project is developing cracked film lithography for depositing transparent contacts on photovoltaic cells. In this method, a suspension of nanoparticles is deposited onto a substrate, where solvent evaporation cracks the drying film, naturally producing a template for metal deposition and subsequent lift-off. The research will focus on developing a cheap drying cracked film template, followed by metal deposition and lift-off. The resulting metal nano-grids will be delivered with excellent transmittance, sheet resistance, and characterized wire width, ensuring their efficient operation in solar cells.

RAPID DEVELOPMENT OF DISRUPTIVE PHOTOVOLTAIC TECHNOLOGIES – SUNLAMP, $2,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Andriy Zakutayev

This project aims to demonstrate potentially-disruptive, novel photovoltaic absorbers by developing proof-of-concept device prototypes composed of defect-tolerant inorganic thin film oxide/nitride absorbers. Defect tolerance is the tendency of a semiconductor to maintain good transport and doping properties despite the presence of crystallographic defects and is a key property of promising photovoltaic materials. The project uses the rapid development approach, which combines high-throughput theory with accelerated experiments to rapidly optimize materials and architectures.

STREAMLINED MODULE MANUFACTURING USING BACK CONTACT SOLAR CELLS AND CONDUCTING ADHESIVES – SUNLAMP, $125,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Talysa Klein

This project is fabricating modules of back contact silicon solar cells by patterning metal onto the module backsheet or back glass and attaching unmetallized cells to it using a conducting adhesive. The conducting adhesive consists of conductive microspheres embedded in an adhesive and will conduct only in the out-of-plane direction, allowing patterned doped areas on the rear side of an unmetallized back contact solar cell to be conductively bonded to a patterned metal on a backsheet or back glass without patterning the adhesive. This eliminates the complex cell metallization and stringing steps, replacing them with a single metal patterning step on a backsheet/back glass. The cell metallization step would concurrently be the first module assembly step, resulting in lower module cost.

Understanding Reliability and Mitigating Degradation

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

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 PV modules. Sandia National Laboratories, Lawrence Berkeley National Laboratory, and SLAC National Accelerator Laboratory are also collaborating in the consortium.

ADDRESSING SOILING: FROM INTERFACE CHEMISTRY TO PRACTICALITY – SUNLAMP, $6,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Lin Simpson

Natural soiling has reduced the energy output of photovoltaic systems since the inception of the technology. Soiling is a complex problem that increases uncertainty and drives up the levelized cost of energy through lost energy production, increased operation and maintenance costs, and financing rates. This project is developing a predictive soiling model and a soiling rate map of the nation based on the available and, if necessary, additionally collected data and use it to provide operations and maintenance guidance to the industry.

FROM MODULES TO ATOMS: INCREASING RELIABILITY AND STABILITY OF COMMERCIALLY RELEVANT PHOTOVOLTAIC TECHNOLOGIES – SUNLAMP, $5,998,946

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Steve Johnston

The project is studying reliability-related defects in major photovoltaic technologies that include silicon, cadmium telluride, and copper indium gallium selenide using imaging and microscopy characterization tools along with multi-physics modeling to derive the causes of power-limiting defects that are responsible for potential-induced degradation in silicon, meta-stability and transient degradations in cadmium telluride, and increased-degradation due to reverse-bias breakdown in copper indium gallium selenide. This project will draw on module samples to develop predictive degradation models and improved testing protocols.

MANUFACTURING AND RELIABILITY SCIENCE FOR COPPER INDIUM GALLIUM SELENIDE PHOTOVOLTAICS – SUNLAMP, $4,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Lorelle Mansfield

This project aims to overcome the largest challenges to investor confidence and long product lifetime in copper indium gallium selenide: meta-stability, potential-induced degradation, and shading-induced hot spots. This project is developing cells with a thin absorber layer that will have cost and reliability advantages due to higher reverse breakdown currents. In addition, the project will improve reliability of copper indium gallium selenide to the level of silicon by quantifying and developing mitigation strategies for meta-stability and potential-induced degradation.

PHOTOVOLTAIC RISK REDUCTION THROUGH QUANTIFYING IN-FIELD ENERGY – SUNLAMP, $4,500,000

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

This project is developing standardized methods for determining degradation factors, which will reduce the perceived and actual financial risk associated with solar photovoltaic deployment. In addition, partially shaded photovoltaic system performance models are being validated and added to simulation software used by installers, increasing the accuracy of performance prediction. The project also expands the geographically diverse photovoltaic performance database using the micro-inverter data.

REDUCING PHOTOVOLTAIC PERFORMANCE UNCERTAINTY BY ACCURATELY QUANTIFYING THE PHOTOVOLTAIC RESOURCE – SUNLAMP, $2,500,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta

This project uses an innovative approach to compile data for the lab's Photovoltaic resource that will open new opportunities for significantly higher accuracy in photovoltaic performance prediction and assessment. The work will provide more accurate irradiance data by testing different types of sensors to determine the most consistent and reliable measurement technologies, while also improving satellite-derived irradiance data.

REGIONAL TEST CENTER OPERATIONS – SUNLAMP, $8,249,432

National Renewable Energy Laboratory, Sandia National Laboratories | Principal Investigators: Joshua Stein and Chris Deline

The Regional Test Center program aims to support technical innovation in the U.S. solar sector by validating the performance of new photovoltaic products in multiple climates at five sites. All sites represent a range of irradiance, temperature, and precipitation averages. This project supports the operation, maintenance, and management of the sites and provides the opportunity to add new collaborative projects with industry partners across the Regional Test Centers.

SCIENTIFIC APPROACH TO REDUCING PHOTOVOLTAIC MODULE MATERIAL COSTS WHILE INCREASING DURABILITY – SUNLAMP, $2,500,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Nick Bosco

This project is developing metrics to quantify the performance, safety, and reliability of encapsulants and backsheets at both the material and module level. This includes identifying the material properties that govern their performance degradation, developing the metrics to quantify these properties, surveying historically deployed modules to obtain a threshold value for these properties, and conducting outdoor and indoor accelerated exposure tests to analyze the kinetics of degradation and develop physics-based models that describe the degradation.

SOLAR ENERGY RESEARCH INSTITUTE FOR INDIA AND THE UNITED STATES – $7,500,000

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

This project, which is co-led by the Indian Institute of Science, develops and prepares emerging solar electric technologies by lowering the cost per watt of photovoltaic and concentrating solar power. Scientists focus efforts on high-impact fundamental and applied research and development, overcoming barriers to technology transfer by cutting the time from discovery to technology development and commercialization through effective coordination, communication, and intellectual property management, and creating a sustainable network from which to build large collaborations and foster a collaborative culture and outreach programs.

STABLE PEROVSKITE SOLAR CELLS VIA CHEMICAL VAPOR DEPOSITION – SUNLAMP, $125,000

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

The project aims to produce more stable perovskites which are grown by a scalable chemical vapor deposition method without halides or iodine, which are the main contributors to perovskite degradation.

SUPPORT OF INTERNATIONAL PHOTOVOLTAIC MODULE QUALITY ASSURANCE TASK FORCE – SUNLAMP, $10,055,000

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

This project supports the Photovoltaic Module Quality Assurance Task Force to develop the international test standards necessary to validate the quality of photovoltaic modules and determine service lifetimes. The project will improve the quality of modules, implement a conformity assessment system for photovoltaic power plants to meet the requirements of international standards, and develop and implement a rating system to ensure durable design of modules.

DEGRADATION ASSESSMENT OF FIELDED COPPER INDIUM GALLIUM SELENIDE PHOTOVOLTAIC MODULE TECHNOLOGIES – SUNLAMP, $3,000,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Bruce King

Conducted at the Regional Test Centers, this project reduces the uncertainties surrounding long-term reliability and performance of copper indium gallium selenide photovoltaics by measuring real-world performance and degradation rates of fielded systems and by publishing accurate, predictive performance models.

IMPROVING PHOTOVOLTAIC PERFORMANCE ESTIMATES IN THE SYSTEM ADVISOR MODEL WITH COMPONENT AND SYSTEM RELIABILITY METRICS – SUNLAMP, $600,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Geoffrey Klise

This project improves the forecasting of lifetime photovoltaic system performance, operations, and maintenance costs by incorporating the Photovoltaic Reliability and Performance Model into the widely-used Solar Advisor Model software platform.

PHOTOVOLTAIC LIFETIME PROJECT – $2,427,072

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

This project this is conducting and analyzing long-term monitoring of performance of photovoltaic modules, investigating equipment widely deployed across the country, and addressing multiple deployment climates. A major focus of the project is on early-life degradation of photovoltaic modules, which may indicate stepwise degradation functions that are too subtle to be detected through typical outdoor monitoring.

PHOTOVOLTAIC STAKEHOLDER ENGAGEMENT INITIATIVES – SUNLAMP, $89,000

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

The project will support the International Energy Agency Photovoltaic Power Systems Programme, the Photovoltaic Performance Modeling Collaborative, as well as the Underwriters Laboratories, the International Electrotechnical Commission, and the National Electric Code committee work.

Training Next Generation Researchers

NATIONAL CENTER FOR PHOTOVOLTAICS COMMUNITY ENGAGEMENT – SUNLAMP, $999,775

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Mowafak Al-Jassim

This project supports the National Center for Photovoltaics educational and outreach activities, such as the Hands-On Photovoltaics Experience for graduate students.

Spotlight On: National Laboratory Research

For more than 70 years, the Department of Energy's 17 national laboratories have served as leading institutions for scientific innovation, tackling critical scientific challenges from renewable energy expansion to the origins of our universe. Today 40-50 percent of SETO's funding is awarded to national labs, where researchers use world-class facilities to develop innovations that lower the costs of solar energy. These unique facilities possess capabilities to address large-scale, complex research and development challenges with a multidisciplinary approach that emphasizes translating basic science to innovation.

The Solar Energy Technologies Office (SETO) works with national labs through three-year laboratory funding programs (i.e., the $230 million SunShot National Laboratory Multiyear Partnership (SuNLaMP) for FY16-FY18), as well as funding opportunity announcements. SuNLaMP projects target high-impact problems and explore new approaches that can lower the cost of solar energy and enable greater solar adoption. Projects must meet agreed-upon objectives, deliver on milestones, yield valuable results, and remain relevant to the current research and development needs of the technology and the solar industry.

Two of the 17 national labs are uniquely suited to help advance solar research:

- The National Renewable Energy Laboratory (NREL) in Golden, Colorado conducts cutting-edge research and development to improve photovoltaic efficiencies and better understand and improve the reliability of PV technology. NREL is also home to the Energy Systems Integration Facility, a unique research and test facility that helps solar and other energy technologies seamlessly integrate with the country's electric grid.
- Sandia National Laboratories in Albuquerque, New Mexico is home to the National Solar Thermal Test Facility, which focuses on advancing concentrating solar power (CSP) technology. This facility develops and tests new CSP technologies so they are able reach lower costs and risks while achieving higher efficiencies, temperatures, and reliability. Sandia also runs the Regional Test Centers, test facilities for validating PV technology in different climates.

The national labs also play a large role in conducting informative analysis on solar technology and the solar industry. Researchers use bottom-up, techno-economic cost modeling to benchmark current technology and system costs, as well as to inform the potential commercial relevance of technology development and system installation improvement pathways. In addition, foundational analysis from the labs provides impartial information to a broad set of stakeholders, helping address the non-hardware costs and deployment barriers of going solar.

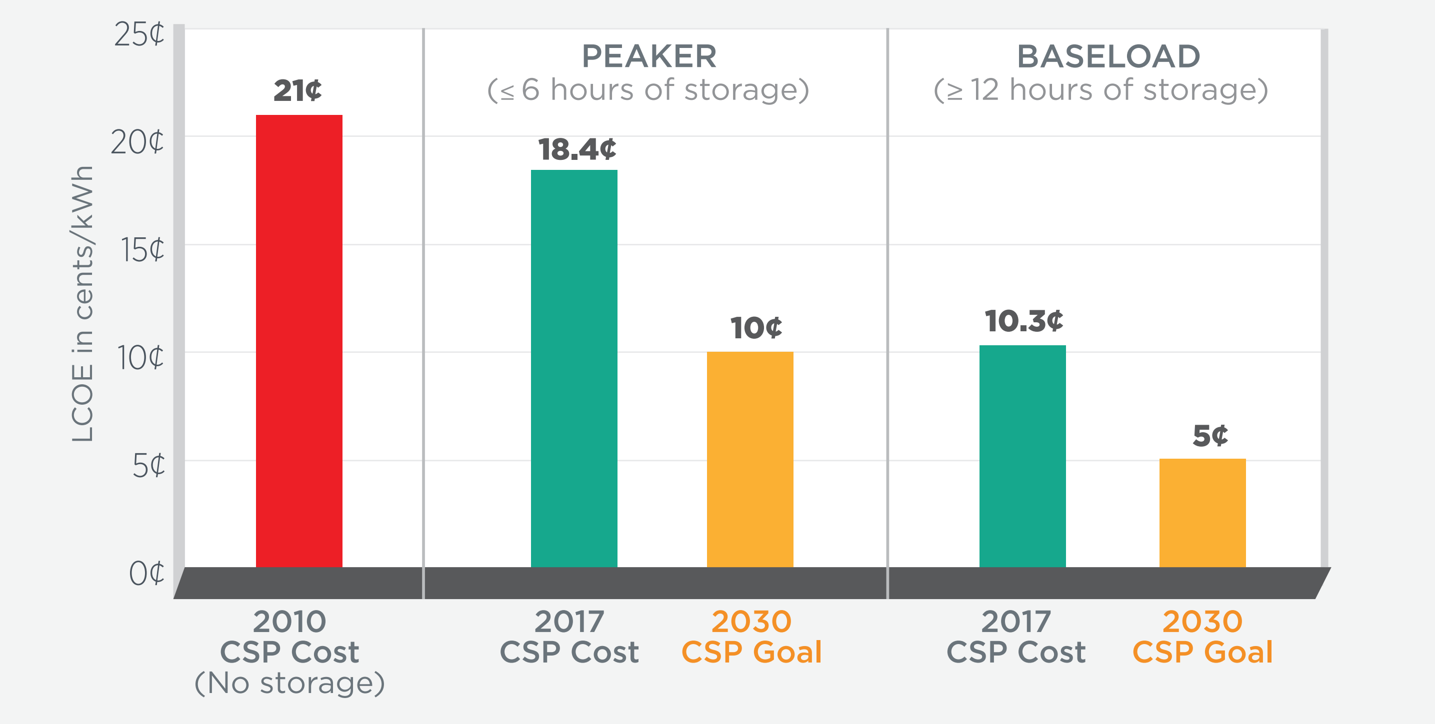
Beyond the SuNLaMP funding program, SETO conducts research projects with the national labs and provides additional funding to the Grid Modernization Lab Consortium, which works with labs from across the country to support critical research and development in advanced storage systems, clean energy integration, standards and test procedures, and a number of other key grid modernization areas. The labs are helping to frame new grid architecture design elements, develop new planning and real-time operations platforms, provide metrics and analytics to improve grid performance, and enhance government and industry capabilities for designing the infrastructure and regulatory models needed for successful grid modernization.

Concentrating Solar Power

The Solar Energy Technologies Office's Concentrating Solar Thermal Power (CSP) subprogram supports early-stage research and development of CSP technologies. Projects in the CSP portfolio focus on novel technologies that will integrate thermal storage, lower cost, increase efficiency, and improve reliability compared to current state-of-the-art technologies. This includes the exploration of new concepts for operations, system designs and innovations in the collector, receiver, thermal storage, heat transfer fluids, and power block subsystems. Most of all, the CSP subprogram seeks out transformative concepts with the potential to break through existing performance barriers.

CSP is a unique form of solar energy because of its ability to incorporate storage and therein generate electricity on demand. By changing the relative sizes of the different CSP subsystems, plants can be configured as peaker systems or baseload systems. Solar thermal technologies can also be used to generate heat for applications beyond electricity, such as water desalination, thermochemistry (including generation of fuels), and other industrial thermal processes.

Concentrating Solar Power Progress and Goals



Since 2011, the levelized cost of electricity for CSP has decreased significantly. Cost reductions have occurred throughout the various subsystems that exist within a CSP plant: the collector, where sunlight is first gathered and focused; the receiver, where concentrated sunlight is used to create thermal energy; the power block, which converts thermal energy into energy that can be used in our homes; thermal storage, which allows energy availability on demand; and the thermal transport subsystem, which moves heat from the solar receiver through thermal energy storage and delivers that heat to a power cycle. The office's 2030 cost targets for a CSP peaker (≤6 hours of storage) and baseload (≥12 hours of storage) plants are 10 cents and 5 cents respectively.

See a list of active funding programs below, followed by a description of all active CSP projects.

Funding Program	Year Announced	Amount Awarded
Concentrating Solar Power: Concentrating Optics for Lower Levelized Energy Costs (CSP: COLLECTS)	2016	$9M
CSP: Advanced Projects Offering Low LCOE Opportunities (CSP: APOLLO)	2015	$32M
CSP SunShot National Laboratory Mulityear Partnership (SuNLaMP)	2015	$29M
Physics of Reliability: Evaluating Design Insights for Component Technologies in Solar (PREDICTS)	2013	$4M
Multidisciplinary University Research Initiative: High Operating Temperature Fluids (MURI HOT Fluids)	2012	$10M
Concentrating Solar Power SunShot Research and Development (CSP R&D)	2012	$56M

Each project is displayed as follows:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

ACTIVE COMPETITIVE AWARDS

Collectors

UNIQUE SINGLE-AXIS TRACKING PLANAR WAVEGUIDE OPTICAL COLLECTOR FOR CSP MODULES – COLLECTS, $628,478

Agira, Inc. | Boston, MA | Principal Investigator: Bal Mukund Dhar

This project is developing a very low-cost, flat optical collector based on refraction and total-internal reflection at optical interfaces between silicone polymers of different refractive indices. Incoming sunlight is progressively bent and eventually trapped within a glass substrate. Additional benefits include ease of installation and low operations and maintenance costs. The result will be a novel CSP collector which, when manufactured at large scale, will help to bring the cost of electricity below the target of $0.06 per kilowatt-hour.

ENHANCEMENT OF OPTICAL EFFICIENCY OF CSP MIRRORS FOR REDUCING OPERATION AND MAINTENANCE COSTS VIA NEAR-CONTINUOUS OPERATION – APOLLO, $1,150,000

Boston University | Boston, MA | Principal Investigator: Malay Mazumder

This project is using laboratory-scale, electrodynamic-screen, self-cleaning solar technology with heliostat mirrors and parabolic troughs in large-scale solar plants. The objective is to reduce both the need to clean mirrors with water and the degradation of CSP collector performance due to deposited dust. Building upon a feasibility demonstration of self-cleaning CSP optics, the team will develop new manufacturing processes that are scalable to full-size production and conduct extensive field tests in collaboration with several industrial partners and national labs.

LOW-COST CONCENTRATED SOLAR POWER COLLECTOR – COLLECTS, $1,483,299

Hyperlight Energy | La Jolla, CA | Principal Investigator: Greg Mungas

This project is demonstrating at large scale the performance of its linear Fresnel reflector CSP collector, which captures the sun’s energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube. The project uses lightweight, low-cost materials to hold the mirror surfaces in position. The primary bearing surface is a waterbed enclosed on four sides by low-profile walls. The bottom of the waterbed is a commodity pond liner, which is ubiquitous in the agricultural space because of its low cost, rugged durability, and life span of more than 30 years.

GREEN PARABOLIC TROUGH COLLECTOR INSPIRED BY AN ARCHITECTURAL PARADIGM – COLLECTS, $1,740,564

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

This project seeks to drive down the material and assembly costs of the traditional parabolic trough collector by using an outdoor-proven structural material that is 15 percent of the price of congenitally-used steel, and a different structure using trusses on the concave side of the parabola. This structure minimizes the amount of material needed to achieve the stiffness that it requires, and reduces the number of assembly fixtures and process steps in construction. The project aims to develop the concept by designing, building, and testing an outdoor full-scale prototype.

DIELECTRIC METASURFACE CONCENTRATORS – COLLECTS, $2,000,000

University of California, San Diego | San Diego, CA | Principal Investigator: Boubacar Kante

This project is increasing the acceptance angle of solar concentrators using planar dielectric metasurfaces. Metasurfaces are extremely thin surfaces with unique properties that change the behavior of light in ways that are counterintuitive to an observer. Currently, existing solar concentrators only work for direct light, which requires a multi-axis tracking system to follow the sun's path. By achieving a wider acceptance angle, tracking systems will not have to move as much, potentially lowering the cost of the solar collector for a comparable efficiency performance.

DEVELOPMENT OF A PLANAR FOCUSING COLLECTOR FOR CSP – COLLECTS, $1,381,879

University of Illinois at Urbana Champaign | Urbana, IL | Principal Investigator: Kimani Toussaint

This project is developing a flat solar collector that acts like a conventional curved trough collector. The planar focusing collector is a potentially lower-cost alternative to the conventional parabolic trough concentrator. The collector will be manufactured using specially designed metasurfaces. These metasurfaces are made from nano- and micro-structured thin, metallic surfaces that change the behavior of light in ways that are counterintuitive to an observer. Novel roll-to-roll manufacturing will also be developed to meet design specifications and cost requirements at large scale. The final deliverable will be a flat focusing element that focuses sunlight with 97 percent efficiency or higher.

Receivers and Heat Transfer Fluids

SOLAR RECEIVER WITH INTEGRATED THERMAL STORAGE FOR A SUPERCRITICAL CARBON DIOXIDE POWER CYCLE – APOLLO, $2,600,000

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

This project is integrating 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.

THERMODYNAMICALLY STABLE, HIGH-TEMPERATURE, LONG-TERM ANTI-OXIDATION CERMET SOLAR SELECTIVE ABSORBERS – APOLLO, $656,831

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

This project is developing thermodynamically stable, long-term anti-oxidation cermet solar selective coatings through the use of nanoparticles. The goal is to achieve over 1,000 hours of operation at 700° Celsius in air with a solar absorbance greater than 95 percent and thermal emittance less than 10 percent. The coating will be applied to Norwich Technology's vacuum-free SunTrap CSP receiver systems for prototype analysis, achieving a thermal efficiency greater than 90 percent at 700° Celsius.

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

Oregon State University | Corvallis, OR | Principal Investigator: Kevin Drost

Oregon State University is developing a microchannel solar receiver using supercritical carbon dioxide as the heat transfer fluid. The research will resolve key issues associated with the commercial viability of the technology, which allows for a radical reduction in the size of a 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.

DEVELOPMENT OF 800° CELSIUS INTEGRATED FLOW CHANNEL CERAMIC RECEIVER – APOLLO, $1,211,022

SolarReserve | Santa Monica, CA | Principal Investigator: David Wait

This project is developing a concept for creating affordable, compact, and lightweight receiver panels capable of heating air, carbon dioxide, molten salts, or other corrosive and oxidizing fluids to 750° Celsius, which is 185° Celsius hotter than current receiver design through the use of commercially available silicon carbide ceramics. SolarReserve is also partnering with University of California San Diego to utilize its solar selective coating, which provides greater solar absorptivity, lower infrared emissivity, and can withstand higher temperatures than current state-of-the-art coatings.

HALIDE AND OXY-HALIDE EUTECTIC SYSTEMS FOR HIGH-PERFORMANCE, HIGH-TEMPERATURE HEAT TRANSFER FLUIDS – MURI, $5,500,006

University of Arizona | Tucson, AZ | Principal Investigator: Perry Li

This project is investigating the use of halide salts with oxy-halide additives as a heat transfer fluid in concentrating solar power systems operating at temperatures greater than 800° Celsius. By allowing higher temperature operation, CSP systems can achieve greater efficiencies and thereby reduce the overall system cost.

HIGH-OPERATING TEMPERATURE LIQUID METAL HEAT TRANSFER FLUIDS – MURI, $4,998,834

University of California, Los Angeles | Los Angeles, CA | Principal Investigator: Sungtaek Ju

This project is investigating the use of metal alloys as a heat transfer fluid in CSP systems operating at temperatures up to 800° Celsius. By allowing higher temperature operation, CSP systems can achieve greater efficiencies and thereby reduce the overall cost of electricity production.

Power Conversion and CSP Systems

COMPRESSION SYSTEM DESIGN AND TESTING FOR SUPERCRITICAL CARBON DIOXIDE CSP OPERATION – APOLLO, $3,800,000

GE Global Research | Niskayuna, NY | Principal Investigator: Bugra Ertas

This project is developing an optimal compression system for a modular supercritical carbon dioxide power block operation in highly transient CSP tower applications. The compressor train under development will 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 CSP power tower applications.

SODIUM ION EXPANSION POWER BLOCK FOR DISTRIBUTED CSP – APOLLO, $2,348,780

Georgia Institute of Technology | Atlanta, GA | Principal Investigator: Shekar Balagopal

This project is developing and demonstrating a modular sodium ion expansion power block for CSP with an estimated efficiency in excess of 50 percent. These generators will be most similar to thermoelectric generators, though the ion expansion engines are considerably more efficient. The key to innovation is the use of Ceramatec's patented NaSelect™ and β-Alumina solid electrolytes, which have high sodium ion conductivities for operation in a dual stage heat engine.

DEVELOPMENT OF A HIGH EFFICIENCY HOT GAS TURBO-EXPANDER AND LOW COST HEAT EXCHANGERS FOR OPTIMIZED CONCENTRATING SOLAR POWER APPLICATIONS – CSP R&D $4,586,967

Southwest Research Institute | San Antonio, TX | Principal Investigator: Jeff Moore

This project is developing a supercritical carbon dioxide power cycle that combines high efficiencies and low costs for modular concentrating solar power applications. The technology will be evaluated in a test loop to verify its performance over a wide range of partial-load conditions and during transient operations representative of a typical power cycle.

DEVELOPMENT OF AN ULTRA HIGH EFFICIENCY WIDE-RANGE INTEGRALLY-GEARED SUPERCRITICAL CARBON DIOXIDE COMPANDER – APOLLO, $5,350,000

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

This project is developing an integrally-geared compressor-expander (compander) and a novel centrifugal compressor impeller design for use in 10-megawatt-scale CSP applications utilizing a supercritical carbon dioxide cycle. This integrally-geared compander has the potential to improve efficiency, modularity, and process control over other proposed CSP turbomachinery configurations utilizing a supercritical carbon dioxide power cycle.

ADVANCED SUPERCRITICAL CARBON DIOXIDE CYCLES – APOLLO, $1,899,986

University of Wisconsin | Madison, WI | Principal Investigator: Mark Anderson

This project addresses the fundamental challenges associated with the supercritical carbon dioxide cycle, including the need for a high degree of internal heat transfer that requires substantial heat transfer area. The use of fixed, switched-bed regenerators provides a simple, low-cost alternative for the recuperator. Researchers will design, fabricate, and test a fixed bed regenerator system that is compatible with the operating conditions expected in a supercritical carbon dioxide cycle. The device will be installed in the test loop located at Sandia National Laboratory in order to demonstrate the operation of the regenerator at prototypical conditions.

Thermal Energy Storage

HIGH EFFICIENCY LATENT HEAT BASED THERMAL ENERGY STORAGE SYSTEM COMPATIBLE WITH SUPERCRITICAL CARBON DIOXIDE POWER CYCLE – APOLLO, $1,050,000

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

This project continues the development of a high-efficiency latent heat thermal energy storage system based on a graphite foam filtered through a phase changer material, which has high thermal conductivity. The project will extend the system to make it compatible with supercritical carbon dioxide power cycles, which use heat transfer fluids at temperatures higher than 720° Celsius.

ROBUST, COST-EFFECTIVE HEAT EXCHANGERS FOR 800° CELSIUS OPERATION WITH SUPERCRITICAL CARBON DIOXIDE – APOLLO, $3,845,079

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

This project is creating millichanneled heat exchangers comprised of mechanically-, thermally-, and chemically-robust, high-temperature composite materials and will demonstrate the capability of such heat exchangers for operation in high-temperature heat transfer fluids and supercritical carbon dioxide at a temperature of up to 800° Celsius. The proposed composites are comprised of materials with similar thermal expansion coefficients and have been demonstrated to be highly-resistant to thermal shock and to exhibit the necessary strength to operate in a supercritical carbon dioxide environment at 800° Celsius.

DEMONSTRATION OF HIGH-TEMPERATURE CALCIUM-BASED THERMOCHEMICAL ENERGY STORAGE SYSTEM – APOLLO, $2,000,000

Southern Research Institute | Birmingham, AL | Principal Investigator: Santosh Gangwal

This project is working to demonstrate its novel high-temperature, calcium-based, thermochemical storage system for use with CSP facilities. This system uses a highly refined and tailored reinforced calcium-oxide sorbent undergoing a reversible carbonation reaction in a parallel-plate heat exchanger reactor to produce a highly energy dense storage system with sorbent material derived from a low-cost feedstock.

ACTIVE LAB AWARDS

Collectors

REFRACTORY SOLAR SELECTIVE COATINGS – SUNLAMP, $2,595,531

Argonne National Laboratory | Lemont, IL | Principal Investigator: Jeff Elam

This project is developing high-performance, solar selective coatings for power tower receivers in CSP plants. In CSP tower systems, the receiver is where the reflected light is concentrated and converted to thermal energy. The efficiency of the light-to-heat conversion is an essential factor in determining the overall efficiency of a CSP plant. A reliable and durable solar selective coating can significantly improve efficiency by reducing the amount of light that is re-emitted away from the plant.

ADVANCED ANTI-SOILING COATINGS FOR CSP COLLECTOR MIRRORS AND HELIOSTATS – SUNLAMP, $2,800,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Panos Datskos

This project addresses the need to further develop self-cleaning reflector coatings for solar collectors. When solar collectors get dirty, their ability to collect sunlight is diminished. Through field demonstrations at CSP test sites, researchers are investigating the efficacy and durability of super-hydrophobic coatings that can provide anti-soiling capabilities for trough and heliostat mirrors. In order for the coating to be cost effective, the team is developing a low-cost, industry-standard spray coat technique to apply the anti-soiling coating.

Receivers and Heat Transfer Fluids

HIGH-TEMPERATURE HEAT PIPE RECEIVER FOR PARABOLIC TROUGH COLLECTORS – SUNLAMP, $2,000,000

Los Alamos National Laboratory | Los Alamos, NM | Principal Investigator: Stephen Obrey

This project focuses on the development of heat pipe receiver technology for use with parabolic trough collectors. Heat pipe receivers use the boiling and condensing of a fluid to efficiently absorb the incident concentrated solar energy and transfer the heat to the thermal energy storage system. The lab is combining its expertise in high temperature heat pipes and optically selective glass coatings with Norwich Technologies' expertise in design, construction, and characterization of high-temperature cavity receivers. The resulting technology will reduce the levelized cost of energy through a reduction in system costs, parasitic loads and a net energy conversion efficiency increase.

HYDROGEN MITIGATION – NATIONAL LAB AOP, $1,318,977

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

This project is a cooperative effort between the lab and Acciona Energy North America. The project's objective is to solve a long-standing performance problem that significantly impacts the electricity output and profitability of parabolic trough power plants. The technical objective is to design, implement, and evaluate a full-scale hydrogen mitigation process at the Nevada Solar One commercial power plant.

Power Conversion and CSP Systems

CONCURRENT OPTIMIZATION OF COMPONENT CAPITAL COST AND EXPECTED OPERATIONS AND MANAGEMENT – SUNLAMP, $3,000,000

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

This project is developing and validating an open-source modeling and simulation tool that optimizes the design and operation for CSP plants by characterizing and forecasting operations and maintenance costs, component failure behavior, and the impact of design and maintenance policies. In addition, researchers will develop detailed performance and cost models leveraging the System Advisor Model, which is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry. These models will maximize profit through thermal storage dispatch optimization and will account for forecast uncertainty, heliostat and receiver stochastic degradation and failure, and operations and maintenance costs including steam turbine service.

LIFETIME MODEL DEVELOPMENT FOR SUPERCRITICAL CARBON DIOXIDE CSP SYSTEMS – SUNLAMP, $2,175,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Bruce Pint

This project seeks to develop a predictive lifetime model for materials in supercritical carbon dioxide conditions similar to CSP applications. Experimental work will generate relevant corrosion, creep, and fatigue data to populate the model and then verify model predictions. The test campaign will mirror the thermal cycling expected in CSP applications. The combination of experiments aims to remove the many unknowns of how supercritical carbon dioxide and its containment material will function over the expected lifetime of a power plant.

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

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

This project is designing, developing, and testing a supercritical carbon dioxide heat exchanger that operates at temperatures higher than 720° Celsius and record-high pressures. In supercritical carbon dioxide heat exchangers, heat is transferred from hot particles to carbon dioxide, which expands in a turbine to generate electricity. Industry experience with similar heat exchangers is limited to lower pressures, lower temperatures, or alternative fluids like steam or water. The lab is partnering with three experienced heat exchanger manufacturers to develop several designs that achieve both high performance and low cost. A prototype unit will be manufactured and tested to confirm key metrics for performance and cost.

Thermal Energy Storage

BINARY METAL CHALCOGENIDES FOR HIGH-TEMPERATURE THERMAL STORAGE – SUNLAMP, $3,450,000

Los Alamos National Laboratory | Los Alamos, NM | Principal Investigator: Stephen Obrey

This project is developing a thermochemical energy storage system that uses binary metal chalcogenides in a modular reactor operating at temperatures of at least 750° Celsius. The proposed chemical cycle stores energy through the heat-driven decomposition of a metal chalcogenide and releases energy by recombining the chemical elements. Because of the cycle's high energy density, this material holds promise for low-cost, high-temperature thermal energy storage.

Core Capabilities

CSP SYSTEMS ANALYSIS – SUNLAMP, $2,249,897

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

This project supports the lab's core capabilities in CSP systems analysis, including upgrades to the System Advisor Model, market analysis of CSP technologies, and cost benchmarking of CSP components. The System Advisor Model is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry. It will be upgraded to facilitate the techno-economic analysis of state-of-the-art CSP technologies currently under development.

NATIONAL SOLAR THERMAL TEST FACILITY OPERATIONS AND MAINTENANCE – SUNLAMP, $2,581,000

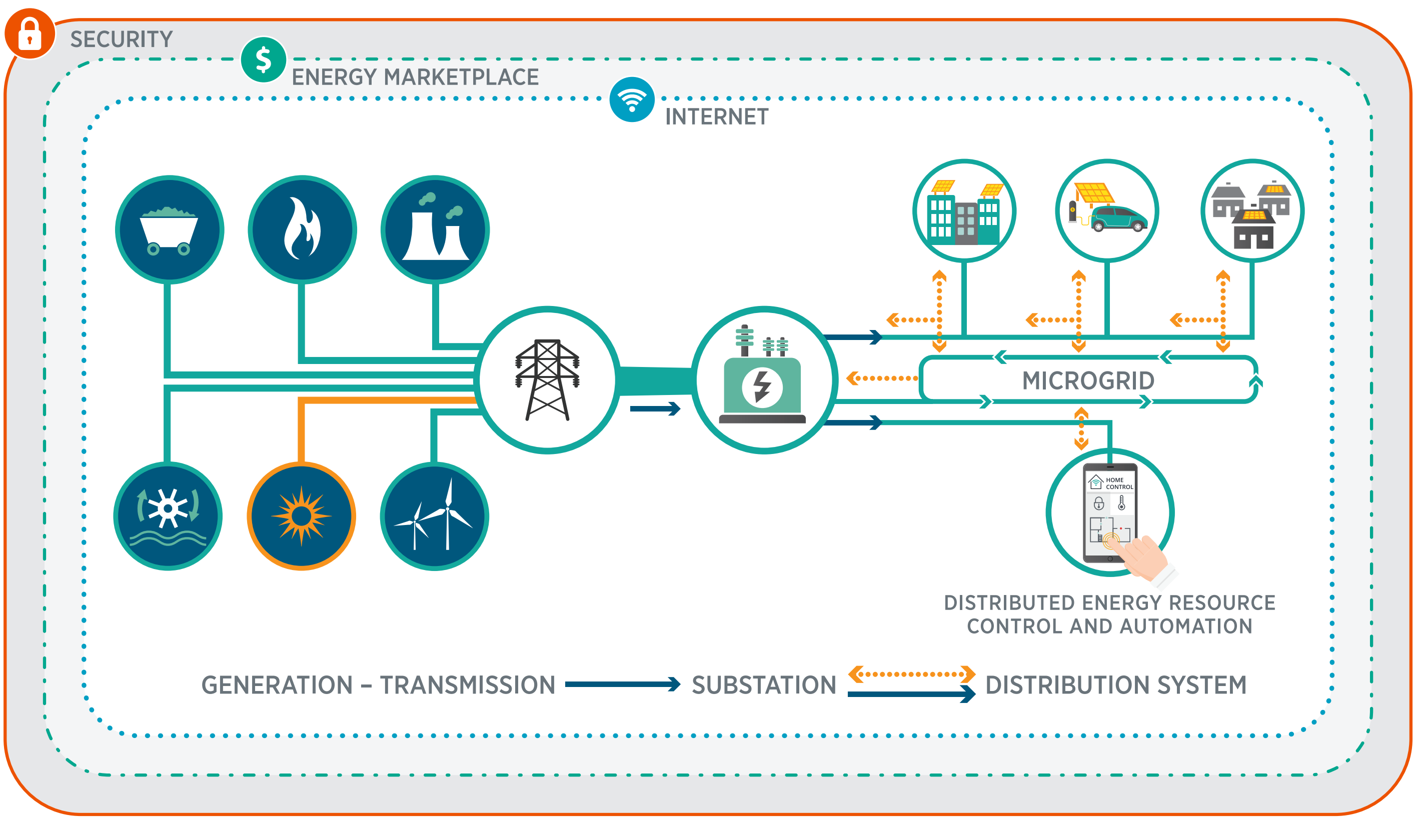
Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Joshua Christian

This project maintains the National Solar Thermal Test Facility, which provides the CSP industry with established test platforms and highly experienced researchers and technologists. This facility allows for development, testing, and application of new CSP technologies that are instrumental in advancing state-of-the-art technology. With expert staff ensuring safe and reliable operation, the facility allows technologies to form the foundation of the global CSP industry and continue to advance the technology to new levels of efficiency, higher temperatures, lower cost

Systems Integration

The Solar Energy Technologies Office's Systems Integration subprogram supports targeted technology research and development (R&D) that addresses the technical challenges with achieving higher levels of solar penetration, while supporting a safe, reliable, secure and cost-effective electric grid.

The installed cost of solar electricity has fallen significantly in recent years, spurring rapid and accelerating deployment of solar energy systems. Solar generation has gone from less than 0.1 percent of the U.S. electricity supply in 2010 to nearly 2 percent in 2017 with a total capacity of nearly 50 gigawatts. Further, the penetration of solar is much higher in some states—reaching 13 percent of electricity in California in 2016, and more than 7 percent in Nevada, Vermont and Arizona. The growth in solar power production emphasizes the need to develop timely and cost-effective technologies that ensure that solar energy contributes to enhancing the reliability, resilience, and security of the nation's electric grid.

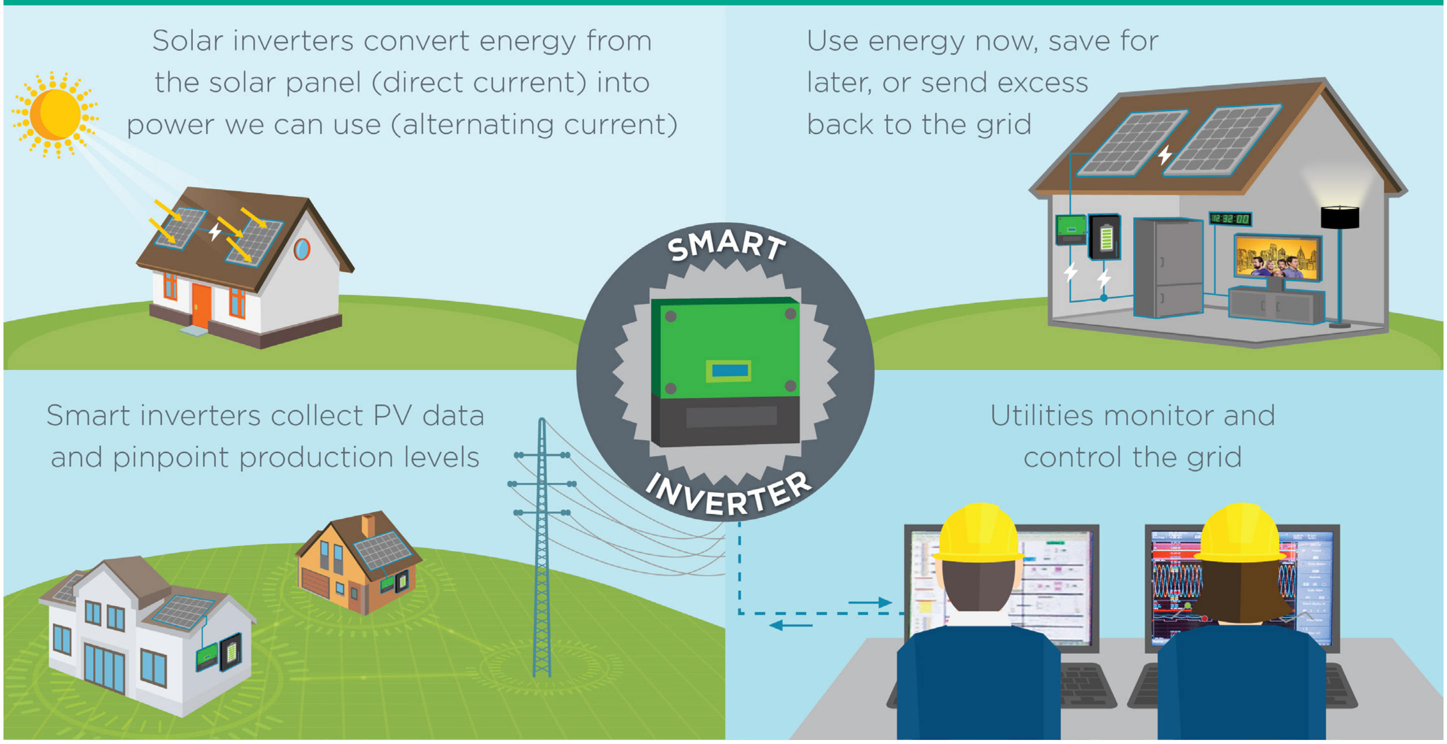


The Systems Integration subprogram works to make solar energy more dispatchable, enabling its use regardless of whether the sun is shining. Projects are working to advance technology that integrates solar with energy storage, as well as building loads, to better match solar energy supply with demand. As the amount of grid-connected solar continues to increase, these solutions will significantly contribute to cost effective and reliable integration of solar generation.

Systems Integration projects also address challenges presented by increasing amounts of solar generation by improving general planning and operation for grid operators with high penetrations of solar. Two-way power flow, coordination of protection devices, transmission-distribution interaction, and reduction in system inertia related to high penetrations of solar electricity are all being addressed by projects in the portfolio.

Power electronics devices, such as inverters, serve as the critical link between solar photovoltaic arrays and the electric grid. Systems integration projects target advances in these technologies that will ultimately help the grid become more reliable, secure, and resilient, including projects that enable advanced grid services, such as the ability to detect and respond to fault events and help to efficiently recover from grid outages.

How it Works: The Smart Inverter



Systems Integration

See a list of active funding programs below, followed by a description of all active Systems Integration projects.

Funding Program	Year Announced	Amount Awarded
Solar Forecasting 2	2017	$12M
Resilient Distribution Systems Lab Call (RDS Lab Call)	2017	$10M
Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE)	2017	$30M
Grid Modernization Lab Consortium (GMLC)	2016	$5M
Sustainable and Holistic Integration of Energy Storage and Solar Photovoltaics (SHINES)	2016	$18M
SunShot National Laboratory Multiyear Partnership (SuNLaMP)	2015	$59M

Each project is displayed as follows:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

ACTIVE COMPETITIVE AWARDS

Solar Integration Planning and Operation

SECURITY CONSTRAINED ECONOMIC OPTIMIZATION OF PHOTOVOLTAICS AND OTHER DISTRIBUTED ASSETS – ENERGISE, $3,241,628

Advanced Microgrid Solutions | San Francisco, CA | Principal Investigator: Steven Alains

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.

INTEGRATED DISTRIBUTED ENERGY RESOURCE MANAGEMENT SYSTEM – ENERGISE, $3,192,302

City of Riverside Public Utilities | Riverside, CA | Principal Investigator: Hamed Mohsenian-Rad

This project designs, deploys, and validates at scale a novel distributed energy resource management system. Its main component is a sophisticated numerical analysis platform that will enable an optimal and active 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 solar penetration. This technology deployment will be transformational to utilities that may not have financial resources to deploy full advanced distribution management systems.

ENHANCED CONTROL, OPTIMIZATION, AND INTEGRATION OF DISTRIBUTED ENERGY APPLICATIONS – ENERGISE, $2,420,000

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 – ENERGISE, $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.

ROBUST DISTRIBUTED STATE ESTIMATOR FOR INTERCONNECTED TRANSMISSION AND DISTRIBUTION NETWORKS – ENERGISE, $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. This approach allows the computational complexity and solution time to be bounded regardless of the system size and number of measurements. The approach utilizes a mixed set of measurements under different network configurations and is able to handle any number of available solar photovoltaic units connected to the distribution system.

KEYSTONE SOLAR ENERGY FUTURE PROJECT – ENERGISE, $3,320,000

PPL Electric Utilities | Allentown, PA | Principal Investigator: Megan Toomey

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 10 distribution circuits. An extensive one-year real-world testing will be performed, proving all of the target parameters before deploying it system-wide.

INTEGRATION OF SOLAR ENERGY INTO POWER GRID OPERATION VIA WIDE-AREA DATA MANAGEMENT SYSTEMS AND A HIERARCHAL CONTROL ARCHITECTURE – ENERGISE, $1,500,000*

Quanta Technology | Raleigh, NC

This project develops a new power grid operation architecture that combines distributed control with centralized dispatch to provide power system frequency and voltage support. This includes the design and development of a new generation of photovoltaic inverters that operates and behaves like a synchronous generator. The solution integrates any available data with a new wide-area photovoltaic monitoring and control platform to increase the visibility and controllability of distributed solar generation resources. It provides an accurate estimation of the current power system status for making control decisions in real-time operations, integrating transmission and distribution control strategies.

VOLTAGE REGULATION AND PROTECTION ASSURANCE USING DISTRIBUTED ENERGY RESOURCE ADVANCED GRID FUNCTIONS – ENERGISE, $2,500,000

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

This project creates an open-source advanced distribution management system that encompasses distribution circuits and distributed energy resource management, including state estimation, voltage regulation, protection coordination, economic optimization, interoperability, and cybersecurity. This system software provides real-time visibility into distribution circuits and optimizes the active and reactive settings to meet voltage regulation, protection, and economic objectives in the presence of forecast uncertainty. The open-source software is being incorporated into a commercial vendor’s platform to validate the technology with extensive testing at 20 feeders located within two utilities.

ELECTRIC ACCESS SYSTEM ENHANCEMENT – ENERGISE, $4,000,000

Southern California Edison | Rosemead, CA | Principal Investigator: Le Xu

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 – ENERGISE, $2,000,000

University of California, Berkeley | Berkeley, CA | Principal Investigator: Carl Blumstein

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.

SCALABLE AND SECURE COOPERATIVE ALGORITHMS AND FRAMEWORK FOR EXTREMELY HIGH PENETRATION SOLAR INTEGRATION – ENERGISE, $2,000,000

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.

DATA DRIVEN MODELING AND ANALYTICS FOR ENHANCED SYSTEMS LAYER IMPLEMENTATION – ENERGISE, $1,886,999

University of Southern California | Los Angeles, CA | Principal Investigator: Viktor Prasanna

This project uses data to develop novel representations of distributed energy resource owners' interactions via data-driven models along with stochastic reserve optimizations that enable net-load balancing in near real-time. The project develops a transformational distributed grid control architecture as a part of an enhanced system layer at the distribution network level that optimizes the coordinated usage of large numbers of variable and distributed resources, decentralized energy storage, and load to ensure real-time, system-wide, net-load management and automated adaptation to real-time variability in a cost-effective, secure, and reliable manner.

ROBUST AND RESILIENT COORDINATION OF FEEDERS WITH UNCERTAIN DISTRIBUTED ENERGY RESOURCES: FROM REAL-TIME CONTROL TO LONG-TERM PLANNING – ENERGISE, $1,774,134

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.

Solar and Energy Storage Integration

AUSTIN SHINES – SHINES, $4,300,000

Austin Energy | Austin, TX | Principal Investigator: Karl Popham

This project is developing a solution adaptable to any region and market structure that offers a credible pathway to a levelized cost of energy of $0.14 per kilowatt-hour for solar energy when augmented by storage and other distributed energy resource management options. The solution aims to establish a template for other regions to follow to maximize the penetration of distributed solar photovoltaics. In addition, the proposed solution will enable distribution utilities to mitigate potential negative impacts of high penetration levels of photovoltaics caused by the intermittency and variability of solar production.

AGENT-BASED COORDINATION SCHEME FOR PHOTOVOLTAIC INTEGRATION – SHINES, $1,036,963

Carnegie Mellon University | Pittsburgh, PA | Principal Investigator: Soummya Kar

This project is developing a distributed, agent-based control system to integrate smart inverters, energy storage, and commercial off-the-shelf home automation controllers and smart thermostats. The system will optimize photovoltaic generation, storage, and load consumption behaviors using high-performance, distributed algorithms.

MICROGRID-INTEGRATED SOLAR-PLUS-STORAGE TECHNOLOGY – SHINES, $4,000,000

Commonwealth Edison Company | Oakbrook Terrace, IL | Principal Investigator: Shay Bahramirad

This project addresses availability and variability issues inherent in solar photovoltaic technologies by utilizing smart inverters for solar-plus-storage with batteries and working synergistically with other components within a microgrid community. This project leverages the microgrid cluster controller, which was funded by the Energy Department, and is connected to the existing 12 megawatt microgrid at the Illinois Institute of Technology.

BENEFICIAL INTEGRATION OF ENERGY STORAGE AND LOAD MANAGEMENT WITH PHOTOVOLTAICS – SHINES, $3,124,685

Electric Power Research Institute | Knoxville, TN | Principal Investigator: Aminul Huque

This project is working with five utilities to design, develop, and validate technology for end-to-end grid integration of energy storage and load management with photovoltaic generation. The technology is a simple, two-level, and optimized control architecture. Its effectiveness will be verified at three field locations.

SUNDIAL - AN INTEGRATED SYSTEM TO ENABLE HIGH-PENETRATION FEEDER-LEVEL PHOTOVOLTAICS – SHINES, $3,493,921

Fraunhofer USA, Center for Sustainable Energy Systems | Boston, MA | Principal Investigator: Kurt Roth

This project is developing a highly scalable, integrated photovoltaics, storage, and facility load management solution. Through the SunDial Global Scheduler, the system tightly integrates photovoltaics, energy storage, and aggregated facility load management to actively manage net system power flows to and from the feeder, regardless of whether these individual components are co-located at the same site, or distributed at different sites.

INTEGRATING SYSTEM TO EDGE-OF-NETWORK ARCHITECTURE AND MANAGEMENT – SHINES, $2,437,500

Hawaiian Electric Company | Honolulu, HI | Principal Investigator: Dora Nakafuji

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 will 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.

Solar Forecasting

ADVANCING THE WEATHER RESEARCH AND FORECASTING SOLAR MODEL TO IMPROVE SOLAR IRRADIANCE FORECAST IN CLOUDY ENVIRONMENTS – SOLAR FORECASTING 2, $1,600,000*

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.

PROBABILISTIC FORECASTS AND OPERATIONAL TOOLS TO IMPROVE SOLAR INTEGRATION – SOLAR FORECASTING 2, $1,800,000*

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 will 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.

COORDINATED RAMPING PRODUCT AND REGULATION RESERVE PROCUREMENTS IN CALIFORNIA INDEPENDENT SYSTEM OPERATOR AND MIDCONTINENT INDEPENDENT SYSTEM OPERATOR USING MULTI-SCALE PROBABILISTIC SOLAR POWER FORECASTS – SOLAR FORECASTING 2, $1,738,630*

Johns Hopkins University | Baltimore, MD | Principal Investigator: Ben Hobbs

This project is advancing 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.

PROBABILISTIC CLOUD OPTIMIZED DAY-AHEAD FORECASTING SYSTEM BASED ON WEATHER RESEARCH AND FORECASTING SOLAR SYSTEM – SOLAR FORECASTING 2, $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 will use 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 UNCERTAINTY MANAGEMENT AND MITIGATION FOR EXCEPTIONAL RELIABILITY IN GRID OPERATIONS – SOLAR FORECASTING 2, $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.

DEVELOPMENT OF THE NEXT WEATHER RESEARCH AND FORECASTING MODEL – IMPROVING SOLAR FORECASTS – SOLAR FORECASTING 2, $1,214,872*

Pacific Northwest National Laboratory | Richland, 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.

OPEN SOURCE EVALUATION FRAMEWORK FOR SOLAR FORECASTING – SOLAR FORECASTING 2, $999,808*

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.

HYBRID ADAPTIVE INPUT MODEL OBJECTIVE SELECTION ENSEMBLE FORECASTS FOR INTRA-DAY AND DAY-AHEAD GLOBAL HORIZON IRRADIANCE, DIRECT NORMAL IRRADIANCE, AND RAMPS – SOLAR FORECASTING 2, $1,316,203*

University of California San Diego | San Diego, CA | Principal Investigator: Carlos Coimbra

This project develops a Hybrid Adaptive Input Model Objective Selection ensemble model to improve solar irradiance and cloud cover forecasts. Major components of this ensemble include a holistic optimization framework and ingestion of new-generation cloud cover products. The goal is to increase the state-of-the-art predictive capabilities for solar generation from their present values of 10 percent to 30 percent (with a stretch goal of 50 percent) consistently for both global horizon solar irradiance and direct normal irradiance.

*Funding amount pending negotiations.

ACTIVE LAB AWARDS

Solar Integration Planning and Operation

AN INTEGRATED TOOL FOR IMPROVING GRID PERFORMANCE AND RELIABILITY OF COMBINED TRANSMISSION-DISTRIBUTION WITH HIGH SOLAR PENETRATION – SUNLAMP, $2,800,000

Argonne National Laboratory | Lemont, IL | Principal Investigator: Shirang Abhyankar

High penetration of solar photovoltaics in electric power grids has created a need for changes to power system planning and operations analysis. Important technical issues such as two-way power flow, coordination of protection devices, transmission-distribution interaction, and reduction in inertia need to be resolved to enable a greater deployment of solar generation. To overcome these technical barriers, this project will develop a suite of software tools that creates a holistic understanding of the steady-state and transient behavior of transmission-distribution networks' interaction under high solar penetration levels, along with the capability of real-time monitoring of the distribution systems and integration of system protection.

CLEANSTART-DERMS – RDS LAB CALL, $2,500,000*

Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, Pacific Northwest National Laboratory | Principal Investigator: Emma Stewart

This project aims to validate and demonstrate a scale a mitigation, blackstart, and restoration strategy for distribution feeders that is based on distributed energy resources. This strategy integrates applied robust control, the communication and analytics layer, and a coordinated hierarchal solution. This work will improve customer reconnection times and help to lower costs for utilities as more distributed energy resources are added to the grid.

CYDER: A CYBER PHYSICAL CO-SIMULATION PLATFORM FOR DISTRIBUTED ENERGY RESOURCES IN SMART GRIDS – SUNLAMP, $4,000,000

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

This project focuses on developing a modular, scalable, and interoperable tool for power system planning and operation that will seamlessly integrate with utilities' existing tools to enable analysis of high penetration of distributed energy resources. The tool will enhance current utility tools by providing a computationally efficient platform that will be capable of quasi-static time series simulation and smart inverter controls with in-feed data from real-time distribution sensor measurements.

GRID RESILIENCE AND INTELLIGENCE PLATFORM – RDS LAB CALL, $3,000,000*

Lawrence Berkeley National Laboratory, SLAC National Accelerator Laboratory | Principal Investigator: Sila Kiliccote

This project is working 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 goal is to enable faster recovery of the grid.

INCREASING DISTRIBUTION RESILIENCY USING FLEXIBLE DISTRIBUTED ENERGY RESOURCES AND MICROGRID ASSETS ENABLED BY OPENFMB – RDS LAB CALL, $3,000,000*

National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory | Principal Investigator: Kevin Schneider

This project aims to accelerate the deployment of resilient and secure distribution concepts through the flexible operation of traditional assets, distributed energy resources, and microgrids using OpenFMB, which is a framework for distributed intelligent nodes that interact with each other through loosely coupled, peer-to-peer messaging for fielded devices and systems at the grid's edge. Treating distributed energy resources and microgrids as boundary conditions will enable greater system flexibiltiy with adaptive settings.

DYNAMIC BUILDING LOAD CONTROL TO FACILITATE HIGH PENETRATION OF SOLAR PHOTOVOLTAIC GENERATION – SUNLAMP, $3,000,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Teja Kuruganti

This project aims to develop, demonstrate, and validate a sensing and control mechanism for using power loads to address variable photovoltaic generation, which will reduce two-way power flow and mitigate voltage instability on distribution level circuits. The availability of this technology will enable increased penetration of renewables while weakening the challenges that arise due to their intermittency in generation by using flexibility on load side.

FREQUENCY RESPONSE ASSESSMENT AND IMPROVEMENT OF THREE MAJOR NORTH AMERICAN INTERCONNECTIONS DUE TO HIGH PENETRATIONS OF PHOTOVOLTAIC GENERATION – SUNLAMP, $2,200,000

Oak Ridge National Laboratory | Oak Ridge, TN | Principal Investigator: Yilu Liu

As the number of solar photovoltaic installations continues to grow exponentially, one of the major challenges to grid stability will be mitigating decreasing system inertia and deteriorating frequency response. Preliminary independent studies on two North American interconnections have already demonstrated that the overall frequency response will deteriorate significantly with increasing renewable generation. This project will investigate the frequency response and system inertia impacts with high solar penetration levels for all three major interconnections: the Eastern Interconnection, Western Interconnection, and the Electric Reliability Council of Texas.

ENABLING HIGH PENETRATION OF DISTRIBUTED PHOTOVOLTAICS THROUGH THE OPTIMIZATION OF SUB-TRANSMISSION VOLTAGE REGULATION – SUNLAMP, $3,000,000

Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Nader Samaan

This project is developing a coordinated real-time sub-transmission Volt/VAR control tool to optimize the use of reactive power control devices for stabilizing voltage fluctuations caused by intermittent photovoltaic outputs. In order to capture the full value of the Volt/VAR optimization, the project team will couple this tool with an optimal future sub-transmission Volt/VAR planning tool for short- and long-term planning analyses. Together, these real-time control and planning tools will remove a major roadblock in the increased penetrations of utility-scale and residential solar.

RAPID QUASI STATIC TIME SERIES SIMULATIONS FOR HIGH-RESOLUTION COMPREHENSIVE ASSESSMENT OF DISTRIBUTED PHOTOVOLTAIC IMPACTS – SUNLAMP, $4,000,000

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

This project accelerates quasi static time series simulation capabilities through the use of new and innovative methods for advanced time-series analysis. Currently, this type of analysis is not commonly performed in photovoltaic interconnection studies because of the data requirements and computational burden. This project will address both of these issues by developing advanced methods that greatly reduce the required computational time and by developing high-proxy data sets.

DESIGNING RESILIENT COMMUNITIES: A CONSEQUENCE-BASED APPROACH FOR GRID INVESTMENT – RDS LAB CALL, $750,000*

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 will investigate how a community can be designed to be resilient through coordinated grid investment, and how electric utilities of various configurations (such as municipal, investor-owned, or cooperative, vertically vs. horizontally integrated) can plan for resilience and benefit from these investments. The project will develop detailed case studies for San Antonio, Texas and Buffalo, New York.

VISUALIZATION AND ANALYTICS OF DISTRIBUTION SYSTEMS WITH DEEP PENETRATION OF DISTRIBUTED ENERGY RESOURCES – SUNLAMP, $4,000,000

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

For high penetration of distributed energy resources like solar, electric power grid operators and planners must be able to incorporate large datasets from photovoltaic sources, local and line mounted precision instruments, customer load data from smart meters, and electric vehicle charging data into their analyses. This project will design and implement a platform for the visualization and analytics of distribution systems with high penetrations of distributed energy resources. This unified data analytics platform will enable the integration of massive and varied data streams for real-time monitoring with analytics, visualization, and control of distributed energy resources in distribution networks.

GRID MODERNIZATION LAB CONSORTIUM: DEVELOPMENT OF INTEGRATED TRANSMISSION, DISTRIBUTION, AND COMMUNICATION MODELS – GMLC, $1,350,000*

Argonne National Laboratory, Idaho National Laboratory, Lawrence Livermore National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | Principal Investigator: Henry Huang

This project is building on best-in-class lab capabilities to develop an integrated, flexible, open source framework for coupling transmission, distribution, and communication models and simulations. It will also validate framework and models on hardware testbed. Real-world testing with partners will include distributed and wide area controls with distributed energy resources.

Solar and Energy Storage Integration

CONCENTRATING SOLAR POWER IN A SUNSHOT FUTURE – SUNLAMP, $2,125,000

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

This project investigates concentrating solar power and its ability to increase the overall penetration of solar energy while lessening the variability impacts of solar photovoltaics. Concentrating solar power is unique among solar technologies in that it can provide dispatchable energy through high-efficiency thermal energy storage. Researchers will analyze these next-generation power plants and their ability to provide valuable grid services.

Power Electronics

COMBINED PHOTOVOLTAICS AND BATTERY GRID INTEGRATION WITH HIGH-FREQUENCY MAGNETICS ENABLED POWER ELECTRONICS – SUNLAMP, $4,238,040

National Energy Technology Laboratory | Pittsburgh, PA | Principal Investigator: Paul Ohodnicki

This project is developing new power electronics devices, systems, and materials to address power electronic and dispatchability challenges that result from connecting hundreds of gigawatts of solar energy onto the electricity grid. These devices will incorporate advanced high-frequency magnetics along with the latest wide bandgap silicon carbide switches. This design enables cost-effective grid integration of photovoltaics while increasing its dispatchability.

ADDITIVELY MANUFACTURED PHOTOVOLTAIC INVERTER – SUNLAMP, $4,478,288

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Madhu Chinthavali

Integrating hundreds of gigawatts of photovoltaic solar power onto our country's electric grid requires transformative power conversion system designs that find a balance between performance, reliability, functionality, and cost. This project is developing a unique inverter design that combines the latest wide bandgap, high-voltage, silicon carbide semiconductor devices with new technologies, such as additive manufacturing and multi-objective magnetic design optimization. By developing an additively manufactured inverter, researchers aim to significantly reduce the cost of photovoltaic power electronics.

GRID MODERNIZATION LAB CONSORTIUM: GRID FREQUENCY SUPPORT FROM DISTRIBUTED INVERTER-BASED RESOURCES IN HAWAII – GMLC, $310,000*

National Renewable Energy Laboratory, Sandia National Laboratories | Principal Investigator: Andy Hoke

This project is developing, simulating, and validating practical solutions in Hawaii that enable distributed energy resources to help mitigate bulk system frequency contingency events on a time-scale ranging from milliseconds to seconds. It is also validating the ability of real hardware inverters to support grid frequency in an environment that emulates the dynamics of a Hawaiian Electric Company power system.

STABILIZING THE POWER SYSTEM IN 2035 AND BEYOND: EVOLVING FROM GRID-FOLLOWING TO GRID-FORMING DISTRIBUTED INVERTER CONTROLLERS – SUNLAMP, $3,849,999

National Renewable Energy | Golden, CO | Principal Investigator: Brian Johnson

Adding large amounts of photovoltaic solar energy onto the grid creates significant challenges for future grid operations, since the electric power grid currently operates with rotational inertia from fossil fuel-driven machines. However, inverters are power-electronic devices with no inherent inertia. This project is developing a suite of inverter controllers to ensure the long-term viability of electric power grid infrastructure and address the large reductions in system-wide inertia with high penetrations of solar. These grid-forming inverter controllers will allow each inverter to act as a controllable voltage source that dynamically adjusts its output to ensure system-level stability, synchronization, and voltage regulation.

Sensors and Communications

OPPORTUNISTIC HYBRID COMMUNICATIONS SYSTEMS FOR DISTRIBUTED PHOTOVOLTAIC COORDINATION – SUNLAMP, $2,709,398

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Bri Mathias Hodge

As more distributed solar power is added to the electric power grid and becomes an increasing proportion of total energy generation, the grid must support more stringent requirements to ensure continued reliable and cost-effective grid operations. New communications systems are needed to allow for bidirectional information exchange between distributed photovoltaic generators and various information and controls systems of the electric power grid. This project is developing a hybrid communications system to meet the needs of monitoring and controlling millions of distributed photovoltaic generators, while taking advantage of existing communications infrastructure, which will greatly reduce the costs necessary to provide these services.

SOLAR RESOURCE CALIBRATION, MEASUREMENT, AND DISSEMINATION – SUNLAMP, $2,441,133

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Manajit Sengupta

This project enables the operation of a baseline calibration process that is used to maintain the accuracy of irradiance sensors for instrument vendors and users, including virtually every utility-scale photovoltaic power plant in the country. In addition, this project supports the operation and scientific accuracy of the National Solar Radiation Database, which maintains a record of hourly irradiance values calculated from satellite-based measurements across the contiguous United States and Hawaii. Finally, the project also supports the creation and dissemination of standards and reference information regarding the science and practice of measurement of solar radiation.

SECURE, SCALABLE, STABLE CONTROL AND COMMUNICATIONS FOR DISTRIBUTED PHOTOVOLTAICS – SUNLAMP, $2,700,000

Sandia National Laboratories | Albuquerque, NM | Principal Investigator: Ray Byrne

This project enables high penetrations of solar generation on the grid by updating the current technical metrics for grid communications with a new distributed control and communications architecture that clearly explains the impact of each metric on the grid. A clearer understanding of the variability of each metric will result in optimal levels of performance, reliability, cost, and security.

ADVANCED SENSOR DEVELOPMENT – GMLC, $1,300,000**

Lawrence Berkeley National Laboratory, National Energy Technology Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | Principal Investigator: Tom King

This project increases visibility throughout the energy system including transmission, distribution, and end-use by developing low-cost, accurate sensors. Additionally, next-generation asset-monitoring devices help determine state of grid components prior to failure.

Codes and Standards

ACCELERATING SYSTEMS INTEGRATION CODES AND STANDARDS (ASICS) – SUNLAMP, $3,000,000

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

This project focuses on accelerating the revision process of the IEEE 1547 series and UL 1741 standards and testing procedures. Collectively, these standards are the foundational documents that are mandated for integrating solar energy systems with the electric distribution grid. Establishing accelerated development of new interconnection and interoperability requirements and conformance procedures will allow for more photovoltaic solar energy to be added to the grid.

STANDARDS AND TEST PROCEDURES FOR INTERCONNECTION AND INTEROPERABILITY – GMLC, $3,600,000*

Argonne National Laboratory, Idaho National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | Principal Investigator: Ben Kroposki

This project builds on prior efforts to develop interconnection and interoperability standards and test procedures. It leverages existing activities spanning multiple DOE programs to harmonize requirements across jurisdictions, eliminate conflicting requirements across technology domains, and streamline conformance test procedures to the fullest extent possible.

Solar Grid Integration Analysis

GRID MODERNIZATION LAB CONSORTIUM: GRID ARCHITECTURE – GMLC, $2,100,000**

Argonne National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | Principal Investigator: Jeffrey Taft

This project is building a new stakeholder-driven architecture for grid modernization, provide it to the industry with the tools they need to adapt it to their needs, and use it to inform program managers.

GRID MODERNIZATION LAB CONSORTIUM: METRICS FRAMEWORK – GMLC, $600,000**

Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | Principal Investigator: Michael Kintner-Meyer

This project is developing an integrated suite of grid modernization metrics that leverage current industry practices and emerging industry additions, while developing new metrics that reflect evolving grid attributes and architectures. Researchers will conduct baseline modernization assessments and provide ongoing dashboard for policy makers, regulators, and industry stakeholders.

LABORATORY VALUATION ANALYSIS – RESILIENT DISTRIBUTION SYSTEMS, $750,000**

Argonne National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | 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 will provide 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.

SYSTEM ADVISOR MODEL – SUNLAMP, $2,232,001

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Janine Freeman

This project focuses on the System Advisor Model, a performance and finance model designed to facilitate decision making for people involved in the renewable energy industry. It makes performance predictions and cost of energy estimates for grid-connected power projects based on installation, operating costs, and system design parameters that users enter into the tool. This project will improve and maintain many features of the tool that has been instrumental in advancing the solar industry. Basic maintenance for the PVWatts calculator tool will also be completed.

GRID MODERNIZATION LAB CONSORTIUM: SOUTHEAST REGIONAL CONSORTIUM – GMLC, $200,000**

Oak Ridge National Laboratory, Savannah River National Laboratory | Principal Investigator: Joe Cordaro

This project is identifying measurement requirements and data management and communication systems to enable full visibility of the grid system. This methodology includes defining the grid state, developing a roadmap, and creating a framework to determine sensor allocation for optimal results.

GRID MODERNIZATION LAB CONSORTIUM: VERMONT REGIONAL PARTNERSHIP ENABLING THE USE OF DISTRIBUTED ENERGY RESOURCES – GMLC, $850,000**

Argonne National Laboratory, Idaho National Laboratory, Lawrence Livermore National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | Principal Investigator: Robert Broderick

This project is analyzing distributed energy resource integration, control, validation of wind and solar prediction, and a techno-economic analysis of energy storage in Vermont to inform utilities seeking to meet the state's renewable energy goal.

GRID MODERNIZATION LAB CONSORTIUM: DISTRIBUTION SYSTEM DECISION SUPPORT TOOL DEVELOPMENT AND APPLICATION – GMLC, $990,000**

Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory | Principal Investigator: Mike Coddington

This project is developing tools, identifying gaps, and providing technical assistance and training for state regulators and small to medium utilities on advanced distribution system planning for a modernized grid that incorporates high levels of distributed energy resources.

GRID MODERNIZATION LAB CONSORTIUM: FUTURE ELECTRIC UTILITY REGULATION – GMLC, $750,000**

Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, National Energy Technology Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories | Principal Investigator: Lisa Schwartz

This project provides analysis to state public utility commissions that are considering incremental and fundamental changes to electric utility regulation. It also enhances utility financial analysis modeling tools focused on ratemaking and regulatory issues that arise with increased penetration of distributed energy resources.

NORTH AMERICAN RENEWABLE INTEGRATION STUDY – $900,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Gregory Brinkman

In this project, the U.S. Department of Energy Wind and Solar Energy Technologies Offices, Natural Resources Canada, and the Mexican Ministry of Energy are working together with researchers on a North American study of the issues and opportunities associated with the integration of large amounts of renewable energy into their respective electric power systems. The goal of the study is to help inform and assist power system planning entities, electricity system operators, government energy agencies, legislators, and regulators to better understand the implications of integrating large amounts of renewable resources into the Canadian, U.S., and Mexican electrical systems.

**Funding amounts listed for GMLC and Resilient Distribution Systems projects represent only the portion funded by the Solar Energy Technologies Office; other offices throughout the Department of Energy contribute to each project's overall budget.

Spotlight On: University Research

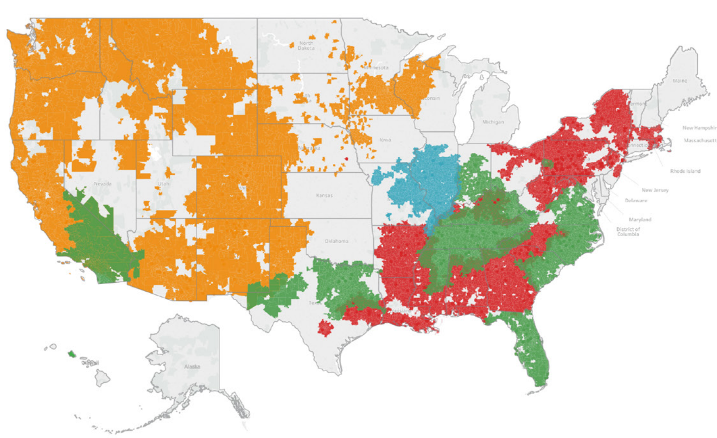
Universities across the country conduct research and development projects with SETO funding that span all subprograms. Since 2011, approximately $225 million has been awarded to more than 150 colleges and universities throughout the United States. Universities are critical to advancing solar energy technology. These institutions are better suited than private industry to conduct high-risk, exploratory research due to their ability to develop next-generation concepts without worrying about generating profits. Universities have faculty and facilities that allow for the development of new technologies that have the potential to advance the field, break performance barriers, and reach record-low costs. They also assist in lowering the non-hardware costs of going solar though projects that investigate the decision-science and motivations at play when consumers decide to go solar and what makes them more likely to do so.

University research develops the next generation of solar industry researchers. It is in classrooms and labs that students are exposed to solar technology and can become interested in pursuing solar energy careers. When conducting graduate-level studies, students often have the opportunity to work on projects that address the challenges our nation faces as the amount of grid-connected solar continues to increase and to develop expertise that positions them to tackle the challenges of the future.

SETO also offers four types of fellowships for recent graduates, as well as experienced scientists and engineers. Fellows apply their scientific and technical expertise to the development of solutions for issues facing the solar energy field.

SETO also supports the role universities play in developing the next generation of electric utility sector professionals. SETO's Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) program is a research, training and education framework at colleges and universities nationwide that increases the knowledge and skills required to operate an electric grid with high penetrations of solar electricity and other distributed technologies.

Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) Utility Partner Reach and Scale



GEARED Consortia

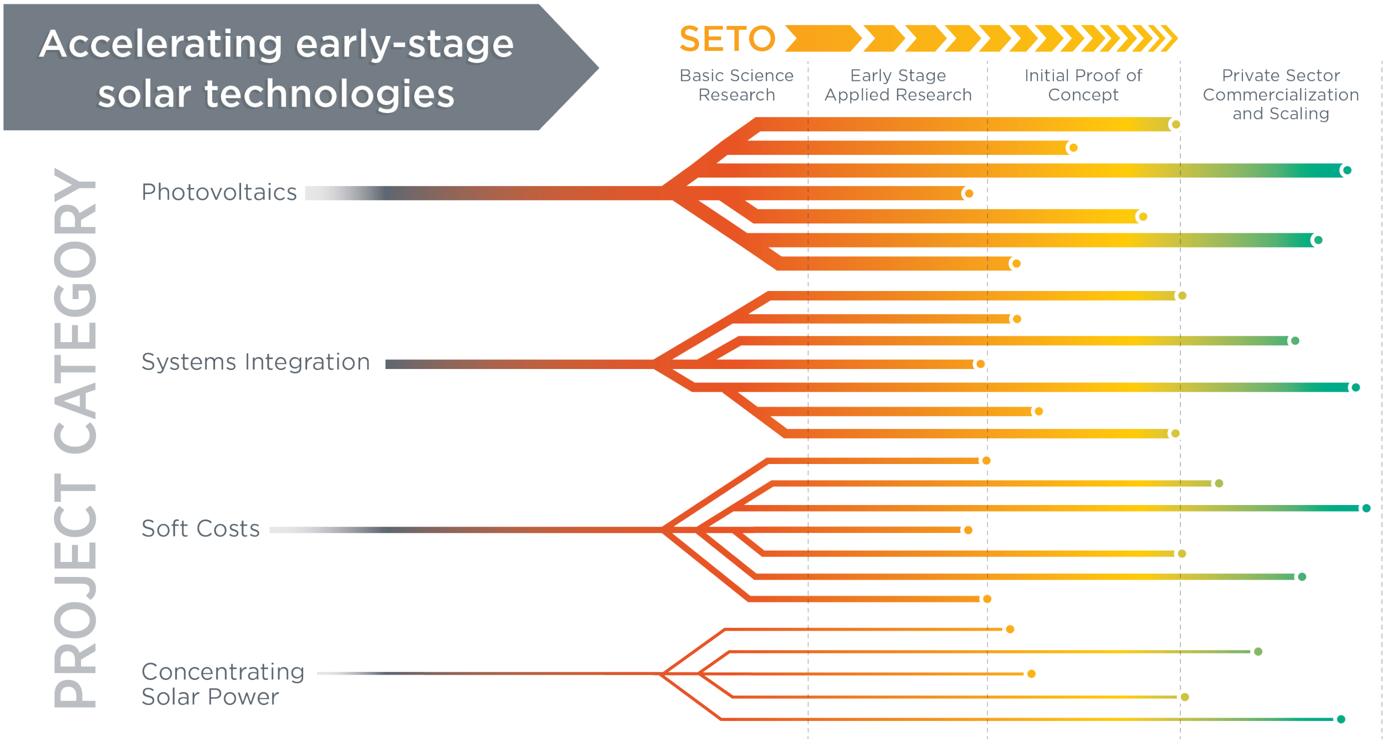
- Center for Grid Engineering Education West (**GridEd West**)
- Center for Grid Engineering Education East (**GridEd East**)
- Foundations for Engineering Education in Distributed Energy Resources (**FEEDER**)
- Mid-America Regional Microgrid Education and Training Consortium (**MARMET**)

This map shows the service territories of utility partners involved in GEARED and uses zip code level data from the National Renewable Energy Laboratory Utility Rate Database, last updated in April 2017.

Through collaborative consortia of universities and utilities, the GEARED program develops courses designed to prepare the next generation of electric grid operators for increasing amounts of solar energy.

Technology to Market

The Solar Energy Technologies Office's Technology to Market subprogram funds projects that develop and validate groundbreaking, early-stage technology and business models to strengthen concepts and develop a path to accelerate innovations to the market. Also known as Innovations in Manufacturing Competitiveness, the Technology to Market subprogram targets funding gaps that occur at the pre-prototype and pre-commercial stages of industry R&D. Historically, projects have focused on photovoltaics, photovoltaics system components, concentrating solar power and power electronics technologies, as well as innovations to reduce soft costs such as financing, interconnection, and operations and maintenance.



Technological innovation in the solar industry can lower the cost of solar energy for more consumers. However, it's not always easy for new ideas to surmount the barriers to commercialization. That's where the Technology to Market subprogram has been helping, providing technical assistance and financial resources that allow companies to conduct research, develop practical applications for their concepts, then conduct testing and validation of their models with the long-term goal of creating a commercially viable product.

Technology to Market projects that work to improve solar hardware cover a wide range of technologies: individual components of a solar panel or concentrating solar power plant, inverters that allow solar panels to feed energy back into the electricity grid, and the racking structures found on rooftops and utility-scale solar installations. Over the course of a project, awardees determine the best applications for specific hardware, develop it from a concept into a prototype, test its ability to function in representative real-world settings, and define a potential path to the market so the hardware can play a critical role in reducing the cost of solar-generated electricity.

Cutting-edge research and development also helps the solar industry to reduce the cost of manufacturing solar technologies. Technology to Market projects de-risk both near- and long-term innovations that can build a strong solar energy manufacturing sector and supply chain in America, while producing cost-competitive solar products that keeps pace with the rising domestic and global demand for affordable solar energy.

Through Fiscal Year 2017, one annual funding program under Technology to Market encompassed projects at all stages of technology development with the goal of developing pathways to commercialization for disruptive innovation. In addition, the subprogram provides funding for solar projects in other program offices throughout the Department of Energy:

- The **Small Business Innovation Research and Small Business Technology Transfer** program encourages U.S.-based small businesses to engage in high-risk, innovative research and technology development with the potential for future commercialization.
- The **Small Business Vouchers** pilot program gives small businesses access to support from national lab researchers in a draw down voucher format, which helps companies overcome critical technology and commercialization challenges by leveraging lab expertise and capabilities.
- The **Technology Commercialization Fund** is designed to increase the number of energy technologies developed at DOE's national labs that graduate to commercial development and achieve commercial impact by pairing lab innovators with the private sector in order to facilitate technology transition to the private sector.
- The **Innovative Pathways** program is developing new means by which to attract private capital earlier in the technology development cycle to reduce needs for government funding.

See a list of active funding programs below, followed by a description of all active Technology to Market projects.

Funding Program	Year Announced	Amount Awarded
Innovative Pathways	2017	$3.5M
SunShot Technology to Market 3 (T2M3)	2017	$25M
Small Business Voucher Pilot (SBV)	2016–2017	$1M
Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR)	2009–2017	$39M
Technology Commercialization Fund	2016–2017	$2M
SunShot Technology to Market 2: Incubator 11, SolarMat 4 (T2M2)	2016	$25M
SunShot Technology to Market: Incubator 10, SolarMat 3, SunPath 2 (T2M1)	2015	$23M
SunShot National Laboratory Multiyear Partnership (SuNLaMP)	2015	$3M
Solar Manufacturing Technology 2 (SolarMat 2)	2014	$24M
Photovoltaic Manufacturing Initiative (PVMI)	2011	$110M

Each project is displayed as follows:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

ACTIVE COMPETITIVE AWARDS

Technology Commercialization and Business Innovation

FIRST-LOOK FUND – AN EARLY-STAGE ALIGNED INTERMEDIARY TO ENHANCE THE FLOW OF PRIVATE CAPITAL INTO ENERGY COMPANIES – INNOVATIVE PATHWAYS, $928,736

Activation Energy | San Francisco, CA | Principal Investigator: Matt Price

This project aims at creating a business-model-agnostic investment vehicle (First-Look Fund) that provides small investments to concept-stage companies and provides access to information that will reduce uncertainty and risk misalignment for investors.

PREDICTIVE MODULE DEGRADATION AND FAILURE IDENTIFICATION SOLUTION – SBIR/STTR, $150,000

Advanced Power Electronics Corporation | Orlando, FL | Principal Investigator: John Elmes

This research is focused on the development of a highly capable photovoltaic module diagnostics technology that can be integrated into existing solar power system components. The diagnostics system will greatly improve the efficiency and effectiveness of long term solar system operation and maintenance.

AMICUS O&M COOPERATIVE – T2M2, $358,013

Amicus Solar Cooperate | Boulder, CO | Prinicpal Investigator: Amanda Bybee

This project creates a nationwide network of independent solar operations and maintenance (O&M) professionals. The members of this network share common infrastructure, software platform, legal agreements, reports templates, and training to ensure that clients with geographically diverse assets receive consistent service, regardless of the system location. This network model will lead to greater service coverage and standardized rates. Applying the cooperative business model to this market sector will address current market gaps by providing streamlined, cost-effective O&M services to ensure that commercial and industrial solar photovoltaic systems fulfill their performance expectations over the short and long term.

ADVANCED LOW COST INTERMETALLIC COATINGS FOR MOLTEN SALT PUMP IMPELLER – SBIR/STTR, $150,000

Applied Thermal Coatings | Chattanooga, TN | Principal Investigator: Jeff Henry

Advanced low cost intermetallic coatings will be developed to protect molten salt pump impeller against aggressive molten salt corrosion and blade tip erosion in concentrating solar power systems.

LOW-COST SENSOR FOR SOLAR RESOURCE ASSESSMENT AND MICROCLIMATE MONITORING – SBV3, $140,000

Arable Labs, Inc. | Princeton, NJ | National Lab Partner: National Renewable Energy Laboratory | Principal Investigator: Aron Habte

This project will help Arable Labs to refine its Pulsepod technology, a low-cost remote sensor package that includes fast-response solar irradiance detection. The lab's calibration facility will perform spectral and broadband calibration of the Arable Labs system in outdoor conditions, develop correction methodologies, and assist Arable Labs in publishing the results. This technology has the potential to increase solar deployment and improve the operations of photovoltaic and concentrating solar power plants through rapid solar resource assessment at reduced costs.

INTEGRATION OF BATTERY MODELING WITH SOLAR BUILDING ENERGY STORAGE – SBIR/STTR, $149,698

Battery Informatics | Poulsbo, WA | Principal Investigator: Bjorn Frogner

This project is developing software that will improve the economics of using lithium ion batteries for energy storage in the context of energy management of buildings. The solution will allow customers to offer battery installations that will provide 10 to 20 percent more value than current solutions.

SOLAR BUILDING ENERGY STORAGE MANAGEMENT – SBIR/STTR, $150,000

Blazetech | Woburn, MA | Principal Investigator: Albert Moussa

The adoption of electrical energy storage technologies in the power systems can play a vital role in improving the grid stability and resiliency. Thus, developing a robust energy management software is crucial for a widespread deployment of energy storage systems along with distributed energy resources.

FLEXIBLE ALL-METAL PIPES AND PIPE COUPLINGS FOR HIGH-TEMPERATURE FLUID TRANSPORT – SBIR/STTR, $1,591,592

Brayton Energy | Hampton, NH | Principal Investigator: Bill Caruso

Rotational pipe couplers for high-temperature molten salt are required to reduce the cost of renewable electricity generated by solar plants. This project will develop a flexible coupler made entirely out of metal. The coupler has a smooth internal shape, which prevents fluid from being trapped in convolutions such as those present in existing rotational couplers. It is optimized to be highly flexible while still able to withstand the pumping pressures required in typical molten salt plants. It will be able to move through 180^0 of motion daily for the entire lifetime of a solar plant. Future applications may include additional fluids, such as supercritical carbon dioxide.

TESTING HIGH TEMPERATURE, HIGH EFFICIENCY SILICON CARBIDE RECEIVER TUBES FOR CENTRALIZED SOLAR POWER PLANTS – SBV, $160,000

Ceramic Tubular Products | Lynchburg, VA | National Laboratory Partner: Sandia National Laboratories | Principal Investigator: Matt Walker

This project will allow Ceramic Tubular Products to chemically, mechanically, and thermally test its silicon carbide composite tubing, which was developed for the nuclear industry, at the National Solar Thermal Test Facility for use in concentrating solar power plants. The intent is to develop high-efficiency, low-emissivity receiver tubes to create a receiver that can operate at temperatures up to 800^0 Celsius. This will enable future power plants to operate at higher temperatures and efficiencies.

501Vc: A NEW MODEL FOR INVESTING IN ENERGY INNOVATION – INNOVATIVE PATHWAYS, $1,000,000

Clean Energy Trust | Chicago, IL | Principal Investigator: Ben Gaddy

Clean Energy Trust will launch a new investment model to attract a new class of investors to early-stage cleantech businesses. The model combines the structure of a venture capital fund with the benefits of a mission-driven, non-profit organization. Leveraging philanthropic donors' support, the new model will address the longer time horizons, capital requirements, and bounded upsides that have driven investors from cleantech.

sCO_2 POWER CYCLE WITH INTEGRATED THERMOCHEMICAL ENERGY STORAGE – T2M3, $1,000,000

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

Echogen and Southern Research will design, model and test a novel integrated supercritical carbon dioxide (sCO_2) power cycle and thermochemical energy storage system for concentrating solar power. The system will use CO2 both as a power cycle working fluid and as a reactant in the thermochemical energy storage reactor. The team will design, build and test a prototype-scale sCO_2 power cycle and reactor to validate the design and performance of the system.

REDUCING STORAGE COST WITH PHOTOVOLTAIC FORECASTING AND LOAD CONTROL – T2M2, $999,922

Edgepower Inc. | Aspen, CO | Principal Investigator: Nathan Glasgow

This project allows EdgePower to enhance its building energy management technology that integrates solar forecasting and load control tools by adding battery storage control capabilities. The prototype under development will establish standardized communication protocols between the building energy load gateway, the photovoltaic system, the energy storage system, and the solar forecast server. The integration of battery storage control capabilities will allow facilities with commercial solar to reduce their demand charges, making solar energy a more affordable option for businesses.

THE DEMOCRATIZATION OF SOLAR: EXPANDING THE COMMERCIAL AND INDUSTRIAL SOLAR MARKET TO SMALL AND MEDIUM BUSINESSES THROUGH FINANCIAL RISK MITIGATION – T2M3, $800,000

Energetic Insurance | Boston, MA | Principal Investigator: Jeff McAulay

Energetic Insurance will research novel, data-driven, actuarial models that will allow for substantial expansion of the commercial solar market by mitigating off taker credit risk through the deployment of a unique new insurance product. Funding will be used to develop the advanced underwriting models and enable collaboration with lenders, project developers, and insurance companies. The project will result in a new insurance policy being issued on commercial and industrial solar projects across the country.

CREATION OF AN ONLINE B2B PLATFORM SPECIFICALLY DESIGNED FOR THE U.S. SOLAR MARKETPLACE – T2M2, $700,000

EnergyBin LLC | Rochester, MN | Prinicpal Investigator: Van Sy

EnergyBin is creating an online marketplace for overstock and hard-to-find components in the solar industry, reducing project construction and maintenance costs while providing a means by which decommissioned materials can be reused. This members-only platform will provide a place for engineering, procurement, construction, manufacturers, distributors, and other firms to sell overstock that would otherwise sit in storage facilities, and to provide these companies with discounted, warrantied solar project components from vetted, reputable sources. In addition, the platform will also have the ability to supply operating projects with replacement parts that are otherwise unavailable or have extended delivery times.

AN ONLINE MARKETPLACE THAT ALLOWS CONSUMERS TO COMPARISON SHOP FOR SOLAR EQUIPMENT, FINANCING, AND LABOR, INDEPENDENTLY – T2M3, $1,600,000

EnergySage | Boston, MA | Principal Investigator: Jamie Biggar

This project will apply 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.

DEVELOPING AGGREGATED DATA SETS TO STANDARDIZE THE COLLATERAL VALUATION PROCESS UTILIZING AN ECONOMIC PRICING MODEL – SBIR/STTR, $1,723,613

Energy Sense Finance | Tampa, FL | Principal Investigator: Mark Handschy

Energy Sense Finance is developing solar valuation data sets to assist real estate appraisers, along with other professionals involved in the solar transaction process, in determining the asset value of both existing and proposed solar photovoltaic systems. The new approach recognizes that the lack of verifiable data is a current barrier to developing credible opinions of value for solar as an asset class. The solution utilizes data sets to better align current solar valuation methodologies with those used in traditional, low cost of capital lending markets. By removing barriers to credible valuation of solar systems, this web application can establish a verifiable solar asset value even before financing is issued and a system is installed. This will benefit homeowners, real estate appraisers, realtors, lenders, insurance companies, green raters, credit rating agencies, and third party owners among others by streamlining the solar valuation process and effectively opening up access to a lower cost of capital.

SCALABLE DIRECT-TO-CONSUMER COMMUNITY SOLAR – T2M2, $1,250,000

CleanChoice Energy (formerly Ethical Electric) | Washington, DC | Principal Investigator: Daniel Murray

This project builds a platform and underlying business architecture to enable the sale of community solar at a significantly lower cost per customer acquired than comparable residential solar sales. Leveraging its competitive retail electricity experience, CleanChoice is creating the customer acquisition, finance, and development tools needed to offer solar as a subscription at scale. This project will generate the demand for community solar and a method to deliver it at scale, dramatically increasing the availability and cost-effectiveness of community solar projects.

SOLAR LOAD BALANCING SIMULATOR – SBIR/STTR, $1,150,000

Extensible Energy | Lafayette, CA | Principal Investigator: John Powers

This project will develop modern software tools to assist electricity customers in commercial buildings to maximize the use of distributed solar within the facility where the solar array is installed. The software will save customers money on their energy bills and will allow the electric grid to support a higher percentage of solar generation.

HELIOSCOPE ENERGY PERFORMANCE MODELING VALIDATION – SBV, $56,000

Folsom Labs | San Francisco, CA | National Laboratory Partner: National Renewable Energy Laboratory | Principal Investigator: Janine Freeman

This project will assist Folsom Labs with the validation of its existing HelioScope technology, a modeling software that helps design solar projects. Using the lab's analysis and comparisons of similar existing projects, this project aims to provide municipalities and financial institutions with the confidence to adopt this model over other, more costly and time-consuming processes.

AUTOMATIC REFERENCE FOR EMPIRICAL SOILING – SBIR/STTR, $150,000

Fracsun | Atascadero, CA | Principal Investigator: Scott Lewis

The accumulation of dirt on solar panels has drastic, but measurable, effects on the performance of solar arrays. This project will focus on developing and manufacturing a device that addresses this issue by measuring the dirt accumulation and calculating the best day to wash the solar array.

ACHIEVING UBIQUITOUS SOLAR THROUGH MARKET TRANSFORMATION AND GRID INTEGRATION – T2M2, $799,287

Genbright | Hingham, MA | Principal Investigator: Joe Crespo

This project creates a commercial third party aggregation platform to integrate distributed energy resources (DERs), including solar, into wholesale electricity markets as a means to increase their value to the grid and decrease soft costs. The software platform will facilitate this market access through a combination of open source data repositories with information necessary to participate in various markets and enhancements to existing DER asset management software. Finally, through this project, Genbright will demonstrate both the technical capability of the platform on a small scale of diverse DERs and the commercial potential to expand to a much larger portfolio of DERs.

DEVELOPMENT OF NOVEL ALLOYS IDENTIFIED BY HIGH-THROUGHPUT COMPUTATIONAL METHODS FOR USE IN CONCENTRATED SOLAR POWER COMPONENTS – SBIR/STTR, $150,000

HiFunda LLC | Salt Lake City, UT | Principal Investigator: Isaac Corn

HiFunda and Brigham Young University will develop new improved alloy materials based on high-throughput computational analysis for use in high temperature corrosive applications such as concentrating solar power, nuclear reactors, turbines and aircraft components.

LINEAR FRESNEL COLLECTOR FOR CONCENTRATING SOLAR POWER SYSTEMS – SBV, $75,000

Hyperlight Energy | La Jolla, CA | National Laboratory Partner: National Renewable Energy Laboratory | Principal Investigator: Guangdong Zhu

This project will use lab assistance for thermal modeling, assessment, and evaluation to help the company develop thermal battery storage options for use in solar thermal and geothermal hybrid power plants. Hyperlight Energy lacks the system analysis capabilities to evaluate the value of thermal storage in a geothermal and solar hybrid application. The lab voucher will allow for multiple thermal storage options to be tested.

INTERPLAY SOLAR TRAINING PLATFORM: A NEW SYSTEM OF LEARNING – T2M2, $1,250,000

Interplay Learning | Del Mar, CA | Principal Investigator: Doug Donovan

This project develops the first 3D, interactive, training simulation tool for solar installers and employees. Through this training platform, installers will improve quality control, reduce construction costs from mistakes, and provide a better experience for their employees. These gaming-quality simulations immerse the trainee in a life-like learning environment and are supported by an intelligent system of learning that is both scalable and practical in application.

SOFTWARE DEVELOPMENT: A TOOL FOR SMART INTEGRATION OF SOLAR POWER – T2M2, $1,762,968

Kevala, Inc. | San Francisco, CA | Principal Investigator: Susie Monson

This project is developing a platform for solar energy system developers that uses sophisticated analytics and detailed local distribution systems data to help reveal where demand and grid value for solar and solar-plus-storage are most beneficial. The tool can also help at the regulator and commission level by increasing transparency and facilitating long-term planning activities. This new software lowers financial risk by providing transparency into the current and future value of projects based on their location.

KRYPTON SHINE – T2M3, $885,711

KryptonCloud | San Francisco, CA | Principal Investigator: Ed Albanese

Krypton is researching a product to photovoltaic operations and maintenance organizations learn from every data point to increase asset performance and improve productivity. Krypton unifies data from disparate sources, is developing machine learning to detect anomalies in real-time, and provides rich applications to monitor and visualize events.

AN OPEN SOURCE PROACTIVE ENERGY MANAGEMENT SYSTEM FOR INTEGRATED CONTROL OF ENERGY STORAGE AND SOLAR POWERED BUILDINGS – SBIR/STTR, $150,000

Leaptran | San Antonio, TX | Principal Investigator: Jeff Xu

Leaptran develops a control and communication software platform that enables the integrated control of battery energy storage and solar-powered buildings so that grid can penetrate renewable and distributed energy sources deeply. The solution will integrate building energy management and battery energy storage to unlock the potential for battery in buildings.

NOVEL CORROSION AND EROSION PROTECTIVE AMORPHOUS ALLOYS COATINGS – SBIR/STTR, $150,000

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

The program will develop unique amorphous alloys coatings with high corrosion and erosion properties using high-velocity oxygen fuel technique. This novel approach will increase concentrating solar power throughput and improve the overall properties of manufactured parts.

INSTALLATION AND SOFT COST REDUCTION FOR HORIZONTAL SINGLE AXIS TRACKERS – T2M2, $1,999,644

Nevados Engineering | San Francisco, CA | Principal Investigator: Yezin Taha

This project is working to optimize Nevados' horizontal single-axis tracker design for potential manufacturing. The technology helps solar developers build commercial solar projects on lands that are raised and uneven and would typically not be considered for solar development. This creates more site options and eliminates major construction costs. This project will update the product design in an effort to find cost-cutting opportunities and further testing will be conducted to demonstrate the reliability and robustness of the single axis tracker design.

BUILDING WINDOWS WITH TRANSPARENT PHOTOVOLTAICS TO LOWER COSTS – T2M3, $2,500,000

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

Next Energy Technologies Inc. (NEXT), has developed transparent photovoltaic coatings for integration into commercial windows. NEXT's low-cost, wet-coated materials selectively absorb and convert light in the infrared and UV spectrum while allowing significant visible light transmission with colors that are desirable to the window market. The 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 will enable NEXT to transition from small-scale 3.5" units produced using laboratory processes to larger format devices utilizing manufacturing-relevant processes.

DEVELOPING OPTIMAL CONTROL TECHNOLOGY FOR DISTRIBUTED ENERGY RESOURCES (DOCTDER) – SBIR/STTR, $1,149,881

Nhu Energy | Tallahassee, FL | Principal Investigator: Rick Meeker

The Nhu Energy team is developing breakthrough control technology to drastically improve the value proposition for distributed energy resources such as solar photovoltaic, storage, electric vehicles, and price-responsive load, to enable significant improvements to electric power system resiliency, economics, and environmental impact.

NON-REFLECTIVE SOLAR PANELS FOR SOLAR ARRAYS IN GLINT OR GLARE SENSITIVE LOCATIONS – SBV, $129,000

Nishati, Inc. | McLean, VA | National Laboratory Partner: Sandia National Laboratories | Principal Investigator: Bruce King

Over 120 gigawatts of solar energy potential exists on lands at or near public airports, small private airfields, and military airfields and training areas in the United States. A barrier to full and efficient implementation of photovoltaic arrays on these lands is the risk of visual impairment to aircrew or tower personnel caused by glint or glare. Nishati Inc. is combining proven materials and design elements with new solar panel assembly techniques to produce a non-reflective commercial photovoltaic panel. The company will use Sandia National Laboratories' specialized equipment and methods for photovoltaic module optical characterization and performance testing to will quantify reflectivity characteristics and low-reflectivity performance benefits, which will aid in understanding materials and methods to further optimize modules.

A SOFTWARE PLATFORM TO DRIVE DISRUPTIVE INNOVATION IN SOLAR PERFORMANCE ASSURANCE THROUGH SOFTWARE AUTOMATION – T2M3, $796,810

Omnidian | Seattle, WA | Principal Investigator: David Kenny

Soft costs associated with solar installation continue to act as a prohibitive factor in the expansion of solar technology, at times comprising of up to 64 percent of the cost of a new solar system. Omnidian is creating an analytical, predictive performance model able to remotely and automatically diagnose performance issues in solar systems thereby driving down these soft costs across the solar industry. This project will result in a scalable asset management offering to the solar market, lowering the risk associated with solar investment, freeing up capital tied down in large-scale residential portfolios, and providing homeowners with continuous monitoring and a system performance guarantee.

RELIABLE AND SECURE BIDIRECTIONAL COMMUNICATIONS LINK FOR DISTRIBUTED ENERGY RESOURCES – T2M3, $480,000

Operant Solar Corporation | Santa Rosa, CA | Principal Investigator: Randall King

Operant Solar has developed a network gateway that reliably, securely, and inexpensively connects distributed energy resources such as residential solar sites to the internet. Currently, the industry relies on single path internet connections that are unreliable. Twenty percent of fleets have dropped offline, becoming invisible to their operators and creating significant operations and management issues for companies. Operant's innovative software protocol provides a wireless backup connection between sites. The protocol, developed by a consortium led by the University of California, Los Angeles, can securely parallel an extremely long-range wireless mesh protocol with standard internet connections, such as WiFi or cellular. The concept is similar to smart meter networks used by utilities, but for more widely dispersed applications, like solar systems.

HIGHLY EFFICIENT STEEL CABLE SOLAR PHOTOVOLTAIC MOUNTING SYSTEM – T2M3, $1,000,000

P4P Energy | Carbondale, CO | Principal Investigator: Michael Fuller

P4P has developed a unique photovoltaic panel suspension system utilizing tensioned cable design to reduce cost of solar parking structures. P4P'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 is researching a high volume, high efficiency product that will be both aggressively competitive and aesthetically pleasing.

CUSTOMER ACQUISITION PLATFORM FOR ROOFTOP SOLAR PROPERTY ASSESSED CLEAN ENERGY FINANCING – T2M3, $1,500,000

Pace Avenue | Oakland, CA | Principal Investigator: Gary Kremen

Pace Avenue is researching an online platform that will target and prequalify eligible homeowners, specifically low and moderate income homeowners, for Residential Property Assessed Clean Energy (R-PACE) financing. R-PACE is a financing mechanism for solar, energy efficiency, and water conservation upgrades for residential property owners. Homeowners will be matched with the most appropriate solar and energy efficiency product bundle, R-PACE administrator, and installer.

THE PECAN STREET LEVERAGED ASSETS FOR TECHNOLOGY FEASIBILITY REVIEW, OPTIMIZATION AND MARKET VALIDATION (PLATFORM) FOR PRODUCT LAUNCH – INNOVATIVE PATHWAYS, $1,000,000

Pecan Street Inc. | Austin, TX | Principal Investigator: Suzanne Russo

Pecan Street Inc. and the Translational Research Institute created the PLATFORM (Pecan Street Leveraged Assets for Technology Feasibility, Optimization, and Marketing review) for Product Launch to demonstrate and validate a new model for dramatically improving the effectiveness of investments in clean energy technologies and accelerating market entry of disruptive technologies. Over the past five years Pecan Street has developed a platform that integrates data-driven market intelligence, lean product development and validation methods, rapid prototyping, and collaboration between industry and the technical community. The PLATFORM model leverages these assets to co-locate the resources required to carry an innovative idea into a commercializable product while at the same time aligning progressive stages of market validation with funding and providing verified technology impact reports that unlock new impact investing opportunities. Product demonstrations within the testbed will allow utilities and key players in the energy space to evaluate technologies without risk or commitment. The model introduces a critical paradigm shift in clean energy innovation that overcomes the critical barriers to market adoption and enables a step change in how these technologies are developed, funded, marketed, and procured.

HIGH TOUGHNESS CERMETS FOR MOLTEN SALT PUMPS – SBIR/STTR, $150,000

Powdermet | Euclid, OH | Principal Investigator: Haixiong Tang

Concentrated solar power electricity generation is calculated to achieve cost competitiveness when operating over 700^0 Celsius but requires new materials to handle the high temperature and corrosive properties of heat transfer fluid and thermal energy storage media. Development of metal matrix ceramic nanocomposites promises long life and lower cost pump components.

PARTNERSHIPS FOR INTELLIGENT ENERGY – INNOVATIVE PATHWAYS, $663,817

Powerhouse Accelerator | Oakland, CA | Principal Investigator: Emily Kirsch

Powerhouse LLC will design, develop, and pilot systematic approaches to facilitating partnerships between early-stage clean energy companies and industry or investors. The team will aim to meet ambitious targets for supporting startups to secure mentors, channel partners, and capital. Program findings will be distributed for replication by energy commercialization organizations. At scale, this framework will accelerate the commercialization and deployment of clean energy technologies, including solar.

ULTRA-COMPACT HIGH EFFICIENCY MULTI-LEVEL GAN-BASED PHOTOVOLTAIC INVERTER – T2M3, $922,693

Power Integration Laboratory | Urbana, IL | Principal Investigator: Robert Pilawa

The project objective is to research methods to develop a hardware prototype of a scalable multi-level, interleaved 60-100 kilowatt photovoltaic inverter, comprising several sub-modules that enable various power levels to be implemented using a common framework with advanced grid support features.

MIDDLEWARE ORIENTED COMMUNITY SOLAR PLATFORM – SBIR/STTR, $1,149,560

ProjectEconomics | New York, NY | Principal Investigator: Eric Dahnke

Community solar has the potential to increase access to solar for households and businesses that cannot put solar panels on their roofs. ProjectEconomics is developing its community solar platform to help utilities and third parties deliver community solar programs efficiently at scale.

CO-SIMULATION OF TRANSMISSION AND DISTRIBUTION FOR GENERATOR INTERCONNECTION ANALYSIS IN AN ADVANCED ANALYTICS ELASTIC CLOUD COMPUTING ENVIRONMENT – T2M2, $700,000

GridUnity (formerly Qado Energy) | Summit, NJ | Principal Investigator: Brian Fitzsimons

This project enables utilities to conduct rapid forecasting and planning of distributed energy resource deployment combinations through the use of hybrid distribution/transmission models. The rapid addition of distributed generation creates concerns among utilities and regional transmission operators about impacts on transmission. The development of transmission impact functionality will drive down interconnection times of large commercial and small utility projects, which are known for their lengthy queues.

LOW-COST WIRELESS VOLTAGE AND CURRENT MONITORING OF THE DISTRIBUTION GRID – T2M3, $1,999,812

SenSanna Incorporated | Arnold, MD | Principal Investigator: Jacqueline Hines

SenSanna Incorporated is working to enhance the resilience and reliability of the distribution grid and to enable increased levels of solar and other distributed energy sources through the use of cost-effective distributed wireless monitoring systems. LineSenSTM systems wirelessly measure current, voltage, and temperature on power lines without any batteries in the line units and without harvesting energy from the power lines. Unlike other line sensor systems, LineSenSTM operates even at zero current, providing current and voltage waveforms, relative phase, and temperature data for a cost similar to simple fault indicators.

RE-DESIGNING THE CONCENTRATING SOLAR POWER THERMAL ENERGY STORAGE SYSTEM TO ENABLE HIGHER TEMPERATURE PERFORMANCE AT REDUCED COST – T2M3, $2,000,000

SolarReserve | Santa Monica, CA | Principal Investigator: William Gould

SolarReserve is working with the National Renewable Energy Laboratory and others to develop designs that will eliminate the need for expensive alloys and lower costs in today's hot tanks operating at 565o to 580o Celsius and in tomorrow's systems that will use a much higher operating temperature. The research will reduce costs in two ways. First, the introduction of internal insulation within the tank will reduce the temperature of the steel pressure boundary enabling designers to use less expensive alloys. This internal insulation may take the form of ceramic or metallic materials and structures and may take advantage of the inherently low thermal conductivity of a layer of stagnant salt adjacent to the pressure boundary. The second aspect of the work consists of relocating the salt pumps from their present position, suspended above the roof of the tanks on expensive platforms cantilevered from nearby building steel, to a point at or below grade. In their new location, the pumps and the required supporting structures will be much cheaper and more conventional.

DESIGN AND RELIABILITY IMPROVEMENTS FOR HIGH-TEMPERATURE PARABOLIC TROUGH SOLAR FIELDS – T2M3, $1,600,000

Solar Dynamics | Broomfield, CO | Principal Investigator: Patrick Marcotte

Parabolic trough technology is the most commercially mature CSP technology, but its hydrocarbon-based heat transfer fluid limits the upper operating temperature of power plants. As a result, trough plants must use an indirect molten salt thermal energy storage design that is not as efficient or cheap as storage is in molten salt tower plants. The next major advance for trough technology is the move to using molten salt directly as the heat transfer fluid in the solar field. This project introduces innovative solutions to address the two of the key issues still to be resolved for using molten salt in trough plants: the cost of the molten salt freeze recovery system in the solar field and the development of a reliable collector interconnection that works with molten salt.

A RELIABLE AND LOW-COST MONOLAYER BACKSHEET FOR CRYSTALLINE SILICON SOLAR MODULES – T2M2, $399,981

Soliculture | Scotts Valley, CA | Principal Investigator: Glenn Alers

This project develops backsheets for silicon photovoltaic modules that solves fundamental problems with current products on the market. This new technology removes tie layers, which are known to cause reliability problems such as delamination and moisture ingress, and replaces a polyester film that can recrystallize at certain temperatures.

HIGH TEMPERATURE, RAMAN SPECTROSCOPY BASED, INLINE, MOLTEN SALT COMPOSITION MONITORING SYSTEM FOR CONCENTRATING SOLAR POWER SYSTEMS – SBIR/STTR, $150,000

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

Sporian Microsystems will research and develop a novel, high temperature, in-line, monitoring system to help next generation concentrating solar power (CSP) plants efficiently provide low-cost renewable energy. The monitoring system will leverage Raman Spectroscopy to track chemical composition (e.g. oxygen ad moisture) in the high temperature molten salt within the thermal storage loop of the CSP plant. The data obtained will help to ascertain the health of the molten salt, e.g. whether it is decomposing, as well as identify impurities, e.g. leached metals, that might be contained within the mixture. In-line monitoring of the molten salt at high temperature will help to elucidate fundamental chemical mechanisms at play and ultimately result in high temperature (700 C) thermal storage systems that are more reliable and affordable.

ACCELERATED EXPOSURE TESTING OF SUNDOG SOLAR TECHNOLOGIES – SBV, $50,000

Sundog Solar Technology | Arvada, CO | National Laboratory Partner: National Renewable Energy Laboratory | Principal Investigator: Robert Tirawat

This project will aid in the development of Sundog Solar's advanced reflector technology. Sundog will test the weatherization design of its protective coating materials for solar reflectors on the lab's Ultra Accelerated Weathering System, which will move the technology closer to commercialization.

SUNFOLDING MASS-MANUFACTURED TRACKERS FOR HIGH PERFORMANCE PHOTOVOLTAIC SYSTEMS – T2M2, $1,999,999

Sunfolding, Inc. | San Francisco, CA | Principal Investigator: Leila Madrone

This project is further developing a modular, single-axis tracker system powered by air pressure in polymer bellows that has the flexibility and installation simplicity of a fixed-tilt system. The key is a distributed, mass-manufactured drive system with shared control. This tracking system opens up new opportunities to significantly reduce component costs, improve efficiencies in construction and site design, and improve long-term reliability for all tracking solar projects. This project will build upon the demonstrated technical successes by applying advanced U.S. manufacturing and automated assembly techniques to achieve significant cost reductions.

APPARATUS FOR OPTIMIZING PHOTOVOLTAIC SOLAR MANUFACTURING EFFICIENCY THROUGH REAL-TIME PROCESS FEEDBACK AND SPECTRAL BINNING OF CELLS – SBIR/STTR $992,930

Tau Science Corporation | Beaverton, OR | Principal Investigator: Greg Horner

This project is developing light engine and detection electronics to extract spectral response metrics from a PV cell without the need to make electrical contact to the material stack. The technology revolutionizes PV characterization by bringing the most fundamental measure of a solar cell performance--spectral response-- to application areas that are impractical or unobtainable using existing techniques. Applications include inline monitoring of cells prior to metallization, accessing information from individual cells once they are assembled into PV solar modules without the need for light or electrical biasing, and monitoring of metallized cells without the breakage loss inherent to techniques requiring electrical contact.

MOBILE IN-SITU IMAGING OF PHOTOVOLTAIC MODULES – SBIR/STTR, $150,000

Tau Science Corporation | Hillsboro, OR | Prinicpal Investigator: Greg Horner

The nation's electric grid depends upon the reliable generation of electricity, and as solar modules are added in greater numbers, they require unique inspection and qualification techniques. This project will develop a non-contact scanner that can operate at night in solar fields to detect various failure and degradation modes.

PROTOTYPE TESTING OF AN ENCAPSULATED THERMAL ENERGY STORAGE FOR CONCENTRATING SOLAR POWER – SBV, $170,000

Terrafore Technologies, LLC | Minneapolis, MN | National Laboratory Partner: Argonne National Laboratory | Principal Investigator: Dileep Singh

This project will allow Terrafore to improve its innovative method of storing high-temperature thermal energy using phase change of inorganic salts inside ceramic capsules contained in a single tank. Using Argonne's expertise in high-temperature technologies, the performance and reliability of the technology will be tested with the goal of developing a more efficient and robust prototype for concentrating solar power plants. This will enable more efficient, compact energy storage at high temperatures for distributed power plants.

UNLOCKING UTILITY DATA TO ADDRESS SOLAR SOFT COSTS THROUGH A UTILITYAPI OPENESPI DATA CUSTODIAN – T2M3, $923,750

UtilityAPI | Oakland, CA | Principal Investigator: Daniel Roesler

UtilityAPI is building an Underwriters Laboratory-certified Green Button Connect product that enables utilities to implement the Green Button Connect standard specifically for solar consumers and solar providers. Green Button Connect is an interface that utilities can deploy to enable their customers to easily and securely access their utility data and share it with qualified third-party providers of services in a consumer-friendly and computer-friendly format.

Manufacturing: Innovation and Scale-Up

INTERCONNECT CIRCUIT MANUFACTURING TECHNOLOGY – T2M1, $2,500,000

CelLink Corporation | San Carlos, CA | Principal Investigator: Kevin Coakley

This project is developing a flexible conductive backplane that will provide module manufacturers with efficiency gains and a reduction in manufacturing cost per watt. Through proprietary fabrication techniques and advanced materials, CelLink's conductive backplanes are much more conductive, larger, lighter, and less expensive than traditional flexible circuits. These attributes are uniquely suited to the needs of rear-contact solar modules and other power electronics applications.

CATALYZING PHOTOVOLTAIC MANUFACTURING IN THE U.S. WITH NEXT-GENERATION DENSE CELL INTERCONNECT PHOTOVOLTAIC MODULE MANUFACTURING TECHNOLOGY – T2M1, $5,499,551

Cogenra Solar | Fremont, CA | Principal Investigator: Gilad Almogy

This project is developing a first-of-its-kind 50 megawatt per year photovoltaic module manufacturing line based on the company's innovative Dense Cell Interconnect technology, which rewires the photovoltaic module. The approach increases module output power by reducing metal shading, eliminating gaps between cells, and decreasing resistance, resulting in a lower module price per watt. Higher efficiency also reduces balance of system and installation costs. This technology eliminates module degradation associated with ribbons and solder joints and significantly increases lifetime power output, which further reduces the levelized cost of energy. This project will broaden the technology to mainstream photovoltaic applications.

HIGH THROUGHPUT EPITAXIAL GROWTH OF SILICON WAFERS WITH DEEP BUILT IN JUNCTIONS FOR SOLAR CELLS – T2M2, $3,000,000

Crystal Solar Inc. | Santa Clara, CA | Principal Investigator: Ruiying Hao

Crystal Solar has a unique process of fabricating monocrystalline silicon wafers using an epitaxial deposition process that leads to high-quality kerfless wafers. This process also allows Crystal Solar to deposit built-in junctions and surface fields in the wafers, which reduces downstream cost-in-cell processing. The project focuses on improving the base substrate reuses and process yield to lower the cost of epitaxial wafers through automation of the pilot process line. Additionally, high-efficiency cells will be fabricated to demonstrate the readiness of the epitaxial substrate with traditional solar cell processing.

LOW CAP-EX, HIGH SPEED ROLL-TO-ROLL PEROVSKITE SOLAR MODULE DEVELOPMENT – T2M3, $2,000,000

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

Energy Materials Corporation 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.

BRITTLE FRACTURE WAFERING OF SILICON INGOTS FOR LOW-COST, HIGH-EFFICIENCY CRYSTALLINE SILICON SOLAR CELLS – T2M3, $1,073,288

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

Halo Industries will develop and prototype 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.

REFINEMENT OF THE FLOATING SILICON METHOD: A LOW-COST MONOCRYSTALLINE SILICON WAFER MANUFACTURING PROCESS – T2M3, $1,500,000

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

Leading Edge Crystal Technologies 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 unprecedentedly high production rates, underpinning a potential 60 percent cost reduction over existing single crystal wafer. 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.

ONE-STEP SUPER EMITTERS FOR HIGH-EFFICIENCY SOLAR CELLS – T2M1, $2,000,000

Picasolar | Fayetteville, AR | Principal Investigator: Douglas Hutchings

Imperfections in a solar emitter, a critical layer that collects the current-producing charge carriers in a solar cell, causes significant efficiency loss in most of the commercial solar cells. Picasolar's Hydrogen Super Emitter perfects emitters after cells are already made, helping to use less silver, avoid multiple processing steps and disruptions, and improve efficiency gains. The technology is a one-step, low-temperature process that electrically deactivates 99.5 percent of the dopants at the surface of the solar cell. This significantly lowers surface recombination, or the charge carrier losses experienced in the surface layer of a solar cell, thus helping to make the solar cells more efficient. In addition, Picasolar will create a tool that uses this new process and will integrate it into a high-volume manufacturing line.

ADVANCED MANUFACTURING TOOLSET FOR LOW-COST COPPER METALLIZATION OF HIGH-EFFICIENCY HETEROJUNCTION SOLAR CELLS AND GLASS-GLASS BIFACIAL MODULES – T2M2, $4,993,823

Sunpreme Inc. | Sunnyvale, CA | Principal Investigator: Farhed Moghadam

This project is developing an advanced manufacturing toolset and process technology for low-cost copper metallization of high-efficiency heterojunction solar cells and glass-glass bifacial modules. While copper electrodes are well-known to be the best option for high-performance solar cells, very few are made with copper due to the complex and costly process needed to pattern it. This project adapts technologies from the ultra-cost-sensitive printed circuit board industry and modifies them for processing solar cells with higher throughput.

COST-EFFICIENT AND HIGHLY WEATHER-RESISTANT SOLAR PANEL BACKSHEET PRODUCED THROUGH CONTINUOUS CO-EXTRUSION PROCESSING – T2M3, $443,120

Tomark-Worthen | Nashua, NH | Prinicpal Investigator: Christopher Thellen

Photovoltaic backsheet is a critical component to most solar modules as it provides insulation and protection to the module from environment forces such as moisture and ultraviolet light. Tomark-Worthen LLC will use novel thermoplastics to develop a backsheet material that is lower in cost than fluoropolymer-based backsheet in the field today, while reducing solar panel replacement costs by providing more than a 30-year expected service-life. This novel backsheet is created through co-extrusion, which allows for recycled content to be used in the production of the backsheet without the use of adhesives and polyethylene terephthalate, which are known to suffer from hydrolytic degradation in solar applications.

ACTIVE LAB AWARDS

Technology Commercialization and Business Innovation

ASSESSMENT OF WATER INGRESS IMPACT ON EFFICIENCY DEGRADATION IN PHOTOVOLTAIC MODULES – TECHNOLOGY COMMERCIALIZATION FUND, $150,000

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

Building upon previous work that has shown the feasibility of Fourier transform infrared spectroscopy for non-destructive measurement of water ingress in photovoltaic modules, this project is designing a prototype instrument, deploying it in a production facility to gather data on a broad variety of solar modules and materials, and quantifying the impact of water ingress on product efficiency and reliability.

OPTIMAL, RELIABLE BUILDING-INTEGRATED ENERGY STORAGE – TECHNOLOGY COMMERCIALIZATION FUND, $525,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Ying Shi

The lab, partnering with Eaton Corporation, is developing control strategies that co-optimize battery lifetime with energy storage system performance to maximize the value proposition in residential and commercial behind-the-meter applications. Building upon lab-developed control-oriented battery prognostic models, which are based on battery degradation physics, the project will improve the net present value of building-integrated photovoltaic power by augmenting with optimal, reliable energy torage and reduce the warranty risk associated with deploying energy storage in disparate markets where battery's daily load characteristics vary greatly.

IMPROVING CLOUD-BASED PERFORMANCE OF DISTRIBUTION PLANNING – TECHNOLOGY COMMERCIALIZATION FUND, $300,000

Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Frank Tuffner

This project, in partnership with GridUnity, aims to reduce utility analysis time for smart grid and distributed energy resource integration studies within the cloud-based GridUnity platform by significantly improving GridLAB-D simulation time by implementing targeted parallelization and data management techniques.

SOLAR THERMOCHEMICAL REACTION SYSTEM FOR HYDROGEN FUEL CELLS – TECHNOLOGY COMMERCIALIZATION FUND, $1,000,000

Pacific Northwest National Laboratory | Richland, WA | Partners: SoCal Gas, STARS Technology Corporation | Principal Investigator: Robert Wegeng

The goal of this project is to significantly advance the Dish-Solar Thermochemical Advanced Reactor System (Dish-STARS), an innovative combination of parabolic dish concentrators and micro- and meso-channel process technology, as applied to renewable natural gas and electrical power generation.

Cost Analysis: Technology, Competitiveness, Market Uncertainty

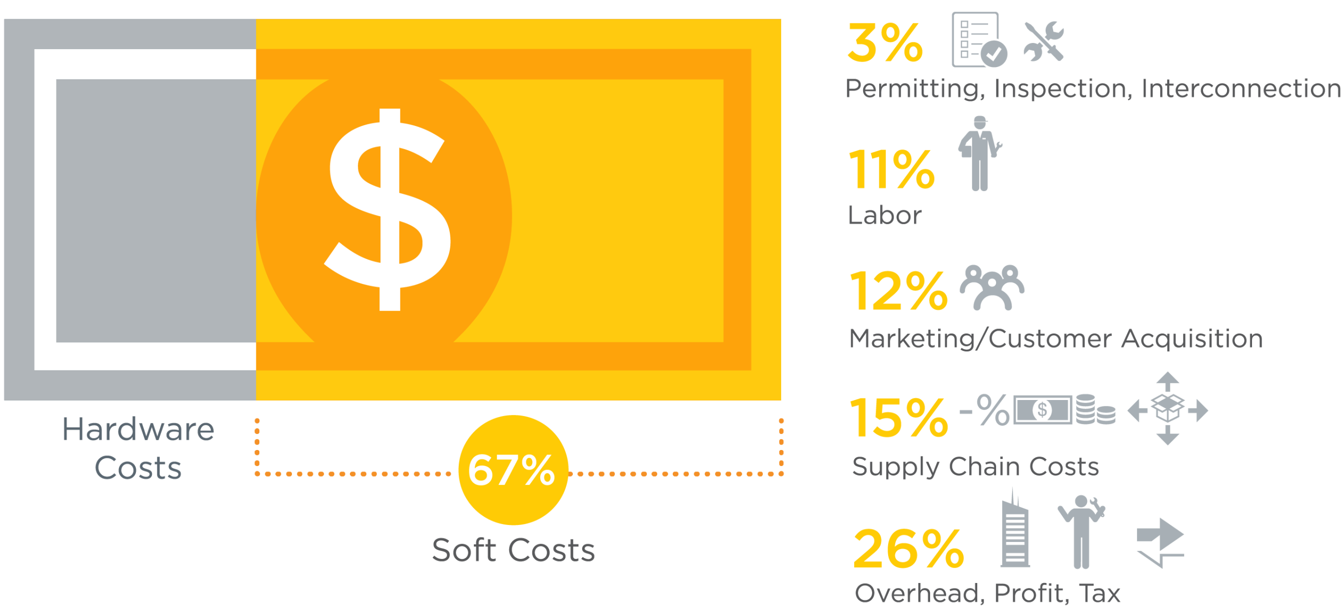
SOLAR TECHNOLOGY COST MODELING AND COMPETITIVE ANALYSIS – SUNLAMP, $3,000,000

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

This project uses bottom-up techno-economic cost modeling to both benchmark current technology and system costs, and to inform the potential commercial impacts of technology development and system installation improvement pathways. In combination with economic studies of critical materials supply-demand dynamics and possible price trajectories, this project also examines the potential impact to dependent module technology costs and deployment levels.

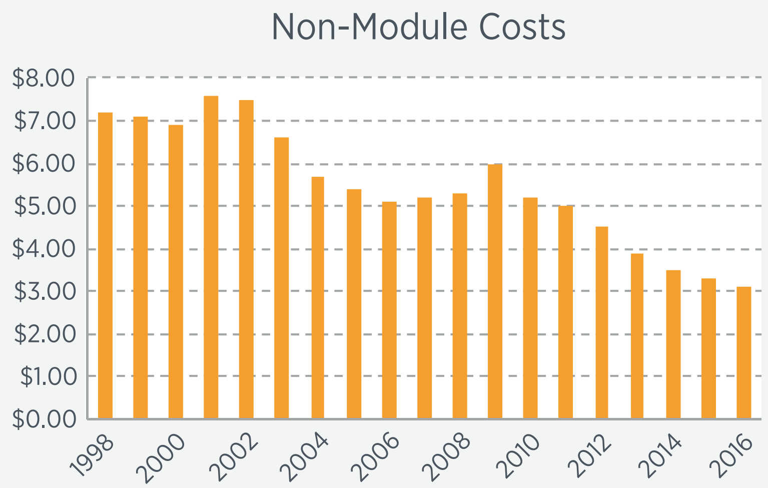
Balance of Systems – Soft Costs

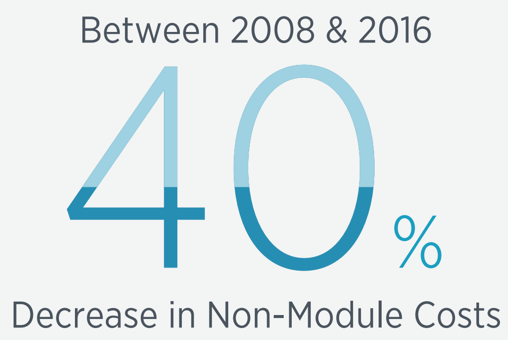
The Solar Energy Technologies Office's Balance of Systems Soft Costs subprogram works to address challenges associated with non-hardware costs of solar electricity, reduce the regulatory burden of adding solar to the grid, and identify technology-neutral pathways that provide affordable and reliable solar electricity to American consumers. For residential systems, soft costs account for nearly 70 percent of the total cost of a new solar system. This includes financing, customer acquisition, supply chain costs, permitting, installation labor, and sales taxes, as well as developer overhead and profit.



The underlying causes of solar soft costs include the perceived risk associated with new technology, emerging business models, and the rapid introduction and growth of distributed energy resources. These challenges are layered into an energy market landscape with differing policies and regulations from state to state, many of which have not been updated and do not yet accommodate changes in resilience, reliability, consumer choice, digital and communications functions, and increased coordination and competition among technologies. Many of these challenges can be effectively overcome by addressing information gaps.

Soft Costs are Declining





Projects managed by the Soft Costs subprogram fall into three categories:

FOUNDATIONAL RESEARCH, DATA, AND ANALYSIS: This work aims to conduct high-impact analysis that can reduce soft costs for solar, while simultaneously creating new methods for conducting research and analysis, including agent-based modeling, machine learning, and other advanced data approaches. When possible and practical, real-world data is used to improve the quality and relevance of analysis. The tools and results of these analyses are used to inform activities across SETO.

INSTITUTIONAL SUPPORT: Innovation in the solar industry happens at a fast pace. Soft cost programs integrate insights from studies of the science of innovation, as well as analysis of emerging business models and market impacts, to examine the results of ground-tested new program and policy strategies for state and local governments. These impacts cross the boundaries of utility, business, financial, policy, and regulatory issues. This work supports the exchange of new insights and lessons learned that continue to help the energy sector adapt in a period of rapid change.

TRAINING: More than 260,000 people are employed by the solar industry, a number that has nearly tripled since 2010. More training opportunities are required to ensure a technically skilled workforce that is capable of modernizing our electric grid to handle increasing amounts of solar energy. SETO has supported the development of new certifications to fill the need for third-party validation of the skills and competence of the workforce. As more utilities add solar energy and require employees who have the knowledge of renewable energy integration, SETO has supported training programs at universities to train the next generation of engineers to handle a rapidly changing grid. SETO also supports solar training for professionals in related fields like design, real estate, and finance. These training opportunities will ensure that solar energy has a stable supply of qualified professionals and supports American competitiveness.

See a list of active funding programs below, followed by a description of all active Soft Costs projects.

Funding Program	Year Announced	Amount Awarded
Solar in Your Community Challenge	2017	$5M
Solar Energy Evolution and Diffusion Studies 2 – State Energy Strategies (SEEDS2-SES)	2016	$21M
Solar Training and Education for Professionals (STEP)	2016	$10M
Orange Button℠ - Solar Bankability Data to Advance Transactions and Access (SB-DATA)	2016	$3.6M
Solar Powering America by Recognizing Communities (SPARC)	2015	$13M
Solar Market Pathways	2015	$16.5M
SunShot National Laboratory Multiyear Partnership (SuNLaMP)	2015	$24M
Grid Engineering for Accelerated Renewable Energy Deployment (GEARED)	2013	$15M
Solar Utility Networks: Replicable Innovations in Solar Energy (SUNRISE)	2013	$8M

Each project is displayed as follows:

Project Title – Funding Program, Amount Awarded

Awardee Name | Awardee Location | Principal Investigator

Project Description

ACTIVE COMPETITIVE AWARDS

Foundational Research, Data, and Analysis

ADVANCING SOLAR INNOVATION FOR LOW AND MODERATE INCOME HOUSEHOLDS: ANALYSIS OF THE ARIZONA EXPERIENCE – SEEDS2-SES, $729,995

Arizona State University | Tempe, AZ | Principal Investigator: Jacqueline Hettel

This project identifies key socioeconomic factors and social values that enable and constrain solar adoption in low- and moderate-income communities in Arizona. The team is developing an accessible and easy-to-understand database of social drivers for solar adoption and non-adoption. By closely studying the areas that represent a large portion of the state's population, this project provides insights regarding adoption patterns that will not be observed in larger-scale national studies. In addition to assessing Arizona, the project will begin to compile driving factors for adoption in select communities within Arkansas, Georgia, and Mississippi.

UNDERSTANDING ADOPTION OF A KEY SOFT COST REDUCTION STRATEGY: MODELING ADMINISTRATIVE CHOICES REGARDING STREAMLINED SOLAR PERMITTING – SEEDS2-SES, $1,199,935

Center for Sustainable Energy | Oakland, CA | Principal Investigator: Margaret Taylor

This project analyzes streamlined solar permitting and the associated bundle of standardized ordinances, documents, and practices. The team studies different authorities having jurisdiction throughout California that have adopted streamlined solar permitting at different times in the recent past, as well as those that have not. By analyzing this diversity of jurisdictions, the team is able to scientifically design streamlined solar permitting packages that are ideally suited for other jurisdictions around the country, and will design such packages in at least two other states.

ORANGE BUTTON PHASE 3: STANDARDIZING DATASETS – SB-DATA, $1,000,000

kWh Analytics | San Francisco, CA | Principal Investigator: Jonathan Xia

This project supports the adoption of industry-led data standards, including the development of a data format translation software tool that which will instantly translate original data formats into data standards, significantly reducing the effort and time required to adopt the data standards, leading to 60 percent adoption of data standards by the U.S. solar market within two years.

MODELING PHOTOVOLTAICS INNOVATION AND DEPLOYMENT DYNAMICS – SEEDS2-SES, $1,275,000

Massachusetts Institute of Technology | Cambridge, MA | Principal Investigator: Jessika Trancik

This project evaluates the mechanisms driving photovoltaic system cost reductions, delving deeply into specific past technological innovations and policies, and prospectively assessing solar's potential for future cost reduction. New datasets and advanced modeling frameworks are being developed, which will provide a complete picture of how specific technology and policy developments led to the dramatic cost reduction in photovoltaics in recent decades. In addition, this project provides insights for policymakers, engineers, and other stakeholders to inform their research and development investments and policy designs in the future.

ORANGE BUTTON PHASE 3: STANDARDIZING DATASETS – SB-DATA, $400,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Debbie Brodst-Giles

This project is developing tools to convert paper-based solar records to machine-readable formats and establish a marketplace for standardized solar datasets. This platform will provide an open source data repository, easy access to data that is housed on the internet, a central catalog for solar energy data, a means to combine data, a gateway to common data standards, and a searchable interface.

UNLOCKING WIDESPREAD SOLAR ADOPTION: UNDERSTANDING PREFERENCES OF LOW- TO MODERATE-INCOME HOUSEHOLDS TO CREATE SCALABLE, SUSTAINABLE MODELS – SEEDS2-SES, $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.

ORANGE BUTTON PHASE 1: CONVENING STAKEHOLDERS – SB-DATA, $615,426

Smart Electric Power Alliance (formerly Smart Grid Interoperability Panel) | Boston, MA | Principal Investigator: Aaron Smallwood

This project convenes stakeholders and managing working groups to define the requirements of the project. It focuses on driving out inefficiencies in data exchanges that lead to reduced soft costs associated with solar projects. The work completed helps integrate data standards across the life cycle of a solar project.

DATA-DRIVEN UNDERSTANDING OF LOW- TO MODERATE-INCOME CUSTOMERS’ ADOPTION AND FINANCIAL QUALIFICATION IN COMMUNITY SOLAR – SEEDS2-SES, $816,090

Solstice Initiative | Boston, 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 and FICO score, as well as 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.

MACHINE LEARNING FOR SOLAR TECHNOLOGY PORTFOLIO MANAGEMENT – SEEDS2-SES, $699,940

SRI International | Arlington, VA | Principal Investigator: Christina Freyman

This project creates a data-driven tool that describes the development of different solar technologies through the use of machine learning and text analytics. The tool identifies the types of variables, and the influencers that impact them, that enable a solar energy technology to transition across readiness levels using unique solar energy data sources. In doing so, the model helps explain prior technology transitions, as well as predict the likelihood of a technology's advancement to future readiness levels.

ORANGE BUTTON PHASE 2: ESTABLISHING DATA STANDARDS – SB-DATA, $1,638,765

SunSpec Alliance | Santa Clara, CA | Principal Investigator: Thomas Tansy

This project is establishing an open, easy-to-adopt solar data architecture and standards —comprised of uniform data taxonomy, information models, data schemas, data exchange protocols, functional specifications for interoperability, compliance test suite and reference software—that will enable the free flow of data between existing software products that address critical aspects of the solar asset life cycle. This system will leverage the inherent capabilities of existing international data standards, extend them using uniform data taxonomy built with industry consensus, and combine them with common data exchange technologies, thus establishing a basic dictionary for interchange of interoperable datasets created throughout the solar project lifecycle.

KNOWLEDGE SPILLOVERS AND COST REDUCTIONS IN SOLAR SOFT COSTS – SEEDS2-SES, $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 the importance of knowledge spillovers, the types of knowledge most likely to spill over, and how policies can be designed to address them.

COUPLED SOCIAL AND INFRASTRUCTURE APPROACHES FOR ENHANCING SOLAR ENERGY ADOPTION – SEEDS2-SES, $1,225,961

Virginia Polytechnic Institute and State University | Blacksburg, 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 – SEEDS2-SES, $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.

Institutional Support

VIRTUAL NET METERING MARKET DEVELOPMENT PLAN – SOLAR MARKET PATHWAYS, $712,269

California Center for Sustainable Energy | San Diego, CA | Principal Investigator: Ben Airth

This project is examining the awareness, effectiveness, and use of virtual net metering in California and beyond. Currently, the ability to expand solar adoption outside of traditional commercial or single-family rooftop systems has been a challenging proposition for solar markets throughout California and elsewhere. This project aims to expand the application of virtual net metering to multifamily and multi-metered homes and facilities.

SOLAR PLUS STORAGE FOR RESILIENCY – SOLAR MARKET PATHWAYS, $1,321,200

City and County of San Francisco Department of the Environment | San Francisco, CA | Principal Investigator: Alison Healy

This project is expanding the solar market by serving as a national model for integrating solar and energy storage into existing disaster preparedness plans. The project team is working closely with stakeholders to overcome regulatory, financial, and technical barriers and create a roadmap for deploying solar with storage for resilience both locally and nationally.

NYSOLAR SMART DISTRIBUTED GENERATION HUB – SOLAR MARKET PATHWAYS, $859,720

City University of New York | New York, NY | Principal Investigator: Tria Case

This project is creating a roadmap for the integration and tracking of resilient solar systems, which can supply emergency power and provide energy storage, as well as conducting analysis for deploying resilient solar energy systems on designated critical infrastructure facilities. Additionally, the project is developing a calculator that will help capture the full spectrum of value streams for solar systems with battery storage, such as supplying emergency power, peak shaving, and load shifting capabilities, consequently providing decision makers with the necessary tools to make educated investments.

STATE STRATEGIES TO BRING SOLAR TO LOW- AND MODERATE-INCOME COMMUNITIES – SEEDS2-SES, $1,730,000

Clean Energy States Alliance | Montpelier, VT | Principal Investigator: Diana Chase

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 a plan of action that matches its programmatic needs, demographic profile, solar potential, and financial resources.

FACILITATING DEPLOYMENT OF COMMUNITY SOLAR PV SYSTEMS ON ROOFTOPS AND VACANT LAND IN NORTHEAST ILLINOIS – SOLAR MARKET PATHWAYS, $1,238,308

Cook County Department of Environmental Control | Chicago, IL | Principal Investigator: Deborah Stone

This project identifies and establishes models for community solar and eliminates barriers to implementation through the assessment of the current community solar marketplace in Northeast Illinois and identification of the potential market. The project analyzes the economics of different ownership structures, then identifies the structural, regulatory, and policy barriers to community solar and proposes approaches to eliminate those barriers. Detailed analysis of pilot case studies will create models and lessons learned that can be replicated across the region to help other projects in the region succeed.

A SOLAR MARKET PATHWAY FOR INDEPENDENT COLLEGES IN VIRGINIA – SOLAR MARKET PATHWAYS, $807,563

Council of Independent Colleges of Virginia | Bedford, VA | Principal Investigator: Robert Lambeth

The Council of Independent Colleges is leading a program to boost Virginia's solar market by partnering with 15 of its member colleges and their hometown communities. This collaborative and replicable approach will guide campuses through the process of preparing for installation and purchasing solar panels, reducing operating costs and demonstrating associated economic benefits.

LOCAL ENERGY MATTERS: SOLAR MARKET DEVELOPMENT IN DULUTH, MINNESOTA – SOLAR MARKET PATHWAYS, $209,000

Ecolibrium3 | Duluth, MN | Principal Investigator: Jodi Slick

This project is working with state and local stakeholders to develop residential rooftop, community, and commercial solar projects, further developing the local market in Duluth. The project focuses on reducing soft costs through the development of simplified processes for permitting and interconnection. Over three years, one megawatt of capacity will be installed with a cost reduction goal of 50 percent.

SOLAR MARKET PATHWAYS NATIONAL COORDINATOR – SOLAR MARKET PATHWAYS, $1,872,845

Institute for Sustainable Communities | Montpelier, VT | Principal Investigator: Debra Perry

This project creates a learning network that enables communications, coordination, and shared learning across the 14 organizations in Solar Market Pathways. This includes providing targeted technical assistance to help awardees develop high-caliber, technically sound, broadly supported plans, models, and strategies. The team also identifies and disseminates best practices and lessons learned from program partners' experiences to advance solar deployment throughout the country.

SOLAR POWERING AMERICA BY RECOGNIZING COMMUNITIES SOLSMART DESIGNATION PROGRAM – SPARC, $2,998,450

International City/County Management Association | Washington, DC | Principal Investigator: Andrea Fox

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.

THE SOLAR ENDOWMENT: A PHOTOVOLTAIC INVESTMENT ROADMAP FOR U.S. UNIVERSITIES AND FOUNDATIONS – SOLAR MARKET PATHWAYS, $1,025,400

Midwest Renewable Energy Association | Custer, WI | Principal Investigator: Nick Hylla

U.S. colleges and universities are currently in a position to make substantial solar project investments both on and off campus. To facilitate these investments, this project is working with stakeholders at four universities to create solar investment proposals for consideration by university governance boards. This campus stakeholder engagement is led by student solar deployment teams and builds off of past program success with the U.S. Department of Energy Solar Decathlon and similar student-led projects. This effort showcases the potential of university solar investments, advances favorable board policies to govern solar investments, and provides a roadmap for universities across the country to deploy solar, thereby advancing sustainability goals.

MINNESOTA SOLAR PATHWAYS: ILLUMINATING PATHWAYS TO 10 PERCENT SOLAR – SEEDS2-SES, $1,999,964

Minnesota Department of Commerce | St. Paul, MN | Principal Investigator: Stacy Miller

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.

MONTANA COMMUNITY-SCALE SOLAR STRATEGY PROJECT – SEEDS2-SES, $380,000

Montana State Energy Office | Helena, MT | Principal Investigator: Garrett Martin

This project is developing a cost-effective, community solar energy strategy for Montana that will expand access to solar energy. The project aims to develop model community solar projects that will be promoted across the state to meet the needs of interested consumers and communities, as well as electric utilities or cooperatives.

SOLAR UTILITY NETWORK DEPLOYMENT ACCELERATOR – SUNRISE, $3,645,657

National Rural Electric Cooperative Association | Arlington, VA | Principal Investigator: Debra Roepke

This project is developing standard designs for 0.25, 0.5, and 1 megawatt solar projects and accelerating photovoltaic maturity at electric cooperatives through these standardized designs, streamlined financing, packaged insurance, and extensive training and outreach. Partnering with 17 cooperatives in 15 states that cover more than 150 counties enables the deployment 23 megawatts in less than three years with aggressive cost reduction targets. This project's replicable designs and models will help a significant number of the 800+ electric cooperatives nationwide.

FLORIDA ALLIANCE FOR ACCELERATING SOLAR AND STORAGE TECHNOLOGY READINESS – SEEDS2-SES, $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 will lay the foundation to enable Florida municipal and cooperative utilities to reach 10 percent of solar in their electricity capacity in less than 10 years.

COMMUNITY SOLAR FOR THE SOUTHEAST – SEEDS2-SES, $1,000,000

North Carolina Clean Energy Technology Center | Raleigh, NC | Principal Investigator: Achyut Shrestha

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.

NORTHEAST SOLAR ENERGY MARKET COALITION – SOLAR MARKET PATHWAYS, $599,908

Pace Energy and Climate Center | White Plains, NY | Principal Investigator: Karl Rabago

The Pace Energy and Climate Center, in concert with a regional coalition of solar photovoltaic business associations including Maine, Massachusetts, Vermont, New Hampshire, New York, Connecticut, New Jersey, Rhode Island, and Pennsylvania, are working to create a thriving and efficient regional market for solar photovoltaic technology. This project establishes the coalition, identifies and engages with critical market initiatives, and communicates best practices to a wide range of audiences, all with the primary mission of harmonizing northeastern state solar markets.

FINDING PENNSYLVANIA'S SOLAR FUTURE – SEEDS2-SES, $550,000

Pennsylvania Department of Environmental Protection | Harrisburg, PA | Principal Investigator: David Althoff

This project uses detailed scenario modeling to analyze current solar development and legislation and determine how they will be applied in 2030 under a scenario where up to 10 percent of electricity sales are from solar generation. The project will inform strategies that help meet state energy goals, develop environmental compliance plans, and increase grid resiliency. This work will result in a well-informed solar deployment plan that will be available to policymakers, regulators, industry, investors, and consumers. This project is expected to help lower the costs, increase the speed, and lower the barriers to solar market expansion in Pennsylvania.

WASATCH SOLAR PROJECT – SOLAR MARKET PATHWAYS, $600,000

Salt Lake City Corporation | Salt Lake City, UT | Principal Investigator: Vicki Bennett

Salt Lake City and its partners are developing a comprehensive, long-term solar deployment strategy, conducting an analysis of the value of rooftop solar, advancing a statewide solar financing program, and integrating solar in emergency preparedness planning. These program strategies ensure continued solar price reductions, increased market penetration, and improved market certainty for Utah's solar industry and consumers. The project will propel Utah's solar market toward a long-term goal of installing 1,075 megawatts of solar by 2024.

COMMUNITY SOLAR DESIGN MODELS FOR CONSUMER, INDUSTRY, AND UTILITY SUCCESS – SOLAR MARKET PATHWAYS, $705,830

Smart Electric Power Alliance | Washington, DC | Principal Investigator: John Sterling

This project is conducting comprehensive and collaborative research on the intersection of community solar business models and consumer demographics to develop more standardized program design options. By producing a range of more standardized, streamlined, and cost-effective business models that can be easily localized for different regions across the country, this project will spark the growth of community solar programs more closely aligned with the needs and interests of consumers and stakeholders.

COMMERCIAL PROPERTY ASSESSED CLEAN ENERGY FOR TAX-EXEMPT AND PUBLIC ENTITIES – SOLAR MARKET PATHWAYS, $900,034

The Solar Foundation | Washington, DC | Principal Investigator: Alexander Winn

This project is working with state and local governments across the country to make Property Assessed Clean Energy (PACE) financing a reality for tax-exempt organizations that have previously been unable to use this financing method. This type of financing will allow affordable housing units, schools, and nonprofit organizations to receive loans for solar energy installations and repay them through a special property tax assessment.

SPARC SOLSMART TECHNICAL ASSISTANCE – SPARC, $9,999,996

The Solar Foundation | Washington, DC | Principal Investigator: Philip Haddix

This project provides technical assistance support to communities pursuing SolSmart designation. The team will enable at least 300 communities across the U.S. to qualify for the SolSmart designation 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.

SOLAR IN YOUR COMMUNITY CHALLENGE – SYC, $5,000,000

State University of New York Polytechnic Institute | Utica, NY | Principal Investigator: Michael Fancher

This prize challenge aims to expand solar electricity access to all Americans, especially underserved segments such as low- and moderate-income households; state, local, and tribal governments; and nonprofit organizations. In order to make solar more accessible and inclusive for every American, the challenge works to spur the development of new and innovative financial and business models that serve non-rooftop solar users, such as community solar. Offering $5 million in cash prizes and technical assistance over 18 months, the challenge supports teams across the country to develop projects and programs that expand solar access to underserved groups, while proving that these business models can be widely replicated and adopted by similar groups. In addition to teams, the challenge supports technical assistance providers that assist teams by providing resources to develop their business models.

SOLAR AND DISTRIBUTED GENERATION AS KEY ELEMENTS IN MEETING VERMONT'S COMPREHENSIVE ENERGY PLAN GOALS – SOLAR MARKET PATHWAYS, $533,361

Vermont Energy Investment Corporation | Burlington, VT | Principal Investigator: David Hill

This project is conducting a broad research process involving scenario analyses to examine how solar and distributed generation will contribute to meeting Vermont's target of providing 90 percent of the state's energy from renewable resources by 2050. The project will produce a consensus-based document indicating how high levels of solar deployment over the next five and 10 years are possible, and how an advanced solar market will interact with and will be enabled by development across seven strategic areas, including: storage, fuel switching for transportation and space conditioning, and reaching low- and moderate-income market segments.

VIRGINIA SOLAR PATHWAYS PROJECT – SOLAR MARKET PATHWAYS, $2,430,682

Virginia Electric and Power Company/Dominion Virginia | Richmond, VA | Principal Investigator: John Larson

This project engages a broad-based team that includes representatives from state government, research institutions, local communities, and solar businesses to develop sustainable models for solar deployment that will benefit Virginians and others throughout the Southeast. The project addresses the challenges and identifies the opportunities related to operational capabilities, systems impacts, and economics, such as soft cost reduction, to lead the Southeast in the development of new utility-administered solar models that can be broadly implemented in many low-cost regulated environments.

SOLAR PLUS STRATEGIES FOR OREGON AND WASHINGTON – SEEDS2-SES, $2,050,000

Washington Department of Commerce | Olympia, WA | Principal Investigator: Jaimes Valdez

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 is working 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 – SEEDS2-SES, $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 analysis to mitigate or remove the impact of interconnection, reliability and rate design barriers to distributed solar photovoltaic deployment in the Western Interconnection. If successful, the project will result in greater deployment of distributed solar in the Western Interconnection than is currently predicted.

Training

TRAINING FOR STATE OFFICIALS TO MAKE SOLAR MORE INCLUSIVE, AFFORDABLE, AND CONSUMER FRIENDLY – STEP, $568,000

Clean Energy States Alliance | Montpelier, VT | Principal Investigator: Warren Leon

This project develops resources and training for public officials, mostly at the state level, on how to deal with two issues that have important implications for the future cost and continued public acceptance of solar energy. The first issue is ensuring inclusive participation in the solar economy, especially for those with low and moderate incomes and those without solar-friendly roofs. The second issue is helping consumers find and use reputable, competent vendors and contractors.

LEVERAGING INDUSTRY RESEARCH TO EDUCATE A FUTURE ELECTRIC GRID WORKFORCE – GEARED/ STEP, $5,798,035

Electric Power Research Institute | Knoxville, TN | Principal Investigator: Thomas Reddoch

In 2013, the Electric Power Research Institute collaborated with four universities and 17 utilities and system operators to establish the GridEd Distributed Technology Training Consortium in the eastern United States. This consortium aims to effectively combine utility and industry research with educational expertise in power engineering. The project team is empowering new and continuing education students to become not only competent and well informed engineers, but also influence major technological, social, and policy decisions that address critical global energy challenges. This project received additional funding under the Solar Training and Education for Professionals program in 2016, which allowed it to establish a new consortia in the western United States. The Center for Grid Engineering Education in the West leverages the existing structure, knowledge, and successes from the GridEd-East team, and adds new three new utility partners in California, Arizona, and Oregon.

TRAINING REAL ESTATE PROFESSIONALS TO FIND THE VALUE OF SOLAR – STEP, $445,027

Elevate Energy | Chicago, IL | Principal Investigator: Pamela Brookstein

Elevate Energy educates residential real estate agents, appraisers, and appraiser regulatory officials about solar energy systems through web-based, continuing education classes. The lack of current solar information for these professionals is slowing demand for residential solar by decreasing its contribution to resale value and often presenting challenges to home sellers with solar installations. The project also works to add an expanded solar component to the Multiple Listing Service, or MLS, a suite of services used by real estate professionals to establish contractual offers on properties, facilitate cooperation with other brokers, and distribute listing information.

MULTIMEDIA SOLAR KNOWLEDGE LIBRARY – STEP, $430,727

George Washington University | Washington, DC | Principal Investigator: Amit Ronen

The GW Solar Institute at the George Washington University is developing multimedia solar energy training materials that can be used to train a spectrum of diverse audiences. The resulting solar knowledge library serves as an invaluable resource for other program awardees who are directly engaging and training communities as diverse as real estate agents, financiers, and state regulators and policymakers.

INTEGRATION OF SOLAR TRAINING INTO ALLIED INDUSTRY PROFESSIONAL DEVELOPMENT PLATFORMS – STEP, $2,200,000

Interstate Renewable Energy Council | Albany, NY | Principal Investigator: Laure-Jeanne Davignon

This project creates an engagement strategy to facilitate the integration of state-of-the art solar training into existing professional development platforms for firefighters and fire code officials. This includes using integrated technology solutions, such as online 3D interactive simulations and mobile tools and resources. Through this training and professional development platform, this project hopes to train more than 10,000 firefighters and fire code officials who will be able to communicate the information to another 90,000 people.

NATIONAL NETWORK ADMINISTRATOR OF GEARED – GEARED, $1,100,000

Interstate Renewable Energy Council | Latham, NY | Principal Investigator: Joseph Sarubbi

The Interstate Renewable Energy Council and the Smart Electric Power Alliance, operating as the national network administrator of Grid Engineering for Accelerated Renewable Energy Deployment (GEARED), facilitate efforts to build a national framework for power systems training and curriculum that will accelerate the growth of power systems programs and human capacity.

THE MID-AMERICA REGIONAL MICROGRID EDUCATION AND TRAINING CONSORTIUM – GEARED, $4,999,976

Missouri University of Science and Technology | Rolla, MO | Principal Investigator: Suzanna Long

This consortia is integrating cutting-edge research and advanced instructional methods to create a flexible, evolving approach to microgrid training for all levels of students. This effort aims to impact more than 500 technical employees by offering certificates, professional development hours, continuing education credits, and engineering degrees through a variety of workshops, short courses, and semester courses.

STATE STEP PARTNERSHIP: STATE SOLAR ENERGY TRAINING AND NETWORK – STEP, $950,616

National Conference of State Legislatures | Denver, CO | Principal Investigator: Glen Anderson

This project uses a three-phase learning approach to develop a solar training program for state regulators, legislators, and energy officers using traditional instruction, interactive games and simulations, and peer exchange. It aims to train 45 policy and energy leaders at two in-person trainings, and another 150-200 legislators, legislative staff members, and energy officials via a series of four webinars. In addition, the project will create a toolkit that will be promoted electronically to more than 10,000 legislators, legislative staff, and energy officials. This training program also connects these policymakers with experts from national laboratories, universities, and other providers of technical assistance.

PERSONNEL CERTIFICATIONS FOR THE DESIGN, INSTALLATION, AND MAINTENANCE OF PHOTOVOLTAIC SYSTEMS – STEP, $1,119,195

North American Board of Certified Energy Practitioners | Clinton Park, NY | Principal Investigator: Shawn O'Brien

This project is developing three new industry-validated personnel certifications for individuals working in photovoltaic operations and maintenance and in mid-scale system design and installation. These new certifications fill the need for third-party validation of the skills and competence required for the solar labor force, as represented in professional credentials in these sectors. North

American Board of Certified Energy Practitioners (NABCEP) is also improving and updating its current Photovoltaic Installation Professional Certification program and examination. In addition, NABCEP aims to have certified at least 100 new solar professionals in these programs by completion of the award.

SOLAR READY VETS® – STEP, $1,947,730

The Solar Foundation | Washington, DC | Principal Investigator: Ed Gilliland

This project takes an innovative approach to providing transitioning veterans with promising civilian career paths in solar energy while also providing the solar industry with highly qualified and motivated workers.

SOLAR TRAINING NETWORK – STEP, $2,107,862

The Solar Foundation | Washington, DC | Principal Investigator: Ed Gilliland

This project connects solar workforce trainers, solar employers, and individuals interested in working in the solar industry. By developing and expanding training and workforce capacity building nationwide, it builds on the success of the earlier Solar Instructor Training Network.

SOLAR TRAINING FOR DESIGN PROFESSIONALS – STEP, $799,949

Trust for Conservation Innovation | Oakland, CA | Principal Investigator: Maureen Guttman

This project supports the development and dissemination of solar reference materials and training for building design professionals. The project targets multiple interrelated audiences in the building design field, leveraging the similarity of educational materials needed, while establishing consistency in and amplifying understanding.

FOUNDATIONS FOR ENGINEERING EDUCATION FOR DISTRIBUTED ENERGY RESOURCES – GEARED/STEP, $3,670,000

University of Central Florida | Orlando, FL | Principal Investigator: Zhihua Qu

This project consists of seven universities in the Southeast United States, eight utility companies, five supporting industry partners, two national labs, and a research center. This consortium is upgrading the existing power systems engineering workforce by improving programs at participating universities and developing a pipeline of new power systems engineers and engineering faculty. Through the efforts of this consortium, a new group of engineers will enter the workforce capable of re-engineering the existing electrical grid infrastructure to include a highly sophisticated communications platform. This project received additional funding to expand research, curriculum development, and education and training activities to five additional university partners in California, Hawaii, Pennsylvania, and Texas.

ACTIVE LAB AWARDS

Foundational Research, Data, and Analysis

TOWARDS A LOW-COST SOLAR FUTURE: TRACKING AND ANALYZING SOLAR COST, PRICE, AND MARKET TRENDS – SUNLAMP, $2,503,530

Lawrence Berkeley National Laboratory | Berkeley, CA | Principal Investigator: Ryan Wiser

This project consolidates efforts to measure solar cost reduction, identify pathways for further cost reductions, and speed solar deployment. The team is building large and varied datasets to track and analyze trends in the cost, performance, and pricing of solar systems through the Tracking the Sun and Utility-Scale Solar reports. This will provide foundational analysis to help address the remaining non-hardware cost and deployment barriers.

PUBLIC UTILITY COMMISSION ANALYTICAL SUPPORT - $1,500,000

Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory | Principal Investigator: Charles Goldman

This project is a collaboration between three labs to provide high-impact research and analysis for state public utility commissions on technical issues related to the integration of solar photovoltaics, both alone and combined with other distributed energy resources within the country's electricity system. In addition to the state-specific analyses, the project will use these analyses to prepare broader studies applicable to the larger stakeholder community. A successful program will result in innovative solutions in the selected topic areas that can be replicated by other public utility commissions.

INNOVATIVE FRAMEWORK TO INCREASE DISPERSION OF LAB DATA – SUNLAMP, $1,540,672

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Debbie Brodst-Giles

This project supports hundreds of new collaborations and partnerships for startups and growing companies through effective dissemination of lab data, models, and tools. Specifically, this project will create new relationships within the industry to shape priorities on tool enhancements and define opportunities for co-development of tools, such as the Utility Rate Database and OpenPV.

MEETING SUNSHOT COST AND DEPLOYMENT TARGETS THROUGH INNOVATIVE SITE PREPARATION AND IMPACT REDUCTIONS ON THE ENVIRONMENT (INSPIRE) – SUNLAMP, $1,650,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jordan Macknick

This project achieves cost reductions through the first comprehensive assessment of baseline costs, cost reduction strategies, and environmental impact reduction strategies. The assessment covers site preparation practices for utility-scale solar projects, opportunities for addressing environmental impacts, and innovative siting practices to minimize impacts, such as utilizing contaminated lands and co-locating solar projects on agricultural lands. Extensive industry stakeholder engagement will guide translation of the results into industry-focused products that reduce costs and increase development.

STRATEGIC ANALYSIS: CORE ANALYTICAL SUPPORT TO SUNSHOT – SUNLAMP, $1,499,736

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

This project provides core analytical support that will enable the Solar Energy Technologies Office to carry out its activities more effectively and efficiently. Laboratory analysts will draw on multiple internal and external data sources, as well as management and staff, to develop timely information and analysis. This project will continue the longstanding collaboration with the labs and leverage ongoing work to better serve the Energy Department's needs.

TOWARDS A LOW-COST SOLAR FUTURE: BASELINES, TRAJECTORIES, AND IMPACTS – SUNLAMP, $2,700,000

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

This project accurately quantifies the soft and hard costs of solar in order to target research and development activities that increase market transparency, disseminate research that guides accelerated solar deployment strategies, and identify opportunities to facilitate solar cost reductions. This foundational analysis will help address the remaining non-hardware cost and deployment barriers to achieving ubiquitous solar.

SOLAR-CENTERED GRID – SUNLAMP, $960,000

Pacific Northwest National Laboratory | Richland, WA | Principal Investigator: Laurie Miller

This project increases solar energy penetration into the national power grid by investigating new ways to overcome solar integration barriers. Developing new methods will allow pooling of solar resources over larger geographical areas in bulk electricity markets in order to revise overly restrictive power grid operational processes and practices.

Institutional Support

ALIGNING UTILITY AND SOLAR INTERESTS: UTILITY REGULATION AND PLANNING FOR A SUNSHOT FUTURE – SUNLAMP, $1,200,001

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 PHOTOVOLTAICS AND REAL ESTATE: HARNESSING BIG DATA TO DRIVE DEMAND, INCREASE TRANSPARENCY, AND LOWER BALANCE OF SYSTEM COSTS – SUNLAMP, $1,071,229

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 will analyze the impact of these systems on home values and other factors, which will allow for increased growth of the solar market by providing real estate professionals and potential adopters with accurate valuations.

BEST PRACTICES FOR OPERATION AND MAINTENANCE OF PHOTOVOLTAIC AND STORAGE SYSTEMS – SUNLAMP, $1,821,787

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

This project addresses the needs of the rapidly growing photovoltaic operations and maintenance industry to ensure that solar projects are maintained at a high level of consistency and quality. A working group of financial and legal firms, solar developers, operations and maintenance service providers, and utilities will contribute to a best practices document, sharing field data in a performance database and a failure and reliability database. The group will also create a cost model to estimate costs of delivering a program that considers system characteristics and what conditions determine the optimal cleaning and repair schedules for solar projects. This work will enable financial firms to easily categorize, predict, and support solar projects with lower financing costs, which will increase the effectiveness of operations and the resulting energy delivery and reduce the cost of maintaining photovoltaic systems.

SOLAR ENERGY INNOVATION NETWORK – $11,000,000

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Kristen Ardani

This project brings together teams composed of electric utilities, regional planning commissions, state and local governments, and others from across the United States. These teams work to develop innovative solutions that explore new approaches to solar market barriers, reduce integration risks, and increase market opportunities. The network supports selected project teams through in-person, facilitated peer learning and targeted research and analysis over an 18-21 month period.

SOLAR-PLUS-STORAGE: REMOVING BARRIERS THROUGH COST-OPTIMIZATION AND MARKET CHARACTERIZATION – SUNLAMP, $1,203,909

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Joyce McLaren

This project examines cost-optimal system configurations for solar-plus-storage through data-driven, model-based analysis and creates an economic-based customer adoption classification for these systems. The analysis will be completed through data collection from existing solar-plus-storage projects, world-class modeling tools, and innovative methodologies to identify optimal configurations at the project level, as well as stakeholder engagement.

UNTAPPED MARKETS: CATALYZING MID-SCALE SOLAR DEPLOYMENT THROUGH DEEP-DIVE ANALYSIS AND DECISION SUPPORT – SUNLAMP, $1,458,635

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Jenny Heeter

In collaboration with the Environmental Protection Agency's Green Power Partnership, this project aims to increase the deployment of mid-scale photovoltaic systems by identifying important untapped market segments, then engaging relevant stakeholder groups to identify and solve key market barriers, while providing technical tools and expertise to empower decision makers. This project will also help solar developer and installer communities by providing analyses that quantify the size and suitability of potential markets, while defining barriers and opportunities for mid-scale solar energy systems.

SUNSHOT STATE SOLAR TECHNICAL ASSISTANCE TEAM NETWORK – SUNLAMP, $1,978,337

National Renewable Energy Laboratory | Golden, CO | Principal Investigator: Elizabeth Doris

With thousands of state-level legislators and a range of state energy office models throughout the country, there are significant challenges to directly informing policymakers about program support mechanisms. This project creates the Solar State Technical Assistance Team Network, which will multiply state policy and program assistance programs by partnering with, training, and deploying information through trusted government membership organizations. Combined, these organizations will provide non-advocacy solar information to every state-level government in the United States.

Training

PROMOTION OF PHOTOVOLTAIC SOFT COST REDUCTIONS IN THE SOUTHEASTERN UNITED STATES – SUNLAMP, $1,480,000

Savannah River National Laboratory | Aiken, SC | Principal Investigator: Elise Fox

This project creates a replicable model for solar soft cost reduction in South Carolina through human capacity-building at the local level and direct efforts to harmonize policy at the regional level. This effort will close the gap between South Carolina installed costs of residential rooftop solar and national averages and develop a portable and replicable model that can be applied to other jurisdictions in the future.

U.S. DEPARTMENT OF
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