Systems Integration

The SunShot Initiative Systems Integration subprogram aims to dramatically increase the penetration level and enable widespread deployment of solar in the nation's electrical power system by addressing the associated technical and regulatory challenges. Considering a penetration scenario of 100 GW of solar interconnected on the nation's grid, the challenges are quantified and addressed in the activity areas of Grid Performance and Reliability, Dispatchability, Power Electronics, Communications, and Plant Performance and Reliability. The program funds projects at the national laboratories, industry, and universities (Fig 2.) through competitive funding solicitations that map to the five activity areas and targets, as depicted in Fig. 1.
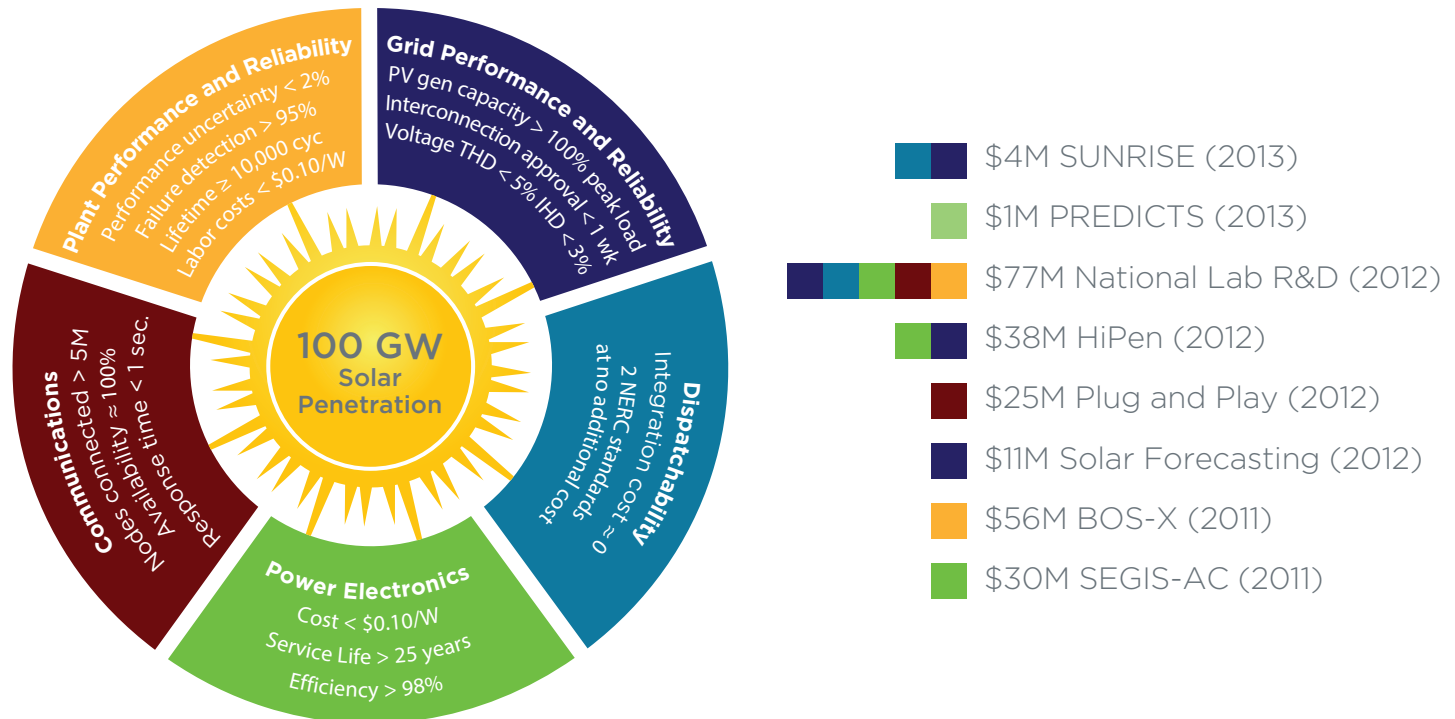

Figure 1. Systems Integration activity areas mapped to funding opportunities.

Grid Performance and Reliability: The current projects in the Grid Performance and Reliability activity area focus on achieving high penetration at the distribution level (<69 kV) and on the transmission grid in a safe, reliable and cost-effective approach. In order to accomplish these goals, SunShot supports: developing state-of-the-art utility modeling, simulation, and analysis tools to address technical issues surrounding grid planning, operations, and reliability; developing advanced grid-friendly PV interconnection technologies; accelerating cost-effective deployment of PV generation on the distribution and transmission grid; developing validated inverter, solar system planning, operations and feeder models to enhance PV

integration analysis techniques; demonstrating the feasibility of high-penetration PV scenarios under a wide range of system conditions through laboratory and field testing; advancing interconnection and performance standards and codes to enable high levels of PV integration for grid reliability; and engaging with industry and stakeholders to inform and receive feedback on PV integration.
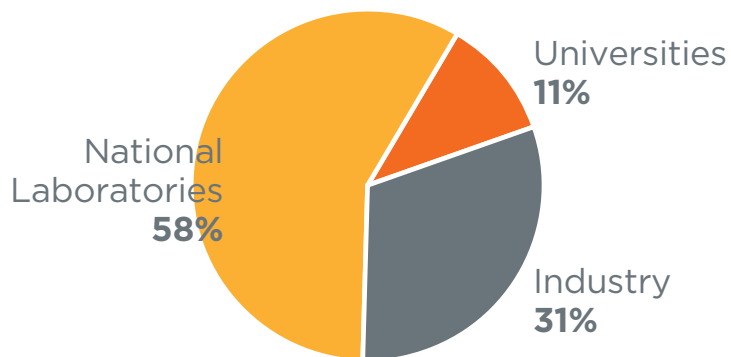

Figure 2. Systems Integration R&D portfolio funding distribution among national laboratories, industry and universities for FY13.

Dispatchability: The Dispatchability activity area of the portfolio aims to ensure that solar power plants based on PV and CSP technologies at utility and distributed scales are capable of being dispatched in a fashion that is comparable to or better than conventional power plants. SunShot addresses the issue of dispatchability with a two-pronged approach: **a)** extensive analyses to understand the impact of high penetration of solar power plants on the bulk power system and distribution system operations, and **b)** research on understanding and enhancing the dispatch capability of PV solar power plants, and investigating the value of varying energy storage capabilities for CSP plants. SunShot also supports the development of standardized methods for testing grid performance of PV solar power plants, and exploring and demonstrating the value of energy storage.

Power Electronics: Power Electronics are intelligent devices that can maximize the power output from the PV arrays on the one side and serve as the interfaces to the electric grid (or end use circuits) on the other, while ensuring overall system safety, reliability, and controllability. A technical challenge for power electronics is the optimal tradeoff between these three design drivers of performance, reliability, and cost. In order to accomplish these goals, SunShot supports cost reductions and efficiency improvements through: innovative circuit design, development of advanced components and optimal control; development of power electronics technologies to improve energy yield while reducing balance of system (BOS) hardware costs, process costs and installation time; development and field demonstration of smart inverter functionalities; and development of accelerated life testing methods and physics of failure models to predict faults and improve reliability.

Communications: To effectively inform grid operations with high-level integration of solar, visibility is required across multiple spatial scales (from the end user load through the distribution substation and beyond) and at multiple time scales (from microseconds to hours and days). Advances in information, Communications, and sensor technologies are needed to adequately monitor the behavior and manage the impact of the solar technologies integrating into the grid. Enterprise level integration of PV management systems, with grid management systems, is also critical to provide important information to grid operators. In order to achieve these goals, SunShot supports the development of open and interoperable communication and control architectures, communication requirements such as network latency, scalability, and availability, smart inverter communication standards such as IEC 61850, DNP3, and SEP 2, and enterprise integration standards based on common information model (CIM). SunShot also supports the implementation of standard communication protocols in inverter hardware and enterprise software and demonstration of end-to-end system integration and interoperability on actual distribution feeders with utilities.

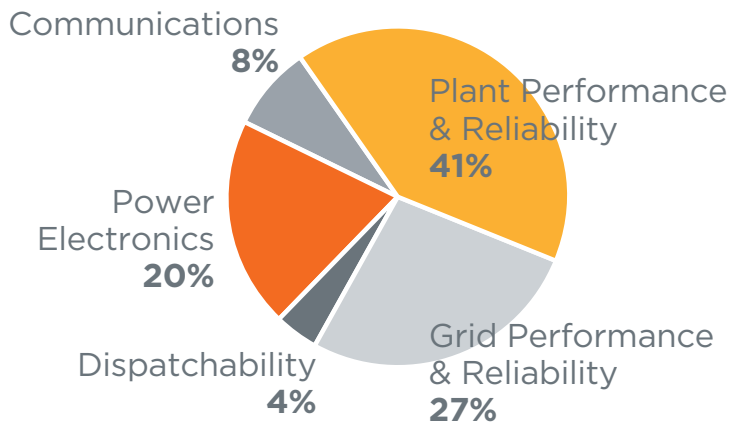## Systems Integration activity areas funding distribution

Figure 3. Distribution of funding for the ongoing awards for the Systems Integration activity areas.

Plant Performance and Reliability: As part of the Plant Performance and Reliability activity area, the program also funds R&D to provide the information and tools that solar module manufacturers, system integrators, project developers, and the financial community need to support their efforts to reduce installed system and operations and maintenance

(O&M) costs. SunShot funding aims to improve and reduce uncertainty in PV product and system performance, lifetime, durability, and availability; thereby reducing risk and associated costs such as the cost of and time to obtain financing, cost of warranties and service agreements. An allied objective is to reduce material costs and speed the installation time of the associated racking and wiring hardware. The subprogram also funds five regional test centers across the nation in support of this activity area.

The projects in the subprogram's portfolio address the goals of the five activity areas (Fig. 3) toward the overall SunShot Systems Integration vision. The active projects in the five activity areas are briefly described in this volume. Building on the significant strides made so far, the program looks forward to continuing to advance the forefront of technologies toward the SunShot goal.

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Grid Performance and Reliability

SunShot funding is designed to accelerate cost-effective deployment of PV on the distribution and transmission grids, demonstrate the feasibility of high-penetration PV scenarios under a wide range of system conditions through laboratory and field testing, and advance interconnection and performance standards and codes to enable high levels of PV integration for grid reliability. SunShot supports the development of state-of-the-art utility modeling, simulation, and analysis tools to address technical issues surrounding grid planning, operations, and reliability; advanced grid-friendly PV interconnection technologies; and validated inverter, solar system planning, operations and feeder models to enhance PV integration analysis techniques. Through its funding programs, SunShot and its awardees engage with industry and stakeholders to inform and receive feedback on PV integration.

SunShot technical targets for grid performance and reliability:
- PV generation capacity >100% of peak load on the line segment of distribution feeder circuit
- Adverse effect of inverter conversion efficiency (associated with non-unity power factor) in the LCOE <3%
- Voltage THD (Total Harmonic Distortion) effect of PV <5% and individual harmonic <3%
- PV short circuit current contribution <1 P.U.
- Interconnection study approval time based on advance screening methodology <1 week
- Interconnection study cost to customer <$1000
- Availability of quasi-static-time-series analysis (QSTS) modeling and realtime data analytics tools
- Advanced multi-inverter anti-islanding schemes and certification tests validated and implemented for high penetration PV scenarios

IMPACTS OF HIGH PENETRATION OF PV WITH ENERGY STORAGE AT FLAGSTAFF ARIZONA
Arizona Public Service | Flagstaff, AZ | $2.2M | Hi-Pen | 01/2010–09/2014

The project team will evaluate the impacts of high penetrations of distributed PV and energy storage on a dedicated feeder to identify the technical and operational modifications that could be deployed in future feeder designs. Models describing the interactions between operations and weather/PV/feeder equipment are being developed and validated with actual feeder data so that results will be broadly applicable to other utility projects.

MODELING AND ANALYSIS OF HIGH-PENETRATION PV IN FLORIDA
Florida State University | Tallahassee, FL | $2.0M | Hi-Pen | 04/2010–10/2014

This project aims to leverage simulation-assisted R&D based on a wide variety of Florida feeders that already incorporate high levels of PV power. Working with utilities, the team will evaluate and model impacts of the effects of high-penetration PV on distribution and transmission. Validated models that include characterization of the Florida solar resource will be developed for the range of feeder designs, and power management solutions will be evaluated.

MODELING AND ANALYSIS OF HIGH-PENETRATION PV IN CALIFORNIA
National Renewable Energy Laboratory | Golden, CO | $3.3M | Hi-Pen | 10/2009–09/2014

The project team will utilize field verification to improve the ability to model and understand the impacts of high-penetration PV on electric utility systems and develop solutions to ease high-penetration PV deployments. The team will develop and verify advanced modeling and simulation methods for distribution system planning and operations; define the impacts of high penetration levels of PV on the distribution and transmission grid with high-fidelity simulation tools; develop a handbook of validated models and solutions for the stakeholder community; and provide simulation-assisted evaluation/de-risking of technology solutions to enable successful integration of high levels of PV.

INCREASING DISTRIBUTED PV PENETRATION LEVELS
National Renewable Energy Laboratory | Golden, CO | $3.7M | National Laboratory R&D | 10/2013–09/2015

This project will improve existing utility modeling tools and develop new conversion tools in an effort to improve interconnection screens and studies to assist utilities, PV developers, stakeholders and regulatory agencies. The team will develop Hardware in the Loop methods, create advanced visualization tools, lead the development of interconnection standards and codes, engage with key industry stakeholders, including the Federal Energy Regulatory Commission and state Public Utility Commissions, and develop educational materials for utility personnel.

ACCELERATING COST-EFFECTIVE DEPLOYMENT OF SOLAR GENERATION ON THE DISTRIBUTION GRID
Sandia National Laboratories | Albuquerque, NM | $3.3M | National Laboratory R&D | 10/2013–09/2015

The goal of this project is to remove grid access barriers, reduce the cost for solar generation and produce the following outcomes: 1) provide a full and complete data-driven technical foundation that supports revised SGIP (Small Generation Interconnection Procedure) screens, 2) develop new ways to use feeder classifications to estimate possible impacts of high-penetration scenarios, 3) develop a tool to create high-resolution solar data for any location on a feeder for use by utility planners and university students to conduct impact studies, and 4) develop new screening procedures and implement new SGIP screens nationwide.

Systems Integration

ACCELERATING DEVELOPMENT OF ADVANCED INVERTERS

Sandia National Laboratories | Albuquerque, NM | $2.6M | National Laboratory R&D | 10/2013–09/2015

This project will enable the use of inverter grid-support and ride-through functions on distributed generation resources by addressing issues with islanding and implementation of inverter manufactures through development of: affordable communications-based anti-islanding scheme; collaborative controls that provide grid support and prevent islanding; and development of testing procedures that validate function performance.

TRANSMISSION & ALTERNATIVES ANALYSIS AND STRATEGIC STAKEHOLDER ENGAGEMENT

National Renewable Energy Laboratory | Golden, CO | $2.1M | National Laboratory R&D | 10/2012–09/2014

During this project, NREL will examine the Western Interconnection large-scale stability and frequency response under high solar and wind penetration and identify means to mitigate adverse performance impacts via transmission reinforcements, storage, advanced control capabilities or other alternative means. The second activity is to improve the understanding and better utilization of advanced PV controls through field testing and demonstration on a real utility-scale PV plant via partnership with a collaborating energy industry member. To accomplish this goal, NREL will identify a potential partner(s), establish a technical review committee, and develop and implement a detailed scope of work and test plan for a field project to demonstrate the grid-friendly capabilities of utility-scale PV power plants. The third activity is to create a validated, flexible, 3-phase, cycle-by-cycle model of PV inverters and PV plants, and their associated controls in the Power System Computer Aided Design (PSCAD) program, which is both well established and fully supported. The proposed model is generic and open source in nature, easy to modify for different implementations by different manufacturers, and will accommodate future enhancements required by the regional reliability organization or local utilities as the solar PV penetration increases. NREL will communicate the tools, methods, and results from grid integration research to targeted stakeholders. The goal is to engage the utilities, regulators, policymakers, and organizations that establish reliability and operational rules to ensure that they have the tools and data needed to study high solar penetrations and understand the reliability and balancing impacts of solar. This effort involves a threefold strategy: **1)** participation in utility forums and the Utility Variable Generation Integration Group (UVIG), **2)** participation in technical committees, **3)** engagement with regulators, policymakers, and other key stakeholders, and **4)** provide specific technical support and input to the transmission planning process in the Western Interconnection.

OPERATIONAL SIMULATION TOOLS AND LONG TERM STRATEGIC PLANNING FOR HIGH PENETRATIONS OF PV IN THE SOUTHEASTERN U.S.

Electric Power Research Institute | Palo Alto, CA | $0.87M | SUNRISE | 10/2013–09/2015

In collaboration with the Tennessee Valley Authority Southern Company, the Sacramento Municipal Utility District, the California Independent System Operator, and other partners, EPRI will develop: high-penetration solar future scenarios in the southeastern U.S., distribution grid-feeder clustering and characterization, models for solar generation hosting capacity, and power production simulation. These tools, processes, and studies will be used to assess the full breadth of operational and business impacts posed by high levels of solar generation and to formulate associated strategic plans for the southeastern U.S. that ensure both system reliability and utility financial health. This project will result in an end-to-end strategy and operations project that leverages prior efforts, including DOE-funded projects, and provides a pathway for successfully integrating large amounts of solar generation.

This project will further disseminate analytical results, operational tools, and strategic planning processes to allow for replication that advances PV integration beyond simply the traditional "sunny" regions.

COMPREHENSIVE SOLUTIONS FOR INTEGRATION OF SOLAR RESOURCES INTO GRID OPERATIONS
AWS Truepower | Albany, NY | $0.39M | SUNRISE | 10/2013–09/2015

This project primarily looks at the benefits from more cost-effective unit commitment and dispatch, and reduction in balancing reserves due to reducing uncertainty in solar forecasting. This project will improve the Pacific Northwest National Laboratory's ramp and uncertainty prediction tool by incorporating accurate forecasting of solar generation, and then integrate the tool with the Siemens market applications software currently used by the California Independent System Operator (CAISO) to perform unit commitment and dispatch. This project will utilize probabilistic forecast algorithms for solar energy production of large-scale PV plants and rooftop PV installations, to enable CAISO to incorporate solar generation forecasts directly into their tools that perform power system operations, thus reducing the uncertainty and hence the costs of system integration of solar generation into the bulk power system.

INTEGRATION OF BEHIND-THE-METER PV FLEET FORECASTS INTO UTILITY GRID SYSTEM OPERATIONS
Clean Power Research | Napa, CA | $0.5M | SUNRISE | 10/2013–09/2015

This project looks at the improvement in accuracy of load forecasting in California that can be realized from forecasts of behind-the-meter distributed (rooftop) solar PV generation. The forecasts developed are provided to the California Independent System Operator for incorporation into the Automatic Load Forecasting System whose load forecasts will quantify the influence of the increasing penetration of customer-sited or behind-the-meter PV system power production. Also, this project will evaluate distributed solar generation forecast accuracy and apply further improvements in solar forecasting developed by the University of California at San Diego. Forecasting behind-the-meter distributed PV generation power production within a region will enable grid balancing authorities to dispatch generation resources more effectively, significantly lowering the need for additional spinning generation reserves and mitigating the impact on existing reserve capacity. This project is expected to reduce the costs of integrating higher penetrations of PV into the grid by incorporating distributed PV generation forecast into utility planning and operational tools in California, as a replicable and scalable approach that other areas of the country could follow.

DISTRIBUTED RESOURCE ENERGY ANALYSIS AND MANAGEMENT SYSTEM (DREAMS) DEVELOPMENT FOR REAL-TIME GRID OPERATIONS
Hawaiian Electric Power Company | Honolulu, HI | $0.50M | SUNRISE | 10/2013–09/2015

Hawaii has two different Energy Management Systems (EMS) on the islands of Oahu and Maui, and already has very high solar penetration. This project will design new capabilities for these systems to enable visibility to thousands of uncontrolled, distributed rooftop PV resources and factor advanced 15-minute short term wind and solar forecasting capability for the region into the EMS decision-making process. This project is innovative in incorporating solar generation forecasts into the operational EMS and working with two major EMS vendors (Siemens & Alstom) to create advanced EMS software. The results of this project will motivate technology development to enable operational change under high renewables penetration, thereby reducing the cost and impact of integrating large amounts of solar.

INTEGRATED SIMULATION DEVELOPMENT AND DECISION SUPPORT TOOL SET FOR UTILITY MARKET AND DISTRIBUTED SOLAR POWER GENERATION
Electricore, Inc. | Valencia, CA | $0.42M | SUNRISE | 10/2013–09/2015

This project will develop a simulation and decision support toolset that simulates the utility grid in real time and contains a decision support system for effective integration of centralized and distributed solar power generation. This toolset, designed for real-time operations personnel, will be integrated within existing utility procedures. The Distribution Management System will enable real-time simulation of distributed solar PV generation in the San Diego Gas & Electric territory. The methodology and enabling software will be available to utilities across the U.S. for widespread adoption and cost benefits for utilities and their ratepayers. This project will further result in improved day-ahead generation commitments and real time operations, and increased reliability and system balancing from improved visibility, enabling more efficient and innovative management of utility assets.

A PUBLIC-PRIVATE-ACADEMIC PARTNERSHIP TO ADVANCE SOLAR POWER FORECASTING
National Center for Atmospheric Research | Boulder, CO | $4.1M | Solar Forecasting | 10/2012–09/2015

In this project, a solar power forecasting system will be configured to forecast across a range of temporal and spatial scales. The system technologies will employ solar radiation and cloud measurements, including images from total sky imagers; satellite observations; local meteorological observations; publicly-available numerical weather prediction (NWP) modeling results, including the high-resolution rapid refresh (HRRR); weather research and forecasting (WRF)-solar model tuned for cloud prediction and radiative transfer modeling; statistical blending of forecast technologies tuned to prediction times from 15 minutes to 36 hours; irradiance to power conversion models; displays tuned to the needs of the end user; and built-in assessment metrics. These technologies will be incorporated into a prototype solar power forecasting system that will be tested in collaboration with utilities and independent system operators (ISOs) in geographically diverse areas, including Long Island, Colorado, coastal California, and Hawaii. Each component will be verified and validated using specially designed evaluation techniques. The system will be deployed in operational environments of utility and ISO partners with engagement of commercial forecast providers, who will tailor the methods to the needs of the deployment. This iterative process will incorporate user feedback and assess the economic value of the forecasts. The results will be widely disseminated through publications, workshops, and software. The impact of this effort will be enhanced solar power forecasting that is integrated into utility operations, advancing the penetration of renewable energy.

WATT-SUN: A MULTI-SCALE, MULTI-MODEL, MACHINE-LEARNING SOLAR FORECASTING TECHNOLOGY
IBM | Yorktown Heights, NY | $3.9M | Solar Forecasting | 10/2012–09/2015

This work aims to develop a novel approach to solar forecasting, which will not only combine and integrate different prediction models but also use state of the art machine learning technologies to drastically improve the accuracy of predictions. Similar to the recently demonstrated Watson computer system, the proposed technology will leverage deep machine learning and self-adjusting voting algorithms to decide between various forecasting models and expert systems. The approach will yield the best forecasts and more importantly, continuously improve and adjust as the system is operating and evolving. The solar forecasting framework is independent of proprietary weather or solar radiation models and enables the technology to scale and to be adopted by solar producers, electrical utilities, independent system operators (ISOs), and other stakeholders. The forecasting will also be validated at multiple sites with significantly different weather patterns. The team will work closely with utilities, solar power

producers, and ISOs to integrate the proposed technology and to determine the value of solar forecasting on daily operation, load modeling, optimizing spinning reserve, and day ahead planning.

SOLAR FORECAST IMPROVEMENT PROJECT
National Oceanic and Atmospheric Administration | Boulder, CO | $2.0M | Solar Forecasting | 02/2014–01/2017

DOE will work with NOAA and the awardees of the Solar Forecasting funding opportunity, the National Center for Atmospheric Research (NCAR) and IBM, to provide a pathway for public dissemination of weather model improvements resulting from the research conducted by NCAR and IBM on solar forecasting. This activity falls under the Memorandum of Understanding signed by the two agencies in 2011, in which they agreed to collaborate to advance the science and services needed in support of weather-dependent and oceanic renewable energy. NOAA will consult with IBM and NCAR in areas of NOAA's expertise including numerical weather prediction (NWP), irradiance forecasting, cloud-tracking algorithms, ground-based measurements, model verification, and metrics. Further, NOAA will provide baseline global horizontal irradiance (and later, direct normal irradiance) forecasts from the 3 km High-Resolution Rapid Refresh (HRRR) and an advanced version of the 13 km Rapid Refresh (RAP) models. NOAA will provide these grids and all other needed model grids, as well as consult the NCAR and IBM teams, as needed, on use of the model fields. NOAA will also provide a clear pathway for HRRR, RAP, and NWP model assimilation from research into the NOAA operational model suite, thus realizing the goal of operational solar forecasts.

SOLAR VALUE ANALYSIS AND MARKET PENETRATION MODELING
National Renewable Energy Laboratory | Golden, CO | $3.4M | National Laboratory R&D | 10/2012–09/2015

This project will help implement a comprehensive framework for characterizing solar technical and economic potential and representing solar technologies in capacity-expansion models by conducting foundational model development and analysis activities. The results from this project will improve upon existing modeling efforts in both utility-scale (wholesale) markets and distributed (retail) markets and continue to evaluate the interaction between these two market sectors. In the utility sector, the proposed research will further evaluate key drivers of economic competitiveness. These include solar prices, local solar resources, electric-sector market dynamics (e.g., load growth, regional renewable portfolio standards and other policies, the existing mix of conventional generation resources and transmission infrastructure, fuel prices, and retirements of conventional generators), the value of solar generation (e.g., solar capacity value, the impact of solar variability on the need for additional operating reserves, and the change in these factors with increasing solar deployment), project-level investor risk, and several other factors. In the distributed PV sector, the proposed research will continue ongoing analysis of the retail value of PV, including, for example, how customers weigh the costs and benefits of PV ownership. Filling this gap will help to inform the development of policies aimed at encouraging the type of solar market growth envisioned under the SunShot Initiative.

ADVANCING SOLAR INTEGRATION ON TRANSMISSION SYSTEMS
Sandia National Laboratories | Albuquerque, NM | $3.1M | National Laboratory R&D | 10/2012–09/2015

Sandia's 3-year integrated program incorporates elements of each of the SunShot Transmission Grid Integration (TGI) research areas: System Integration Study Template, Models and Tools Improvement, and Transmission Analysis and Transmission Alternatives. Strategic stakeholder engagement and information dissemination are also an integral part of the proposed activities, to ensure the broadest possible impact. The work plan is organized into four tasks: **1)** Improve simulation models for solar generation

interconnection and grid planning, **2)** Improve methods and tools for the analysis of high penetration scenarios, **3)** Evaluate the technical feasibility of high penetration solar deployment, and **4)** Enhance critical stakeholder engagement to disseminate TGI information.

CORE COMPETENCIES FOR SOLAR RESOURCE ASSESSMENT
National Renewable Energy Laboratory | Golden, CO | $3.3M | National Laboratory R&D | 10/2012–09/2015

The Core Competencies for Solar Resource Assessment project aims to improve the tools and methods to measure solar radiation and therefore reduce uncertainty in predicting solar output and improve the bankability of financing solar projects. This project has three tasks that conduct research on advancing solar resource measurements: Task 1–Broadband and Spectral Calibration and Measurement; Task 2–Continue developing the National Solar Radiation Data Base (NSRDB); and Task 3–Standards and Expert Committees. Task 1 is focused on reducing spectral and broadband solar measurement uncertainty through improvement in instrumentation, calibration and cross-comparison. NSRDB is the most widely used public solar radiation database in the U.S. In Task 2, the NSRDB will be updated with high-resolution, satellite-based solar radiation datasets created using a state of the art physical model thereby providing users with a lower uncertainty, higher-resolution dataset to use. Finally in Task 3, international consensus on standards in solar measurement and modeling is developed to represent the state of the art knowledge through continuous formal engagement of various stakeholders such as through participation in developing radiometric standards, through American Society for Testing Materials International.

SOLAR RESOURCE MODELING AND MEASUREMENT RESEARCH
National Renewable Energy Laboratory | Golden, CO | $2.3M | National Laboratory R&D | 10/2012–09/2015

The Solar Resource Modeling and Measurement Research project aims to improve the tools and methods to measure solar radiation and therefore reduce uncertainty in predicting solar output and improve the bankability of financing solar projects. This project has two tasks that conduct research on advancing solar resource measurements: Task 1–Satellite Based Modeling and Validation, and Task 2–PV System Derived Data. In the first task, the advanced Geostationary Operational Environmental Satellite Solar Insolation Product Project seeks to advance the state of the art in satellite-based solar resource assessment and reduces the uncertainty of the solar resource data through improvements in the physics of the resource-assessment method. The cost associated with conventional measurements of solar radiation using thermopile instruments prevents wide scale measurement of the solar resource. Therefore, in the second task, the goal is to develop and validate cost-effective instruments and methods for gathering solar radiation data, which will facilitate improved ground-based solar resource data availability.

ADVANCED SOLAR RESOURCE MODELING AND ANALYSIS
Sandia National Laboratories | Albuquerque, NM | $1.2M | National Laboratory R&D | 10/2012–09/2015

The dominant contribution to uncertainty in projected power and energy from solar arrays arises from uncertainty in the estimated solar resource. Uncertainty in estimated irradiance stems from uncertainty in the models that translate satellite measurements to estimated irradiance; portray the spatial and temporal variation in irradiance over a power plant's footprint or over a fleet of solar power systems; and separate global horizontal irradiance into its beam and diffuse components. This project performs R&D leading to improved models which can reduce these uncertainties and thus lead to reduced financial and technical risk to solar

power deployment. The key activities for this project are: improve irradiance estimated from satellite data through extensive validation of the emerging Global Solar Insolation Project's Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) estimates, improve upon current methods to represent the geographic smoothing of irradiance over the spatial extent of utility-scale power plants, as well as over fleets of solar power systems, provide guidance for the number of sensors required for accurate spatial irradiance measurement, and improve models that estimate DNI and plane-of-array (POA) irradiance from GHI.

UTILIZATION OF RENEWABLE ENERGY TO MEET NEW NATIONAL CHALLENGES IN ENERGY AND CLIMATE CHANGE

Howard University | Washington, DC | $0.3M | MURA | 09/2010–09/2014

This research project models integrated networks of renewable energy resources and loads and evaluates the generation balance through appropriate storage and control design. As part of the project, design of performance indices will be developed for achieving generation/load balance, frequency control, and power quality and reliability under different disturbances. Education and training in this project includes high school, undergraduate and graduate students in simulation and hands-on research development of the integrated scheme.

Dispatchability

The SunShot Initiative supports research to better understand the impact of high penetration of solar power plants on the transmission and distribution electricity grids. SunShot also supports the development of standardized methods for testing grid performance of PV solar power plants and exploring and demonstrating the value of energy storage.

SunShot targets for dispatchability of solar power plants:

- Meet or exceed generator performance standards specified by NERC and individual power grids that are applicable for conventional power plants.
- Satisfy the above metric without increase in cost.
- Ensure treatment of solar power plants in a manner similar to conventional generators without additional integration cost.

MODEL-BASED INTEGRATED HIGH-PENETRATION RENEWABLES PLANNING AND CONTROL ANALYSIS
PHI Holdings, Inc. (PEPCO) | Washington, DC | $1.0M | SUNRISE | 10/2013–09/2015

This project will implement integrated transmission and distribution system high-penetration distributed energy resource (DER) interconnection, planning, monitoring and control analysis that will cover PEPCO's entire operating area. This project will quantify individual and combined effects of PV and DER, system configuration, equipment and control changes on renewable penetration levels, system efficiency and reliability, and ensure that the common model and model-based algorithms allow same data, data validation, and analysis to be used for all activities. This project is expected to result in significant increase in solar penetration capacity in the distribution system 10-15% beyond where it would be without the proposed project.

INTRA-HOUR DISPATCH AND AUTOMATIC GENERATOR CONTROL DEMONSTRATION WITH SOLAR FORECASTING
University of California | San Diego, CA | $0.5M | SUNRISE | 10/2013–09/2015

This project will demonstrate an operational tool for reducing costs associated with real-time dispatch and automatic generation control for different solar penetration scenarios in the Sacramento region. Innovative features of this project include clustering analysis on the expected solar variability per region for the Sacramento Municipal Utility District system, day-ahead and real-time load forecasts for the whole service areas and within clusters, and uncertainty quantification for integrated solar-load for both distributed and central station PV generation. This project is expected to reduce power system operation costs by committing appropriate amounts of energy resources and reserves, as well as to provide operators a prediction of the generation fleet's behavior in real time for realistic PV penetration scenarios.

OPERATIONAL ANALYSES, MODELS AND TOOLS IMPROVEMENT
National Renewable Energy Laboratory | Golden, CO | $3.5M | National Laboratory R&D | 10/2012–09/2015

This project consists of multiple activities conducted by NREL. The first activity is a study that analyzes the impact of large-scale deployment of wind and solar in the Eastern Interconnection of the U.S. The Eastern Renewable Generation Integration Study (ERGIS) analyzes two strategies for reaching 30% combined wind and solar targets and informs stakeholders about the operational impacts of these two strategies. The second activity analyzes the optimal method for operating reserve requirements with high solar penetrations. The first objective is to improve a software tool that models both the holding and deployment of reserve capacity to be used by a large system operator. The second objective is to understand the nontraditional factors that influence the need for operating reserve and compare how these should contribute to optimal operating reserve requirements for a balancing area. The third activity is to examine in detail the value proposition for CSP technology, focusing on the implementation and use of CSP with thermal energy storage. NREL will evaluate the ability of CSP to provide dispatchable energy, firm system capacity, and ancillary services. Further, the value of CSP will be compared to other sources of system flexibility, especially in enabling higher penetrations of variable generation resources such as PVs. The final activity in this project is to create a new national solar database with higher temporal and spatial resolution, and provide public access to this data to reduce the costs and risks of integrating solar power systems into the electric power grid.

Power Electronics

SunShot funding supports cost reductions and efficiency improvements through innovative circuit design, advanced components, and optimal control mechanisms. Specifically, research in this area supports the development of power electronics technologies to reduce balance of system (BOS) hardware costs, reduce installation time, and improve energy yield, as well as the development of plug-and-play technologies to reduce installation time and process costs. SunShot awardees are developing and demonstrating smart inverter functionalities and developing accelerated life testing methods and physics of failure models to predict faults and improve reliability.

SunShot technical targets for power electronics and related aspects:
- Conversion efficiency >98%
- Cost <$0.10/W (for utility-scale inverter)
- Service life 25 years
- Include grid support funtions (e.g., Volt/Var, voltage ride through)

TRANSFORMING PV INSTALLATIONS TOWARD DISPATCHABLE, SCHEDULABLE ENERGY SOLUTIONS
Advanced Energy | Fort Collins, CO | $3.1M | SEGIS-AC | 09/2011–06/2015

Advanced Energy will address three important needs in the further deployment of PV systems: **1)** demonstrating and commercializing a new anti-islanding method utilizing Phasor Measurement Units (PMUs), **2)** demonstrating a set of advanced grid support functionalities of power electronics, and **3)** demonstrating a novel "ramp rate controller" to enable control of the downward ramp rate of a PV plant under transient cloud conditions.

EXTREME COST REDUCTIONS WITH MULTI-MEGAWATT CENTRALIZED INVERTER SYSTEMS
Alencon, LLC | Hatboro, PA | $3.0M | SEGIS-AC | 09/2011–12/2014

Alencon will develop and commercialize a new type of transformational power electronic technology to utility-scale PV systems based on novel, patent-pending ideas. A 99.1% efficient, centralized inverter with a capacity of up to 100 megawatts lies at the heart of the Alencon system. Feeding this single inverter is an advanced harvesting network that utilizes string-wise maximum power point tracking and high DC voltage (2500 VDC) nodes that are easy to install and maintain.

SMART GRID READY PV INVERTERS WITH UTILITY COMMUNICATION
Electric Power Research Institute | Knoxville, TN | $4.5M | SEGIS-AC | 09/2011–05/2015

EPRI will develop, implement, and demonstrate smart-grid ready inverters with grid support functionality and required utility communication and control links to capture the full value of distributed PV. The key elements are: **1)** head-end communications at the utility operations center through integration of distributed energy resource (DER) distribution management system (DMS),

2) back-end DER plant master controller, and **3)** smart grid functionality built into inverters. PV inverter grid support functions will be put into practice using the distributed network communication protocol that enables utility operators to interact from central office-level DMS to the plant. Real world demonstrations will be carried out in three regions of the United States with four major utilities, each of which have different types of utility operating systems and implementations of utility-scale PV inverters.

MODULE EMBEDDED MICRO-INVERTER SMART GRID READY RESIDENTIAL SOLAR ELECTRIC SYSTEM
GE Global Research | Niskayuna, NY | $1.5M | SEGIS-AC | 09/2011–04/2015

GE will develop and demonstrate a new microinverter that is functionally integrated with the AC module to reduce packaging and materials cost for both the microinverter and the module laminate, and a new intelligent circuit breaker that reduces microinverter cost by offloading duplicate safety and protection functions in an AC module system to a dedicated branch circuit.

INTEGRATED MICROINVERTERS FOR ENABLING TRUE ACPV MODULES
SolarBridge Technologies | Austin, TX | $1.7M | SEGIS-AC | 09/2011–12/2014

SolarBridge will develop a novel residential PV system consisting of a PV module with an integrated "Universal PV-Dock" and a high-reliability, low-cost, high-efficiency microinverter. The collective system forms an ACPV module that simultaneously increases energy harvest and reduces balance of systems costs. The proposed system also addresses many practical aspects of the PV installation cost, such as supply chain and inventory management, late (or field) adaptation of products, and communications for data collection and performance monitoring, thereby yielding a substantially lower levelized cost of energy.

DEVELOPMENT AND DEMONSTRATION OF SMART GRID INVERTERS FOR HIGH-PENETRATION PV APPLICATIONS
University of Hawaii | Honolulu, HI | $5.1M | SEGIS-AC | 09/2012–06/2015

The University of Hawaii will demonstrate the advanced residential PV solutions at two widely different utilities. On the island of Maui, smart PV inverters and control and management software will be combined with retrofits to existing PV inverters with the goal of evaluating the ability of the systems to mitigate voltage fluctuations caused by variability of PV systems, contribute to grid stability during frequency excursions and faults, and report real-time PV output to both the utility and customer. The project team will also install new PV inverters with the goal of enabling higher PV penetration on a secondary distribution network.

PV SYSTEM RELIABILITY
Sandia National Laboratories | Albuquerque, NM | $4.6M | National Laboratory R&D | 10/2012–09/2015

Sandia will conduct research to address widespread reliability and safety issues in today's PV systems. Specifically, the team will investigate PV arc-fault and ground fault issues and inverter reliability. Arc fault R&D efforts will assist with the development of arc-fault detector/circuit interrupter certification standards through Underwriters Laboratories task groups and the International Electrotechnical Commission Technical Committee. Inverter reliability efforts will utilize the electro-thermal modeling tool, piecewise linear electrical circuit stimulation, and lab and field testing to evaluate and optimize inverter designs to achieve a 25-year inverter lifetime under realistic usage conditions (including advanced inverter functionality, such as Volt-Ampere Reactive support).

MODULE LEVEL POWER ELECTRONICS RELIABILITY AND ACCELERATED TESTING STANDARDS
Sandia National Laboratories | Albuquerque, NM | $1.4M | PREDICTS | 10/2013–03/2016

Sandia leads the collaborative development and initial implementation of industry-standard tests for module level power electronics reliability in stand-alone and module-integrated configurations. Test development will utilize a sound physical understanding of failure mechanisms and degradation modes with extensive laboratory and field testing incorporated to validate the tests and test protocols that are developed and to ensure broad applicability across the industry.

HIGH-PENETRATION PV WITH ADVANCED POWER CONDITIONING SYSTEMS
Virginia Polytechnic Institute and State University | Blacksburg, VA | $2.6M | Hi-Pen | 04/2011–12/2014

Virginia Tech will develop and commercialize three advanced power conditioning designs that enable high penetration PV systems without adversely impacting utility operation. The team is also establishing guidelines about the PV hosting capacity a feeder can accommodate depending upon feeder design, and will validate approaches to mitigate effects.

DISTINCT: DIVERSITY IN SOLAR TALENT THROUGH INNOVATIVE CURRICULUM AND TRAINING: AN INTEGRATED RESEARCH & EDUCATION APPROACH TOWARDS CREATING DIVERSITY AND ADVANCING UTILITY-SCALE SOLAR TECHNOLOGY
University of Texas | San Antonio, TX | $0.75M | DISTANCE | 09/2013–09/2016

This research is focused on the concept design and development of an innovative N-port power electronic converter that is modular, compact and cost-effective. The converter will provide a distributed, high-voltage internal electrical architecture with an integrated high-frequency, high-voltage, solid-state transformer. An integral component of this effort is to significantly enhance the "smart" integration of functionalities that go well beyond conventional grid support functions and accommodate solar resource variability due to widespread deployment of solar.

Communications

SunShot supports the development of open and interoperable communication and control architectures, enterprise integration standards based on common information model (CIM), smart inverter communication standards, and communication requirements such as network latency, scalability, and availability. Project teams working in this area are implementing standard communication protocols in inverter hardware and enterprise software, and demonstrating end-to-end system integration and interoperability on actual distribution feeders with utilities.

SunShot technical targets for communications and related aspects:
- Open and interoperable communication and control architectures
- Hundreds of thousands of connected nodes
- Near 100% network availability
- Real-time or near real-time network response

DEVELOPMENT OF AN INNOVATIVE PLUG AND PLAY PHOTOVOLTAIC ELECTRIC SYSTEM
North Carolina State University | Raleigh, NC | $2.2M | Plug and Play | 01/2013–04/2015

NCSU's Systems Engineering Center will develop a new plug-and-play PV technology to improve all aspects of residential solar PV systems through major innovation, refinement, and standardization. The key efforts are: **1)** reducing the costs of the structural elements, installation, and mounting components, **2)** reducing the cost and improving the performance and reliability of the electrical components, **3)** simplifying the integration of the panels into the electrical grid, including communications, control, and safety considerations, and **4)** designing for the market.

PLUG AND PLAY SOLAR PV FOR AMERICAN HOMES
Fraunhofer Center for Sustainable Energy Systems | Boston, MA | $8.8M | Plug and Play | 01/2013–01/2016

The Fraunhofer CSE will develop a new plug-and-play PV system that self-checks for proper installation and safety and communicates with the local utility and local jurisdiction to request permission to feed power into its smart meter. The utility and locality will remotely grant permission to the system to connect, and the PV system will immediately start to produce power to either consume in-house or feed into the distribution grid. In addition, the team will work with the national codes and standards community to identify hurdles for such a system, propose code changes, and develop technologies that will enable the system to be listed by Underwriters' Laboratories and therefore not subject to local building inspections. Progress of the technology development will be demonstrated yearly with partnering utilities and localities.

Plant Performance and Reliability

To support solar plant performance and reliability, SunShot supports R&D of characterization and diagnostic tools, data, analysis, and models to quantify, predict, and improve performance, lifetime, durability, and availability at both the component and plant/system level. SunShot also supports the development of standards and codes to provide confidence in the safety, reliability, and performance of commercial components and systems, as well as products that integrate one or more components to include building-integrated photovoltaics (BIPV), integrated grounding, and module-integrated racking. Program goals in this area include drastically reducing the part counts of associated balance of plant hardware, incorporating lean processes in hardware installation, and using alternative/innovative materials for racking, module backsheets, and module frames.

SunShot technical targets for plant performance and reliability as well as balance of plant hardware costs include:

- Provide the sufficient research data to support the approved publication of consensus standards for comparative lifetime testing of PV modules.
- Enable the creation of a consensus standard for PV system energy performance evaluation that reduces the level of uncertainty by >2% and reduces the business process time associated with negotiating performance guarantees to 3 days or less.
- BIPV systems that enable residential solar at <$2.00W
- Materials costs for polymer and steel systems at <$0.15/W and <$0.20/W respectively
- System weight of <2lbs/sqft
- Hardware and electrical labor costs <$0.10/W
- Publication of a validated set of protocols enabling commercial testing laboratories to produce Sandia Array Performance Model coefficients with 90% of predicted model performance values agree within 2% of the results from Sandia National Laboratories
- Automated detection of >95% of PV string failures and system faults with next-generation PV monitoring analysis methods

ADVANCED MEASUREMENT AND ANALYSIS OF PV DERATE FACTORS

Sandia National Laboratories | Albuquerque, NM | $2.6M | National Laboratory R&D | 10/2013–09/2015

This project focuses on improving the accuracy and reducing the uncertainty of PV performance model predictions by addressing several common elements of all PV performance models referred to as "derates." Derates are represented by simple empirical factors that are not tied to underlying physical loss mechanisms. There is significant uncertainty regarding appropriate values for these factors.

CHARACTERIZING EMERGING PHOTOVOLTAIC TECHNOLOGIES

Sandia National Laboratories | Albuquerque, NM | $5.1M | National Laboratory R&D | 10/2013–09/2015

The Sandia team will focus on developing, improving and validating characterization methods for PV modules, inverters and embedded power electronics. Characterization methods are at the heart of technology assessments and provide the basis for accurate modeling of components and systems. Outputs of the project include measurement and analysis procedures that industry can use to better distinguish and understand the performance differences between competing module and inverter products, new component designs and new technologies such as new PV cell designs, inverter topologies and more.

INCREASING PREDICTION ACCURACY

National Renewable Energy Laboratory | Golden, CO | $4.2M | National Laboratory R&D | 10/2009–09/2014

The goal of this project is to quantify and reduce uncertainties in PV system performance models by systematically analyzing, quantifying, and propagating uncertainty using research-quality PV monitoring data in various climates, leading the international PV Performance Monitoring Collaborative (PVPMC) to standardize and document existing and emerging modeling algorithms, making targeted model improvements for concentrating PV technologies and systems, and developing new methods for extracting more information from PV monitoring systems and data streams.

IMPROVEMENT AND VALIDATION OF SOLAR SYSTEMS MODELING ALGORITHMS AND TOOLS

National Renewable Energy Laboratory | Golden, CO | $3.1M | National Laboratory R&D | 10/2013–09/2015

The project team aims to improve system modeling accuracy and risk assessment via research into improved data and algorithms, make robust models available to the PV industry, and improve the characterization of risk and bankability across all markets (residential, commercial and utility). The project's ongoing value to the community is to enable and accelerate research and analysis of solar technologies through the development and dissemination of cutting-edge solar and finance modeling through desktop tool, software engine, and web services such as the System Advisory Model (SAM) and PVWatts.

PREDICTING SERVICE LIFE FOR PV MODULES

National Renewable Energy Laboratory | Golden, CO | $9.9M | National Laboratory R&D | 10/2013–09/2015

NREL is developing a set of accelerated stress tests that can provide quantitative predictions of module service life in a variety of climates for different PV technologies and applications. The developed accelerated stress tests will be incorporated into a set of standards.

QUANTIFYING RISK THROUGH BANKABILITY REPORTS AND STANDARDS
National Renewable Energy Laboratory | Golden, CO | $2.8M | National Laboratory R&D | 10/2013–09/2015

NREL is focusing on the technical details of assessing PV performance risk with the goal of reducing risk (both actual and predicted) and decreasing the time and cost needed to assess this risk. To this end, NREL is developing standards to quantify PV performance, documenting actual PV performance versus predicted performance across large data sets (50,000+), and documenting and standardizing the quantification of degradation rates.

EMERGING TECHNOLOGY CHARACTERIZATION
National Renewable Energy Laboratory | Golden, CO | $3.0M | National Laboratory R&D | 10/2013–09/2015

NREL will conduct research to remove barriers due to uncertainties associated with the performance of emerging technologies. The emerging technologies addressed are thin film and concentrating PV (CPV) modules. The team will develop procedures to stabilize the performance of thin film PV modules (CIGS and CdTe) for measurement of performance at Standard Rating Conditions. The team will also develop and validate testing methods to determine outdoor power ratings of CPV modules and reduce uncertainty from ±10% to ±5%.

IEC AND NEC PV STANDARDS
National Renewable Energy Laboratory | Golden, CO | $2.0M | National Laboratory R&D | 10/2013–09/2015

NREL aims to provide technical validation to reduce uncertainty in predictions of PV performance, quality, safety, and product lifetimes in order to differentiate technologies and products and set baselines for product improvement and investment. This is accomplished by continuing DOE representation and participation in several standards and codes activities to ensure that the best technical work available in the areas of PV measurements and testing are turned into standards and codes. Particular attention is paid to the International Electrotechnical Commission (IEC), the National Electric Code (NEC), and various building codes to support codes that facilitate the growth of PV and avoid codification of requirements that unfairly or inaccurately limit implementation of PV.

INNOVATIVE BALLASTED FLAT ROOF SOLAR PV RACKING SYSTEM
Cascade Engineering | Grand Rapids, MI | $0.60M | BOS-X | 12/2012–07/2014

Cascade Engineering is incorporating a number of material and labor savings opportunities into a lightweight, low-cost, injection-molded plastic solar PV racking system. The goal is to reduce total balance of system costs by 25%.

REGIONAL TEST CENTERS
National Renewable Energy Laboratory and Sandia National Laboratories | Golden, CO and Albuquerque, NM | $12.0M | National Laboratory R&D | 10/2011–Ongoing

SunShot established the Regional Test Centers to further develop standards, establish a technical basis for PV bankability/economic viability, provide geographically diverse test beds for large-scale system demonstrations, and to offer technical assistance and independent validation of PV performance and reliability.

SOLAR INSTALL, MOUNT, PRODUCTION, LABOR, EQUIPMENT (SIMPLE) BALANCE OF SYSTEMS
Georgia Tech Applied Research Corporation | Atlanta, GA | $2.8M | BOS-X | 09/2011–01/2015

Georgia Tech is developing residential, commercial, and utility solar PV racking and mounting systems that reduce hardware and labor costs by 50% over current industry best practices. Design innovations are being pursued across multiple pathways, including: reduced part count, standardization, factory assembly, wire management, reduced roof penetrations, tool-less systems, integrating assembly line processes, pre-panel assembly, significant material reduction, self-squaring, prefabrication, factory assembly, structural/material efficiencies, and self-stability/ballasting.

DEPLOYABLE COMMERCIAL ROOFTOP SOLAR ELECTRIC SYSTEM
GE Global Research | Niskayuna, NY | $1.5M | BOS-X | 12/2011–12/2014

GE is developing a lightweight, mechanically-interconnected, multi-module solar electric array that can enable total installed costs of less than $2.50 per watt. Key innovations include: assembly weight of less than 2 lbs/ft^2; significant reductions in racking weight, material handling costs, and install time; an integrated busway; and optimization for project net present value based on higher energy production revenues on size-constrained commercial rooftops.

DEVELOPMENT AND PRODUCTIZATION OF HIGH-EFFICIENCY, LOW- COST BUILDING-INTEGRATED PHOTOVOLTAIC SHINGLES USING MONOCRYSTALLINE SILICON THIN FILM SOLAR CELLS
Solexel | Milpitas, CA | $7.2M | BOS-X | 09/2011–07/2014

Solexel is developing a building-integrated photovoltaic (BIPV) solar shingle product that demonstrates a business case for achieving a $2 per watt or less total installed cost residential BIPV system at large scale by 2017. The design is incorporating high-efficiency (>21%), flexible, thin monocrystalline silicon cells, very low-cost distributed power electronics circuitry at the cell level, and integrated microinverters.