RESEARCH FUNDED BY THE CALIFORNIA SOLAR INITIATIVE'S RESEARCH, DEVELOPMENT, DEMONSTRATION AND DEPLOYMENT PROGRAM CREATING A SUSTAINABLE SOLAR INDUSTRY BY 2016

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ABSTRACT

The California Solar Initiative (CSI) Research, Development, Demonstration and Deployment Program (RD&D) has a budget of $50 million and provides grant funding to help build a sustainable and self-supporting industry for customer-sited solar in California and to further the CSI goal of 3,000 MW of installed capacity by the end of 2016. To date, the program has conducted two grant solicitations and made 18 awards for a total of $33 million. The research focus areas include grid integration of high penetration PV, improving solar technologies and innovative business models. This paper will provide information on each of the research projects including goals, approach, outcomes and key deliverables. The projects are a multi-faceted approach to meeting the goals of the CSI program as well as achieving wide-spread adoption of solar in the future years. The projects funded by the CSI RD&D program are addressing the market and technical barriers to achieving lower cost and higher performing solar systems.

1. ABOUT THE CALIFORNIA SOLAR INITIATIVE'S SOLAR RESEARCH PROGRAM

The goal of the CSI RD&D program is to help build a sustainable and self-supporting industry for customer-sited solar in California. To achieve this, the program focuses on reducing technology cost and improving performance, filling knowledge gaps to enable wide scale deployment, and supporting the integration of distributed energy into the grid. As the RD&D is funded by California ratepayers, preference is given to projects which focus on California-specific issues. Since California leads the nation in solar installations, issues being faced there today are likely to be shared by other states in the future as they adopt more renewable distributed generation.

The CSI RD&D program utilizes several strategies to maximize the return of ratepayer investment while reducing risk. These include funding different stages of RD&D activities, allocating more funds to mature technologies, leveraging cost-sharing funds from other entities, and building on past experiences in California. The target focus areas include: grid integration; improved solar technologies; and innovative business models. The majority of funds will be spent on projects which can show near-term results – typically within a few years (1).

The California Public Utilities Commission (CPUC) was charged with the responsibility of the RD&D funds and selected Itron, Inc. as the Program Manager for the CSI RD&D program in 2008. Itron is responsible for developing

request for proposals, evaluating grant requests, entering into grant agreements, managing grant projects, conducting program outreach and monitoring progress on all approved projects. To date, Itron and the CPUC have successfully allocated $33 million dollars to 18 research projects across all three target areas. This includes a $10 million dollars award to the Solar Energy Research Center (SERC) located at the University of California, Berkeley.

The SERC will conduct research focused on advanced nanomaterials for solar collectors and electrodes, advanced catalysts for energy-efficient chemistry, and specialized membranes for integrating light harvesting, charge separating, and fuel formation. The SERC is in the design phase, with the 50 percent design development milestone reached in July of 2010.

2. GRID INTEGRATION: HIGH PENETRATION PV

Solar incentives in California have supported customer adoption of solar technologies, however in order to meet the states aggressive goals, these systems need to be integrated into the electricity grid. The impact that high penetration levels of PV will have on the electricity grid is of concern to utilities. The CSI RD&D projects are addressing grid integration of high penetration PV by developing planning and modeling tools as well as testing and developing software and hardware solutions for high penetration PV.

2.1 Planning and Modeling for High Penetration PV

Distributed PV systems are often outside the scope of utility planners and engineers, due to their small size and historically low rates of market-penetration. On a practical level, many utility personnel may not be familiar with the operational characteristics of these systems. In addition, due to the rapid growth in distributed PV systems, utility grid operation models and planning tools lack the ability to account for distributed PV generation technologies and resources. Challenges also exist with the current methods for estimating solar resources and predicting PV system output. Existing solar resource models are based on lower resolution insolation data sets and usually provide only hourly resource values. Only with the emergence of higher concentrations of PV onto distribution feeders has there been recognition that rapid changes in atmospheric conditions over relatively small areas can have significant impacts on the aggregated PV system output and on the associated electricity distribution system.

Existing methods for predicting and planning for high penetration PV limit the ability of utilities to strategically locate this technology within their transmission and distribution (T&D) system. New solar resource and utility planning models provide utilities with the means to identify optimal locations for high density PV installations. As PV and other distributed generation (DG) resources form a larger portion of the electricity generation mix, it will be increasingly important to have electric system planning, design, and operation modeling tools that provide utilities, the solar industry, and utility customers with the ability to accurately assess and forecast energy output and account for distributed PV systems. By demonstrating a more refined understanding of DG responsiveness to external criteria, these research projects seek to transform high levels of DG from a liability into a vital asset for grid planners.

The CSI RD&D Program is funding four planning and modeling projects for high penetration PV. These projects are being conducted by; Clean Power Research; SunPower Corporation, the University of California, San Diego and the University of California, Irvine.

The first planning and modeling project, with Clean Power Research, is developing a free solar resource model (ca.solaranywhere.com) that will provide high temporal (30 minute interval) and spatial resolution (1 km grid) data for use in forecasting and planning tools. The output of this forecasting tool will be compared with actual field data at range of sites representing different plant capacities and irradiance levels. A central tenet of this project is that while variability for a single module may be high, a portfolio of modules shows a much more predictable and stable generation profile. The team will integrate PV modeling capabilities with distribution engineering and analysis tools and create a PV value assessment tool for use by utilities to select and target the best locations for PV. These tools and data streams will be made publicly available for use by installers, manufacturers, developers, utilities and others engaged in the transformation of the electric power grid into a clean energy marketplace.

The second project, with the SunPower team, will produce an improved solar resource model with temporal resolution ranging from 10 minutes to 1 second and spatial resolution going to below 4 km^2. Results of the higher solar resolution data will be validated against PV systems monitored by SunPower in California. The emphasis of this project is to produce the tools and resources necessary to facilitate the study of high penetration PV scenarios in California using industry-standard simulation tools. This project will provide critical information to utility and grid operation planners about solar resource variation and PV behavior under both stable and variable conditions.

The third planning and modeling project is with the University of California, San Diego. This project focuses on providing utilities and the solar industry with electricity

system planning, design and operation modeling tools for accurately assessing and forecasting energy output from distributed PV systems. A one-year dataset of solar irradiances will be generated at 1 km resolution which will inform solar resource maps as well as to forecast PV power output throughout California up to 6 hours ahead. Dynamic system modeling to examine instabilities associated with voltage sags, upset conditions leading to islanding, and reverse power flows on the distribution system will be conducted. These high resolution (both temporal and spatial) resource maps and modeling tools will be a critical component in enabling high levels of PV penetration.

The goal of the University of California, Irvine (UCI) project is to utilize modeling and simulation to quantify PV integration limitations on distribution circuits and to develop and evaluate progressively smarter distribution systems so that higher levels of PV can be accommodated. Monitored field data will be used to develop and verify distribution circuit models, with PV integration limits quantified for these circuits. The UC Irvine team will also evaluate advanced inverters, control strategies, standards, hardware and communications to enable and support increased PV penetration on the distribution system. Results from the project will be used to inform advanced standards.

2.2 Testing and Development of Hardware and Software for High-Penetration PV

Successful grid integration of high-penetration PV requires robust grid, PV communications, control systems, and operational procedures. PV systems will need to be capable of dynamically interacting with varying frequency and voltage conditions on the grid including load and VAR (reactive power) control to improve reliability. New software and hardware tools will emerge in response to these needs. Field testing and demonstrations are needed before these new tools can realize widespread market adoption.

Two CSI RD&D funded projects focus on testing and development of hardware and software solutions to integrate high penetration PV into the electricity grid. These projects are being conducted by Southern California Edison (SCE) and the Sacramento Municipal Utility District (SMUD).

The project with SCE has NREL as a co-investigator and focuses on accelerating the placement of high levels of PV penetration into the existing distribution circuits and identifying new circuit configurations that will help increase penetration levels of PV. For the first year of the project, the team will conduct modeling, simulations, and testing of possible advanced hardware and software solutions. Laboratory testing will be conducted on advanced inverters and control systems, and these advanced systems will be installed in projects in the SCE territory. During the second year, the team will evaluate the advanced technologies that were developed during the first year of the project.

The SMUD project is a partnership with Hawaiian Electric Company (HECO) and will demonstrate new hardware and software tools that will provide communication and management between PV systems and utility controls using advanced metering infrastructure (AMI). The team will develop a software visualization tool that enables identification of high value locations for distributed PV. The tools developed through this project will be tested and validated at residential, commercial, and utility-scale deployments in California and Hawaii. The project will provide utilities with the tools to integrate increased levels of PV into the grid.

3. IMPROVED PV PRODUCTION TECHNOLOGIES

The improved PV production technologies focus area includes testing and demonstration of new solar technologies and strategies with improved performance/reliability and/or lower costs. The projects funded in this focus area aim to demonstrate the viability of distributed concentrating PV (CPV), and combining PV with energy storage. By concentrating the available solar radiation on smaller cell material, CPV systems provide for much higher efficiencies compared to traditional flat plate PV. This is both beneficial to reducing system costs with less cell material requirements as well as more energy production in a given area. However, the current market place lacks data on the reliability and long term performance of such systems to allow for financing of CPV projects. Providing long term performance data and information to establish the bankability and reliability will enable more widespread adoption of CPV in the distributed generation market.

The CSI RD&D Program is funding four projects that focus on improvements to PV production technologies. These projects are being conducted by the SunPower Corporation, Amonix, Inc., Solaria Corporation and Cogenra Solar.

The SunPower Corporation is improving production technologies by demonstrating the integration of advanced energy storage systems in combination with existing PV systems for commercial customers. The SunPower team will work with three energy storage vendors as well as Target Stores to demonstrate better economics with the combination of PV and storage than with each of the technologies separately. The expected range of the test systems are from 80 to 375 kW with 2 to 6 hours of storage. Over the two-year research period, the SunPower team will:

1) Determine if the combination of PV and energy storage is of higher value to the customer and utility than either one alone considering time-of-use rates and a demand response tariff, under actual operating conditions, and 2) Assess the capabilities, reliability and potential degradation of the storage technologies. The ability of the storage technologies to respond to actual or simulated demand response events will also be assessed. This research will provide valuable information regarding the coupling of energy storage with PV in terms of both the economics as well as the reliability of storage technologies.

Amonix, Inc. is working to decrease costs and expand the market adoption of high concentration photovoltaic (HCPV) systems. The Amonix team will monitor the performance of nine 53 kW HCPV systems and associated circuits on the University of California, Irvine electric infrastructure. Metered data and associated models will be used to evaluate and compare grid interconnection and energy management strategies. The team will also look at how to correlate measured weather data with accelerated testing in order to predict lifetime and reliability validation that will help to secure financial investments for future HCPV system deployment. The reliability model will help project owners and the financial community with the data on system reliability and lifetime performance, which should accelerate the adoption of HCPV technology on a much wider scale.

The financial community is hesitant to invest in new technologies that lack a history of performance over time. To overcome this barrier, the Solaria project will conduct demonstrations of concentrating PV at two California sites (Fremont and Dublin). The Fremont demonstration, located at the Solaria manufacturing facility, will be a 110 kW tracking system. The second system, installed at the Alameda County Santa Rita Jail, will test and compare three types of tracking systems with Solaria modules: single axis, dual axis, and polar axis. These tests will allow for further cost and performance comparisons to validate the optimum tracker technology with Solaria modules. The data and results from these demonstrations will reduce the risk for investors to provide financing for these projects. This will help to accelerate the deployment of CPV in the state.

Cogenra Solar, another CPV project, has developed, prototyped and validated the performance of a concentrating PV and thermal co-generation technology. For this research project the team will conduct an 80 kW demonstration of their technology at the Sonoma Wine Company where improved manufacturing and assembly methods will be developed and demonstrated. The field performance of the system will be measured and used to refine economic and financial models. The Cogenra team will also develop an Energy Purchase Agreement business model to facilitate third-party financing for these systems. The solar co-generation system will also be modified to support tri-generation of electricity (heating and cooling). Tri-generation will expand the market for this technology to commercial sites that require cooling and limited hot water. The system will also be modified to provide energy storage for use during peak demand.

4. INNOVATIVE BUSINESS MODELS

The Innovative Business Model focus area includes projects that provide support to the market for solar energy. Successful deployment of new business models is required to meet the goals and objectives of the CSI Program. Testing and demonstration of innovative business models will help support expansion of cost-competitive solar technologies by reducing costs or increasing value of the solar system to owners or utilities. The program supports activities that enhance the competitiveness of new technologies, or to help reach a 'tipping point' into widespread commercialization. This can include projects that involve testing of technologies or measures that enable streamlining of regulatory processes or standards in ways that allow new products to come to market more quickly and at lower costs.

The CSI RD&D Program is funding three projects in the innovative business model category with the research being conducted by Viridity Energy, SolarCity and SunLink.

The project with Viridity will identify new business models for integrating up to 1,000 MW of high penetration PV with distributed energy resources (DER) at the University of California, San Diego (UCSD). Additionally, new tariffs and incentives will be developed and vetted with SDG&E and the California Independent System Operator (CAISO) and tested on the UCSD Microgrid. Lastly, the team will perform integrated cost-benefit analysis of the business models and management strategies and recommend rates and incentives that balance the costs and benefits from the utility, customer and ratepayer perspectives. The development of tariffs and incentives to balance costs/benefits is a critical component to advancing PV generation in the state as well as meeting the goals of the CSI Program. This research will provide valuable information to support both utility operations and the CAISO.

SolarCity has an operational FirmPV installation in San Francisco which utilizes SolarCity's SolarGuard dispatch and monitoring platform and Tesla Motors vehicle battery system. The ability to firm intermittent renewable resources by remotely controlling distributed storage will likely result

in peak demand reductions and system-wide grid network benefits. The SolarCity team will conduct demonstrations on 12 sites to assess system performance along with assessing the economic, reliability and carbon reduction impacts of large-scale deployment of a FirmPV product. PG&E and CAISO, both key potential beneficiaries, will provide guidance on grid related and regulatory concerns while University of California Berkeley will assist in modeling. The team will conduct analysis to determine an optimal tariff product or rate plan that will provide the benefits of FirmPV at the lowest overall cost, along with exploring a range of financing mechanisms that will best enable FirmPV deployment at the customer level. To implement their findings, market niches where financial benefits of FirmPV exceed the additional cost of lithium ion batteries will be identified. SolarCity, a dominant player in the residential PV market, will be the primary channel for commercializing the FirmPV product.

The SunLink project builds on previous achievements to enable automation of structural and array electrical designs. This will support the industry by enabling cost-effective, optimized designed PV systems down to 5kW. It will also support workforce development by expanding the range of general and electrical contractors who can deliver fully-engineered PV system installations. The team will also automate the documentation process from project approval through system installation. System installation and balance of system (BOS) components can account for 50 percent of the cost of a PV system and these costs have not decreased as rapidly as module costs in recent years. Any reduction in BOS costs will have a substantial impact on the installed cost of a PV system. This research is focused on decreasing the time spent on the following: 1) engineering time from system layout to final package, 2) plan checking time and, 3) on-roof array wiring time.

5. CROSS-CUTTING: INTEGRATION OF ENERGY EFFICIENCY, DEMAND RESPONSE AND ENERGY STORAGE WITH PV

For utilities, energy efficiency and distributed PV can help defer the need to build additional peaking generation and T&D system infrastructure. For utility customers, distributed PV provides more control over energy prices. Installing a PV system is one of a number of options available to these customers. Other choices include energy efficiency, energy storage, and demand response. Energy efficiency provides the most cost-effective means for addressing energy use within a home, business or community. Implementing energy efficiency measures not only reduces electricity demand but also helps reduce the size and required capital for a PV system. The choices available can leave customers at a loss to determine the optimum balance of energy efficiency measures and PV system type and size for the specific application. At present, there are no clear guidelines (especially in retrofit situations) on the energy efficiency measures that utility customers should consider prior to, or in conjunction with, procuring a PV system. Additionally, there is a critical gap in the ability of the current market to provide combined energy efficiency services along with PV services for the residential sector. Integration of energy efficiency, demand response, storage along with renewable generation is the path towards zero net energy, both at the individual scale and the community scale.

The CSI RD&D Program is supporting four projects in this cross-cutting area. Research projects that are developing tools to integrate energy efficiency and PV are being conducted by Davis Energy Group / NREL and kW Engineering. Consol is working on a solution for incorporating energy efficiency and PV in the residential retrofit market and the University of California, Davis is demonstrating Zero Net Energy at the community-scale level.

The project by Davis Energy Group with NREL as co-investigator is developing the Building Energy Optimizer for California Existing Homes Beopt-CA (EX) modeling tool that aims to facilitate the integration of energy efficiency (EE), demand response (DR), and energy storage (ES) with PV in the residential retrofit market. The project will use real data to validate the prototypes developed in the modeling tool. The tool will provide utility program managers and contractors with the means to optimize the integration of EE, DR, ES and PV. The team will also develop a recommended series of best practices and conduct training on the Beopt-CA (EX) tool.

The kW Engineering team is developing and verifying an Integrated Energy Project (IEP) data model that will identify best practices for integrating energy efficiency measures with PV system deployment. The IEP Model introduces a common language to project stakeholder software applications and provides a comprehensive, standardized definition for EE/DR+PV projects, as well as a way for stakeholders to communicate with each other about the project. This will simplify and streamline the process, reduce time and costs for both the consumer and contractors, produce a better return on investment for both, and remove a key market barrier for the adoption of both efficiency measures and PV. The IEP model will be available for public access (iepmodel.net) for use in any integration project.

ConSol, in partnership with San Diego Gas & Electric (SDG&E), General Electric (GE) and roofing contractors, is

conducting research aimed at combining a PV system as a cost-effective retrofit measure during a residential re-roof. Six test homes will be selected throughout the SDG&E service territory, spanning a range of economic, geography, vintage, and energy efficiency levels to test GE's new plug and play PV system. One test home will be selected for a zero net energy retrofit, which will include additional efficiency measures, GE's demand-responsive appliances, an integrated home energy management (HEM) system and an energy storage system. Providing training materials for the roofing contractors for combining PV during a residential re-roof retrofit will be a valuable deliverable for the solar industry. Key activities include: 1) Evaluation of the installation costs, barriers and performance of PV during retrofit using the case of GE's plug and play system. 2) Assessment of existing and potential financing options to cover the costs of the PV system, energy efficiency upgrades and non-energy building retrofits (e.g., re-roof) in a single, readily available package. 3) Analysis of target markets and marketing materials for this PV retrofit system. 4) An assessment of the impact that this PV retrofit product, along with efficiency improvements and demand response capability will have on the utility distribution-grid. 5) Development of a business plan for contractors performing re-roofs that could add the installation of this PV retrofit system as a sustainable product offering, independent of the availability of incentives for renewable systems.

Focus Areas	Project Title	Awardee	Grid Integration				Solar Technologies				Business Models				Integration of EE/DR/ES + PV				
			Solar Resource model	Forcasting model	T&D model	Advanced Communication	CPV	Storage	Tracking	Tri-genration	Tariff and incentive design	Regulatory concerns	Design automation	Reducing BOS costs with	Energy Efficiency	Demand Response	retrofit application	Community level solar	Design tools
Grid Integration: High Penetration PV	Advanced Modeling and Verification for High Penetration PV	Clean Power Research	■	■															
	Planning and Modeling for High-Penetration PV	SunPower Corporation	■	■															
	Improving Economics of Solar Power Through Resource Analysis, Forecasting and Dynamic System Modeling	University of California San Diego	■	■															
	Development and Analysis of a Progressively Smarter Distribution System	University of California Irvine - APEP			■	■													
	Analysis of High-Penetration Levels of PV into the Distribution Grid in CA	Southern California Edison/ NREL			■	■													
	High Penetration PV Initiative	Sacramento Municipal Utility District		■	■														
Improved Solar Technologies	PV and Advanced Energy Storage for Demand Reduction	SunPower Corporation						■											
	Improved Cost, Reliability, and Grid Integration of High Concentration Photovoltaic Systems	Amonix, Inc.					■												
	Solaria: Proving Performance of the Lowest Cost PV System	Solaria Corporation					■		■										
	Hybrid concentrating photovoltaic/thermal tri-generation (CPV/T-3G) technology	Cogenra					■			■									
Innovative Business Models	Advanced Grid-Interactive Distributed PV and Storage	Solar City						■			■	■							
	Innovative Business Models, Rates and Incentives that Promote Integration of High Penetration PV with Real-Time Management of Customer Sited Distributed Energy Resources	Viridity Energy									■								
	Reducing California PV Balance of System Costs by Automating Array Design, Engineering and Component Delivery	SunLink											■	■					
Cross-cutting: Integration of Energy Efficiency, Demand Response, Energy Storage and PV	Beopt-CA (EX): A Tool for Optimal Integration of EE/DR/ES+PV for California Homes	Davis Energy Group/ NREL						■							■	■	■		■
	Specify, Test and Document an Integrated Energy Project Model	kW Engineering												■	■				■
	Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar Energy Efficiency Results	ConSol												■	■		■		
	West Village Energy Initiative: CSI RD&D Project	University of California Davis						■				■			■	■		■	

Fig. 1: Matrix of CSI RD&D Projects and Focus Areas

The West Village Project at the University of California, Davis, is one of the first large scale communities that aims to be Zero Net Energy entirely through energy efficiency and on-site generation. The UC Davis team will test and demonstrate existing and new storage technologies for smaller systems in community-wide applications. The team will also research and demonstrate the integration of AMI with PV and DG as well as test and demonstrate hybrid solar (PV/Thermal). The West Village Project will be used to test and evaluate several business models for deploying community distributed solar and will document the most promising one and identify regulatory barriers in the process. The team will also test, demonstrate and assess virtual net metering approaches, energy storage to mitigate the impacts of high penetration PV deployment and the use of solar resource forecasting to optimize storage charging and dispatch. The project is also receiving support from the California Energy Commission's Public Interest Energy Research Program as a Renewable Energy Secure Communities (RESCO) Project and the Department of Energy.

6. PATH TO A SUSTAUNABLE SOLAR INDUSTRY

The CSI RD&D projects and focus areas, as shown in Figure 1, illustrate California's multi-faceted approach to meeting the goals of the CSI program as well as achieving wide-spread adoption of solar in the future years. The projects funded by the CSI RD&D program are addressing the market and technical barriers to achieving lower cost and higher performing solar systems. Progress is being made on developing more efficient and cost effective solar technology, integrating that technology into the utility grid and providing the market support to reach the 'tipping point' to wide spread commercialization. Demonstrating the achievements of these projects and sharing lessons learned with stakeholder groups will support the larger CSI goal of installing 3,000 MW of distributed PV in the State. More details on the projects and about the CSI RD&D Program in general can be found on the program website: **www.CalSolarResearch.ca.gov** .

7. REFERENCES

(1) California Public Utilities Commission., OPINION ESTABLISHING A RESEARCH, DEVELOPMENT, DEMONSTRATION AND DEPLOYMENT PLAN FOR THE CALIFORNIA SOLAR INITIATIVE, Decision 07-09-042, September 20, 2007 http://162.15.7.24/PUBLISHED/FINAL_DECISION/73187.htm