California Solar Initiative

# RD&D: Research, Development, Demonstration and Deployment Program

GO solar CALIFORNIA

Final Project Report:

## *Grid-Ready Plug-and-Play PV Kit*

# Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy Efficiency Retrofits

Grantee:

**BIRAenergy**

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*www.CalSolarResearch.ca.gov*

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***http://www.calsolarresearch.ca.gov/Funded-Projects/***

# Preface

The goal of the California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment (RD&D) Program is to foster a sustainable and self-supporting customer-sited solar market. To achieve this, the California Legislature authorized the California Public Utilities Commission (CPUC) to allocate **$50 million** of the CSI budget to an RD&D program. Strategically, the RD&D program seeks to leverage cost-sharing funds from other state, federal and private research entities, and targets activities across these four stages:

- Grid integration, storage, and metering: 50-65%
- Production technologies: 10-25%
- Business development and deployment: 10-20%
- Integration of energy efficiency, demand response, and storage with photovoltaics (PV)

There are seven key principles that guide the CSI RD&D Program:

1. **Improve the economics of solar technologies** by reducing technology costs and increasing system performance;
2. **Focus on issues that directly benefit California**, and that may not be funded by others;
3. **Fill knowledge gaps** to enable successful, wide-scale deployment of solar distributed generation technologies;
4. **Overcome significant barriers** to technology adoption;
5. **Take advantage of California's wealth of data** from past, current, and future installations to fulfill the above;
6. **Provide bridge funding** to help promising solar technologies transition from a pre-commercial state to full commercial viability; and
7. **Support efforts to address the integration of distributed solar power into the grid** in order to maximize its value to California ratepayers.

For more information about the CSI RD&D Program, please visit the program web site at www.calsolarresearch.ca.gov.

# Acknowledgements

BIRAenergy thanks the California Solar Initiative (CSI) for funding this project – we believe that the project has advanced knowledge, technologies, business models, and implementation of Zero Net Energy (ZNE) solar retrofits. This could not have been done without the CSI RD&D funding. We also wish to thank Itron for their assistance in administering this project, in particular Project Manager Smita Gupta who provided valuable administrative and programmatic advice throughout the duration of the project.

BIRAenergy also acknowledges the contributions of their Key Partners: GE Global Systems and San Diego Gas & Electric (SDG&E). GE provided the PV systems that were at the core of this project, and SDG&E funded the upgrades to the ZNE home. Charles Korman, Ph.D., Chief Technologist, Solar Energy, at GE Global Research was the main contact from GE and was deeply involved and committed to this project from beginning to end. The BIRAenergy team commends Dr. Korman for his large contribution to both this project and the solar industry as a whole. Nate Taylor and Abdullah Ahmed from SDG&E/Sempra Emerging Technologies provided not only funding for the innovative ZNE retrofit, but technical guidance as well.

Mid-way through the project, the team acquired a special partner, Sunverge, who assisted in procuring, installing, and commissioning one of their intelligent energy-storage systems. Jon Fortune and Stina Brock of Sunverge were particularly helpful in the system delivery and setup, as well as assisting with data reduction and illustrating the energy use impacts of the major components in the ZNE home.

The team wants to particularly acknowledge and voice a special *“thank you!”* to the family owning and living in the ZNE test home. While anonymous in this report, we wish to acknowledge the important role they performed, providing their home for the retrofits, and allowing monitoring of their historical, current and future energy usage. They were very prompt in responding to any and all requests from the team relating to the changes, additions and retrofitting of their home, patient with work-schedules and workers, and they remained friendly and helpful throughout the course of this project. The ZNE-related tasks could not have had a more cooperative project volunteer.

# Contents

# Abstract

This project focused on testing and evaluating the Smart-Grid Ready Plug-and-Play Retrofit Solar PV System pioneered by GE. This approach to residential retrofit PV systems, generically referred to as the *Grid-Ready Plug-and-Play PV Kit*, or P&P PV Kit, is the result of several design innovations that reduce the cost and complexity of the mounting system hardware, increase system performance and safety, and simplify and enable installation by standard roofing and electrical contractor trades. Unlike typical rooftop PV systems, installation of this PV-system does not require an electrician on the roof. The entire rooftop installation can be made by the roofer, including the electrical connections between panels, and dropping the end of the wiring harness through the roof. The electrician is needed only to route an electrical cable from under the roof deck to the electrical panel, and to complete the connections of this cable to the unterminated wiring harness dropped through the roof by the roofer, and the other end to a committed breaker in the electrical box.

Several innovations with the GE system have resulted in a less expensive, higher performing product, including: a simple PV mounting system; 40% fewer components than traditional systems; no requirement for an electrician on the roof; the integration of a microinverter into each PV module so the output and connections are 240V AC output. The panels producing AC allows use of a simple plug-and-play electrical harness to make the rooftop electrical connections, and allows the connection between the PV array and electrical panel to be an electrical cable directly from the solar array to the home's electrical distribution panel. Based on the results of this study, GE's system can be priced into the market at under $4.00 per watt, installed, and by 2015 at under $3.00 per installed watt, establishing a path for solar generated electricity to achieve parity with retail electricity in the near-term and without the need for government subsidies. Price parity of electricity from rooftop systems compared with retail electricity also reduces the future need for additional utility-scale power plants as well as the source energy, land-use, environmental, and other such issues associated with new power plants.

This P&P PV Kit was also a key element in retrofitting a test home to be a Zero Net Energy (ZNE), the performance of which was evaluated under this project and the findings summarized in this document and presented in detail in a separate report (Zero Net Energy Home – Design, Development and Implementation).

# Executive Summary

The project evaluated a new, yet to be marketed PV product for retrofit on existing homes developed by GE Global Systems, their *Smart-Grid Ready Plug-and-Play Retrofit Solar PV System*, generically referred to in this report as "Grid-Ready Plug-and-Play PV Kit," or P&P PV Kit. A detailed description on the concept, its features, benefits, performance and cost is given in a GE report for the New York State Energy Research and Development Authority (NYSERDA).[1] This project included field implementation and evaluation of the GE prototype P&P PV Kit on a Showcase Retrofit Home in Chula Vista, CA. Lessons were learned from that installation, and some product design and installation improvements were made, resulting in a beta-test version of the GE pre-product. The beta version was installed and evaluated on five test homes in SDG&D service territory as part of this research

This Grid-Ready P&P PV Kit features simplified hardware and a simplified installation process that can result in lower system installed costs. Key features of the P&P PV Kit include:

- Low assembly part-count
- Quick and simple "insert and capture" PV module mounting assembly
- Plug-and-Play 240Vac PV modules
- Roof-top installation can be done entirely by a roofer – an electrician is not required to be on the roof.

A key design element of this Plug-and-Play system is that each PV module has an integrated micro-inverter that converts the module output to 240Vac, and provides module-by-module interconnection to the grid, via a single wiring harness that connects directly to the house power panel. This new low-cost PV product initially targets the large asphalt-shingle re-roof market and is designed for coordinated installation with the asphalt roofing materials by standard roofer contractor trades with no special tools. An electrician is required to install wiring from under the roof deck to the power panel, and to make the connection to the terminus of the P&P PV Kit wiring harness, dropped through a roof penetration, and at the other end of the electrical cable to the home's electrical panel.

The initial product concept was for installation at re-roof, but this RD&D project determined that the P&P PV Kit could be installed equally successfully at re-roof or as a retrofit on an existing asphalt shingle roof that is in sufficiently good condition to last the 20 year warranted product

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[1] New York State Energy Research and Development Authority (NYSERDA) Final Report. Charles Korman. GE Global Research: "*Smart Grid Ready Residential Solar Electric System*." December 2012.

life. The project target installed-cost for the P&P PV Kit was to be less than $4.25/Watt, including integrated, advanced meter infrastructure (AMI) -capable, home energy monitor and demand response (DR) controller – the GE Brillion Nucleus. As part of this project, a new PV business model was developed based on roofers adding the P&P PV Kit as a product they offer along with their other roofing retrofit products and services. Unlike other PV systems, the P&P PV Kit does not require an electrician on the roof. This allows the roofer to be the lead contractor for the roof *and the PV system they install, on the roof.* This provides a new service line for roofers, and provides the opportunity for roofers to become a new market channel for sales of residential rooftop PV retrofits. This project also produced a report on different financing options that are available to homeowners for rooftop retrofit PVs.

Six homes in the San Diego Gas and Electric (SDG&E) territory had P&P PV Kit systems installed. The first home provided a field "laboratory" as a test-bed for the installation and interconnection process, initial installation costs estimates, and development of a Best Practices Installation Guide. The field-laboratory installation of a prototype system provided significant insights for product improvements that were made before manufacturing and shipping the next five systems that were installed on five down-stream beta-demonstration homes.

One of the five beta-test homes was designated to be a zero net energy (ZNE) home[2] as part of this project. In addition to a 4.8 kW P&P PV system, a package of energy-efficiency upgrades was developed for and installed in this home to make it a ZNE home. The home also received GE-donated Demand-Response, or DR-capable appliances; these DR appliances could be managed and DR-controlled through the Nucleus, a home energy management system (HEM) designed to be capable of communicating with, and receiving DR signals from the AMI meter. In addition to the efficiency, DR, HEM, and PV, the home was also fitted with an intelligent, dispatchable energy storage system that can manage batteries to charge during mid-day periods of electricity over-production from the PVs, and store and deploy the stored energy to provide electricity when needed to reduce peak loads, as well as other times, including nighttime loads and solar intermittency ride-through.

This project was successful in demonstrating that the P&P PV Kit can be installed on the roof by roofers without extensive training and without special tools, eliminating the need for electricians or special contractors for roof-top installations of PV systems. Whether installed as part of a re-roof or as a retrofit to an existing roof, the roofer does the installation of the P&P PV Kit, eliminating any roof-warranty issues which occur with other PV systems that are installed by electricians or specialty contractors.

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[2] A zero net-energy or ZNE home is designed to be efficient so as to need less energy than typical homes, and to have on-site renewable generation (PVs) that can produce as much energy as the home uses, on a net-annual basis.

The project also found that the DC-AC microinverter system both simplifies installation and enhances solar conversion performance. Further, the project showed that the 240Vac system simplifies connection to the meter, and therefore the interconnection with the utility. The Enphase Envoy microinverter system also provides near real-time energy use, solar generation information, and on-going system diagnostics to the consumer, and to the installer if desired. The test installations demonstrated a significant reduction in retrofit PV installed costs. The team determined that P&P PV Kits can be marketed and sold at an installed cost of less than $4.00/W (beating the $4.25/W target). In addition, the project identified market interest and innovative financing programs and integrated these in an innovative business model that shows the opportunity to open an entirely new product sales channel through roofing contractors. If implemented by the roofing industry, this project identifies and quantifies this new, low-cost PV product, installable by roofers that can be a new product line and service upgrade for roofers, including coordination with retrofit efficiency contractors for development of ZNE homes. The inclusion of DR capability and intelligent battery-storage in the ZNE package can schedule electricity storage and deployment to reduce peak loads and also reduce or eliminate demand-curve troughs representing large amounts of off-peak energy generation feeding back into the grid when not really needed. Thus the ZNE package can benefit the consumer and the utility with reduced energy demand and consumption with low, relatively flat demand profiles.

The major project deliverables included:

- Best practices training program and materials for P&P PV installation by roofers and electrical connection by electricians
- Six test homes for the P&P PV install - one as a prototype and five as beta-test installations
    - Installation, monitoring & evaluation of the prototype installation
    - Updates to installation protocol and P&P PV Kit after prototype install
    - Installation, monitoring and performance evaluation of the 5 beta-test installations
- Determination of installed cost, based on manufacturing and installation costs
- Analysis of the retrofit PV market & financing options
- Development of an Innovative business model including a new market channel for Grid-Ready P&P PV Kit products
- Retrofit of one test home to be ZNE by adding energy efficiency, DR-appliances, HEM, intelligent storage, and PVs
    - Monitoring & evaluation of the ZNE test home

# 1. Introduction

California has long been a leader in reducing the energy used in its buildings, primarily new buildings and renovations. As a result, the per-capita energy use in California is approximately half that of the rest of the US.[3] The California Solar Initiative (CSI) Research, Development, Demonstration and Deployment Program (RD&D) was established to help achieve the CSI's goal of installing 3,000 MW of distributed solar by 2016. In 2008, a diverse group of efficiency stakeholders, led by California Public Utilities staff, developed a Long-Term Energy-Efficiency Strategic Plan with aggressive goals to substantially reduce the non-renewable energy use in California's buildings, both new and retrofit. Among the goal results are a 40% reduction in energy use in the existing home market sector by 2020. These aggressive goals will require low-cost, simple to install and use, on-site renewable energy generating systems. Such a product has been developed to the beta-test stage, and such beta-testing has been the focus of a project funded by the California Solar Initiative and, independently the New York State Energy Research and Development Authority (NYSERDA).

This document provides detailed information regarding this new entry in the photovoltaic (PV) residential-retrofit market, referred herein as: ***Grid-Ready Plug-and-Play PV Kit*** (or, simply: Plug-and-Play PV Kit).[4] The information contained in this report derives from the findings and results from the CSI-funded project "Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy Efficiency Retrofits," proposed and managed by BIRAenergy, performed with partners GE and SDG&E. The Plug-and-Play PV Kit was conceived and developed by GE in their Global Systems group and carries the current pre-product name of "Smart-Grid Ready Plug-and-Play Solar PV Re-Roof system." It is currently a pre-product, in early field trials and is delivered to solar installers as a complete, ready to install kit. The PV system can be installed on a typical residential roof in less than a half-day by a roofer (two or three individuals). An electrician is needed to complete the installation; but, following results from this project does not need to go onto the roof. As of this report, the role of the electrician is limited to making the electrical connection at a junction-box on the underside of the roof, between the pig-tail (unterminated end) of the PV system electrical harness and the electrical panel.

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[3] U.S. Energy Information Administration

[4] The name "Grid-Ready Plug-and-Play PV Kit" is an invention of this project and is meant to be descriptive of this type of PV product. It is not a brand name, nor, to the best of the authors' knowledge a name specific to any commercial product.

Some of the tasks from this project are applicable and important to California's renewable energy and efficiency goals beyond the main element of this RD&D project, the P&P PV Kit; therefore, stand-alone, detailed reports of those tasks and their results were developed. Those individual reports accompany this report and are summarized herein. The full, detailed reports for those tasks are not included in this report, rather, only their summaries and conclusions are in this comprehensive project report. The table below provides the name and description of each task and in what document the detailed results can be found. This report is the "Low-Cost Solar PV Project Final Report." All the reports developed in this project are listed in the right-most column of Table 1 below, including this main project report. Other project reports with different names, and in italics, are the separate detailed reports.

**Table 1: Task names, descriptions, and major deliverables for CSI project:**
Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy Efficiency Retrofits. The main project report is called "Low-Cost Solar PV Project Final Report" and the six additional detailed stand-alone reports are listed and shown in italics.

| Task | Task Final Deliverables | Deliverable Report, or Report Containing Deliverable |
|---|---|---|
| Task 1 - Electrical Installation Best Practices | Descriptions of Electrical and Mechanical components | Low-Cost Solar PV Project Final Report |
| Task 2 - Demonstration Home Selection and Retrofit | Final gaps analysis<br>Installation summary report | Low-Cost Solar PV Project Final Report |
| Task 3 - Field Testing, Monitoring and Evaluation | Final installation kit[5]<br>Final Best Practices Guide | Low-Cost Solar PV Project Final Report<br>*Best Practices Training Program* |
| Task 4 - Installed System Cost Rollup | Final Installed Cost Estimate: GE Smart-Grid Ready Plug-and-Play Solar PV Retrofit System | *Detailed Cost Analysis Report* |
| Task 5 - Marketing Materials and Market Surveys | Market analysis, Marketing materials, and Identification of target markets | *Business Model Report* |
| Task 6 - Financing | Report on financing issues and financing packages | *Financing Options Report* |
| Task 7 - Contractor Test Installations | Documentation of Test Installations and Energy performance results (for PV systems) | Low-Cost Solar PV Project Final Report |
| Task 8 - Zero Energy Home | Zero energy home performance results | *CSI ZNE Design, Development & Implementation* |
| Task 9 - Data Aggregation | Plan for aggregating, examining and extrapolating generation and load data | *CSI ZNE Design, Development & Implementation* |
| Task 10 - Energy Use Impacts | Report on energy use impacts | *CSI ZNE Design, Development &Implementation* |
| Task 11 - Business Model | Documented business models | *Business Model Report* |
| Task 12 - Program Management and Reporting | Final reports | Low-Cost Solar PV Project Final Report and 6 additional detailed stand-alone reports, listed in this column, above |

[5] Combines installation materials and Best Practices Guide

# 2. Project Objectives and Approach

1. This project had five major objectives, as identified below. The project findings and results pertaining to the first objective are described in detail in Section 7. The other four objectives and findings deemed to merit a stand-alone, comprehensive report. For those objectives, Section 7 of this report contains a brief summary from the stand-along report. All of the project products, including these stand-alone reports can be found on both the BIRAenergy and CSI websites. On the BIRAenergy site (www.biraenergy.com), they will be posted under Projects/CSI Low-Cost Solar. Evaluation of Low-Cost Solar Product (Grid-Ready Plug-and-Play PV Kit) System Components, Installation Processes relating to Trades required for installation, and Generation Performance. This objective relates to the skill, training and trades required to install these systems, and how those characteristics affect the product going to market, as well as the systems' cost performance/positioning in the market. Key to overall product performance, and market positioning and acceptance relates to the system performance.
2. Analysis and Prediction of Grid-Ready Plug-and-Play PV Kit Installed Costs as a Marketed Product.
3. Review and Identify Innovative Financing Approaches for Installation of PV along with Efficiency Upgrades.
4. Develop an Innovative Business Model Appropriate to Grid-Ready Plug-and-Play PV Kit that could increase the rate of market absorption of rooftop PVs, especially in the retrofit market.
5. Demonstrate Effectiveness of Grid-Ready Plug-and-Play PV Kit in a ZNE Home and evaluate the integration of EE, DR, HEMs, Storage, and PV in the ZNE home.

The project was divided into twelve tasks, with multiple tasks designed to meet the five key objectives listed above. The actual tasks are briefly described in Table 1 above. The overall project approach was to install the P&P PV Kit on homes in different climates and on different house-styles to evaluate and improve the proto-product; to demonstrate this new PV product concept, and based on this experience develop a new business model that could increase the market penetration of rooftop PVs, particularly in the retrofit market. The evaluations included installation procedures and processes, training approaches, materials and processes, electricity generation, and integration with other energy and/or power saving retrofits in a ZNE home. Research results from all aspects of the installations, combined with market research, reviews and assessments of financing programs and related issues, formed the basis from which an innovative business model for the Grid-Ready Plug-and-Play PV Kit was developed.

The project was performed within budget, but with a one-year no cost time extension. The time extension was needed to collect a year of data from the test homes because it took longer than anticipated to (1) get all the test home arrangements made, (2) have the prototype kit ready to install, (3) develop a training facility at local community college (this took so long it was abandoned for the alternative strategy of training the roofers on the actual homes), (4) problems encountered with the initial choice of homes for the ZNE home, and (5) acquiring all the components desired for the ZNE home (EE, DR, HEM, Storage, and PVs), and getting them all installed and working. Even with the extra year for the project, it was possible to collect only a few months of data from the ZNE home. The team is attempting to procure funding to provide the ZNE homeowners with thorough training on all the new informational and controlling devices in their home, achieve as high a level of component integration as possible, and collect data for an additional year from this home. The homeowners are amenable to, and encouraging regarding their participation in an extension of this work for another year.

# 3. Project Outcomes

As noted in the last section, this project had five major objectives.  The major outcomes from the project are organized according to the major project objectives provided in the previous section. Thus there are five subsections. Each subsection covering the results/outcomes relating to that project objective.

## 3.1. Evaluation of Low-Cost Solar P&P PV Kit

The Plug-and-Play PV Kit was evaluated in terms of its system components, installation processes relating to trades required for installation, and the system's generation performance. This objective relates to the skill, training and trades required to install these systems, and how those characteristics affect the product going to market, as well as the systems' cost performance/positioning in the market.  Key to overall product performance, and market positioning and acceptance relates to the system performance.

The Grid-Ready Plug-and-Play PV Kit has several distinctive properties making it less expensive and potentially able to deliver more energy than similar size PV systems, and a PV system design that has the potential to open a new market channel for marketing PV systems to the residential retrofit market.

The Plug-and-Play PV Kit has the following key attributes:

1. The overall system, including the individual panel assemblies, is designed to deliver AC power from each module, rather than the conventional DC. This is accomplished by integrating a microinverter into each solar panel (the underside of a panel with microinverter and wiring connections are shown in Figure 7).  The system, being AC rather than the typical, high-voltage DC allows roof-top installation by a qualified roofer, without the need of a professional electrician on the roof.  A system using these design concepts, provided by GE as a partner in this research project, is described in this report as an example of this approach.
2. The system is designed to be delivered as a simple-to-install kit, including all components that go on the roof included in the kit (kit is illustrated in Figure 4, and an exploded diagram of the system is provided in Figure 5).  Note that the electrician does need to supply and install conduit and wire from the Junction box (J-box) on the underside of the roof (directly underneath the J-box on the roof connected to the PV array) to the electrical panel.
3. The system is designed to be simple and fast to install. In addition, the rooftop installation can be done entirely by a professional roofer without support of an electrician

on the roof. This can significantly reduce installation cost, compared to installation costs of DC systems. (Roofer and Electrician installation Best Practices guides are in Section 6). At the onset of this project, GE estimated their installed costs for the system to be between $4.25 -$4.00/watt for Single Family residential retrofit, compared to current market costs in the range of $6.50/watt. This cost target was achieved (see Section 3.2).

4. The best systems are simple to assemble (both in manufacture and on roof) with relatively few parts, keeping costs down both in manufacture and installation, as demonstrated by the example system provided by GE .
5. The use of microinverters in each panel assembly and the associated AC interconnections reduces system losses from partial shading (a string of DC panels is affected by shading of a single panel in the string). Existing home roofs, compared to new construction, have a higher likelihood of significant roof-shading due to obstructions such as plumbing vents, chimneys, etc., and to mature trees. Given the likelihood of partial shading in existing home, the AC system, will produce more electricity over time than a similar size DC system.
6. Given roofer is main installer, upgrades for solar can be sold as a component of home re-roof, producing a new business model (see section 3.4).

### System Components: Mounting System

Figure 1 shows a mounting system typical of current residential rooftop PV systems. Each module is supported by two rails that attach to the frame. The rails are attached to the roof using brackets or stanchions that are lagged into the trusses or rafters. Because residential roof mounting systems have to address a wide variety of module/frame configurations and custom system designs, they tend to have many component parts. For a typical 5kW system consisting of two rows of 10-12 modules each, the mounting system will have over 700 individual component parts and require an installation time of 2 to 3 days. The same size PV system (5kW) using the innovative P&P PV Kit mounting system requires no more than 32 parts for the brackets, stanchions and other mounting hardware. This reduction in components results in lower manufacturing costs, simpler assembly and system installations, and fewer roof penetrations.

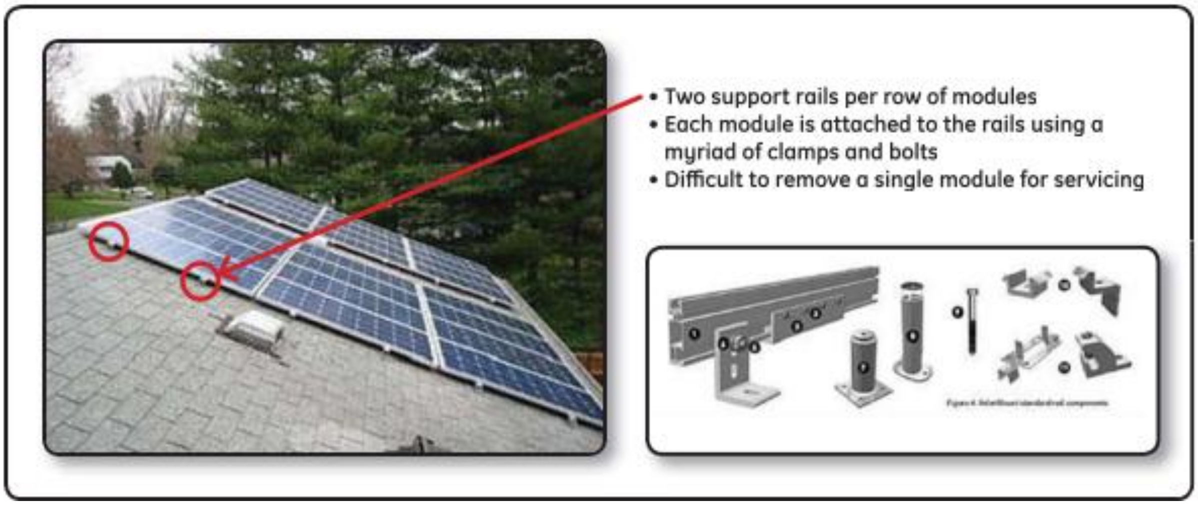



**Figure 1: Complex installation practices typical of current residential solar installations**

Both the CSI and NYSERDA have supported field tests and evaluations of this *Grid-Ready Plug-and-Play PV Kit*, in projects called "Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy Efficiency Retrofits" and "Smart Grid Ready Residential Solar Electric System," respectively. In the CSI projects, research partner GE has provided systems for field installation, testing, and evaluation. These projects have demonstrated that this new PV system-architecture addresses both the installation-related barriers to low-cost and high-solar electric penetration, and provides the potential for integration with in-home and utility demand response (DR) resources. A key advantage offered by the P&P PV Kit is that the rooftop installation can be performed by the roofing contractor trades, with an electrician needed only to run the electrical cable between the underside of the roof and the electrical panel, and to make these connections. This has the specific advantage that there is no need for the electricians to be on the roof. Thus, the Grid-Ready Plug-and-Play PV Kit provides the potential to greatly reduce labor costs and take advantage of broad contractor networks to tap into the large seven million home retrofit roofing market.

The P&P PV Kit represents the integration of three innovative components (See Figure 2):

1. An ac module which is the combination of a dc photovoltaic module ("solar panel") and dc-ac microinverter.
2. A unique "insert and capture" mounting system design that simplifies the physical installation process for a roofing contractor and provides a "plug-and-play" electrical interface that eliminates the handling of high voltage, and simplifies the automatic electrical power and ground interconnection of modules by standard electrical contractors.
3. A home energy manager (HEM) device that interfaces with residential energy loads and the utility advanced meter infrastructure (AMI smart meter), and provides consumers with a real-time view of home energy usage patterns.

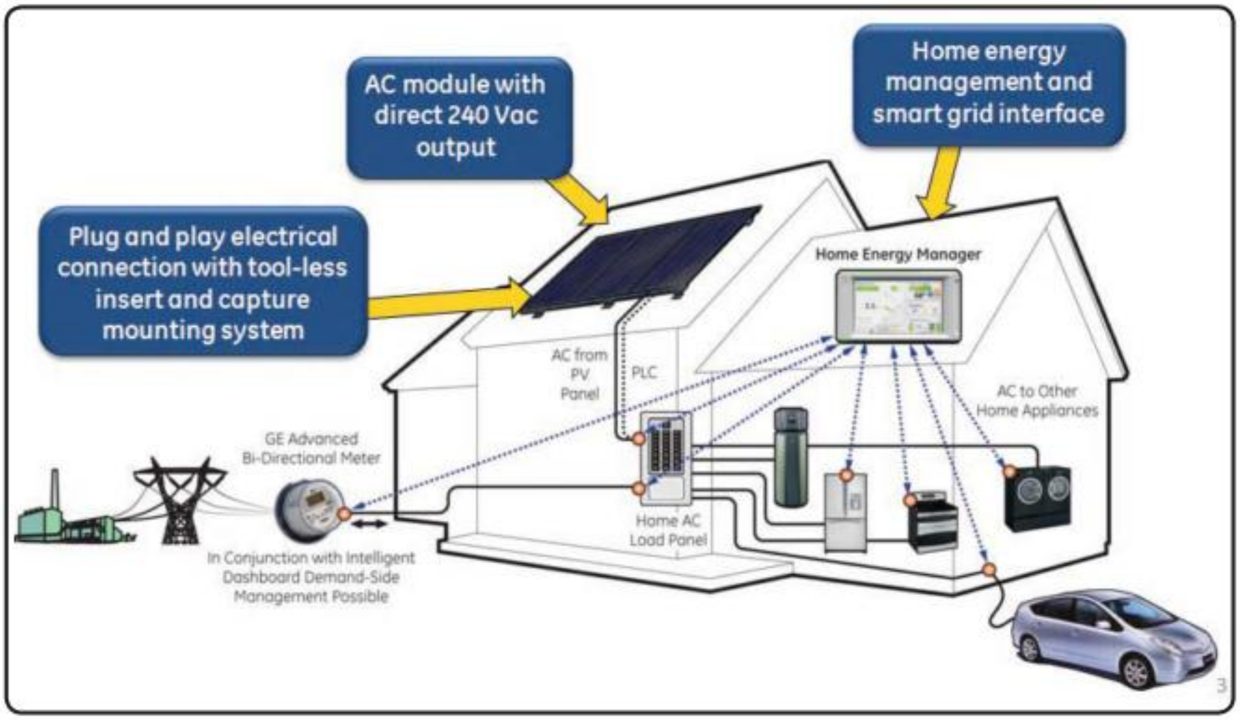



**Figure 2: GE Smart Grid Ready Residential Solar Electric System**

## System Components: Technical and/or market gaps identified in this project

The first California installation of this Grid-Ready Plug-and-Play PV Kit was on a residence in Chula Vista, CA; the system was undergoing a simultaneous evaluation by NYSERDA in NY. This initial installation was part of a Showcase Home, demonstrating solar and efficiency retrofits. This first installation was planned and done singly to provide an opportunity to identify, evaluate, and mitigate any design, permitting, and/or installation issues unique to California. The resulting gaps analysis is based in part on observations made by the roofing and electrical contractors who performed the installation of the GE insert and capture solar electric system for the first time at Chula Vista. Several of these observations have resulted in suggestions for modification or improvement to the beta product and/or installation processes.

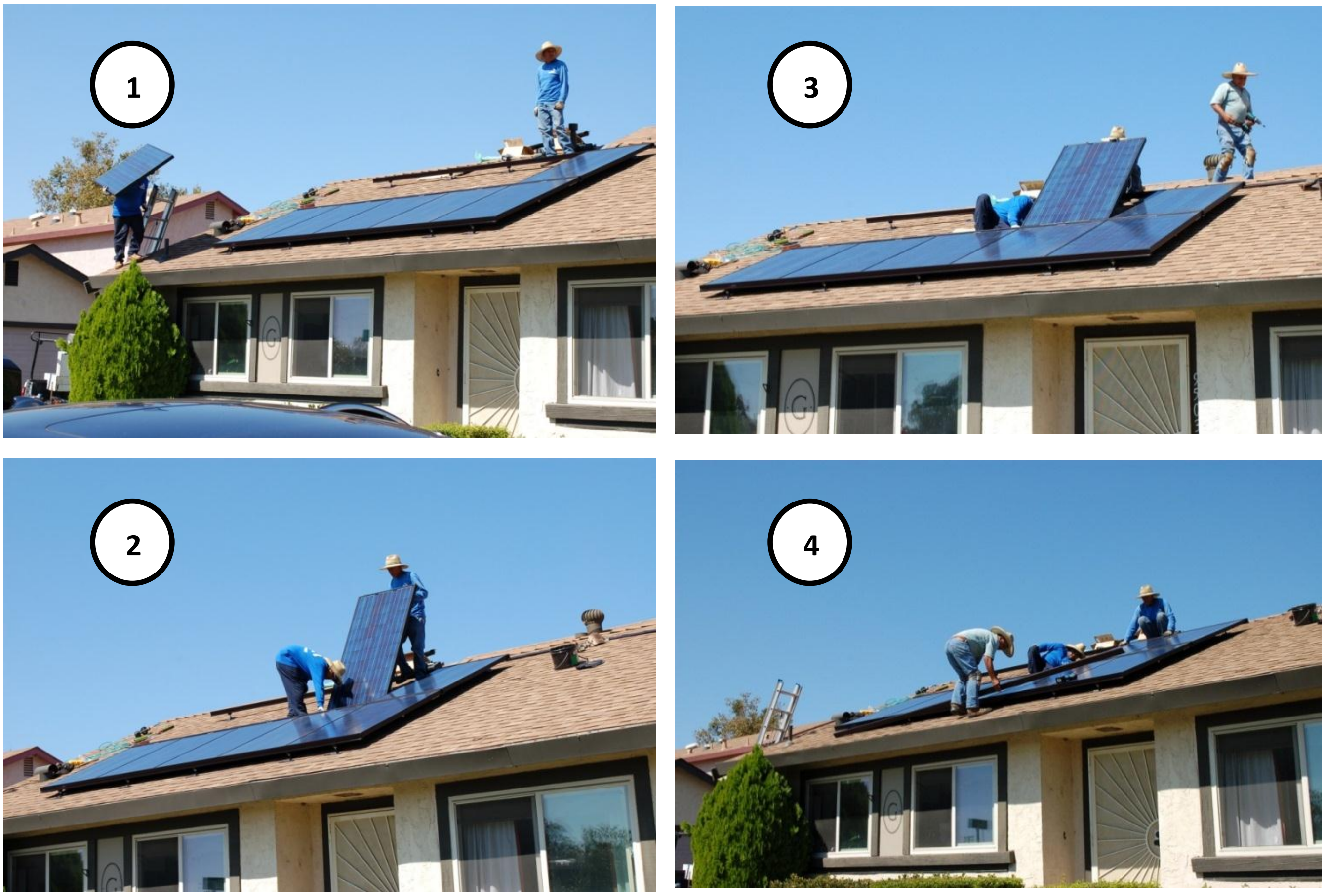



**Figure 3: Panel insert-&-capture installation. Step 1, bring panel onto roof (40 lbs.), 2) insert panel into bottom rail, 3) connect to electrical harness, 4) capture panel with top rail.**

The seven issues identified/raised during the Chula Vista installation are provided below, in each case followed by our team's responses, written primarily by GE (in blue).

1. The roofers suggested the flashing be made wider/more square in order to provide better coverage down the roof. Their concern is that there is not enough area under the cut-in shingles to secure the flashing. Their solution is to nail the flashing down and use a PVC sealant underneath. GE did not have any issues with the current flashing in NY installations. The flashing is not nailed down; as a best practice, a butyl two-sided pad is recommended to provide additional adhesion to the roof and a tight seal in the present of heavy rain and wind. Even without the sheet early GE installations have achieved a high degree of water resistance using the integrated flashing; in addition, most of the stanchions and their flashing are covered by the array so not exposed. The size of the flashing could also be increased, but to-date there is no evidence that this is warranted. A stronger voice of customer would be required to make this change. GE is likely going to reduce the thickness of the aluminum flashing to match other roof flashing products so increasing the overall size would probably not increase the cost. And there may even be some materials that could be lower cost than the current aluminum.

2. There was interest in having additional z-axis adjustment of the rail mounting clips in order to accommodate "wavy" roofs. Further discussion indicated that having a 2-in adjustment range across a rail would be adequate.
   The current stanchion design the threaded post to which the rail clip is affixed already provides an end to end adjustment of slightly greater than 2-inches which should be enough. To date there has not been any need for more than a half-inch adjustment.

3. There was interest in a flashing gasket that is taller to reduce the possibility of leaks.
   The present gasket has a reasonably tight fit over the threaded post and has not shown any deficiencies to date relative to leakage. The gasket region is also not directly exposed to the rain/snow since it is covered by the array but water could be blown up from the underside. GE is researching alternative gaskets. The goal has been to use an off-the-shelf gasket that also has an outdoor environmental rating (in this case PVC).

4. There was discussion regarding a locking nut that would lock the rail clip in place so it would not back down.
   This is an extra part adding to the expense and unnecessary. While the clip is designed to be screwed onto the post and move up and down freely to facilitate adjustment, once the rails and modules are mounted the rail clip can no longer be easily moved.

5. Wire management was identified as a concern. The integrated ac harness needs to be tied up to the rail to keep it from sagging onto the roof. GE is currently using plastic wire clips. A metal wire clip might provide better performance and life. One suggestion was to build in a wire channel into the rail.
   Based on experience to-date, GE recognizes the need to improve the wire management system of their plug-and-play system. A current constraint is the need to use the Enphase Engage AC harness which is ill-suited to integration with the GE insert and capture rail. GE's product roadmap includes a task to redesign the wire management system around a smaller ac connector that is easier to integrate into the rail design.

6. Suggestion that fewer screws be required to secure the module retaining cap.
   Mechanical testing to-date performed by GE has required the 5 screws to provide adequate wind loading margin. Alternatively, a larger screw and a different threaded channel design in the rail could be tested. GE's biggest concern with the design is reattachment once the screws have been removed to repair a module, should one have any problems. So far GE has not experienced any problems but the concern is with stripping the threaded channel.

7. GE's unique method of grounding needs to be approved by inspectors. The inspectors in CA have required that a separate grounding circuit (like in a central string inverter dc system) be added to our installations increasing cost (~ $80.00 for materials) and time up to 2 man-hours). The method of grounding will need to be incorporated clearly in the electrical code. An essential first step will be the full-system certification of the ac module system including grounding through the ac harness.

## System Components: System description (Solar Kit)

Key aspects of the *Grid-Ready Plug-and-Play PV Kit* concept include the use of standardized panel sizes, ac microinverters associated with each panel, and simplified mounting systems, to allow installation and commissioning of a typical 2.4 – 4.8 kW roof-top system by a team of two contractors in a single day. The following sections and figures give details on the example system, provided by GE.

### Panels and Mounting Hardware: Insert and Capture

The insert and capture mounting system has been designed for installation of the solar-panel assembly onto a steep-slope roof. Figure 4 shows all of the components of the Plug-and-Play kit. The basic system building block is a rail mounted 5-module array (1.2 kW for a 235Wdc PV module). The two 16-ft. rails are supported by stanchions that are directly mounted to the rafters and flashed into the roofing system to make them watertight. Also shown are a switch/connector box that provides a flashed, water-proof wire-penetration through the roof (item 8 of Figure 4), and the capability to electrically disconnect the system while on the roof.

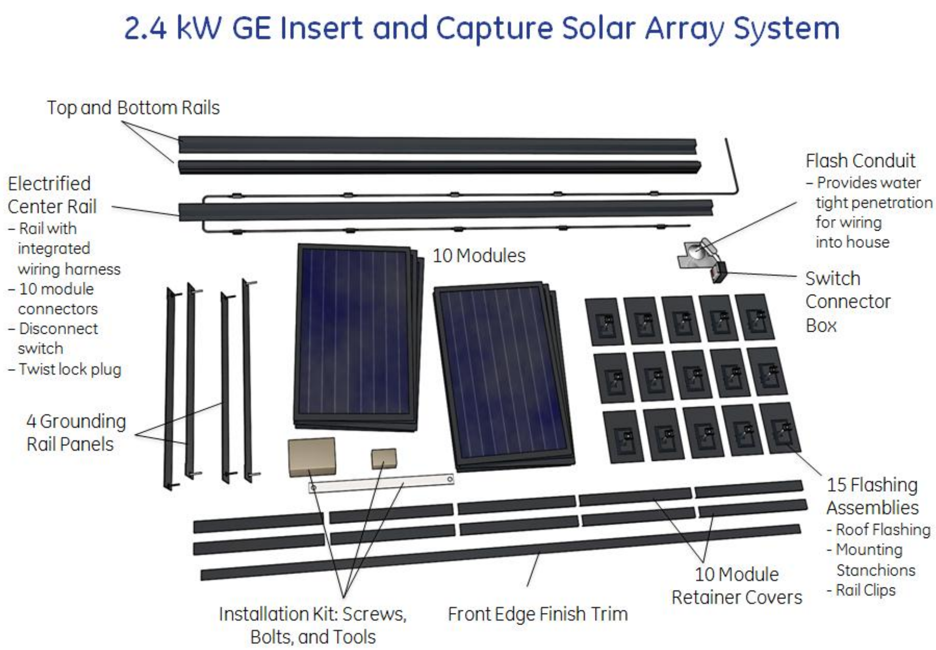



**Figure 4: Illustration of the components of the Plug-and-Play VP Kit, illustrated here by the GE insert and capture 16-ft rail system.**

This 5-module building block can be used to build arrays of different sizes. The addition of a third rail supports a 2nd row of modules giving rise to a 2.4 kW array, and the splicing of multiple 16-ft rails allows the system to grow to 4.8 kW and beyond. The particular approach employed by GE also allows for the splicing of rails to build larger systems.

Figure 5 shows an exploded view of the system with each individual component labeled.

1. PV Module
2. Insert and capture rail

3. Flashed mounting assembly
4. Grounding side panel
5. Top retaining cover
6. Front array panel
7. Plug-and-play wiring harness
8. Switch/Connection box and flashed penetration

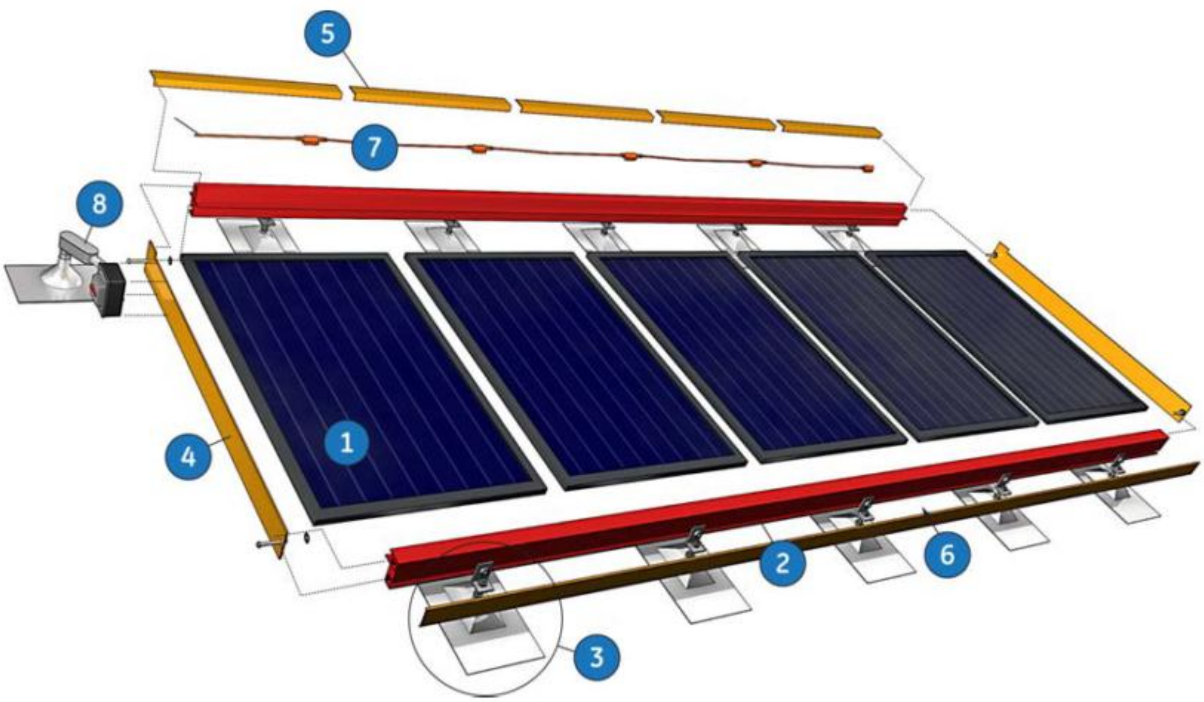



**Figure 5: Exploded view of the insert and capture/plug-and-play mounting system.**

**Figure 6** shows a detailed view of the flashed mounting assembly (item 3 in **Figure 5**, above) as it is installed onto a composite shingle roof. The flashed mounting assembly consisting of the mounting stanchion (2a), flashing (2b), and mounting clip (2c) addresses a major concern with many traditional solar installations—physical penetration of roofing shingles. GAF, the largest U.S. vendor of composite shingle roofing materials contends that a complete penetration and compression of the shingle stack voids roofing warranties and that shingle repair methods (e.g., the use of butyl tape or silicon filler), will not provide reliable long-term prevention of leaks. This should be a concern to any owner of a residential solar electric system that is warranted for 20+ years. The stanchion/flashing system designed by GE allows either coordinated installation with a reroofing operation or installation onto an existing roof using familiar roofing installation processes and tools. The overall process ensures a 25-year leak-tight seal around each stanchion consistent with the roofing warranty. It should be noted that after the flashing is installed, the roof is sealed and the balance of the solar system installation can be completed anytime thereafter.


**Figure 6: Flashed mounting assembly**

## System Components: Plug-and Play-Approach

The plug-and-play aspect of the GE system is based on an AC interconnection harness that is integrated with the insert and capture rail. The interconnection harness is incorporated into the GE system. The Engage interconnection harness is provided by Enphase, and is designed to interface with their M215 microinverter. Each harness consists of four, AWG12 copper conductors in a UV-resistant sheath. The Engage harness is integrated with the center rail harness to provide an AC outlet roughly centered at each ac module position on each side of the rail. This allows both rows of AC modules to be readily plugged in as they are installed. **Figure 7** shows a mock-up bottom view of the module assembly, highlighting attachment aspects, including the system grounding approach.

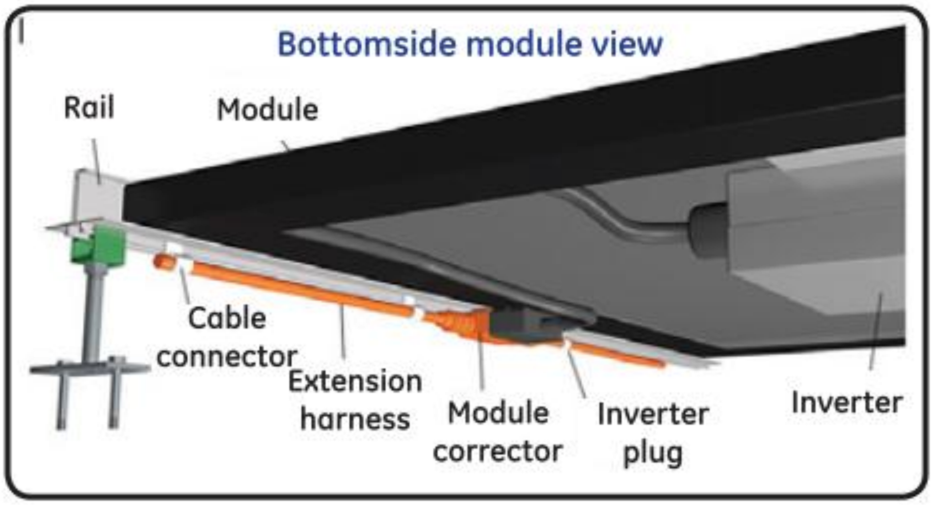



**Figure 7: Bottom view of insert and capture/plug-and-play solar electric assembly**

## System Components: AC Module

The ac module is integral to a simple-to-install plug-and-play system and provides additional system advantages. Figure 8 provides a side-by-side comparison of a traditional solar electric system, which is characterized by a series-connected string of DC photovoltaic (PV) modules, and a central string DC to AC inverter. The DC voltage can be as high as 600 V, limited by UL and the National Electric Code (NEC). The NEC has strict requirements for the safe installation of a high-voltage DC PV system. Compliance with the high-voltage requirements can impact installation cost. In particular, the need for an electrician on the roof to handle all high-voltage source wiring and system grounding connections. For example, all wiring is required to be enclosed in a metal conduit and a separate ground circuit is required to ensure that exposed metal components such as frames and mounting rails are maintained at earth potential.

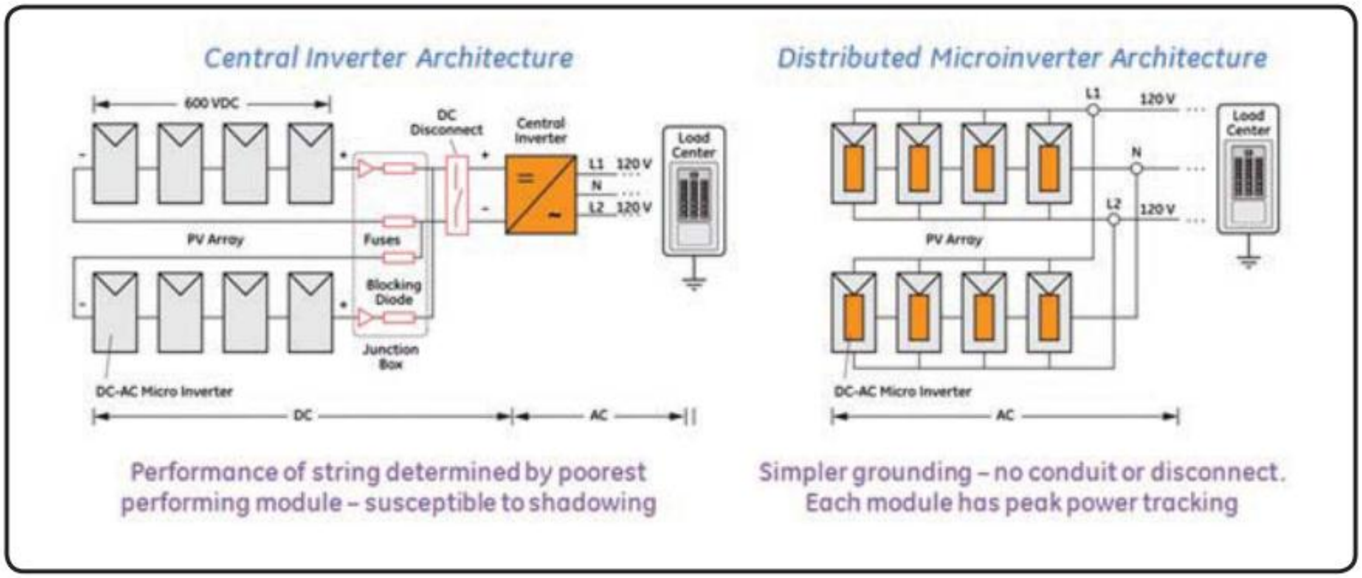



**Figure 8: Comparison of central string and microinverter system architectures**

Even when all of the rules for safe installation are followed, there is still the potential for a system fault which gives rise to a high-voltage DC arc. Several catastrophic building fires reported over the past several years have been attributed to a high-voltage arc caused by a PV system failure, most notably the total destruction of a Target store in CA in 2010. For this reason, as well as a general concern regarding exposure to high voltage, the National Firefighter Protection Association (NFPA) has its own requirements regarding roof access which are accepted in most states, and has a key role in determining future NEC code changes for PV systems.

The more-traditional high-voltage system also has implications for the system installers. Up to 75% of a standard, dc-PV installation training course syllabus is related to configuration of a high-voltage system. A dc-PV module’s electrical characteristics are highly temperature and irradiance dependent and worst case extremes have to be accounted for when designing a system. Selecting a compatible string inverter requires a series of calculations. Design and installation of such a high-voltage system is outside the capabilities of many contractors, and has resulted in a class of North American Board of Certified Energy Practitioners (NABCEP) that command higher installation rates.

A high-voltage series string configuration can also limit system performance. One characteristic of series-connected DC current sources is source limitation of the series current. In other words, the output current (and power) of the series array is determined by the poorest performing PV module. In a system of 10 or more PV modules, power mismatch of 1-2% can be expected, so most simulators presume a power correction factor of 0.98. When shading conditions are factored in, the loss in power can be much greater, with the output of all the modules in the string limited to the production of the most shaded, lowest producing panel.

By contrast, within the AC module architecture, the modules are electrically connected in parallel and each integral microinverter performs independent maximum peak power tracking (MPPT), eliminating global array mismatch and shading effects. Thus, the AC module architecture in the P&P Kit is much more shade tolerant than a typical, series-connected DC string. That is, with the AC modules, the only modules affected by shading are those that are actually shaded, unlike the DC series-connected systems, where the production of entire string is affected by any shading. The few published comparative studies have shown that a shaded series string "gives up" more than 10% of its energy entitlement, relative to a parallel AC module string. The impact of shading on AC vs DC systems may become a very important consideration in the choice of solar system types in residential rooftop residential solar systems. A study if these impacts should be considered.

The AC module architecture with individual microinverters also allows direct monitoring of the output of each module. The Enphase system provides web-based tracking of each solar installation (independently) and of each module of each system, as shown in Figure 9.

The microinverter produces a 240 Vac output essentially converting the DC module into a 240 Vac "solar appliance" that can be directly wired into a residential load panel. Section 960 of the NEC considers all the DC source wiring to be integral to the AC module. Therefore, the grounding and wiring requirements normally associated with a high DC-voltage string are avoided, greatly simplifying installation. In theory, the installation of an AC module should be no more difficult than installation of an AC appliance. The microinverter is mounted to the frame in a manner that ensures an electrical bond between the metal case of the microinverter and PV module frame. This is a critical aspect of the Grid-Ready Plug-and-Play PV Kit, and is incorporated into the GE system.


**Figure 9. Example of Enphase monitoring output. The electricity produced by each panel and by the entire array are provided, along with a running record of the previous seven days**

## System Components: Balance of System (BOS): Connections, Wiring, Disconnects, and Inverters

In addition to panels and the roof-top rail-system to support the panels on the roof, A typical DC system requires an inverter for each string of panels, and often disconnects on either or both the DC and AC sides of the inverter. The BOS also can include roof-side wiring, as well as wire in conduit from the junction box on the underside of the roof, to the inverters (and any disconnects), and finally to the electrical panel.

The Grid-Ready Plug-and-Play PV Kit is simpler. First of all, the inverters are integrated into the panels, not separate hardware; second the wiring system is a harness, included in the kit; third, the roof-top junction-box and pass-through, which also now includes an integrated disconnect, are all part of the kit. The only elements not part of the kit are the junction box for the underside of the roof, to make the connection to the wire (in conduit) that terminates in dedicated breakers in the electrical panel. This wire and conduit is provided and installed by an electrician.

## System Components:  Home Energy Manager

The GE version of the *Grid-Ready Plug-and-Play PV Kit* includes a GE home energy manager (HEM) to monitor and profile solar energy generation and home electrical energy usage. The GE Brillion Nucleus™ HEM control architecture conforms to the specification developed by the non-profit U.S. Demand Response Coordinating Committee to "provide electricity customers in both retail and wholesale markets with a choice whereby they can respond to dynamic or time-based prices or other types of incentives by reducing and/or shifting usage, particularly during peak periods, such that these demand modifications can address issues such as pricing reliability, emergency response, and infrastructure planning, operation, and deferral."  The Nucleus system, shown in Error! Reference source not found.**10**, was originally developed by GE's Consumer and Industrial business as a part of a suite of Demand Response appliances and lighting, acts as the central nervous system for monitoring resource usage and controlling energy consumption within the home.


**Figure 10:  GE Brillion Nucleus Home Energy Management System**

The HEM can provide both real time (kW) and long-term (kWh) trend information on power consumption, solar generation (Figure 10). The HEM also supports integration with demand response systems to enable real-time load shedding in networked appliances. The HEM interfaces with any U.S. load panel through current transformers (CTs) that install directly onto the electrical mains and communicates to the Nucleus through a wireless Zigbee module **(Figure 12**). A similar CT meter interface is provided for the solar array. The Nucleus can also directly communicate to smart meters having Zigbee wireless chip sets providing a convenient interface for the utility. In addition GE also offers a programmable multi-zone thermostat that communicates through the HEM to provide instantaneous energy usage (kW) as well as cost of energy ($kW). The capability of temperature offset during critical events potentially provides the utility with a management tool to shed HVAC load during peak load excursions.

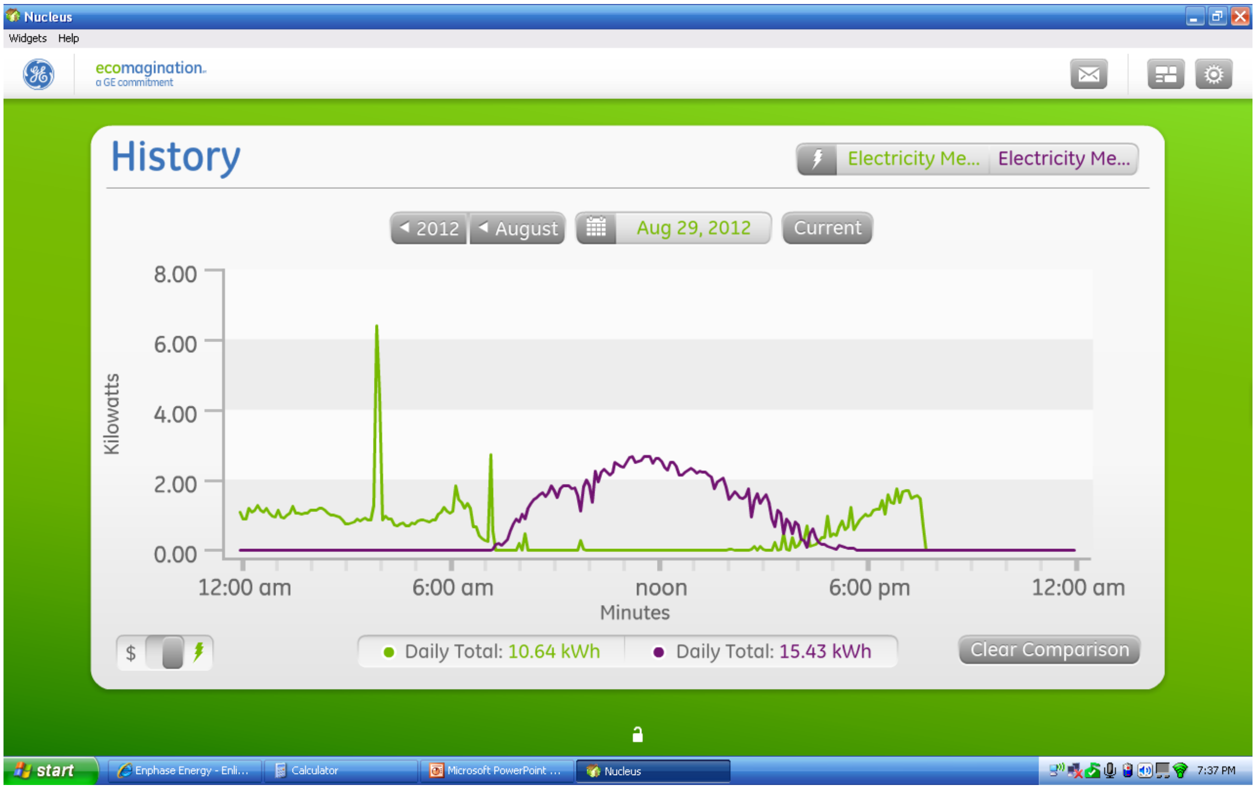



**Figure 11. GE Brillion Nucleus display of electrical residential power consumed and excess generated power delivered back**

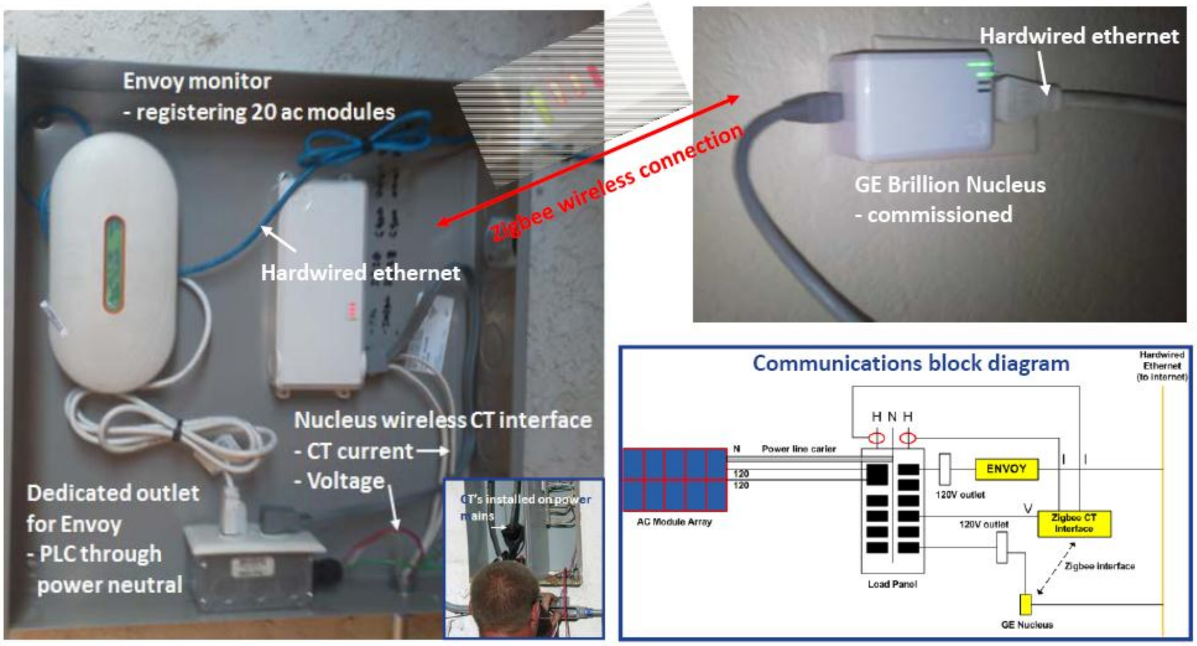



**Figure 12. Configuration of electrical usage and solar generation monitoring hardware.**

## Systems Commissioning

The activation commissioning process for the P&P PV Kit is simple and straightforward using the Envoy communications and control system. The Envoy requires 120V power and was mounted near the electrical panel and powered by a nearby outlet (which in some cases needed to be installed to allow the Envoy to be near the electrical panel). Enphase also supports an on line monitoring tool called Enlighten, which is a no cost option for the M215 microinverter, and is useful in tracking the commissioning process as well as system performance after it is commissioned.

Once the PV system is connected to the electrical panel through a panel breaker, and the breaker is set on, the system is activated, but not yet connected to the grid. Prior to installation of the modules, the serial number for each microinverter was noted. After the PV and Envoy systems are activated, the microinverter serial numbers are entered and the Envoy identifies each microinverter using the serial numbers. It then proceeds through series of functionality and safety checks. The commissioning process takes up to 20 minutes for initiation. All of the activity is reported through the Envoy monitor beginning by the identification of all the microinverters within the array by serial number. The microinverters test the UL-1741 disconnect connect sequence, monitor the grid voltage for over/under voltage conditions and if all is well come on line at the end of the process.

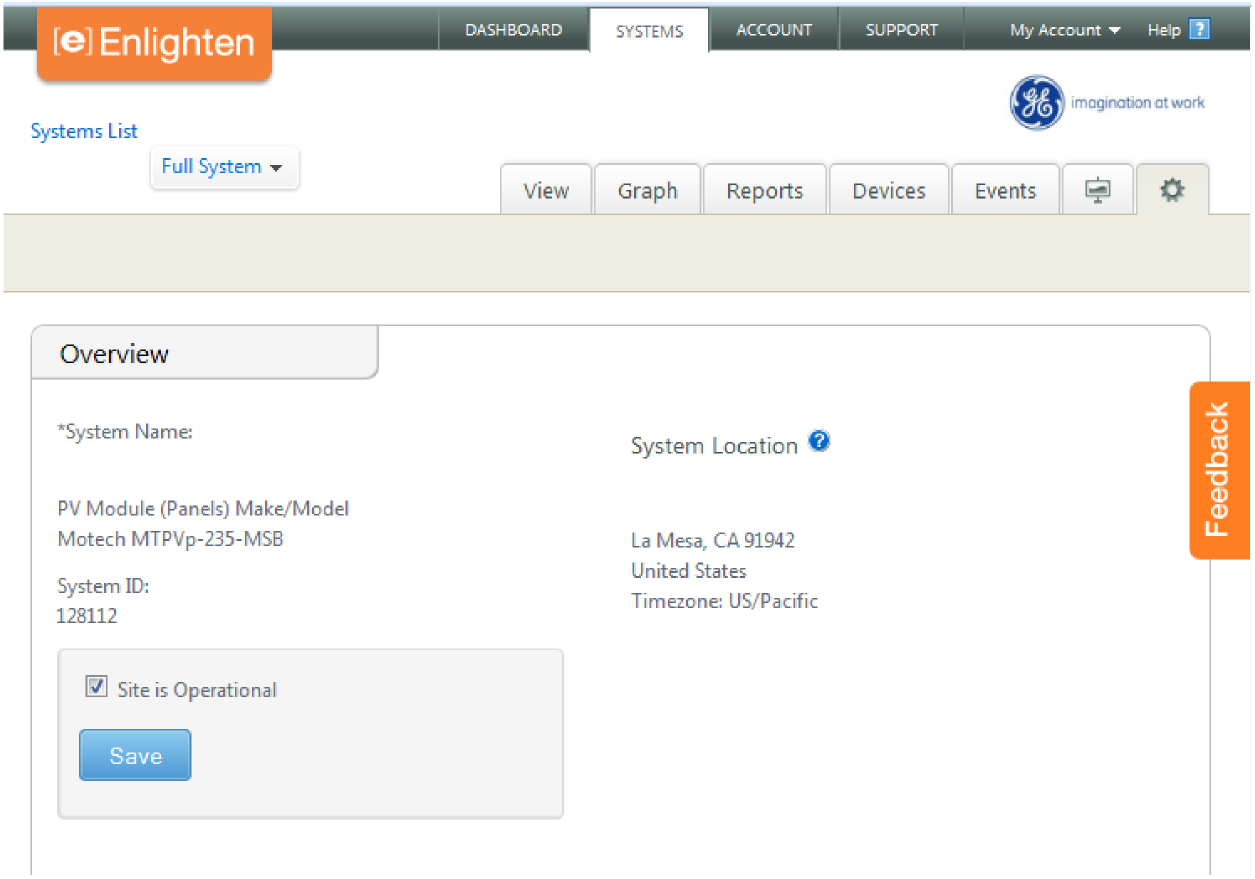
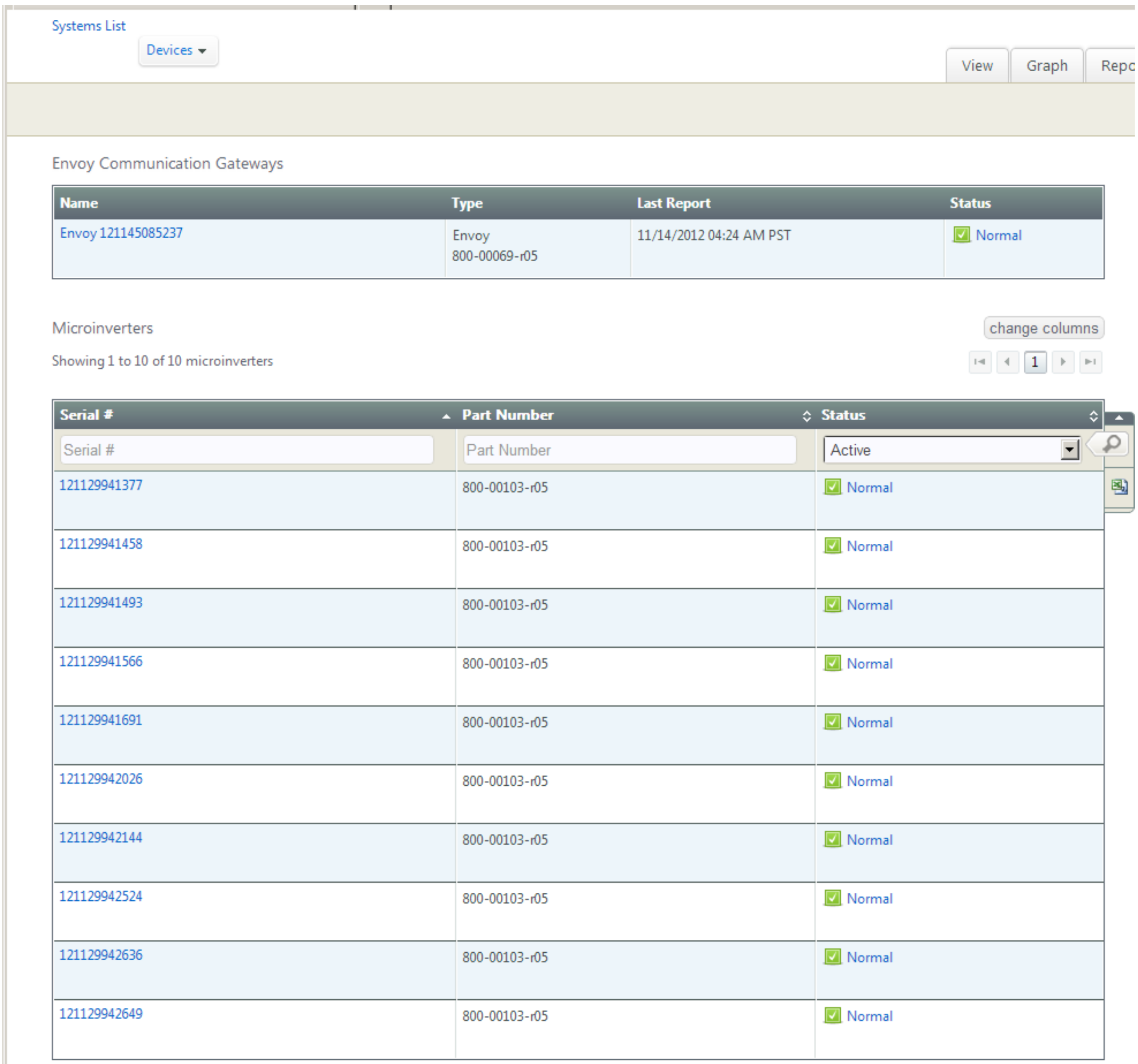



**Figure 13: Example page from the Enphase Enlighten system during commissioning the system installation. The system is identified by the homeowner's name (blocked out in these report examples).**

At the beginning of the process, the Envoy and Enlighten identify the system by the homeowner's name. **Figure 13** is a screen-shot of the Enlighten system at initial startup, simply recognizing the system. Any errors or problems are reported through the Envoy and Enlighten.




| Name | Type | Last Report | Status |
|---|---|---|---|
| Envoy 121145085237 | Envoy 800-00069-r05 | 11/14/2012 04:24 AM PST | Normal |

| Serial # | Part Number | Status |
|---|---|---|
| 121129941377 | 800-00103-r05 | Normal |
| 121129941458 | 800-00103-r05 | Normal |
| 121129941493 | 800-00103-r05 | Normal |
| 121129941566 | 800-00103-r05 | Normal |
| 121129941691 | 800-00103-r05 | Normal |
| 121129942026 | 800-00103-r05 | Normal |
| 121129942144 | 800-00103-r05 | Normal |
| 121129942524 | 800-00103-r05 | Normal |
| 121129942636 | 800-00103-r05 | Normal |
| 121129942649 | 800-00103-r05 | Normal |

**Figure 14: At this stage of Commissioning, the Enlighten system has identified each module and verified that they are all working properly. Notice the right-most column, "Status" is "Normal" for all 10 modules.**

**Figure 14** is another screen-shot of the Enlighten output, taken after successful identification of the microinverters by the Envoy, as reported by Enlighten.

The final step in the commissioning process is for the Envoy to map the location of each microinverter by serial number into its actual and proper location in the module array. Once that step is completed, the Enlighten can provide a graphical representation of the array showing the performance and status of each ac module in real time. Completion of this final step in the automated commissioning process is illustrated in **Figure 15**.

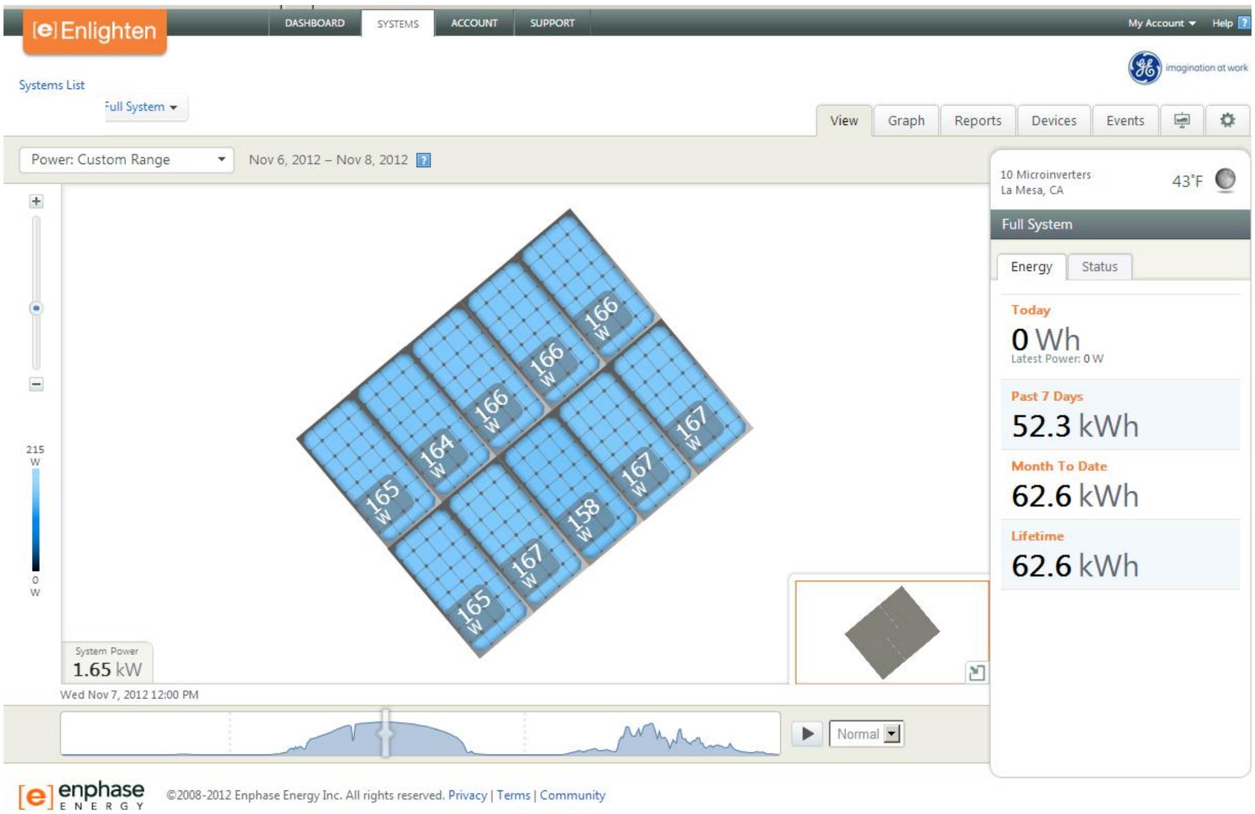



**Figure 15: Enphase Enlighten Dashboard**
All the modules identified and in operation have been verified and their location mapped by Envoy. The Enphase system will now allow the modules to connect to the electrical box. This Enlighten graphic shows the status and output of each module, and system statistics (at the right).

The Best Practice instructs that, following completion of the automated commissioning process has been completed, that the voltage and current be measured and verified at the electrical panel.

## Systems Performance Analysis

For this CSI RD&D project, GE provided six of their kits for evaluation of the *Grid-Ready Plug-and-Play PV Kit* in this project. These six kits were installed onto the roofs of six homes in SDG&E service territory: the first home was a prototype system and installation, being the first system installed in California. As described in Section 5.1.2, improvements were incorporated into the remaining five systems, which were installed as beta-test systems. Both the prototype and beta systems were evaluated , considering the following evaluation issues: the components and assemblies in the kits, the degree of difficulty and trainings needed to complete the installation process, the time required for installation after training, the generation performance over a significant period of time (preferably a year or more), and a detailed cost-estimate for the product, should it go to market, based on the information from this and the NYSERDA projects.

The six kits were installed on rooftops volunteered for this project, one in Chula Vista (the prototype, and Showcase home; see **Figure 16**), two in El Cajon, and one in each of La Mesa, Santee, and Borrego Springs.  The Borrego Springs system was 4.8 kW, twice the size of the other systems, which were 2.4 kW.  The Borrego Springs system was to be the on-site renewable component of a Zero Net-Energy home.  However, there were problems that required changing to a different beta-test home, and the Santee home was chosen and retrofitted with an additional kit, to bring the total PV system size to 4.8 kW.  The home was also retrofitted with substantial energy-efficiency upgrades such that the increase in efficiency reduced the predicted annual energy use requirement to match the predicted annual energy production of the 4.8 kW PV system.  In the original proposal, the designation for a home that produced as much energy as it consumed, on an annual basis, was a "Zero Energy Home."  In 2013, the California Public Utilities Commission and California Energy Commission devised the term Zero Net-Energy, or ZNE home[6]).  The ZNE home and its evaluation are summarized in **Section 3.5** of this report, and detailed in a separate report, entitled "**Zero Net Energy Home – Design, Development and Implementation.**

The energy production of all of the six PV systems was monitored as part of this project.  This section reviews data from all six systems.

**Figure 16. Chula Vista system installed on the Showcase Home, on a new roof (re-roof retrofit).**

**Figure 17** is chart tracking generation performance for a 2.4kW system in Santee, CA. The electricity generated is plotted as dots.  A computer simulation of each installation was performed using the National Renewable Energy Lab (NREL) PVWatts software.  The simulation data is represented by the boxes on the curves, where the heights of the boxes represent the uncertainties in the simulations. This uncertainty is based on such factors as soiling and variability in weather. The size of the measured dots represent 12 kW-hr accuracy in the measured energy. Note that the measured data tracks the simulations reasonably well. Actual irradiance data were not available for each site, so direct comparisons between irradiance and output are not available.  Tracking started in October of 2012 and continued into 2013, but the chart does not include a full year of data.  Evaluation of the project test data near the end of the project determined that the systems hit the performance targets for the levelized cost of energy

[6] A ZNE home produces as much energy from its rooftop PV system as it consumes, on an annual basis.  In this document, the energy is calculated as source energy.

(LCOE). This is discussed in detail in a separate project report, titled Detailed Cost Analysis: GE Smart-Grid Ready Insert and Capture Solar PV, which is summarized in Section 3.2 of this report.

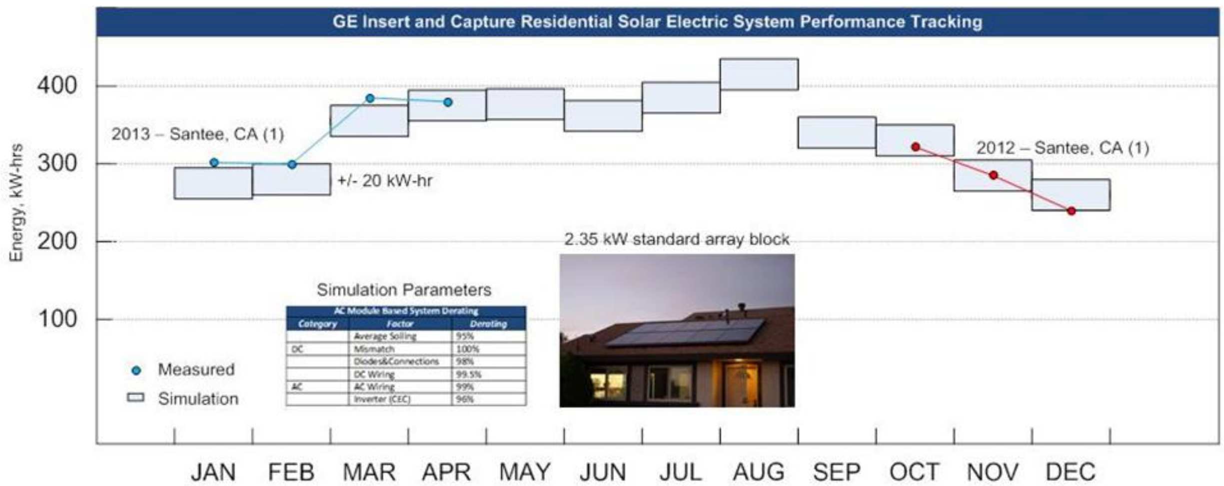



**Figure 17. Performance tracking chart for a 2.4kW system in Santee, CA**

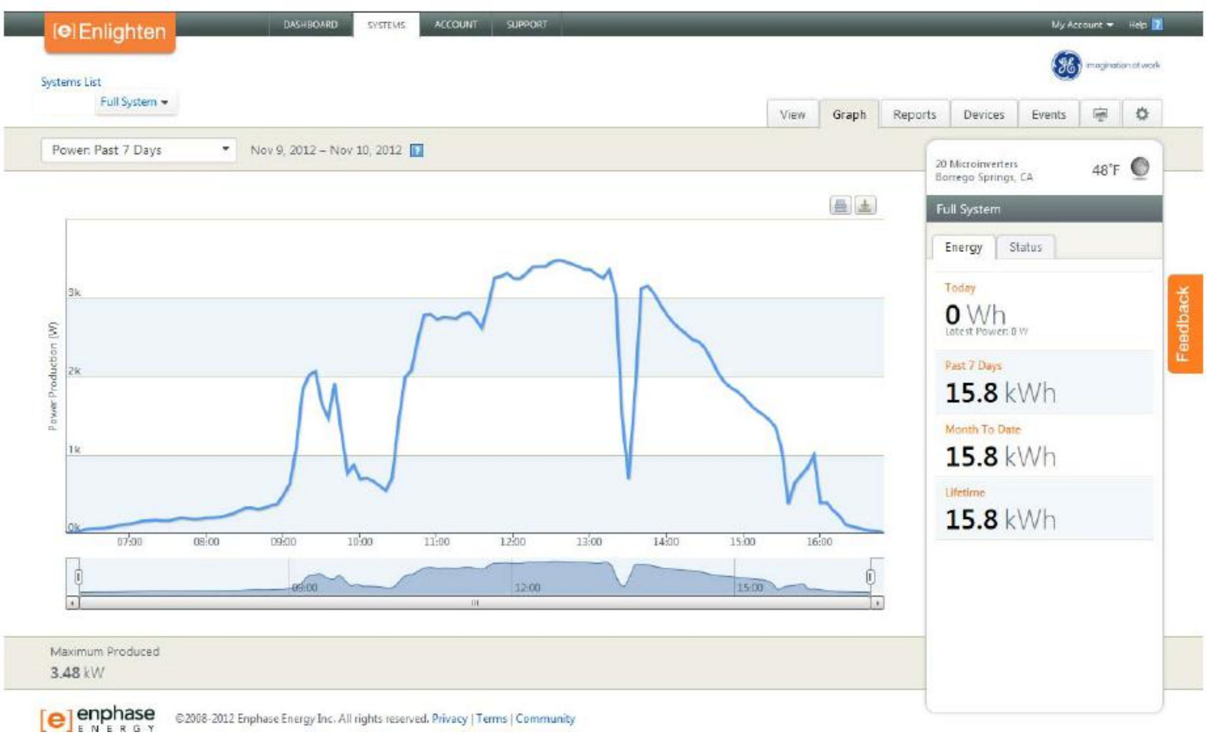



**Figure 18. First full-day of generation from 4.8kW PV system in Borrego Springs, CA**

**Figure 18** is a plot of power produced by the 4.8 kW system in Borrego Springs on the first day following installation, along with the total energy produced that day. The dips in the electricity production were due to clouds temporarily reducing the solar energy striking the array, temporarily reducing the output.

**Table 2** provides comparison data from PVWatts simulations to the measured generation for February through August, 2012, for the Chula Vista Showcase Home[7]. The seven months of data in Table 2 show that the measured electricity produced by the system on the Chula Vista home was 102% of that predicted by the NREL simulation.

**Table 2. Chula Vista Installation Performance Comparison of simulated to measured results**

| Address: | Chula Vista Showcase Home | |
|---|---|---|
| Azimuth: | 246.90 degrees | |
| Roof Tilt: | 23 degrees | |
| Month | Simulated Energy (kWh) | Measured (2012) Energy (kWh) |
| Feb | 275.7 | 266 |
| Mar | 348.9 | 349 |
| Apr | 379.6 | 353 |
| May | 377.9 | 444 |
| Jun | 362.5 | 417 |
| Jul | 386.5 | 410 |
| Aug | 393.3 | 354 |

[7] This was the first system installed; unfortunately the internet connection to the PV system was lost for several months. It was restored and later disconnected by the homeowner.

**Figures 19** and **20** show daily energy measurements for two homes, both located in El Cajon, CA. Note similarities in the pattern of low-energy days (such as October 10, 11, 12, 18, 20, and 21) for the two houses - likely due to weather effects.


**Figure 19. Energy per day measurements - El Cajon Residence 1**


**Figure 20. Energy per day measurements - El Cajon Residence 2**

**Figures 21 - 24** are performance tracking graphs for 2.4kW systems in Chula Vista and El Cajon CA, and a 4.8kW system in Borrego Springs, respectively. As in **Figure 17**, the heights of the simulation boxes represent the uncertainties in the simulations, and the location and size of dots represent the measured energy, as previously described. As with the initial data from the Santee installation in **Figure 17**, the measured data tracks the simulations reasonably well. **Figure 24** has performance tracking graphs that show the initial 2.4kW system, then, after the addition of a second system, the performance vs. simulation for the resulting 4.8kW system.

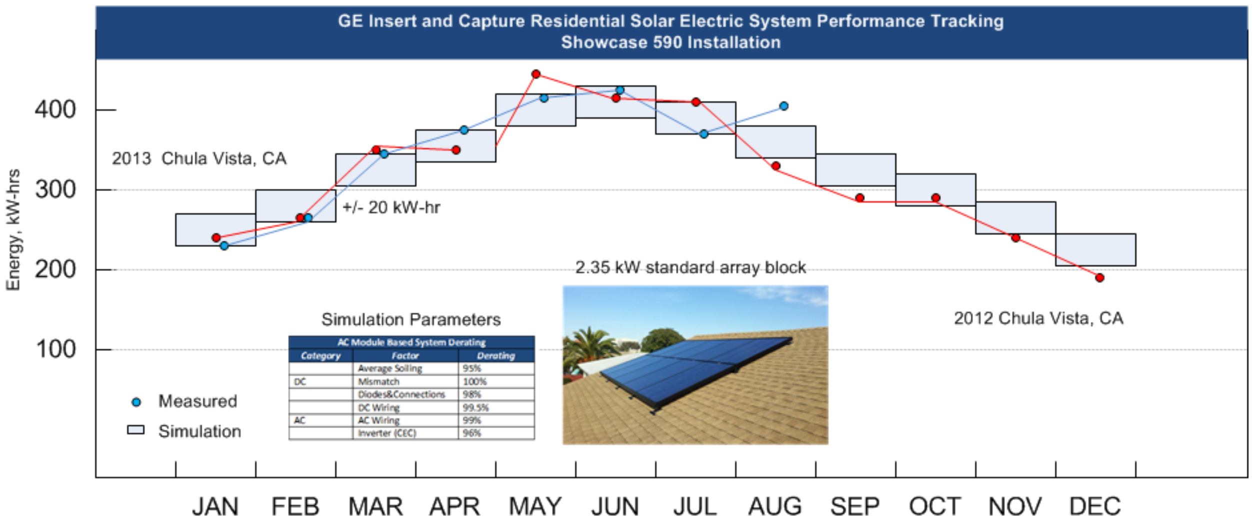



**Figure 21. Performance tracking chart for a 2.4kW system in Chula Vista, CA**

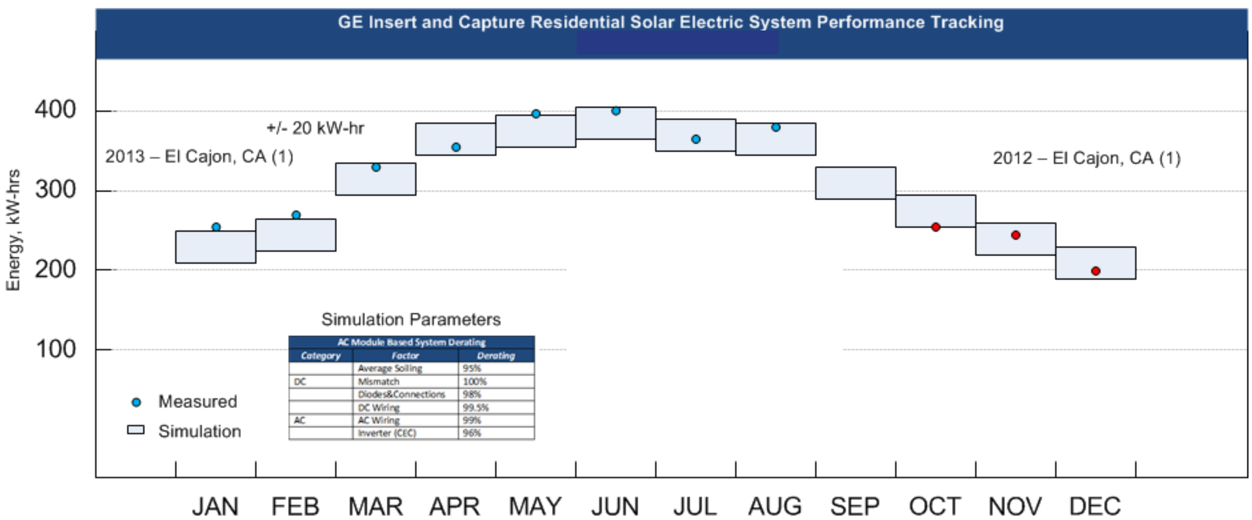



**Figure 22. Performance tracking chart for a 2.4kW system in El Cajon, CA**

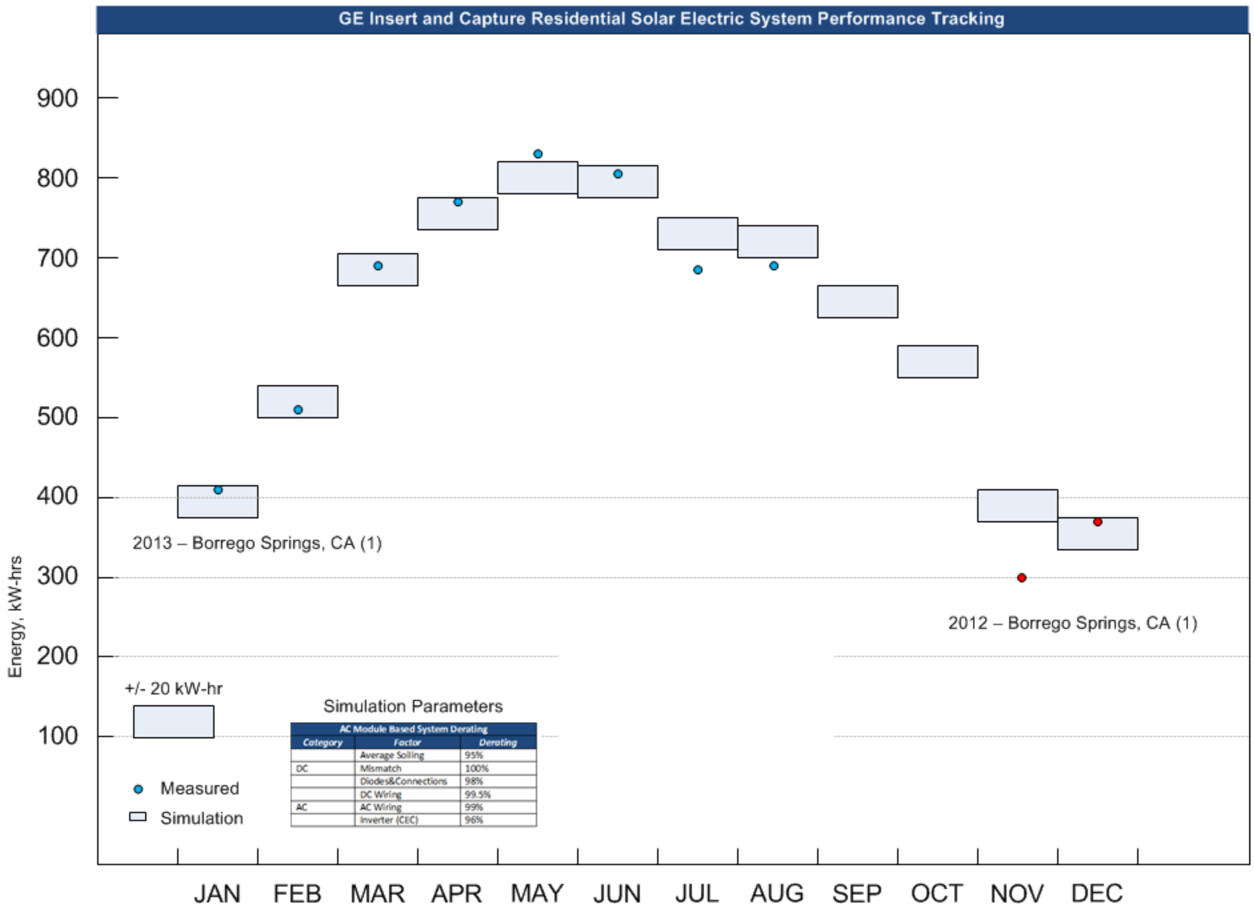



**Figure 23. Performance tracking chart for a 2.4kW system in Borrego Springs, CA**

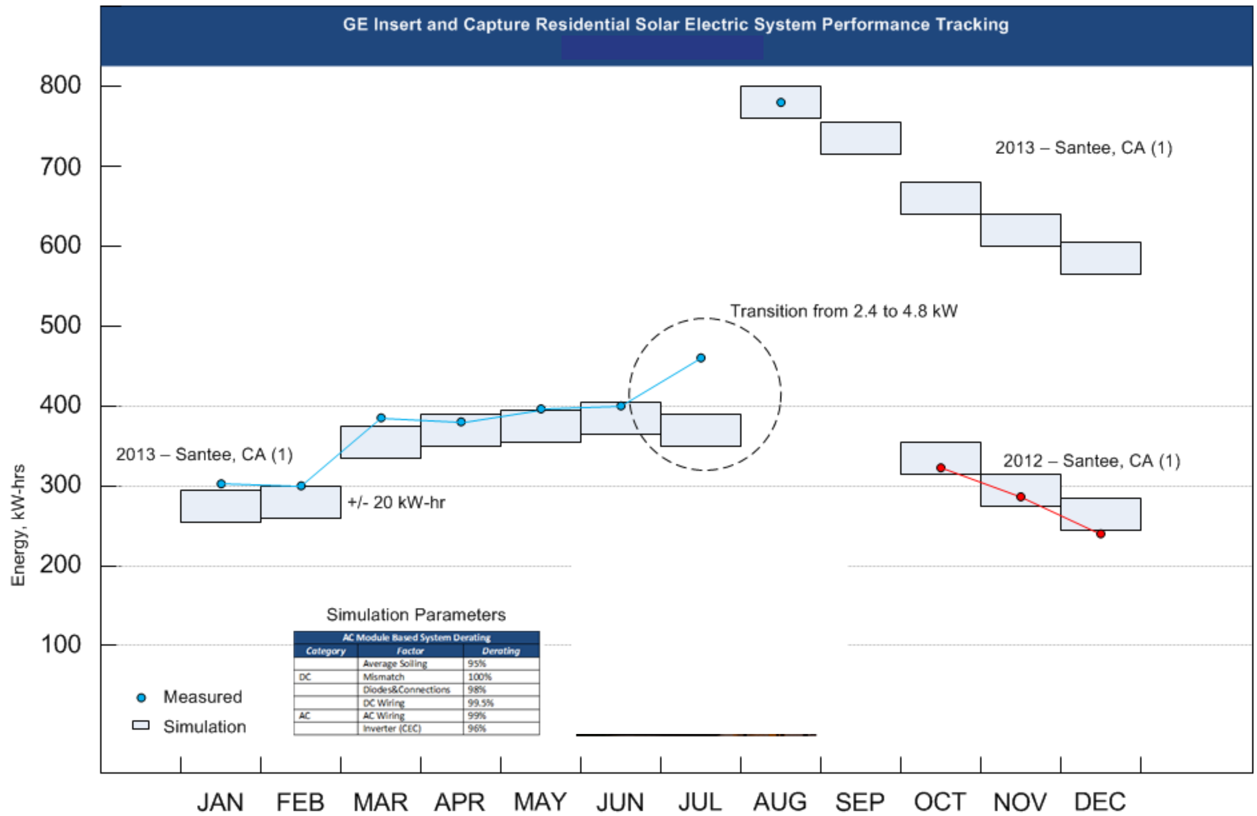



**Figure 24. Performance tracking chart for one of the Santee CA homes, initially with a 2.4kW system, upgraded during July 2013 to 4.8kW. Simulations (boxes) extend past the period of data collected and posted on this graph.**

These data show that the P&P PV Kit systems are all performing at or above expectations. When shading is taken into account, these ac systems really shine. This can be seen in the Borrego Springs system, where some of the panels become partially shaded in the late afternoon, as shown in Figure 25.

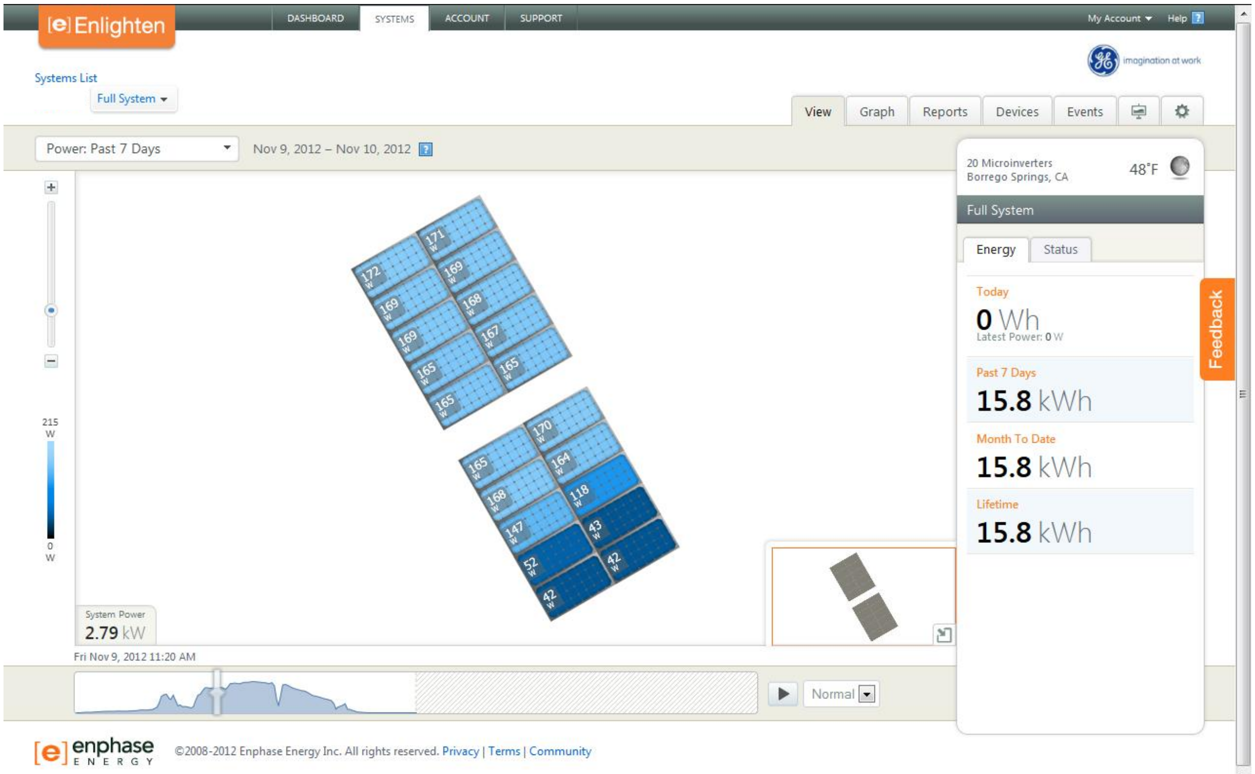



**Figure 25: Late in the afternoon, with the sun low on the horizon, the eastern panels on this system (those in the lower part of this illustration) start to become shaded and produce less electricity.**

Near sunset the eastern-most panels on this system (those in the lower part of the Enlighten display of the system in **Figure 25**) became shaded. The resulting decreased output is due to lower insolation levels from the low sun-angle. The Enlighten system clearly shows the effects of this shading using darker colors for lower generation values, as well as the actual output for each module. Note that, while the output of the shaded modules has dropped into the low 40Vac range, the un-shaded modules are producing 164 – 170Vac. In a dc-string PV system, if the output of one module in a string is reduced, such as in this example by 75%, because they are all connected in series, all the modules in the dc string would be reduced by the same 75%. As discussed in detail below, the differential effects of shading can be a very important distinction between the P&P PV Kit, which employs ac modules and a typical dc system, because in retrofit situation there are significant shading, obstruction, and orientation issues that severely limit the effectiveness of solar on retrofits vs new construction.

Note in **Figure 25** that the significant decrease in generation from some panels losing insolation due to shading does not affect the output of other modules in the two arrays of connected panels. This array behavior is quite different from that of dc strings of panels, where, when the amount of sunlight on one panel in a string goes down, the entire string is significantly affected. To illustrate this point, we can compare the change in output of the 4.8kW P&P PV Kit installed on the Borrego Springs home due to partial shading of the array, with the effect similar shading would have on a hypothetical 4.8kW dc system under the same conditions. For reference, after commissioning the 4.8kW P&P PV Kit on the Borrego Springs home, which faces WSW (258deg azimuth), the system was producing 3469W, with the two sets of 10 panels producing 1747W and 1722W for west and east sets of 10 panels, respectively, see **Figure 26**). Late in the day, as shown in **Figure 25**, there is an effect from partial shading of the eastern-most modules (at the bottom of **Figure 25**) that occurs in addition to the total insolation being reduced by 4% compared to earlier in the afternoon, following commissioning (**Figure 26**). The overall reduction of 4% due to lower sun angle is estimated by comparing the output of 10 modules in the unshaded western array (top of figures 25, 26: 1681W vs 1747W, respectively). However, the 4 modules at the bottom of **Figure 25** are shaded by varied amounts, reducing the module outputs to 42W – 52W each, compared to 164W – 170W from the unshaded modules in the same group of 10. The middle two panels in the lower set of 10 in **Figure 25** are slightly shaded, producing 118W and 147W. In total, the lower set of 10 modules are producing about 34% less power than they would, were none of the modules shaded, and the total system output is 20% lower due to shading and lower overall insulation (estimated above as 4%) reduction and 16% lower if adjusted for reduced insolation.

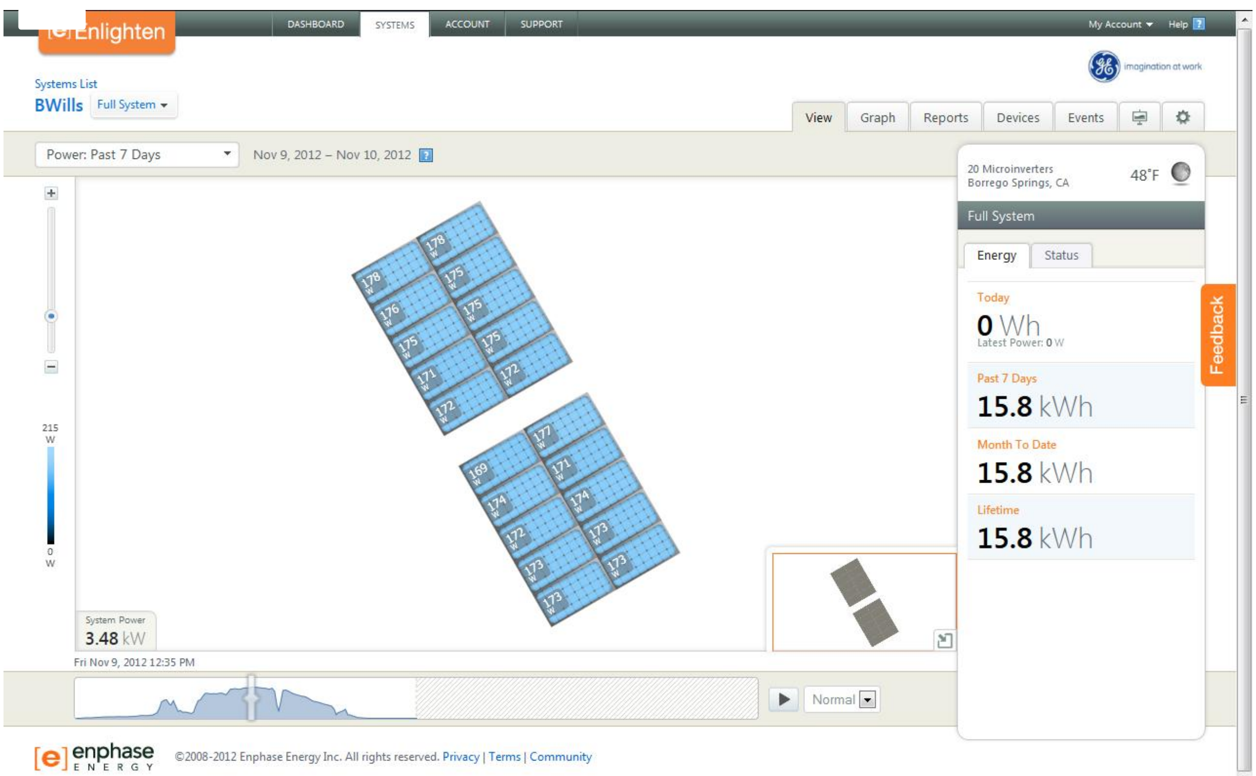



Figure 26: Borrego Springs 4.8 kW system performance map shortly post-commissioning.

The generation from the Borrego Springs 20-module, 4.8kW array shortly after commissioning is shown in **Figure 26**; this is a reference baseline to be compared to the array with partial shading, as shown in **Figure 25**.

Were this system a standard dc-string installation, the entire string of modules would each be reduced to the lowest output of all modules in the string – that being the maximally shaded module, which in this shaded case is 42W, rather than 172W unshaded, a 76% reduction. If two identical systems were compared, one ac system (module arrays wired in parallel) and one dc system (module strings wired in series) both with 20 modules in two sets of modules, just as the 20 module system in **Figures 25** and **26** are in two arrays, with the bottom array shaded as in **Figure 25**. The top array is unshaded and in both installations would produce 1680W (in this example). However, the bottom array is partially shaded, with the lowest output at 42W and, for the ac array, the highest panel in the array producing 170W (see **Figure 25**). If the bottom 10 modules were dc and connected in series, then all 10 modules would be limited to the output of the lowest-producing module, or 42W in this example. Thus, the 10-module string would produce 420W rather than the 1,111 that the lower array is producing in Figure 25. This is a 62% reduction in the output of the lower array, and a 25% reduction in the total 20-module system, in two strings or arrays. The worst case would be if the entire 20 modules made up a single string, then the entire system would produce 840W rather than the 2,792W this ac system is producing, a 70% reduction in output. Over the course of a year, an ac system installed on a roof where the array would experience any significant shading would perform much better than a dc system. This could prove to be an important factor in retrofit applications where there is a greater likelihood and amount of array-shading due to trees, chimneys and other potential obstacles. This is not a significant issue in new construction, and when it does occur in new construction, it typically can be mitigated in the planning stage by moving trees, rotating or flipping the home design on the lot, changing roof design, or other options available to planners. In retrofit situations shading is a much larger issue because trees are mature and were often placed to shade the home, roofs often have chimneys and other roof obstructions that shade otherwise prime areas of the roof that could have accepted solar.

As reported in a recent study of PV market potential in the existing home retrofit market, shading is an important factor in the PV market potential. This study of solar access on rooftops in mature neighborhoods in southern California, found that the percentage of homes in mature neighborhoods of Southern CA that can accommodate a minimal PV system of 1kW dc to be about 24% of the homes, and for a 3.8kW system, chosen as representing the minimum size PV system needed to be able to retrofit a home with a reasonable energy-efficiency package and a PV system to produce a ZNE retrofit, the ability to accommodate this size system in same homes is limited to 11% of the homes[8]. It is quite possible and even likely that these market potentials

[8] Hogan and Hammon: Solar-PV Assessment of Southern California Neighborhoods, 2013; see BIRAenergy website

could be substantially increased if the impact of shading on the PV system were not as extreme as it is in dc systems. A study of the differential market potential for 4kW – 6kW ac and dc PV systems in mature neighborhoods is a recommendation of this project.

## 3.2. Analysis of P&P PV Kit Installed Costs

The complete and comprehensive cost analysis from GE of their Smart-Grid Ready Insert & Capture Plug-and-Play Retrofit PV System is provided in a separate, stand-alone report, entitled ***Detailed Cost Analysis: GE Smart-Grid Ready Insert and Capture Solar PV.***[9] A summary of the approach and results are provided here.

As has been described in the sections above, this project served to evaluate a new approach to residential-retrofit rooftop-solar with several distinctive properties that were posited to, and that do indeed make it less expensive to manufacture, deliver, and install in the residential retrofit market. Those properties are:

1. The overall design, manufacture, and installation philosophy was to keep the product and all processes as simple as possible with a goal of the major installation being on the roof, and that can be installed by roofers without any need for an electrician on the roof.
2. PV modules with integrated microinverters making all connections ac-electricity rather than the conventional dc-electricity. By code, dc electrical connections must be made by licensed electrical contractors. For this product, the modules have microinverters that have electrical cables with connectors that plug into a pre-installed wiring harness. All rooftop connections are 240Vac, and are made using connectors (no loose-wire connections on the roof. Thus an electrician is not required on the roof.
3. The system is designed to be a minimum number of parts to assemble on site; that it is delivered as a simple-to-install kit, including all components that go on the roof included in the kit. The only things not in the kit are the junction box for under the roof, the electrical cable (and possibly conduit) to run from the through-the-roof termination of the PV harness and the electrical nuts to make the connections.
4. The modules are attached to the rails using an "insert-and-capture" system that makes module installation simple and quick.
5. The ac interconnections resulting from including microinverters in each panel assembly substantially reduce system losses from partial shading, thus producing more electricity, particularly in existing homes with established trees.

This section summarizes the findings of this CSI-funded project, in which RD&D partner, GE, provided prototype Grid-Ready Plug-and-Play PV Kits for installation, monitoring, and

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9 Available on the CSI RD&D and BIRAenergy websites.

evaluation of this product and market concept. One element of this research project was to evaluate and demonstrate the GE system as a specific example of a system embodying this concept, and one for which actual installed costs could be determined. The target installed price of for this type of system was set by the research team in its original proposal at $4.25/watt, installed, for Single Family residential retrofit (the proposal and this price target were determined in 2010). This can be compared to the then-current residential retrofit costs that were in the range of $6.50/watt. Assuming purchasing and manufacturing lots of 1,000 kits, this cost goal was met and exceeded during the term of the research project, i.e., the sales price in a one-home-at-a-time retrofit market is currently below the target $4.25/watt, given manufacturing volume of a minimum of 1,000 per batch. This section summarizes the cost aspects of the GE design, including installation, commissioning, and turn-over to the customer. Additional details can be found in the detailed Project Report: ***Detailed Cost Analysis: GE Smart-Grid Ready Insert and Capture Solar PV*** at the sites provided above, at the beginning of this section.

Based upon the costs that have been established through the bill of materials and assembly/kitting analyses and the determination of installation level of effort and cost, the expected cost/pricing for a residential system that can be delivered to a customer in 2013 is summarized by **Figure 27** for a baseline (48-in. stanchion spacing) 2.4 kW GE system. **Figure 27** shows a minimum installed price of $3.97/W, as segmented by the cost of the system components, the mechanical and electrical installation cost, and soft costs associated with permitting, interconnection, and inspection. All of the material costs are based on quotation received in March of 2012 for a volume of 1000, 2.4kW (10 AC module) systems. The major elements of the GE system demonstrated in the project include the AC module at $1.53/W (photovoltaic module at $0.85/W, microinverter at $0.48/W, assembly at $0.20/W) and the insert and capture/plug-and-play mounting system at including electrical harness at $0.40/W. The total cost of materials alone (outside of installation) is $2.37/W

In addition to the electrical components included within the kit there are additional components that are provided by the electrical contractor to complete the installation of the ac circuits. These costs were added to the labor costs, along with a margin for the contractor, to generate a total electrical contractor cost. The final cost, including intermediary soft-costs, and installation labor, but before any margins is just over $3.00/W, providing leeway for margins for the manufacturer, distributor, and installer, and still be under $4.00/W, installed. Given market pull and continued, but at a slower rate, reduced costs for modules and electrical components, GE predicts an installed cost with margins of under $3.50/W by the end of 2014.

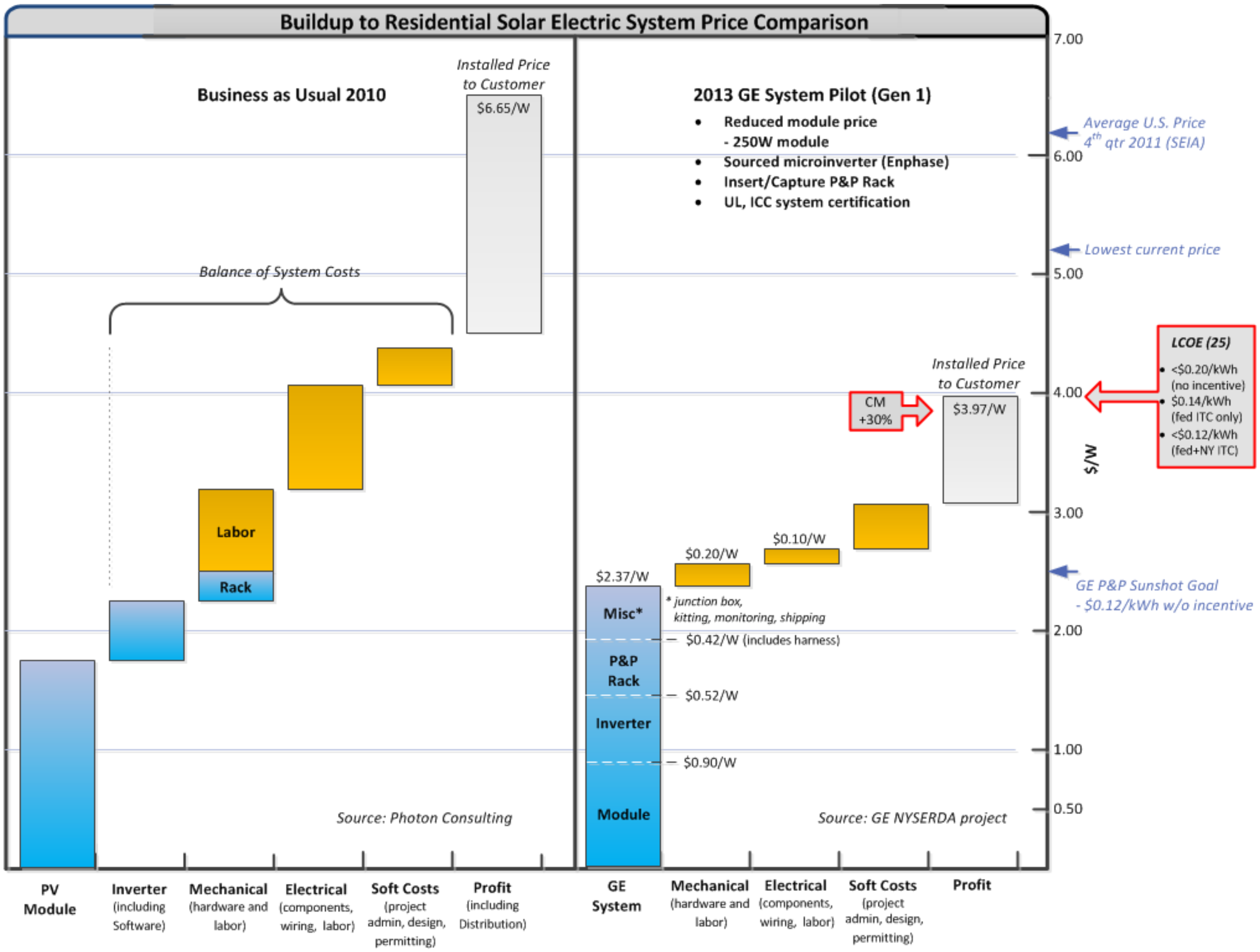


**Figure 27. 2013 Price/Cost for GE residential solar system as determined in CSI project vs. 2010/11 market pricing.**

## 3.3. Innovative Financing of PV and Efficiency Upgrades

The results of this review are in a separate report entitled "*Financing Options for Residential Solar Photovoltaics (PV) & Energy Efficiency*" which can be found on both the CSI[10] and BIRAenergy[11] websites. The Executive Summary is copied here.

Effective financing is unarguably responsible for much of the recent explosive growth in energy efficiency and, in particular, the solar photovoltaic (PV) product markets. According to the Solar Energy Industries Association, average solar PV system prices have declined by 40-percent since the beginning of 2011 – and by more than 50-percent since the beginning of 2010. New leasing programs that take advantage of this dramatic drop in costs are proliferating at astonishing rates. In some States such as California and Colorado, third party companies that lease the solar PV equipment directly to the homeowner are responsible for more than 90-percent of quarterly sales. This trend is expected to continue well into 2014.[12] While not as steep as recent PV market growth, the energy efficiency markets are strong as well, thanks in part to new infrastructure put in place through Stimulus Funding since 2009, the relative high visibility of state and local energy efficiency programs and policies, and a very aggressive U.S. energy services industry.

This report identifies and reviews traditional energy efficiency financing and more recent innovative third party solar PV financing mechanisms and related loan programs that help move the market toward Zero Net Energy (ZNE) goals. Specifically, the authors identify financing program options that integrate financing for the re-roof with PV and energy efficiency improvements that are simple to apply and qualify for, have a competitive interest rate and low up-front costs. Programs that finance the re-roof and the solar PV along with efficiency upgrades are especially important, since comprehensive retrofits are one very effective way to get to ZNE goals.

### Key Concepts to Consider in Energy-Efficiency and PV Retrofits

While performing the research for this report, a number of key concepts emerged regarding residential PV retrofits and accompanying energy efficiency retrofits. These included; how to evaluate the costs and benefits of the various options, and identifying and evaluating the various financial vehicles that would make the retrofits possible for homeowners. When evaluating

[10] http://www.calsolarresearch.org/funded-projects-sobi/74-low-cost-smart-grid-ready-solar-re-roof-product-enables-residential-solar-energy-efficiency-results

[11] www.biraenergy.com/reports

[12] Regulatory Assistance Project, presentation to the Colorado Energy Office, October 28, 2013.

different options for financing solar PV and energy efficiency, the authors believe the following key concepts should be considered.[13]

- The long term costs and benefits that will accrue over the entire lifecycle of a system or equipment being evaluated
- Take advantage of a home energy inspection to provide key data for making energy improvement decisions, and request the following results from the inspection for evaluating the investments from the possible improvements:
    - Energy efficiency improvements, in order of cost-effectiveness, tailored to the home
    - Potential saving from the improvements
    - Potential costs of the improvements
    - Economic analyses of packages of features, including cash-flow and/or lifecycle cost analyses
- Include direct and indirect benefits in the cost-effectiveness analyses
    - Consider not only the energy and cost savings, but also the improvements in household comfort with energy efficiency and reliability improvements that result from the addition of the efficiency improvements and the PV
- Leverage energy efficiency and solar PV retrofits to achieve multiple goals
    - Determine the goals of the retrofit before obtaining a financing product
        - Goals can include: cost savings, energy independence, improved energy reliability, paying off personal debt; obtaining sustainable, whole-house comfort; minimizing home maintenance requirements; air quality improvement and climate mitigation.
- Consult with local lenders and review energy efficiency and solar PV retrofit financing programs
- Know that both the energy efficiency and solar PV equipment have limited, predictable and often different lifespans
    - Be prepared for potential systems failures (e.g., furnaces, water heaters, etc.) by knowing the typical life of important equipment[14]
    - Store and use this information as a triggering event to simultaneously:
        - Replace old, inefficient systems that are at the end of their useful lives
        - Hire a home energy rater before the equipment fails to garner information needed to do timely efficiency and solar PV upgrades, optimizing time, and energy and bill savings, and minimizing inconveniences
- Know that low interest rates are currently, but not permanently available through financing products which may require more paperwork and longer processing times
- Know that making multiple upgrades at the same time is almost always more cost-effective than making them separately:
    - Consider at least all of the upgrades that will result in a neutral cash flow (where monthly payments for improvements at least equal the monthly utility savings).
- The home value should increase after an energy efficient retrofit and solar PV installation

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[13] These key concepts are listed again in the Conclusions section.

[14] NREL's lifecycle database for the expected operable life of various building systems: http://www.nrel.gov/lci/database/default.asp

- Obtain an energy efficient home value appraisal from an appraiser certified under National Appraisal Institute as a "green" appraiser to ensure the appraisal properly includes efficiency and PV upgrades.[15] [16]

## 3.4. Innovative Business Model for P&P PV Kit

The development of a business model appropriate to this produce included a market survey and analysis, as well as a classic approach to developing a market approach for a new product. This information is described in detail in a separate, detailed report titled: "*Business Model: Plug-and-Play Solar PV Kit Innovative Business Model,*" which can be found on both the CSI and BIRAenergy websites.

The conclusions of the Business Model report are:

The report discusses the integrated solar PV product, business model and strategy recommendations for deploying the product, the market opportunity in the existing home market, and the consumer feedback from the owners of existing owners.

### Plug-and-Play Solar PV Kit has Significant Advantages

Plug-and-play, ready-to-install PV system kits, with integrated microinverters, such as the GE system, offer easier and faster installation, potentially increased reliability through integrated microinverters, and a 'plug-and-play' simplicity that makes them less expensive to purchase and install. These AC-PV systems also open the PV market to direct sales through the roofing trades and their sales channels, giving roofing contractors a substantial up-sell opportunity for both PV kits and the PV kits coupled with energy-efficiency upgrade packages. Further, the plug-and-play PV kits provide a large new, potential product offering of roofers' current products, providing a large opportunity for business expansion within the roofing contractor industry. Sales and installations of these plug-and-play PV kits could be made to homeowners either as part of the roofers normal re-roof sales process or as a new product and service offering from roofers – offering PV with energy-upgrade options as retrofit independent of re-roofing.

### Large and Growing Solar PV Market Opportunity

The homeowner survey results, along with the cited research, show how the residential PV market offers an enormous market opportunity in terms of both size and potential growth. Differentiated product offerings such as the plug-and-play PV kit, are well positioned to take advantage of the market and capitalize on this opportunity.

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[15] Residential Green and Energy Efficient Addendum (uses PV system evaluation tool)

[16] Sandia National Laboratories PV Value® System Evaluation Tool: http://energy.sandia.gov/?page_id=8047

### More Innovative Business Model Strategies Required

The integrated solar PV system providers need to adopt and deploy the innovative business model and strategies across the value chains discussed in this report. This includes forming strategic partnerships, selling and marketing through varied marketing channels, deploying a well formulated marketing strategy and messaging, and offering the product through newer distribution channels.

### Focus on Residential Retrofit Market

The plug-and-play PV kit is well positioned for the residential retrofit market, an enormous market within the overall residential solar market. These PV systems can be bundled and cross-sold when a homeowner is getting an energy efficiency retrofit or with a re-roofing. The product could be modified to be used in the new construction market; however, given the size and opportunity in the retrofit market and that product modification would be required for the new construction market, a focus on the retrofit market is logical.

### Bundle PV Systems with Financing Solutions

By addressing the long standing barrier of high upfront cost, new and innovative financing mechanisms such as the PPA and solar leases being offered through third-party financing have helped residential solar PV installations cross an inflection point in adoption. Financing, cost-effectiveness and payback period rank among the top concerns for homeowners who have not yet installed solar. The plug-and-play PV product provider should offer financing solutions when selling and marketing their products either through strategic partnerships with financiers and financial institutions or through vertical integration and business expansion.

### Continue RD&D System Development

A robust and a continual product improvement will ensure that the product continues to enjoy differentiation by being the most innovative product in the rapidly growing competitive field.

## 3.5. Demonstration and Integration of P&P PV Kit, EE, DR, HEMs, and Storage in a ZNE

A series of tasks in this project culminated in the design, implementation, and initial evaluation of a ZNE Test Home that was retrofitted with efficiency 4.8kW P&P PV Kit, EE, DR, HEMs, and storage. This home has been retrofitted, and data collected and analyzed. The home provides a significant opportunity for study and evaluation of integration, operation, and evaluation of these technologies. A final task report was developed as a stand-alone report due to the importance of that work, so that the report is readily available to anyone interested, without having to find the report within another. The Executive Summary and Conclusions from the detailed report Zero Net Energy Home – Design, Development and Implementation are presented here.

A task of the California Solar Initiative RD&D Project: "Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy" was to develop and implement a Zero Net Energy[17] (ZNE) efficiency package for one of the homes involved in the testing and evaluation of the low-cost PV system. To meet the goals of this task, the team established a suite of Integrated Demand-Side Management (IDSM) elements, retrofitted a 1278 sq ft home in an inland valley east of San Diego, California with this package, and is monitoring the different systems' and home's performance. The IDSM suite includes (in loading order), an energy-efficiency (EE) package, appliances and thermostat with demand response (DR) capability, intelligent energy-storage (IES), a home-energy-management system (HEMS) and an innovative low-cost plug-and-play PV system from GE, their GE Smart-Grid Ready, Insert & Capture, Plug-and-Play Solar Retrofit PV System (GE Retrofit Solar PV Kit). The battery-storage system's intelligence and programming functions archive data that provides patterns of energy use to which regular charging and discharging can be programmed to manage recurring loads seen by the grid. The system also has DR-capability to track and moderate demand in real-time, reducing unanticipated peak demand. The various IDSM components came from different manufacturers making integration a challenge, which will be discussed. System costs, including installation were carefully recorded for individual systems and fully-integrated cost/benefit analyses is available in another report.[18] This IDSM retrofit which is also a zero net energy

[17] A zero net energy, or ZNE home optimizes energy-efficiency measures with on-site renewable energy generation (PVs) such that, on a net annual basis, the PVs produce as much energy as the home consumes. Thus a ZNE home must be connected to the grid for electricity and/or gas needed to operate the home when the PV system does not meet the power needed by the home, and, conversely, at times of peak generation, the power output of the PV system exceeds the home's demand, and during such periods the ZNE home will export excess energy generated on-site back into the grid.

[18] Korman and Hammon, CSI Task Report: Detailed Cost Analysis of Grid-Ready Plug-and-Play PV Kit (located on CSI and BIRAenergy websites)

(ZNE) design could also be incorporated into new construction. It has the capability to shape residential loads to virtually any shape desired by the utility for grid optimization, while being totally transparent and unobtrusive to the homeowner.

The Zero Net Energy Home – Design, Development and Implementation report (ZNE report) covers the development of energy efficiency, DR, and storage requirements and design, as well as their implementation in the ZNE home. Initial performance results are described in detail in the ZNE report with the preliminary finding that the ZNE home is performing as designed. This performance is demonstrated in a figure from the ZNE report showing that the actual energy used by the ZNE home is very similar to that predicted by computer modeling of the home and the resulting energy use simulations. See **Figure 28**, below.

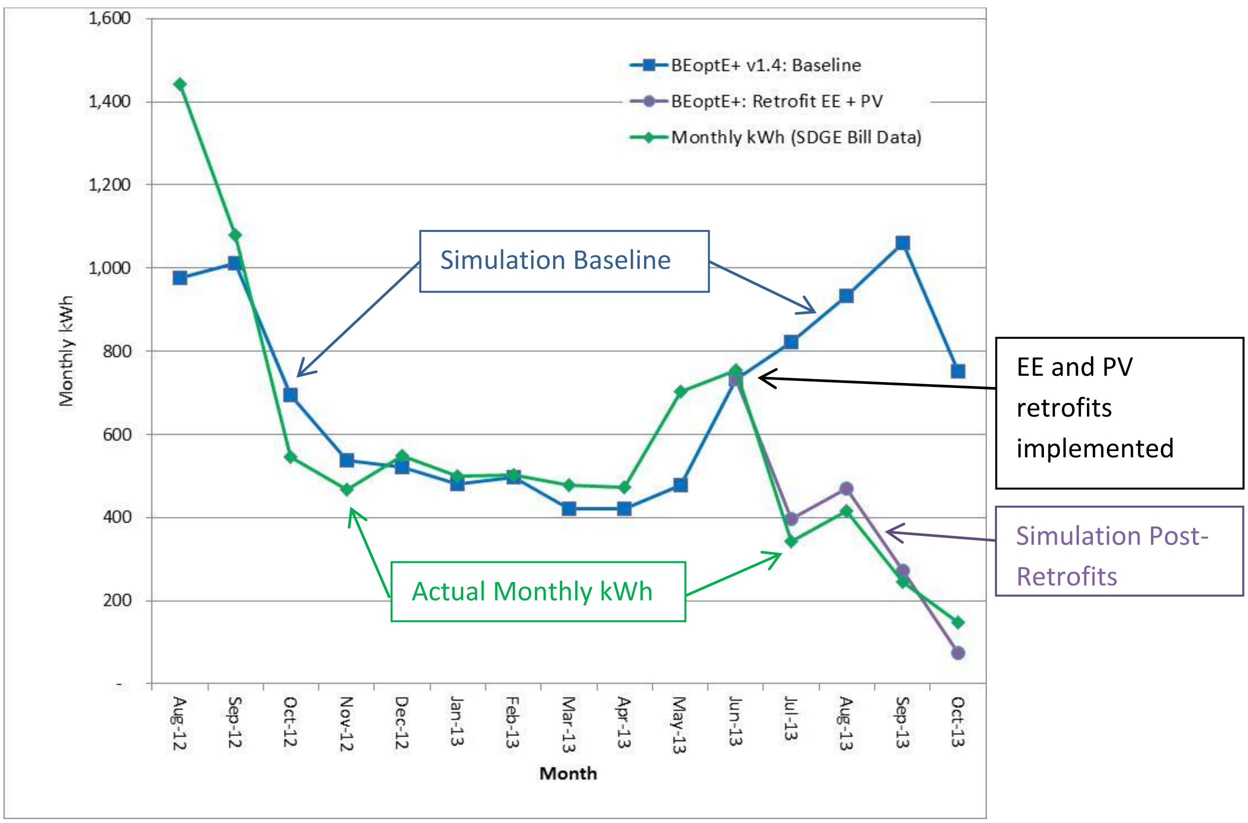


**Figure 28: Baseline and post-retrofit electricity use in ZNE home.**
Monthly kWh from SDG&E Bills are plotted in in green, and BEopt simulations of baseline electricity use are plotted in blue (pre-retrofit, and the baseline continuing post-retrofit). BEopt simulations of post-retrofit electricity use are plotted in purple, starting the month before the retrofits were performed (June) for continuity in the graph. The EE and PV retrofits were performed in July, and the impacts of these retrofits are readily apparent as the difference between the BEopt Baseline and actual kWh, as well as BEopt simulations of kWh post-retrofit, starting in July.

## ZNE Performance and Next Steps

This CSI ZNE home is a very valuable research station that has provided valuable data regarding the actual performance of a ZNE retrofit, including both energy-efficiency and peak-reduction, as predicted. This home can provide substantially more information regarding the integration of different energy and power reducing technologies and techniques. The home has a significant energy-efficiency package the individual components of which could be further evaluated, DR capable appliances and their controller have been installed, but they have not been set up to communicate with any other devices or systems, and are therefore stranded. In addition, the homeowners have not been trained in its use, either as a DR controller or Home Energy Management system. These capabilities should be affected, then tested and evaluated. The home also has a very sophisticated electricity-storage, battery system. There are many different programing and operational states that should be tested and evaluated, to determine optimal system-configurations, of which there could be several, depending upon the home, the distribution system, and the occupant behaviors. These need to be further tested and evaluated.

There is a 4.8 kWac system on the roof; the system has microinverters that can be remotely monitored quite easily using the Enphase Enlighten software to communicate with the microinverters via the Envoy. In fact, there are six systems GE Solar Retrofit PV systems, two 4.8 kWac and 4 2.4 kWac, from this project that could and should be monitored to understand how the microinverters perform and age. Perhaps more importantly, tests could be performed on this system to evaluate the benefits of ac modules when shading occurs on parts or all of one or more panels in an array.

The amount of data collected to date on this ZNE home is limited, and yet has provided exciting and valuable results that the ZNE home is performing as predicted, and that the Sunverge SIS system can manage energy and power on the consumer side of the meter. Initial results showed a peak reduction of 3.4kW in the ZNE home due to the SIS Further evaluation is needed to fully evaluate the potential of the SIS system, including: how to program them, where to put them, how to make them compatible with different types of PV systems (dc and ac, at a minimum), and to evaluate their value to utilities and the consumers.

In summary, this project has developed and begun to test efficiency, DR, storage, HEM, and PV systems that, in a very limited time, with a relatively small amount of data, have produced some very interesting, encouraging, and valuable results. The most significant accomplishment is the development and initial testing of a highly equipped research home that is extremely valuable as a test-site for integration, homeowner use, and performance evaluation of all the elements in the energy-reduction loading order. Most important, this test home is owned and occupied by a very cooperative, interested, and collegial family. Given all that can be learned from this home, California cannot afford to allow this asset to become stranded.

# 4. Key Findings

GE Global Systems conceived of, designed and built the first incarnation of the Grid-Ready Plug-and-Play Retrofit PV Kit. GE was a major partner on this project, providing to the project systems to test and evaluate, along with expertise and labor. The project used their product, which has the current cumbersome but descriptive name, internal to GE: "GE Smart-Grid Ready, Insert and Capture, Plug-and-Play Residential Retrofit Solar PV System." The GE "Smart-Grid Ready, Insert and Capture, Plug-and-Play Residential Retrofit Solar PV System" met all of the goals set for the P&P PV Kit, providing proof of concept and practical implementation of a residential retrofit product. More important, the successful installations and subsequent evaluations demonstrated that the Grid-Ready Plug-and-Play PV Kit clearly provides a new business opportunity for roofing contractors, as described in the business model report. If roofing contractors take up this opportunity, and there is no evident down-side to their doing so, then the roofing contractors provide a whole-new market channel for PVs, increasing the speed of market uptake of PVs. In addition, because the residential PV market potential is severely constrained by roof shading,[19] and given that PVac systems are much less affected by shading than are the PVdc systems, the adoption of PVac systems could substantially increase the market potential for PVs in the residential retrofit market. These conclusions are supported by the findings of this study that the P&P PV Kit has the following attributes:

1. The roof-top installation can be completed entirely by a trained roofing contractor and one or two assistants;
2. The P&P PV Kit is simple to install and requires little training for a roofing contractor, or for the electrical contractor. The inspection of the system is also simple, due to simple system architecture and installation. These factors are important to the system installed cost.
3. A Best Practices Training Guide was developed for each of the roofing contractor and electrician contractor, providing detailed instructions for the installation of a P&P PV Kit.
4. The GE version was estimated to have an installed cost below $4/watt, assuming a 1,000 unit production volume, this being well below the target cost. Further, the system is expected to be below $3/Watt within a year (by the end of 2014).
5. The energy produced by the GE beta P&P PV Kits performed at or above NREL SUM (PVWatts) predictions.

[19] The existing residential market potential is also physically limited by roof orientation and obstacles.

6. The P&P PV Kit employs PVac panels that are connected in parallel, as opposed to typical PVdc panels, that are connected in series. This results in the P&P PV Kit arrays being relatively insensitive to shading, compared with the typical dc string arrays. This could be a very important factor to energy production and cost-effectiveness in the retrofit market, where shading is a prevalent problem.

There were two additional issues that led the team to conclude that additional research and evaluation could and should be performed on the ZNE retrofit home built as part of this project, but that has not been totally integrated and tested.

1. GE provided a set of DR appliances, and a Nucleus controller and Home Energy Management system. This system was to allow control and communications with the smart meter and battery storage in the ZNE home. Unfortunately the Nucleus was not commissioned by the end of the project, in part because the Nucleus has a proprietary Zigbee interface to the DR devices and to the smart meter. For this reason it was not possible to have the Nucleus communicate with the Sunverge SIS intelligent battery storage system, so the emphasis was on integrating the SIS, PVs, and Enphase Enlighten systems for managing grid loads.
2. The combination of P&P PV Kit, energy-efficiency upgrades, and Sunverge SIS were able to reduce peak loads by over 3kW with SIS round-trip efficiency of 93%. These data were collected late in the year, and may be even better in summer months with greater loads, greater PV production, and the high-efficiency of the SIS.

# 5. Recommendations

- The successful evaluation of this new Grid-Ready Plug-and-Play Residential PV Retrofit product included that the ac-modules resulting from the integration of microinverters into the PV panels, provides opportunities that should be further evaluated. The results of this project indicate specific opportunities provided by PVac modules that merit further investigation or support. Major opportunities are:
  - Disseminate the innovative business model to the roofing contractor industry. Because roofers can install the P&P PV Kit system on the roof, it provides a new market opportunity for them and a new distribution channel for PVs. If roofing contractors successfully adopt this business model, they could produce a dramatic increase in solar retrofits on existing homes.
  - Shading is a much larger issue in the retrofit market than new construction, because the landscaping is more mature, and there is a much higher incidence of shading from trees, as well as from housing elements that might shade the array, such as chimneys. The results of this project verified that when a module in the P&P PV Kit is shaded, only the shaded module is affected, unlike typical rooftop PVdc strings, in which the output of the entire string is reduced to that of the lowest producing module (the most shaded module). Additional research should be done to determine the magnitude of this differential effect of shading on the annual output of residential retrofit rooftop PVs. Further, the differential shading effects could have a significant impact on both the market potential for retrofit PV as well as the actual adoption of PVs in the existing home market. These impacts merit study due to the relatively low market potential for residential retrofit PV resulting, at least in part, from shading. Research has shown that solar access in existing homes is very limited due to shading, orientation, and obstructions. It is quite possible that the both the percentage of homes with solar access homes and the amount of access they have could be significantly increased if the residential retrofit market moved from dc to ac modules. Research is needed to determine the market impacts of changing module/systems from dc to ac. Such research would include an analysis of rooftop shading data, improved models of shading, and reassessments of solar potential with PVac systems that are relatively insensitive to shading.
- The ZNE home developed under this project was designed as a test-bed for integrating EE, DR, HEMs, storage (batteries) and PVs. The PV, energy-efficiency, and storage systems are working as predicted. The PV, EE, DR, HEMs, and storage systems have all been installed in the home, but the full integration that was intended to be done under this project has not been completed. The controllers for the different systems (DR, HEMs,

storage, and PVs) came from different vendors and use different communications protocols. It is important to determine and test different methods that could lead to successful communications between these systems and to successfully integrate these functions/technologies. The ZNE home is setup and ready to continue this important part of this CSI project. The time, efforts and funds spent to develop this real-home integration test bed have produced a field-research asset that should continue to be used for this integration research. The homeowners have agreed to allow their home to be used for this purpose for another year, and potentially longer. In addition, they are interested in the project and ready and willing to work with researchers to assist, as occupants, in this research effort. This asset should continue to be used to integrate the technologies.

- The ZNE research home, in addition to providing a research tool for integrating technologies, should be used to experiment with different control and operational strategies for DR, HEMs, and storage. PVs have been shown to decrease distribution system efficiency. Preliminary results from this project show that the combination of storage with PVs can mitigate reduced distribution system efficiencies, and there is evidence that the combined technologies could improve distribution system efficiency above that of a typical community distribution system prior to adding PVs. These efficiency benefits should be studied further, and the impacts of DR and HEMs on distribution efficiency should also be examined. As described in Recommendation 2, the ZNE research home is setup to do this research, and the occupants are willing participants.

# 6. Public Benefits to California

This project successfully tested, demonstrated and evaluated the new Grid-Ready Plug-and-Play PV Kit, and found that it is a valuable addition to the PV market, based on its performance and relatively low cost. In addition, due to its ac-module design, the P&P PV Kit has a substantially decreased sensitivity to shading, which is a limiting factor to PV potential in the residential retrofit market. The ac-module design also provides the opportunity to open a wholly new sales channel in the retrofit market via roofing contractors. The project also provided new insights into ZNE retrofits and advantages and challenges of multi-technology integration in ZNE retrofits. The **key** public benefits are:

1. **A new, cost-effective retrofit PV product**. At less than $4/Watt, this system is below the current market prices for residential retrofits. The cost is low because the system was designed to minimize the number and complexity of parts, simplify installation, and allow lower-cost laborers to do the installations. The cost determined for the P&P PV Kit is in line with the system costs in the current CSI database, and that database includes volume purchases, driving the average cost down. The P&P PV Kit is more expensive than the least expensive PV systems on subdivisions of new homes, which is an inappropriate comparison due to the large differences in volume sales and installations. A more valid comparison is provided in a recent study done for the California Energy Commission[20] that found the installed price of a residential retrofit system was $5.38/Watt in 2012 in California. At $3.99/W for a Grid-Ready Plug-and-Play PV Kit, it is 26% less than the cost published in the CEC report. This is a substantial savings for the public who are considering a PV retrofit, and, according to the CEC report, this PV retrofit system is cost-effective for consumers today.
2. **Excellent performance**. The Grid-Ready Plug-and-Play PV Kit, is not only less expensive than most competition, according to the CEC report referenced in the previous benefit, it performs as well or better than computer simulations predict. This is a rare case where the less expensive product performs as well or better than the more expensive PV systems.
3. **New market channel**. The P&P PV Kit provided proof of concept and practical implementation of a new genre of residential retrofit PV products. The successful installations and subsequent evaluations show that the Grid-Ready Plug-and-Play PV Kit clearly provides a new business opportunity for roofing contractors, as described in

[20] Cost-Effectiveness of Rooftop Photovoltaic Systems for Consideration in California's Building Energy Efficiency Standards, E3, 2013, CEC Publication 400-2013-005

several sections of this report, and is covered in detail in the business model report " Business Model:  Plug-and-Play Solar PV Kit Innovative Business Model."  If roofing contractors take this opportunity, and there is no evident down-side to their doing so, then the roofing contractors provide a whole-new market channel for PVs, increasing the speed of market uptake of PVs.

4. **Shade tolerance**.  The importance of this Grid-Ready Plug-and-Play PV Kit system to the retrofit market is enhanced by its ac-module design as opposed to the typical dc-module design.  The use of ac modules in the P&P PV Kit makes it much less affected by shading than are the (predominant) PVdc systems.  This attribute of the P&P PV Kit could substantially increase the adoption of residential PV retrofits, the market for which is currently severely constrained by roof shading.[21]  Given that shading is a key barrier to the retrofit market, this relative insensitivity to shading could remove this market barrier to wide-spread adoption of PVs on existing homes.

[21] The existing residential market potential is also physically limited by roof orientation and obstacles.

# Glossary

| | |
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| AC or ac | Alternating Current |
| AMI | Advanced Metering Infrastructure |
| BIRAenergy | Prime Contractor |
| BOS | Balance of System |
| CEC | California Energy Commission |
| CPUC | California Public Utilities Commission |
| CSI | California Solar Initiative |
| RD&D | Research, Development, Demonstration and Deployment Program |
| CT | Current Transformer |
| DC or dc | Direct Current |
| Deg | Degrees |
| DR | Demand Response |
| EIA | U.S. Department of Energy-Energy Information Administration |
| GE | General Electric (Global Systems Division) |
| HEM | Home Energy Management (system) |
| IDSM | Integrated Demand Side Management |
| IES | Intelligent Energy Storage |
| LCOE | Levelized Cost of Energy |
| NABCEP | North American Board of Certified Energy Practitioners |
| NEC | National Electric Code |
| NFPA | National Fire Protection Association |
| NREL | National Renewable Energy Laboratory |
| NYSERDA | New York State Energy Research and Development Authority |
| kW | KiloWatts = 1,000Watts |
| PPA | Power Purchase Agreement |
| P&P | Plug-and-Play |
| PV | Photovoltaic solar electric system |
| SDG&E | San Diego Gas & Electric |
| SIS | Sunverge Intelligent Storage |
| UL | Underwriters Laboratory |
| V | Volt |
| Vac | Alternating Current Voltage |
| Vdc | Direct Current Voltage |
| WSW | West-south-west |
| ZNE | Zero Net-Energy (home) |
| ZEH | Zero Energy Home |

# References

## Accompanying Reports

1. Best Practices Training Program
2. Detailed Cost Analysis: GE Smart-Grid Ready Insert and Capture Solar PV
3. Business Model: Plug-and-Play Solar PV Kit Innovative Business Model
4. Financing Options for Residential Solar Photovoltaics (PV) & Energy Efficiency
5. Zero Net Energy Home – Design, Development and Implementation

## Links

CSI RD&D project webpage: http://www.calsolarresearch.org/funded-projects-sobi/74-low-cost-smart-grid-ready-solar-re-roof-product-enables-residential-solar-energy-efficiency-results

BIRAenergy website where reports from this project will be posted: www.biraenergy.com/reports

NREL: Lifecycle database for the expected operable life of various building system: http://www.nrel.gov/lci/database/default.asp

## Other referenced reports

Cost-Effectiveness of Rooftop Photovoltaic Systems for Consideration in California's Building Energy Efficiency Standards, E3, 2013, CEC Publication 400-2013-005

Hogan and Hammon, Solar-PV Assessment of Southern California Neighborhoods, 2013; see BIRAenergy website