Low-Cost Solar Retrofit
Grid-Ready Plug-and-Play PV Kit

Installation, Commissioning, and Performance Report

Technical Report for Tasks 1-4, 7 of CSI RD&D Project: Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy Efficiency Retrofits

For
Itron, Inc., Program Manager
California Solar Initiative (CSI)
Research, Development & Demonstration (RD&D)
Solicitation #2

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Grid-Ready Plug-and-Play PV Kit

Installation, Commissioning and Performance Report

Introduction

This Grid-Ready Plug-and-Play PV Kit is designed to be inexpensive compared with current residential PV systems, including system and installation costs. This concept and product tested and evaluated in this project were developed by GE for the residential retrofit market. The general concept could be provided by others – the goals of this project were to evaluate this product concept, its generation and cost performance, and to examine financing and business models that could help get such lower-cost PV systems into the residential retrofit market. GE designed their system to have minimal parts and to be installed on the roof solely by a roofing contractor, with an electrician needed only to make the connections between the electrical termination passed through the roof to a junction-box (J-box) in the attic and cable in conduit from that J-box to the home's electrical panel. The system is designed to be installed on existing homes, either on existing roofs (asphalt shingle) or during a re-roof.

The five sections of this report document and illustrate the:

1. Components of the kit and how they go together into a complete roof-top system,
2. Grounding details,
3. Prototype system installation, lessons learned and needed improvements; installations of five beta-test systems with improvements incorporated,
4. Commissioning of each system, and
5. The performance of the six test systems over the project period following installations

This report is the integration of deliverables from the CSI Project Tasks 1, 2, and 7. For additional information on the results of this project additional technical reports are available on the CSI and BIRAenergy websites: Stakeholders Report, Detailed Cost Estimate, Zero Net Energy test home report, Residential PV Retrofit Financing Report, Business Model, Market, and Marketing Report, and Final Project Report. Links to the sites with these reports are:

BIRA link

CSI Link

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Acknowledgement

GE was a partner on this project, as a paid team member, as well as donating time, “in-kind”, bringing years of expertise in PV module and systems. In addition, they provided six GE Smart-Grid Ready Insert and Capture Solar Electric Systems, for installation, testing, and evaluation for the retrofit market as the first of its kind: a Grid-Ready Plug-and-Play PV Kit. This project would not have been possible without the huge contributions in time, effort and expertise by Charles Korman, Ph.D., Chief Technologist, Solar Energy, at GE Global Research. The BIRAenergy team commends Dr. Korman for his large contributions to this project and the solar industry as a whole.

Thanks Charlie!

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Grid-Ready Plug-and-Play PV Kit

1. System Components and Exploded Views of Assembled Product

This section shows the individual components, electrical and mechanical, that make up the system, the components assembled into the kit, as delivered to the side, and views of artists renditions of the system "assembled" in an exploded view so the parts are discernable. The picture below is he back-side of one of the PV modules or panels. In the lower left corner of the photograph is the microinverter that makes this panel AC electricity rather than the typical DC. This difference has many ramifications as is demonstrated in this and accompanying project documents. Chief among them are two aspects, both of which pertain to installed system cost: (1) removing any requirement for electricians on the roof and (2) simplicity of the electrical connection – directly into the home electrical panel.

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Electrical Components for a 2.5kW System

AC Module Assembly

Enphase microinverter

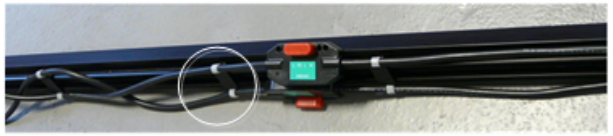
Star washer

AC module (Motech laminate)

Engage Harness

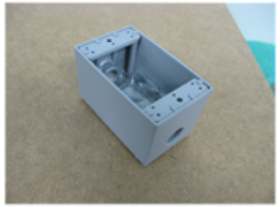
Harness cable clip

Engage harness installed onto rail

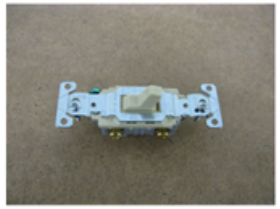


Harness terminator

Metal connector box



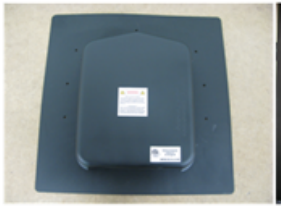
2-pole on-off switch



External switch cover

Switch/Connectpr Box

Flashed Junction Box



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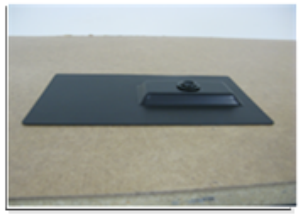
Mechanical Components for a 2.5kW System

Flashing (24/15)



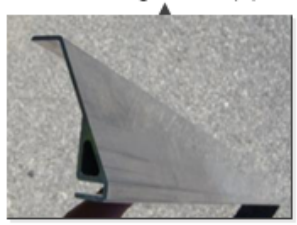
Rail Coupling (0)

Grounding Side Panel (2)

Grounding Screws (4)

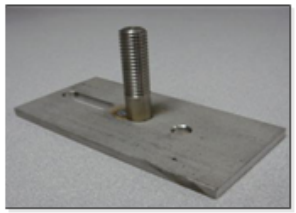
Front Finishing Panel (1)

Grounding Screws (4)



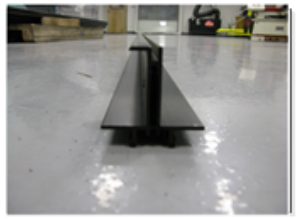
Stanchion (24/15)

Lag Screws (24/12))



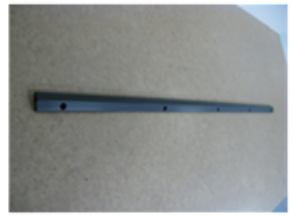
Rail Clip (24/15)

Rail (3)



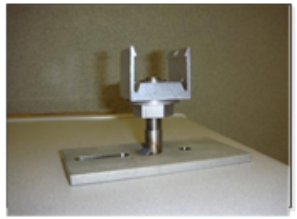
Securing Cover (10)

Grounding Screws (5)

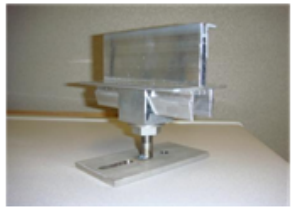


Flashing Assembly

Rail Clip/Stanchion Assembly



Rail Assemly



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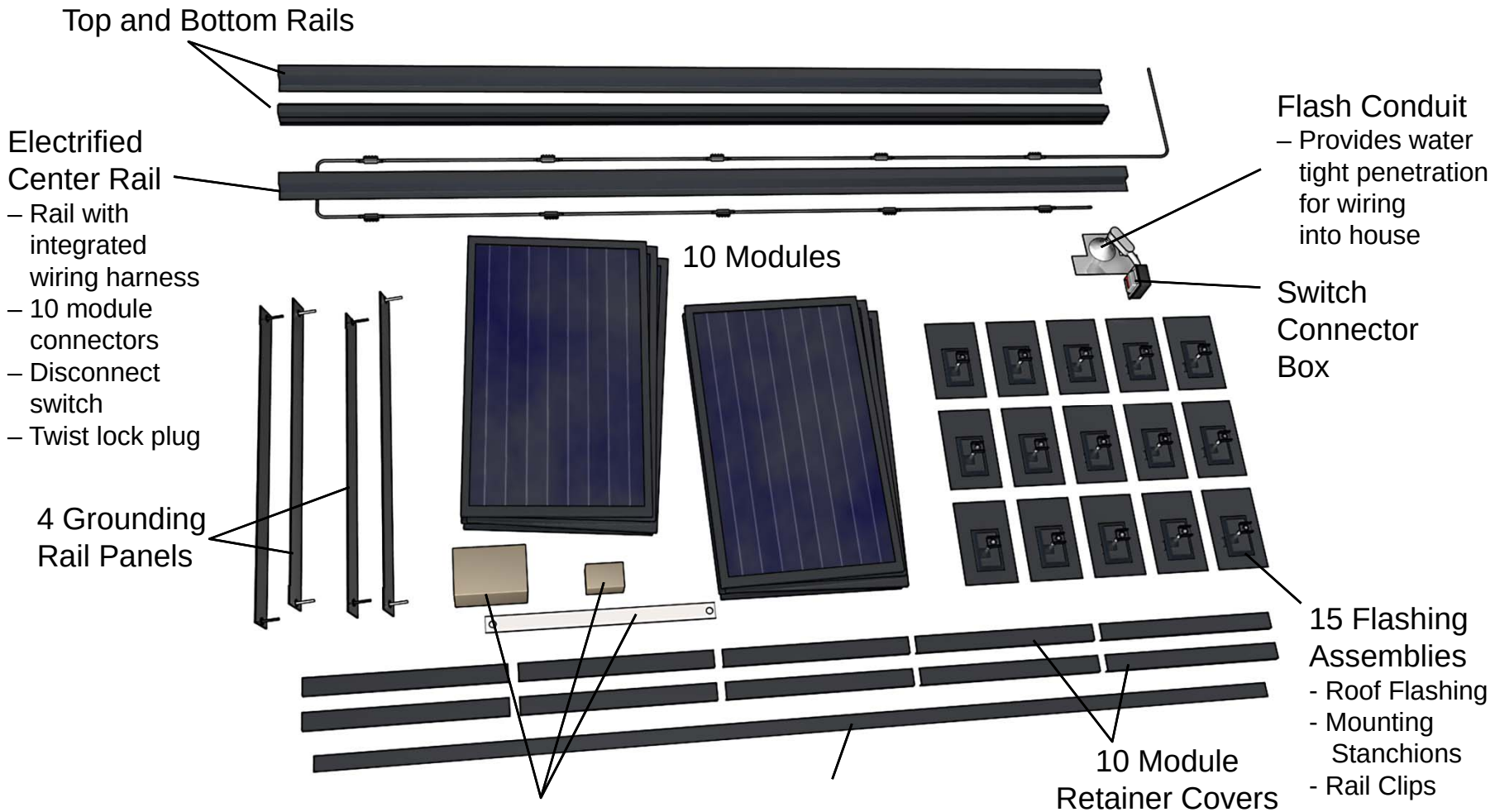
2.4 kW GE Insert and Capture Solar Array System

The Prime Example of a Grid-Ready, Plug-and-Play PV Kit

The PV Kit, as delivered to each site for installation and assembly



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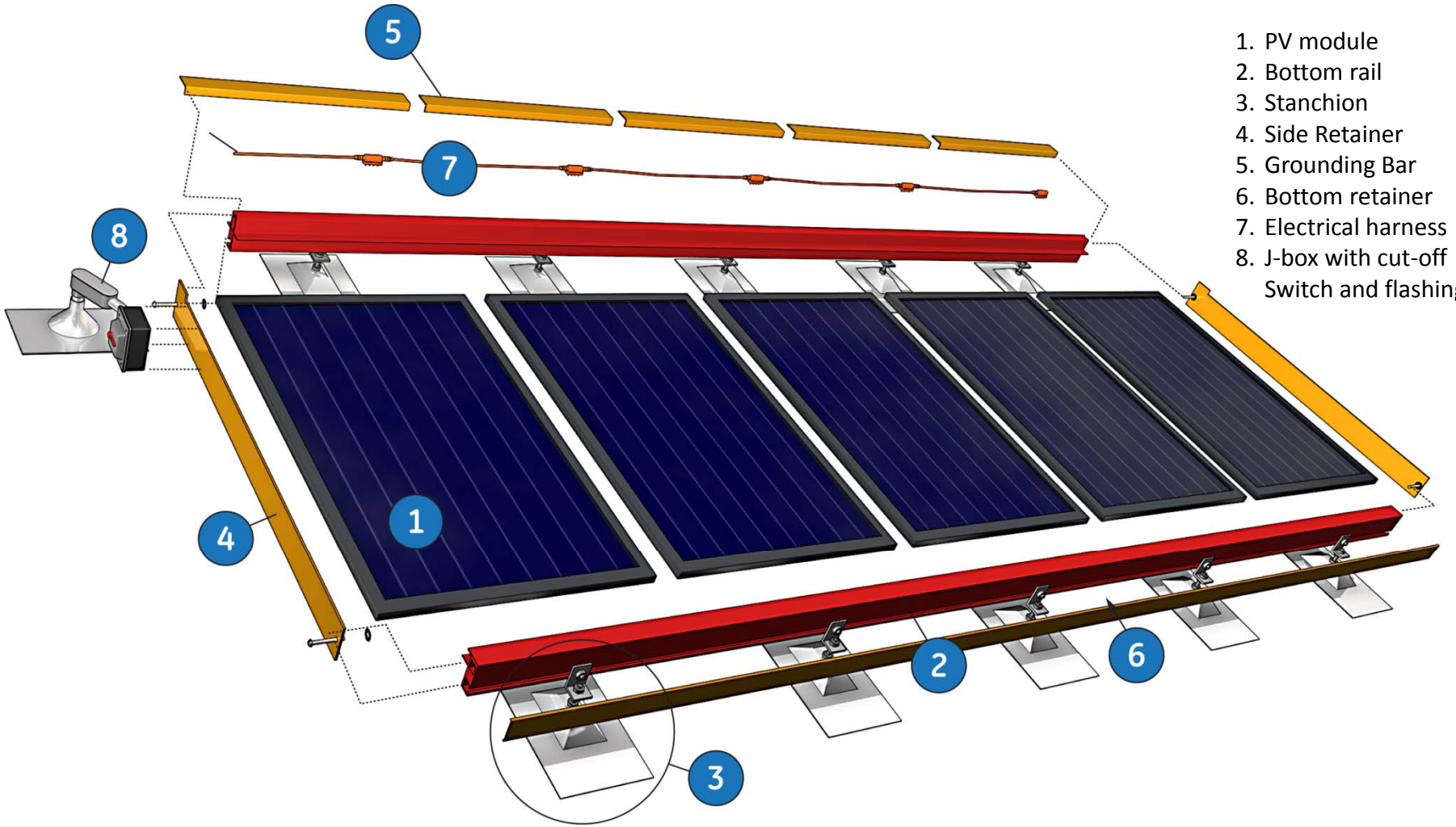
Exploded view of the GE Insert and Capture PV system-

Prime Example of Grid-Ready Plug-and-Play PV System

This 5-panel section is one row of a two-row 2.4kW AC system



1. PV module
2. Bottom rail
3. Stanchion
4. Side Retainer
5. Grounding Bar
6. Bottom retainer
7. Electrical harness
8. J-box with cut-off Switch and flashing

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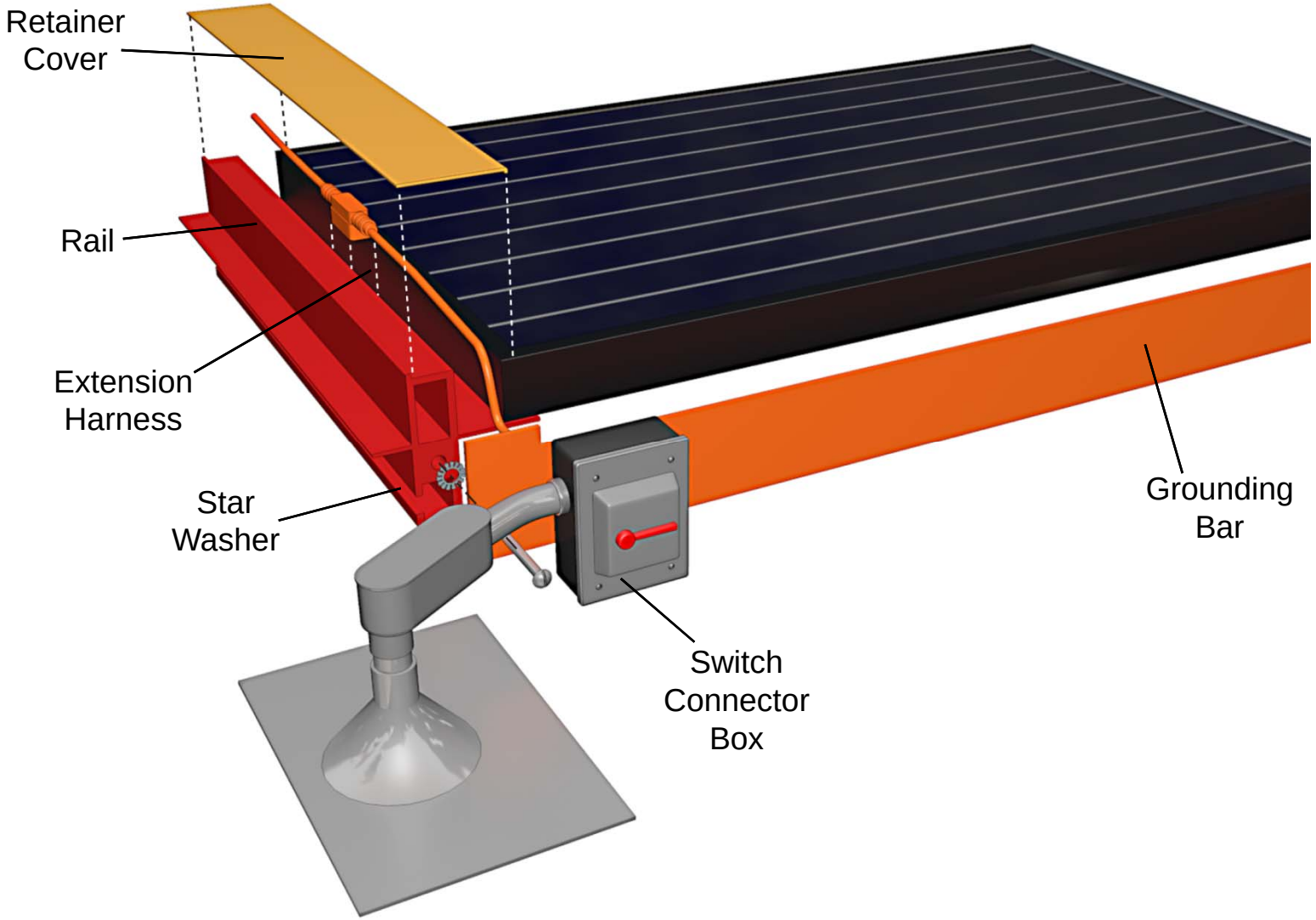
Exploded view of the GE Insert and Capture PV system: Topside Module View



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Grid-Ready Plug-and-Play PV Kit

2. Electrical Grounding and electrical connections from the end of the harness to the electrical panel

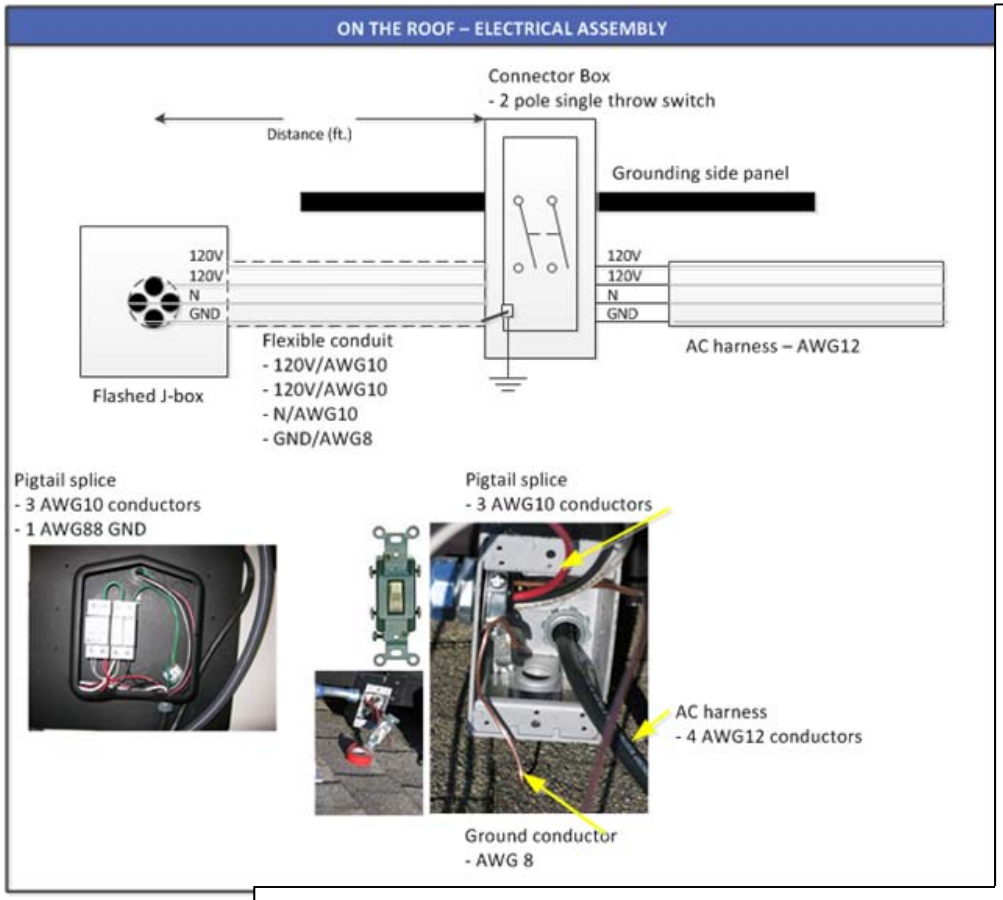
California has different disconnect and grounding rules than that required by the International Electrical Code. In particular, the electrical inspectors want to be able to see the ground wire and that it is connected to each panel, as well as to the ground-stake. The electrical harness in the GE Smart-Grid Ready Insert and Capture Solar PV System has a National Electrical Code compliant ground wire inside the harness that is continuous from one end to the other, and when a panel is connected to the harness, it is simultaneously connected to ground. The harness is connected wire-for-wire in the J-boxes through to the cable going from the roof-underside J-box to the panel, where the ground wire can be terminated to the panel ground or the ground stake.

Nonetheless, in all the installations an additional, visible ground wire was strung along the harness and connected to each panel frame, providing a second ground, which was ultimately grounded with the harness ground to avoid a ground loop. The team sees this grounding issue as temporary, until the inspectors get comfortable with the ground wire, internal to the harness. Being temporary, the cost of running this separate wire, in the field, is not included in the cost estimate.

Also, the prototype installation required an electrician on the roof to position the roof-side J-box, make conduit to carry the harness pig-tail (unterminated wires) into roof-side J-box, through a newly drilled hole in the roof under the flashed J-box, to the J-box on the underside of the roof where it would be connected to a cable in conduit that will connect on its other end to the home electrical panel. A cut-off switch also needed to be added to the roof-side J-box, per local codes. For the beta systems, this switch was added to a box at the terminus of the middle rail, prior to the conduit to the roof-side J-box. These changes were made for all the beta systems so that an electrician was not required to make connections on the roof side.

Grid-Ready Plug-and-Play PV Kit

2. Electrical Grounding and electrical connections from the end of the harness to the electrical panel



The electrical ground for this system is bundled in the electrical harness, providing a continuous ground, whether all panels are connected or not. The more typical practice is to run a separate ground wire from panel to panel grounding each to the next. While this is a more visible approach, it is not as dependable. Nonetheless, because the ground wire was not visible to the inspector, it was required that a separate ground wire was run along the harness, visibly connecting each panel. The ground then had to follow the harness through the roof J-boxes and the cable to the electrical box, to be connected directly to ground in the electrical box.

This additional ground wire is not necessary for a good ground nor to meet the electrical code. Therefore, the added cost of this practice, which the team feels is temporary, is not included in the system cost estimate.

In the prototype, the end of the AC harness was unterminated. This required an electrician to make the connections in the roof-side J-box. To eliminate this , the harnesses on the systems installed on the other five homes were terminated in weather-proof, twist-lock electrical connectors for connecting to the roof-side J-box.

In addition to being prewired with the mate connector for the harness, the updated roof-top J-box was pre-wired with a double-pole, single throw, disconnect switch and a long pig-tail for connecting to the under-roof J-box.

The pictures to the left show the wiring diagram, including the grounding and roof-size disconnect. The Prototype J-box and flashing are also shown..

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2. Modifications to allow roofer to make all electrical connections on the roof; no requirement for an electrician on the roof

Post-prototype systems included a Switch/connector box at the mid-section of the two rows of panels that integrates a 2 pole single throw switch which disconnects the array. This safety cutoff switch is a code requirement based on DC systems and is superfluous in AC systems with microinverters. The individual microinverters disconnect with loss of waveform in the connecting cable. They are nonetheless a standard part of the systems for California.

The newer beta systems include a pre-wired and sealed junction box with twist-on connector for connection of the harness. The flashed junction box also housed 1 surge protector on each 120V line as an added protection measure for the microinverters.

This box is flashed into the roofing and provides a penetration for a 4 conductor pigtail. The pigtail is dropped through a hole drilled through the roof prior to connecting the harness from the array, allowing the roofer to drop the pigtail and make all of the connections on the roof.

The electrician completes the installation by connecting the pigtail to a cable routed through conduit to the house load panel . Each system is on a dedicated 240V w-pole circuit breaker.

Grid-Ready Plug-and-Play PV Kit

3. PV Systems Installations: Prototype and five test homes.

This section of this report documents the installations of the PV retrofit system[1], the Grid-Ready Plug-and-Play PV Kit as embodied in the GE Grid-Ready Insert and Capture Residential Retrofit PV System by newly-trained roofers. Originally, the roofers were going to be trained on a "roof-on-the-ground" training platform at a nearby college. However, the actual construction of that training facility took much longer than originally planned, and, while that facility was finally built, it was not used in this project. Lacking a roof-on-the-ground training platform, the roofers were trained at the installations using training materials that were initiated by GE as part of their NYSERDA-funded project, and that were refined as part of Tasks 1 – 3. Thus, Installation Training Materials, providing Best Practices for installation of this Grid-Ready Plug-and Play PV Kit were developed under this CSI project, and those Best Practices Training Programs are available in the Stakeholders' Report, posted on both the BIRAenregy and CSI websites.

The system installed on the prototype home was the first California system installation, and issues were realized during and following that installation requiring product changes that were embodied in the systems installed on the other five homes. These included the grounding issue, covered in the previous section, and the need for different electrical termination on the roof so that the rooftop installation could be performed entirely by a roofer, with no need for an electrician on the roof. The change in termination and the pass-through of the electrical cable to the underside of the roof is documented in this section Grid-Ready Plug-and-Play PV Kit.

[1] The installations of the prototype and test homes systems documented herein were deliverables for Tasks 1-3 and 7.

Grid-Ready Plug-and-Play PV Kit

3. PV Systems Installations: Prototype and five test homes.

This section provides illustrations documenting each installation. The first page is a map showing the locations on two maps, one with all the locations except Borrego Springs, which is far inland and is on the second map. This allows clear relative locations for the one coastal installation in Chula Vista, and four inland valley locations (La Mesa, El Cajon and Santee). These inland valley locations are 15 – 20 miles (by road) inland from San Diego. Borrego Springs is over 90 miles inland from San Diego and is a very hot desert climate. The first page for each subsection, documenting a system installation is a picture of the home with the system installed. Following that are pages with pictures of each installation, illustrating major steps in the process, and, in some cases, problems encountered and solutions applied. After installation, each system was commissioned. Illustrations of that process are in Section 4 of this document. Following commissioning, the systems' energy production was monitored over a period of about a year following installation of the systems. The systems' performance are documented in Section 5 of this report.

The Santee test home was chosen to be the Zero Net Energy (ZNE) test home, and had a second 2.4kW system installed along with substantial efficiency upgrades. The ZNE package development and performance are in a separate report. In addition to using and refining the installation guides, these prototype and test installations provided the bases for measurement and evaluation of the systems' performance as well as of the potential residential retrofit customer cost to purchase a system (installed cost). A robust and detailed cost analysis based largely on these systems and their installations is provided in the Detailed Cost Analysis, posted on the BIRAenergy and CSI websites, along with the Residential ZNE Retrofit report.

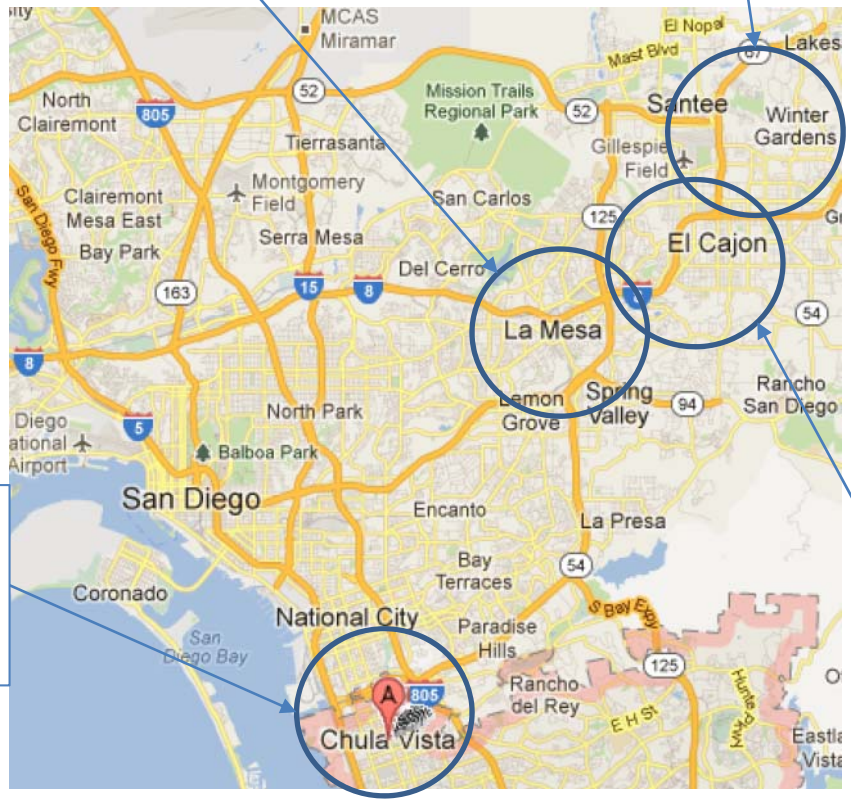
California Solar Initiative Pilot Installations

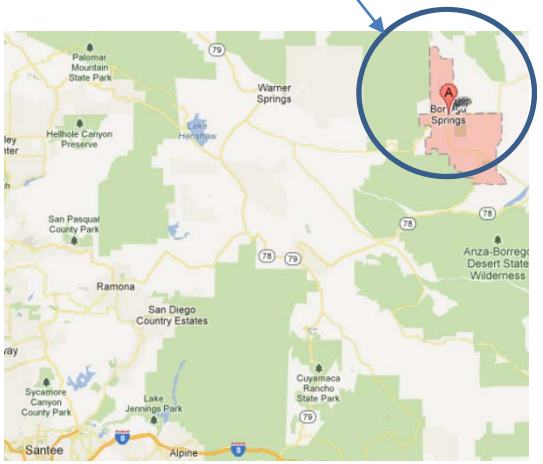
GE Smart Grid Ready Residential Solar Electric System

(2) La Mesa, CA,
Inland Valley CZ10
13 miles from San Diego

(5) Santee, CA
Inland Valley CZ10
18 miles from San Diego

(6) Borrego Springs. CA
Inland desert climate, CZ15
75 miles from El Cajon
91 miles from San Diego





(1) Chula Vista, CA
Prototype system,
First CA installation,
Coastal Climate

(3) and (4) El Cajon, CA
(16 miles inland from
San Diego)

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Grid-Ready Plug-and-Play PV Kit Prototype Installation (Showcase Home)

2.4 kW system installation – Chula Vista, CA

- City of Chula Vista purchased a foreclosure to renovate and showcase as a green home
- Retrofits completed early 2012; open to the public for ~6 months, then sold to a deserving family with loan assistance
- Retrofits include repairs, updating, energy efficiency, green materials and renewable energy. Examples:
- Low VOC paint
- Recycled glass countertops
- Double pane, Argon filled, low-e windows
- EnergyStar appliances
- LED lighting (interior & exterior)
- Solar power
- Solar water heating
- Water heater / thermal space heating
- Drought tolerant landscaping

First CA prototype product for Grid-Ready Plug-and-Play PV Kit, represented by GE Smart-Grid Ready, Insert & Capture, Solar Electric System - First CA installation of prototype of that near market-ready proto-product.

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Grid-Ready Plug-and-Play PV Kit

Installation on Rooftop

Locate rafter, lag in stanchions, use V notch & chalk line to align

Flash stanchions & attach rail clips

Snap in rails (C up roof) & attach wiring harness to center rail

Lay in modules, connect to wiring harness, screw on trim & skirts

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Electrician Installation Tasks

Install junction box & conduit/EMT and pull wire to roof

Install disconnect switch & surge protectors on roof

Install 240V breaker in Service panel & placards per code

Validate system function – meter spinning backwards, Amperage

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Key Learnings from Prototype Installation

Product Design:

A – Big, square flashings to protect roof from leaking
A - Taller mounts w/ leak proof collar
B - Shorter wires, well contained and hidden
C - Lower profile Capture straps - and fewer screws (3 vs 5)
D – Grounding needs to be UL approved (or 3rd party verified)

Grounding was the only show-stopper for the inspection
Field solution: the electrician was required to uninstall each panel and install grounding lugs to run bare copper ground across each panel to obtain approval from the inspector
This rework added significant unnecessary cost and time to the installation: $40 for lugs, 40' of #8 copper, 2 people X 1 hour

Installation Process:

3 roofers plus Supervisor: Trained, reroofed, and installed solar on roof in 3 hours. 2 electricians: completed electrical wiring in 1.5 hours
Should be able to cut the installation time in half

Design changes needed:

Change grounding & get UL approval
Eliminate any requirements for electrician on roof for installation

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Grid-Ready Plug-and-Play PV Kit Installation on Test Home 1

Beta-System: Prototype Problems Solved

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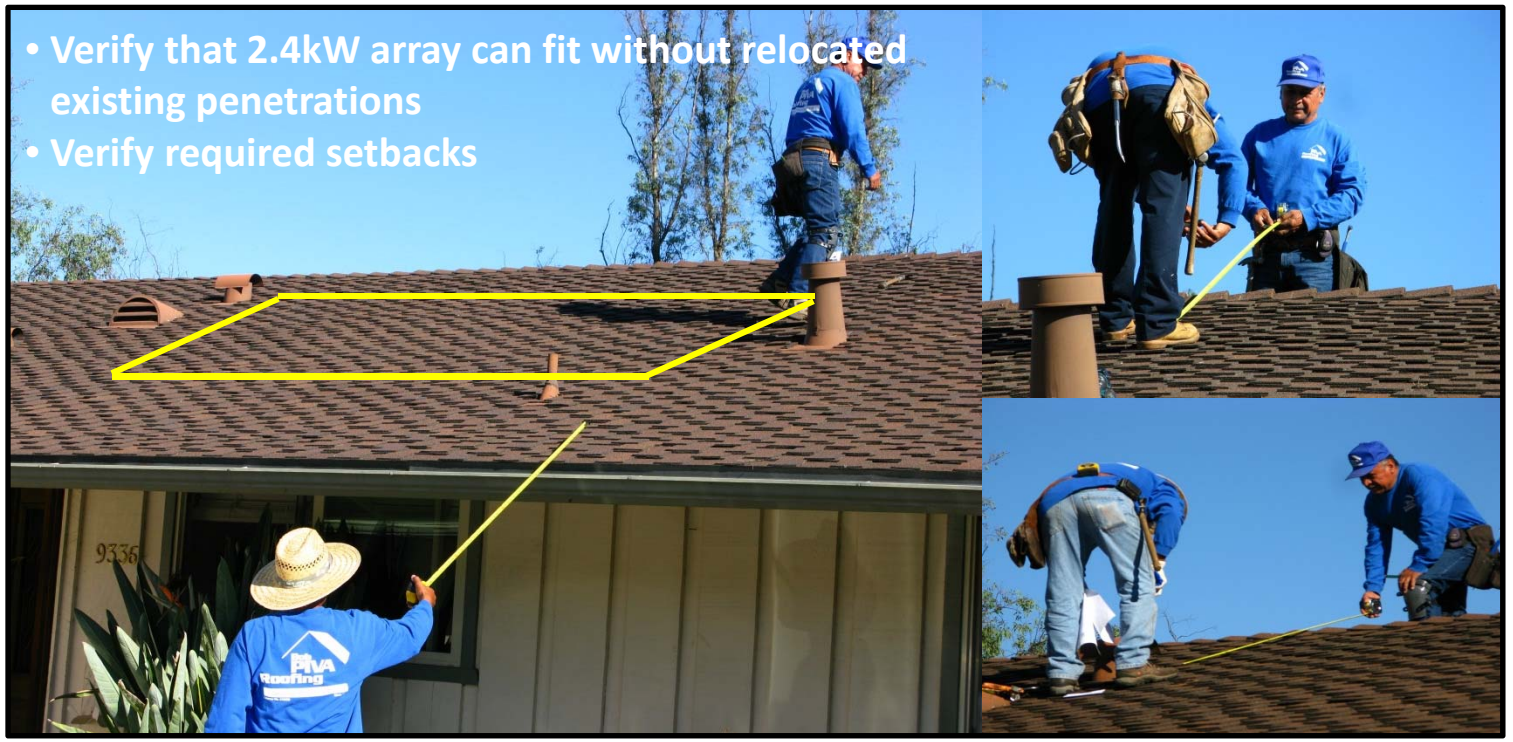
Test Home 1 – La Mesa

Location of array and rafter positions



Once the array position is locked in …

- Checking out the roof
- Identifying positions of rafters

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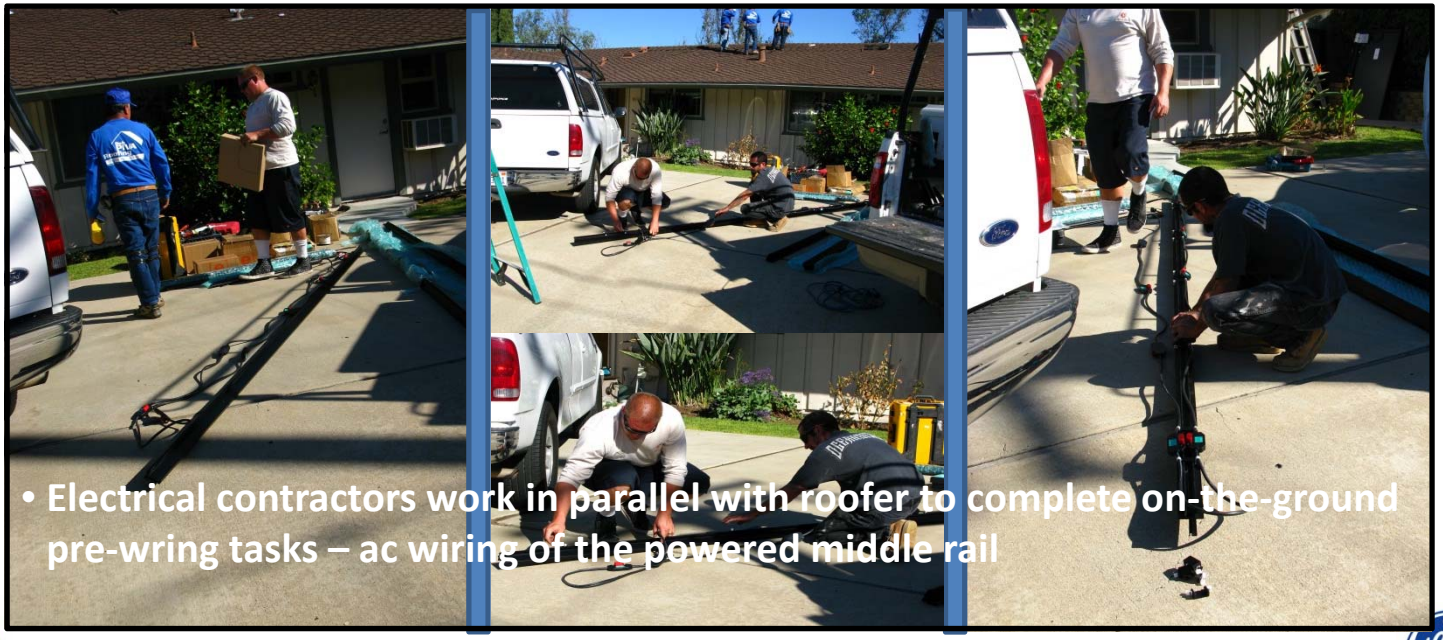
Test Home 1 – La Mesa *Kit is unloaded and ready to go*



- Electrical contractors work in parallel with roofer to complete on-the-ground pre-wring tasks – ac wiring of the powered middle rail

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Test Home 1 – La Mesa

Installation of stanchions

- Installation starts from the ridge
- Upper course of shingles are removed prior to stanchion installation

first row completed … on to the next row

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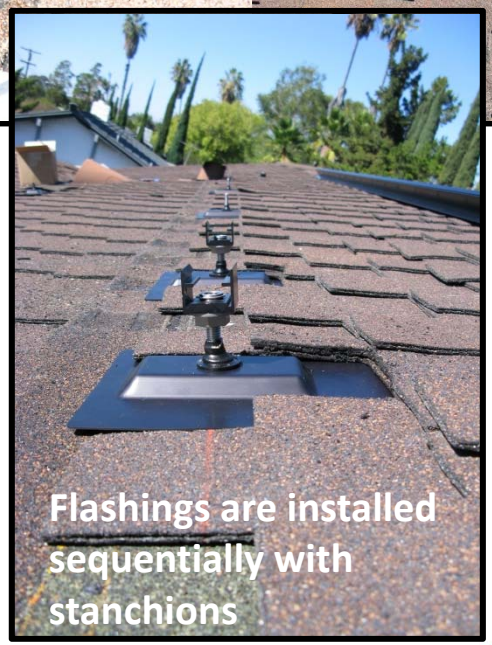
Test Home 1 – La Mesa

Installation of stanchions and flashings

A three-person crew can significantly increase speed of installation when the work is coordinated.



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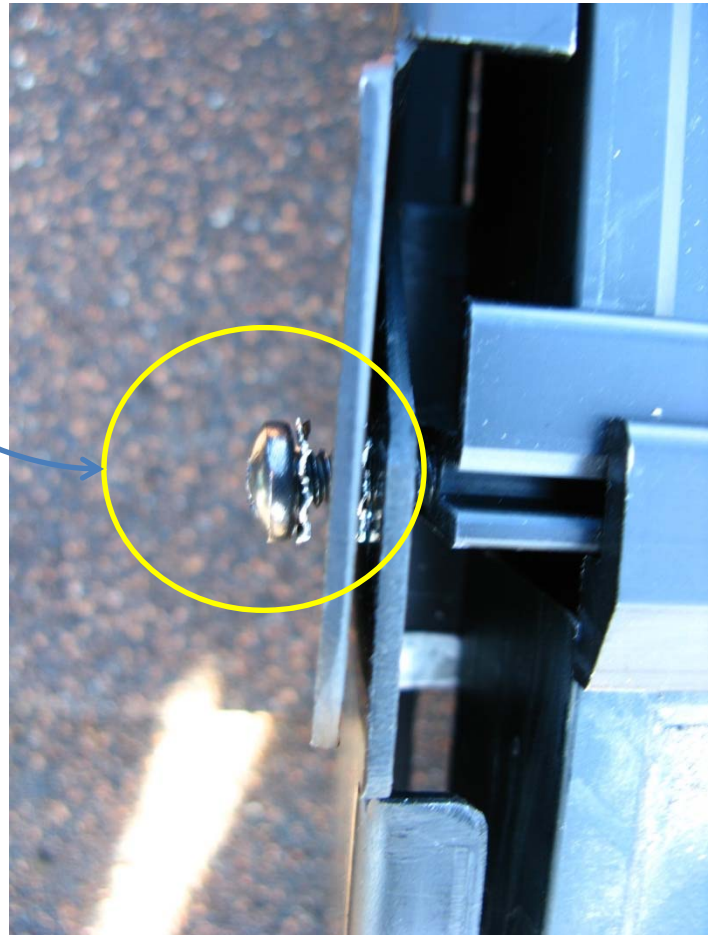
Test Home 1 – La Mesa

Installation of grounding side panels

Grounding side panels overlap. A self-tapping screen and star washer combination are used for attachment to the rail and to achieve electrical bonding between rails



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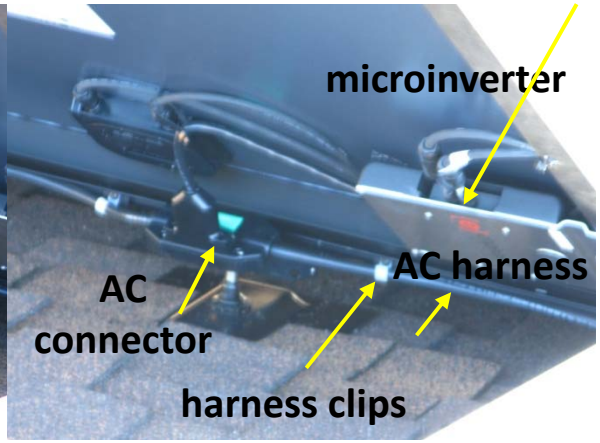
Test Home 1 – La Mesa

AC connection of module



Flashing assembly w/ clip and rail

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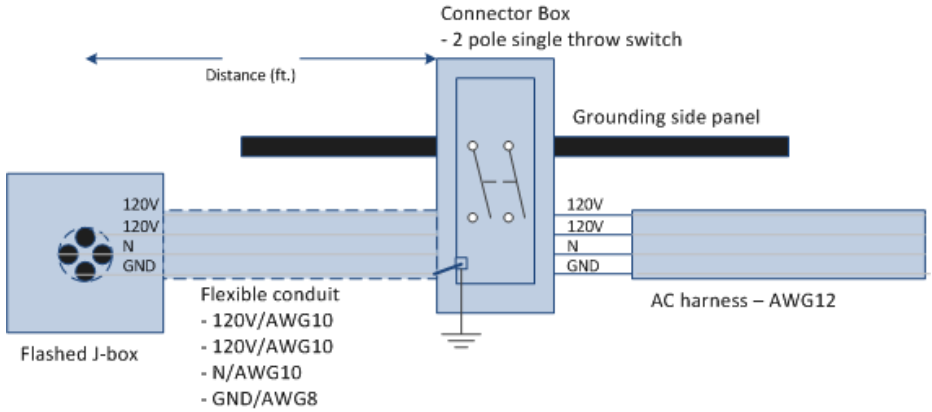
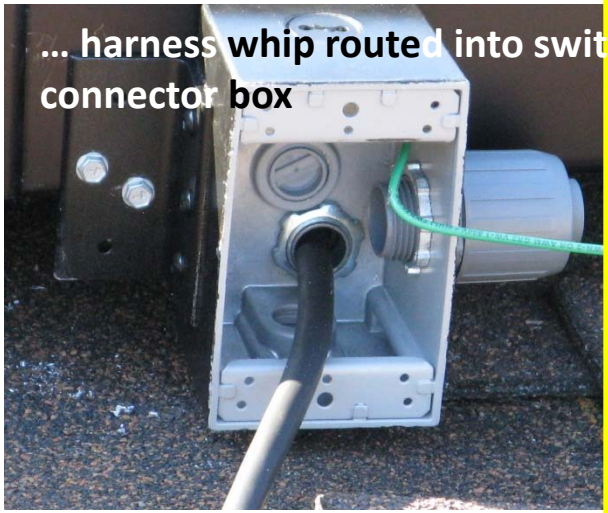
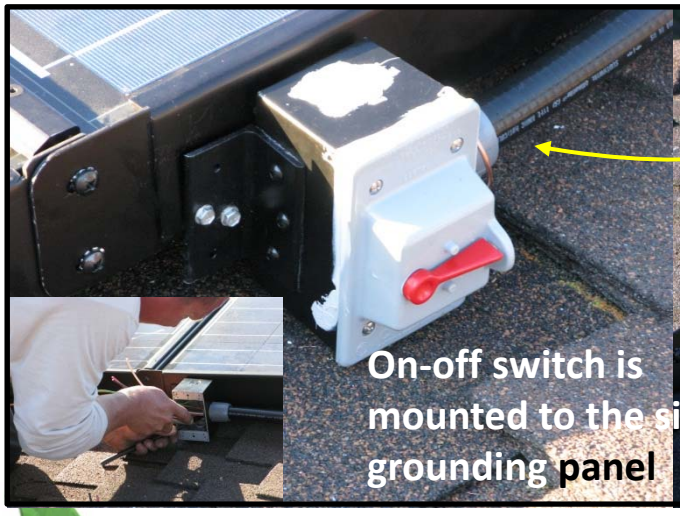
Test Home 1 – La Mesa

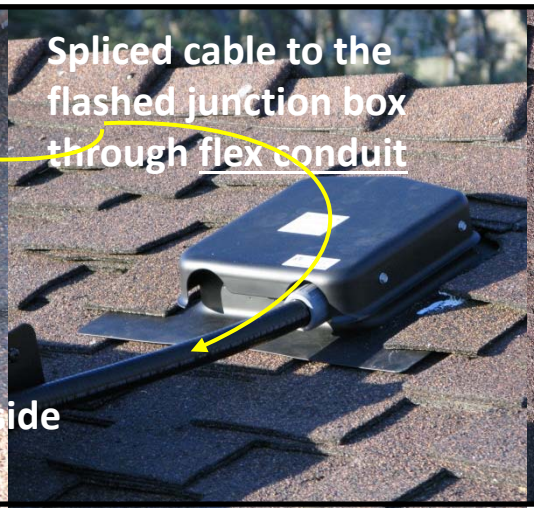
Rooftop electrical Assembly

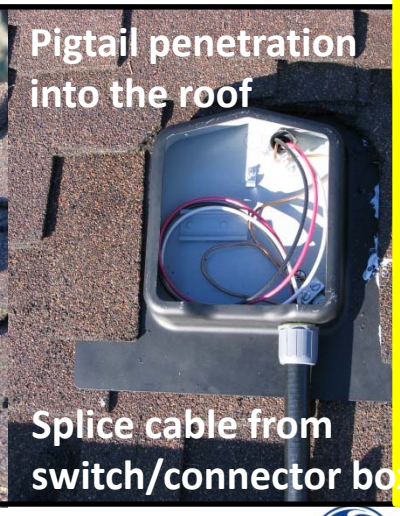
The rooftop electrical assembly brings the wiring into the house. From there











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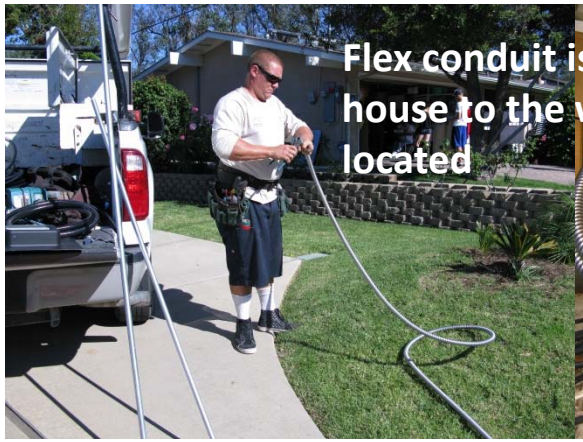
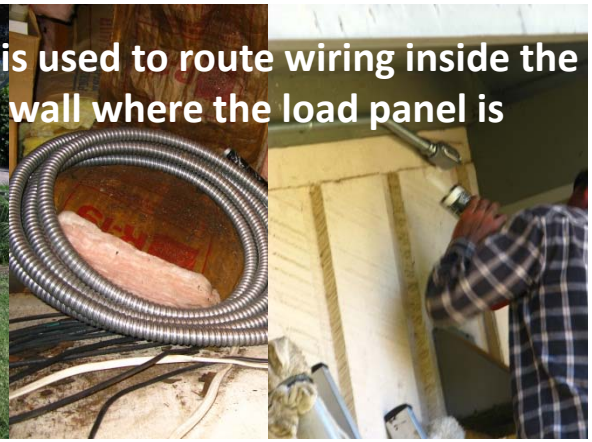
Test Home 1 – La Mesa

Wiring to the load panel

Wiring to the load panel has to conform to the house – this can require a custom solution beyond the roof assembly





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Test Home 2 – El Cajon

2.4 kW beta system installation - El Cajon, CA

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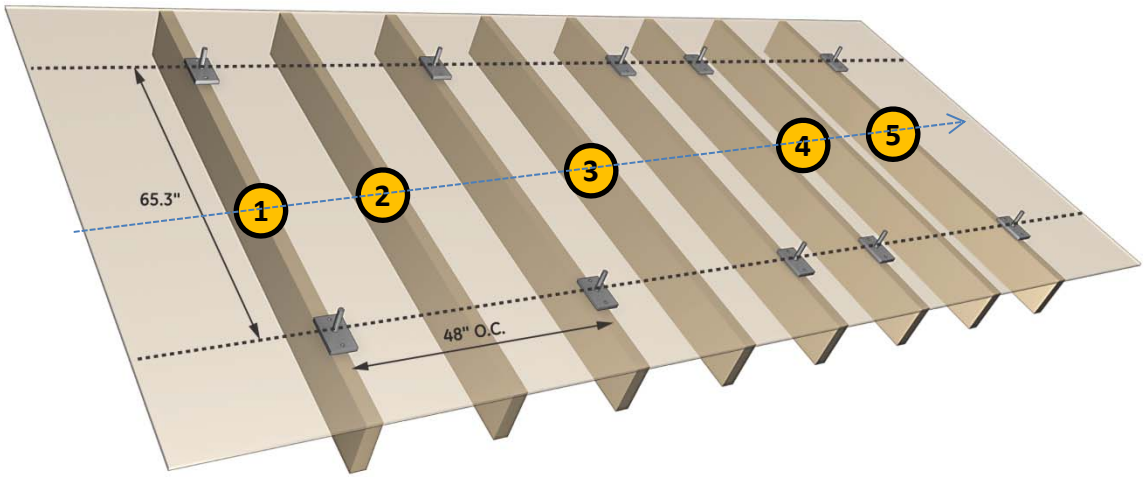
Test Home 2 – El Cajon

Staggering of stanchions in the middle row to balance roof loading



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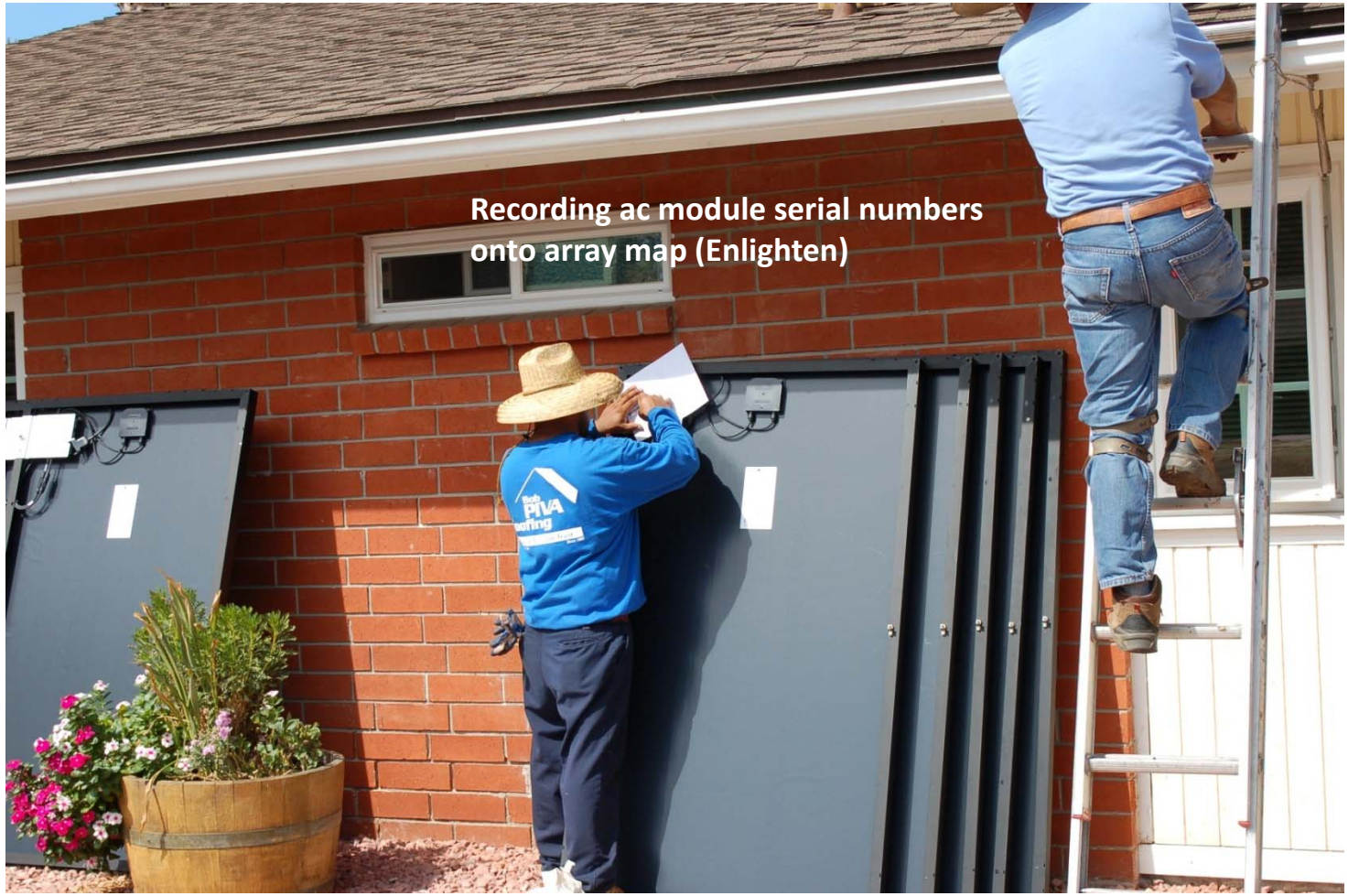
Test Home 2 – El Cajon

Tracking ac module serial numbers prior to installing modules



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Test Home 2 – El Cajon

Non-uniformity in system grounding requirement across the U.S.

Notes:

- GE has a system grounding approach for ac modules that uses the ac harness ground the system similar to an appliance
  - the code is unclear on grounding practices for ac modules
- CE inspectors still require a separate grounding circuit resulting in high cost and longer installation time

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Test Home 2 – El Cajon

GE plug and play installation of ac modules

GE plug and play make connection as simple as an appliance

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Test Home 2 – El Cajon

On-roof adjustment of ac wire harness

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Test Home 2 – El Cajon

Installation of the module retaining cover

The retaining cover installed for each module locks them into place

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Test Home 2 – El Cajon

Installation of the front finishing panel

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Installation of the grounding side panels

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Test Home 2 – El Cajon

Rooftop electrical interface

Safety cutoff switch and flashed penetration assembly

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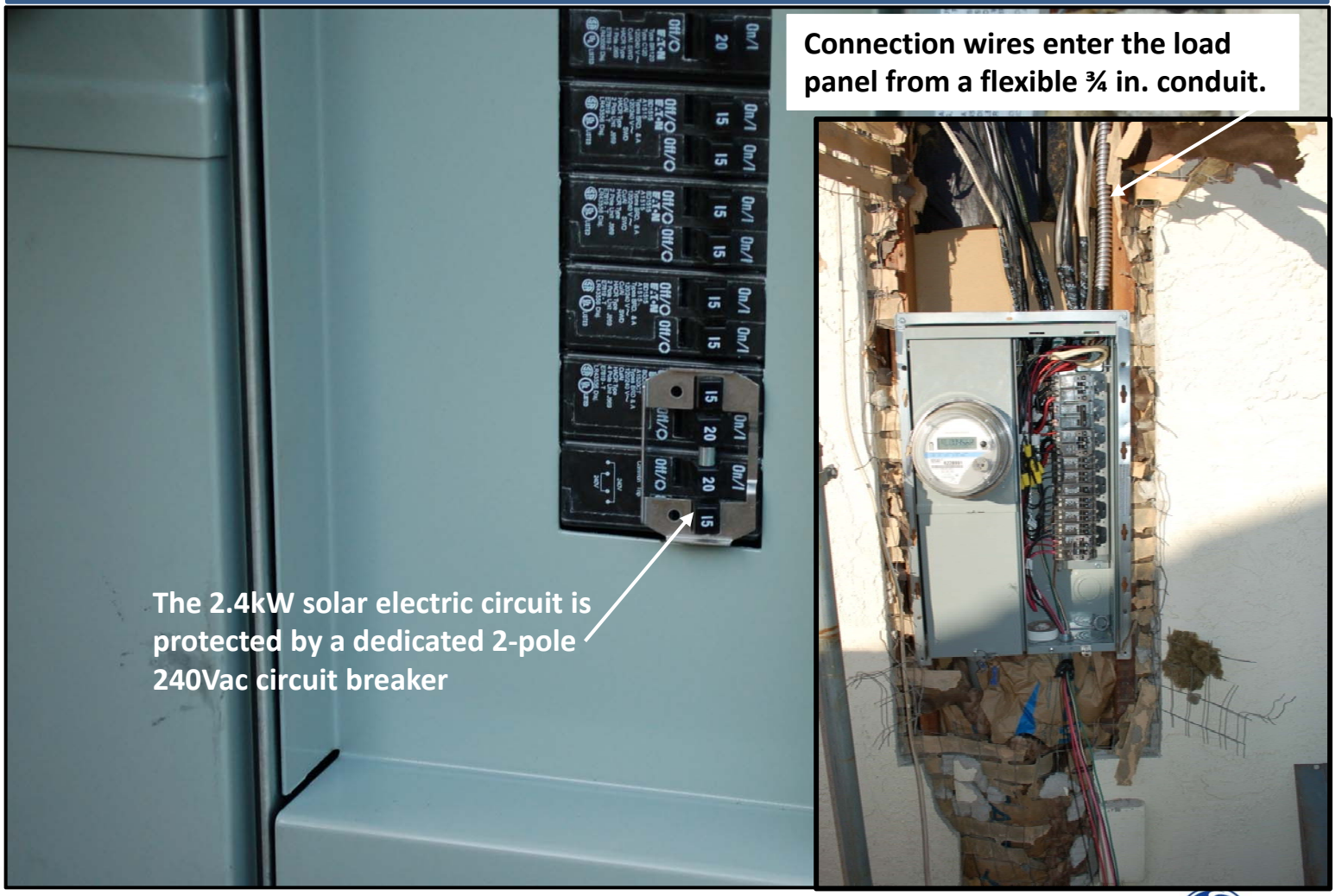
Test Home 2 – El Cajon

Load panel installation

Solar system is on a dedicated circuit having a 2-pole 240Vac circuit breaker



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Test Home 2 – El Cajon

CA requirement for safety/warning placards

PROJECT DIRECTORY:	PROJECT ADDRESS:
OWNER/CLIENT: ADDRESS: TELEPHONE: SOLAR CONTRACTOR: ASGARD ELECTRIC 1501 S MORENO STREET OCEANSIDE, CA 92054 TEL: 760.420.8515	, El Cajon, CA 92020

PHOTOVOLTAIC DISCONNECT

RATED MAXIMUM POWER POINT CURRENT:	7.84	A
RATED MAXIMUM POWER POINT VOLTAGE:	29.96	V
MAXIMUM SYSTEM VOLTAGE:	40.20	V
SHORT CIRCUIT CURRENT:	8.40	A

LABEL 4 (4.5"x1.5" Black Metal With Silver Writing)
(LETTER SIZE: PHOTOVOLTAIC (3/16"), RATED MAXIMUM...(1/8"))
INSTALL AT THE PV DC DISCONNECT
PER NEC 690.14(C)(2), 690.53

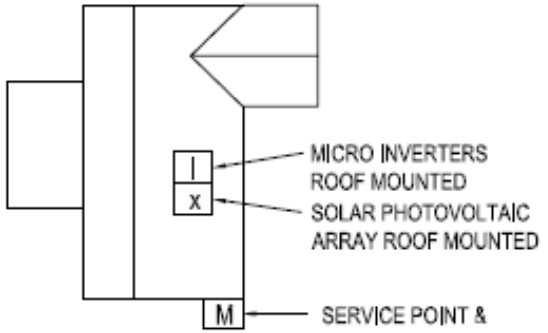
PHOTOVOLTAIC AC DISCONNECT FOR UTILITY USE

OPERATING AC CURRENT:	9	A
OPERATING AC VOLTAGE:	240	V

LABEL 5 (4"x1.5" Black Metal With Silver Writing)
(LETTER SIZE: PHOTOVOLTAIC (3/16"), OPERATING CURRENT...(1/8"))
THE INTERACTIVE SYSTEM POINT OF CONNECTION OR DISCONNECTION MUST BE LABELLED WITH THIS PLACARD
PER NEC 690.54

CAUTION

POWER TO THIS BUILDING IS ALSO SUPPLIED FROM THE FOLLOWING SOURCES WITH DISCONNECTS LOCATED AS SHOWN:



LABEL 7
A PERMANENT PLAQUE SHALL BE INSTALLED AT EACH SERVICE DISCONNECT LOCATION DENOTING ALL OTHER SERVICES, FEEDERS AND BRANCH CIRCUITS SUPPLYING THAT BUILDING. SIGNAGE SHALL BE RED BACKGROUND WITH WHITE ENGRAVED LETTERS
(LETTER SIZE: CAUTION(3/4"), POWER TO...(1/4"), CALL OUTS (1/8"))
PER NEC 690.56 (B), 230.2(E), AND UTILITY REQUIREMENTS)

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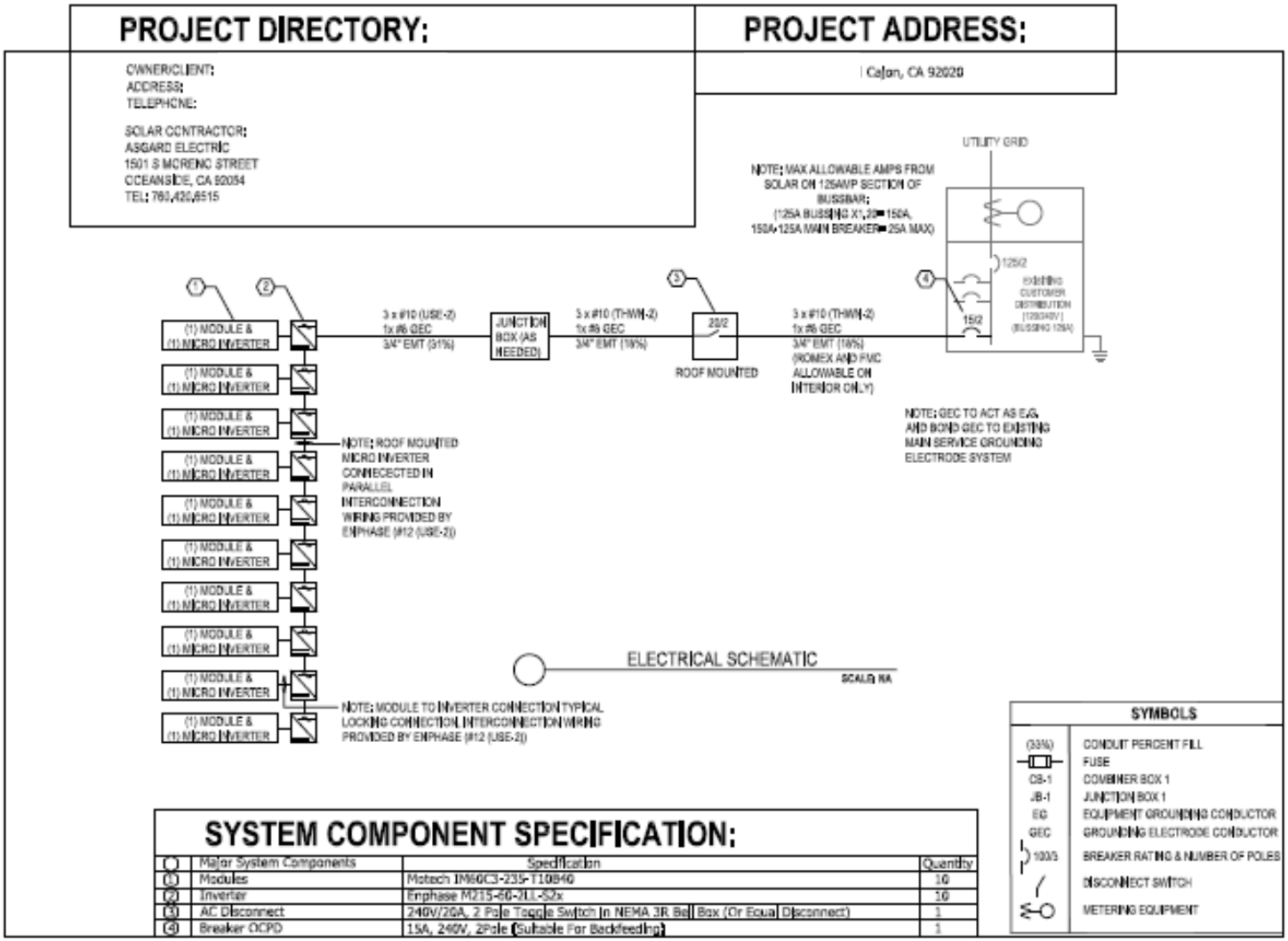
Test Home 2 – El Cajon

Electrical line drawing is required for permitting and interconnect approvals



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Test Home 3 – El Cajon

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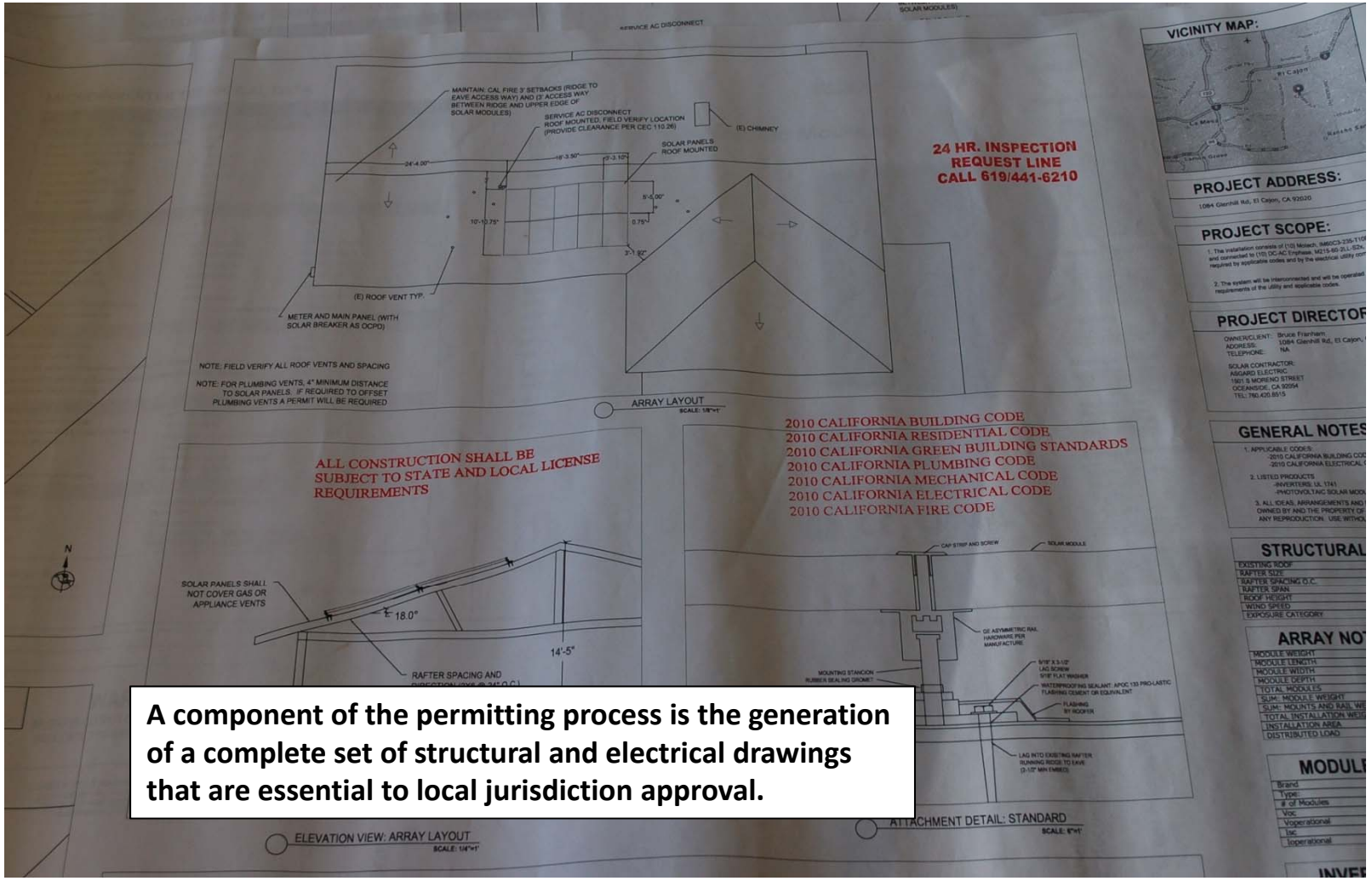
Test Home 3 – El Cajon

Drawings generated for local jurisdictional permit approval



A component of the permitting process is the generation of a complete set of structural and electrical drawings that are essential to local jurisdiction approval.

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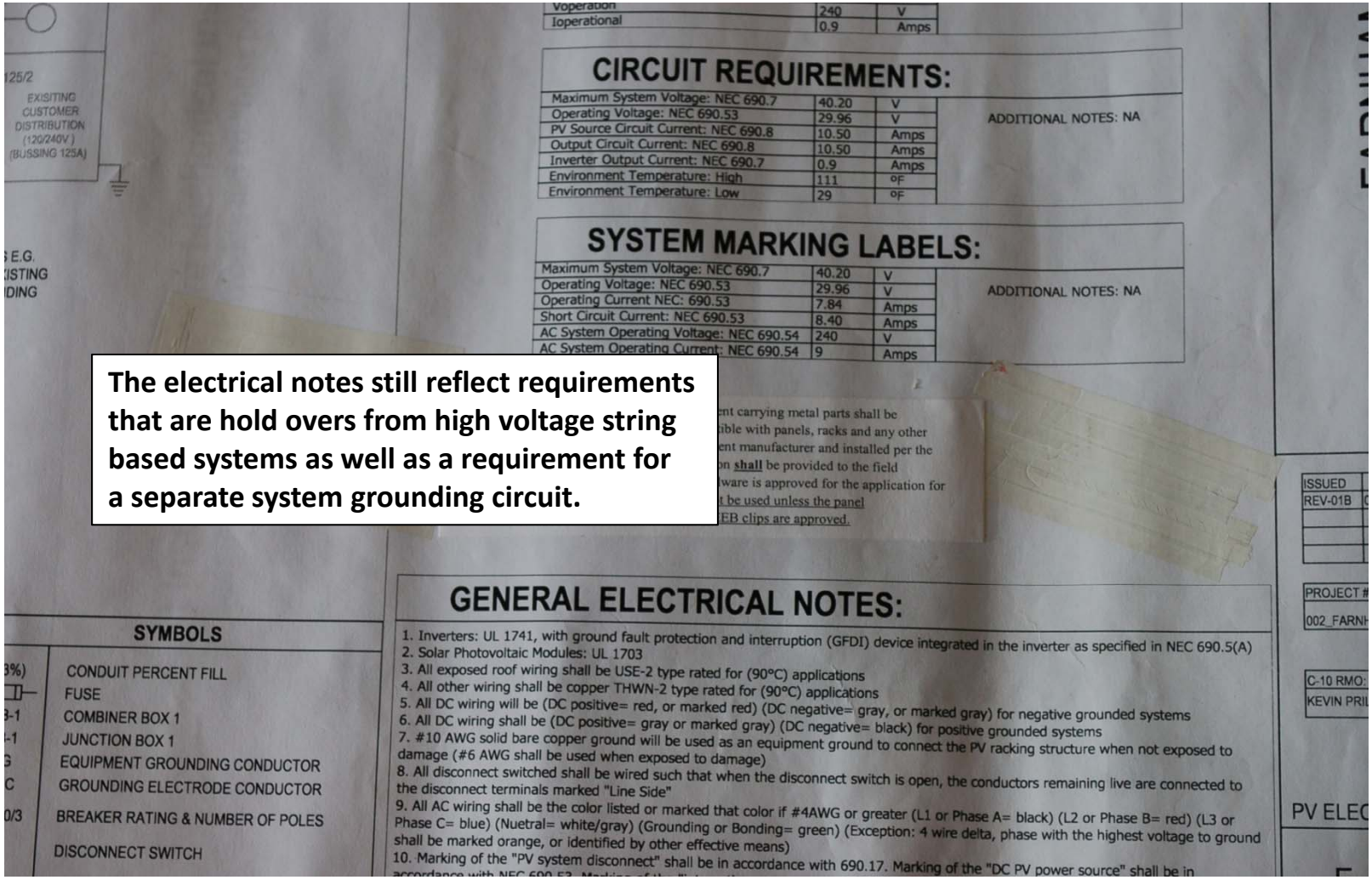
Test Home 3 – El Cajon

Drawings generated for local jurisdictional permit approval



Voperation	240	V
Ioperational	0.9	Amps

CIRCUIT REQUIREMENTS:

Maximum System Voltage: NEC 690.7	40.20	V	ADDITIONAL NOTES: NA
Operating Voltage: NEC 690.53	29.96	V	
PV Source Circuit Current: NEC 690.8	10.50	Amps	
Output Circuit Current: NEC 690.8	10.50	Amps	
Inverter Output Current: NEC 690.7	0.9	Amps	
Environment Temperature: High	111	°F	
Environment Temperature: Low	29	°F	

SYSTEM MARKING LABELS:

Maximum System Voltage: NEC 690.7	40.20	V	ADDITIONAL NOTES: NA
Operating Voltage: NEC 690.53	29.96	V	
Operating Current NEC: 690.53	7.84	Amps	
Short Circuit Current: NEC 690.53	8.40	Amps	
AC System Operating Voltage: NEC 690.54	240	V	
AC System Operating Current: NEC 690.54	9	Amps	

The electrical notes still reflect requirements that are hold overs from high voltage string based systems as well as a requirement for a separate system grounding circuit.

GENERAL ELECTRICAL NOTES:

1. Inverters: UL 1741, with ground fault protection and interruption (GFDI) device integrated in the inverter as specified in NEC 690.5(A)
2. Solar Photovoltaic Modules: UL 1703
3. All exposed roof wiring shall be USE-2 type rated for (90°C) applications
4. All other wiring shall be copper THWN-2 type rated for (90°C) applications
5. All DC wiring will be (DC positive= red, or marked red) (DC negative= gray, or marked gray) for negative grounded systems
6. All DC wiring shall be (DC positive= gray or marked gray) (DC negative= black) for positive grounded systems
7. #10 AWG solid bare copper ground will be used as an equipment ground to connect the PV racking structure when not exposed to damage (#6 AWG shall be used when exposed to damage)
8. All disconnect switched shall be wired such that when the disconnect switch is open, the conductors remaining live are connected to the disconnect terminals marked "Line Side"
9. All AC wiring shall be the color listed or marked that color if #4AWG or greater (L1 or Phase A= black) (L2 or Phase B= red) (L3 or Phase C= blue) (Nuetral= white/gray) (Grounding or Bonding= green) (Exception: 4 wire delta, phase with the highest voltage to ground shall be marked orange, or identified by other effective means)
10. Marking of the "PV system disconnect" shall be in accordance with 690.17. Marking of the "DC PV power source" shall be in

SYMBOLS

- CONDUIT PERCENT FILL
- FUSE
- COMBINER BOX 1
- JUNCTION BOX 1
- EQUIPMENT GROUNDING CONDUCTOR
- GROUNDING ELECTRODE CONDUCTOR
- BREAKER RATING & NUMBER OF POLES
- DISCONNECT SWITCH

EXISITING CUSTOMER DISTRIBUTION (120/240V) (BUSSING 125A)

ISSUED
REV-01B

PROJECT #
002_FARNH

C-10 RMO:
KEVIN PRIL

PV ELEC

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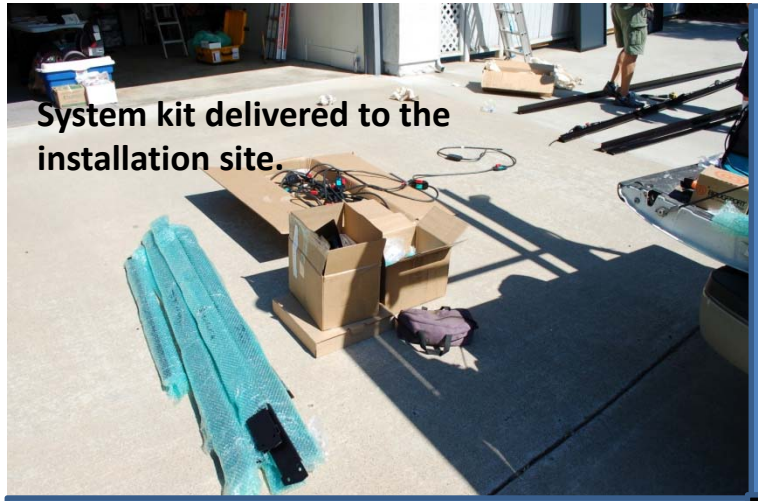
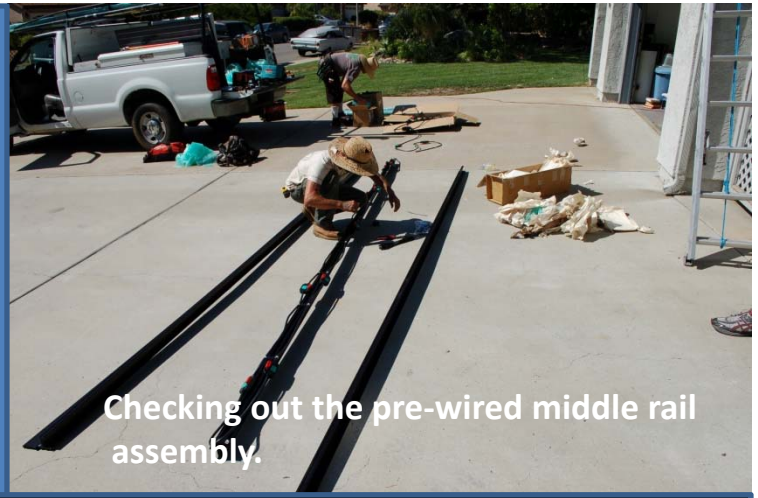
Test Home 3 – El Cajon

Site set-up





System kit delivered to site

Notes:

- Single story residence does not require safety harness, power ladder, etc. so set up is easy

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Test Home 3 – El Cajon

Roof layout – 3 ft. from ridge

Notes:

- CA requirement is array has to be at least 3 ft. from the ridge
- system can go all the way to the eave

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Test Home 3 – El Cajon

Stanchion installation

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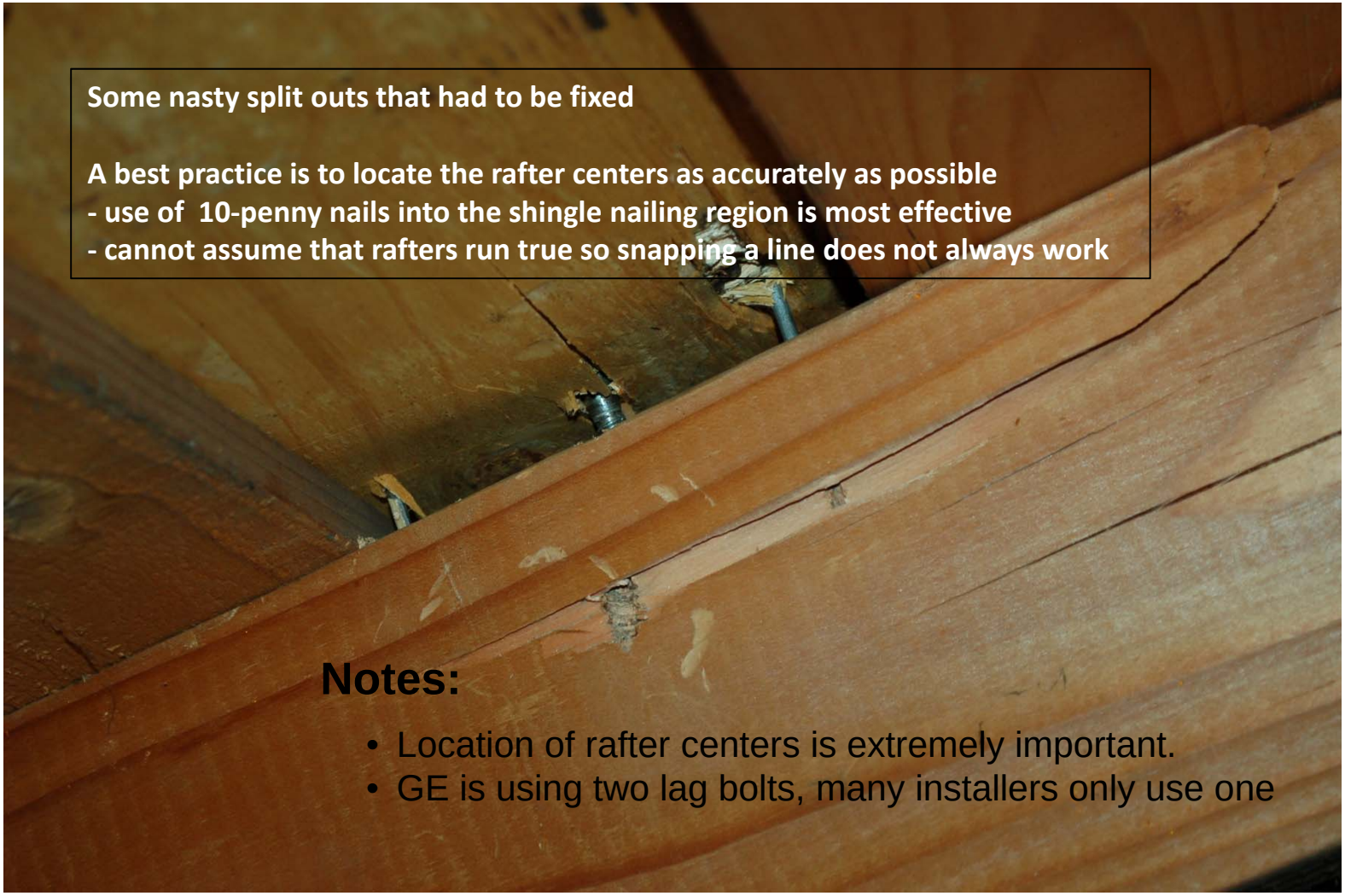
Test Home 3 – El Cajon

All split outs have to be fixed



Notes:

- Location of rafter centers is extremely important.
- GE is using two lag bolts, many installers only use one

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Test Home 3 – El Cajon

Flashing installation use of a PVC sealant

Sealant is used to enhance weather tightness of flashing installation

Notes:

- Other option is use of an Everbond™ butyl pad underneath the flashing
- Sealant on the bottom of the flashing should be sufficient
  - however the CA roofing contractors nail down the flashing

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Adjusting the rail position

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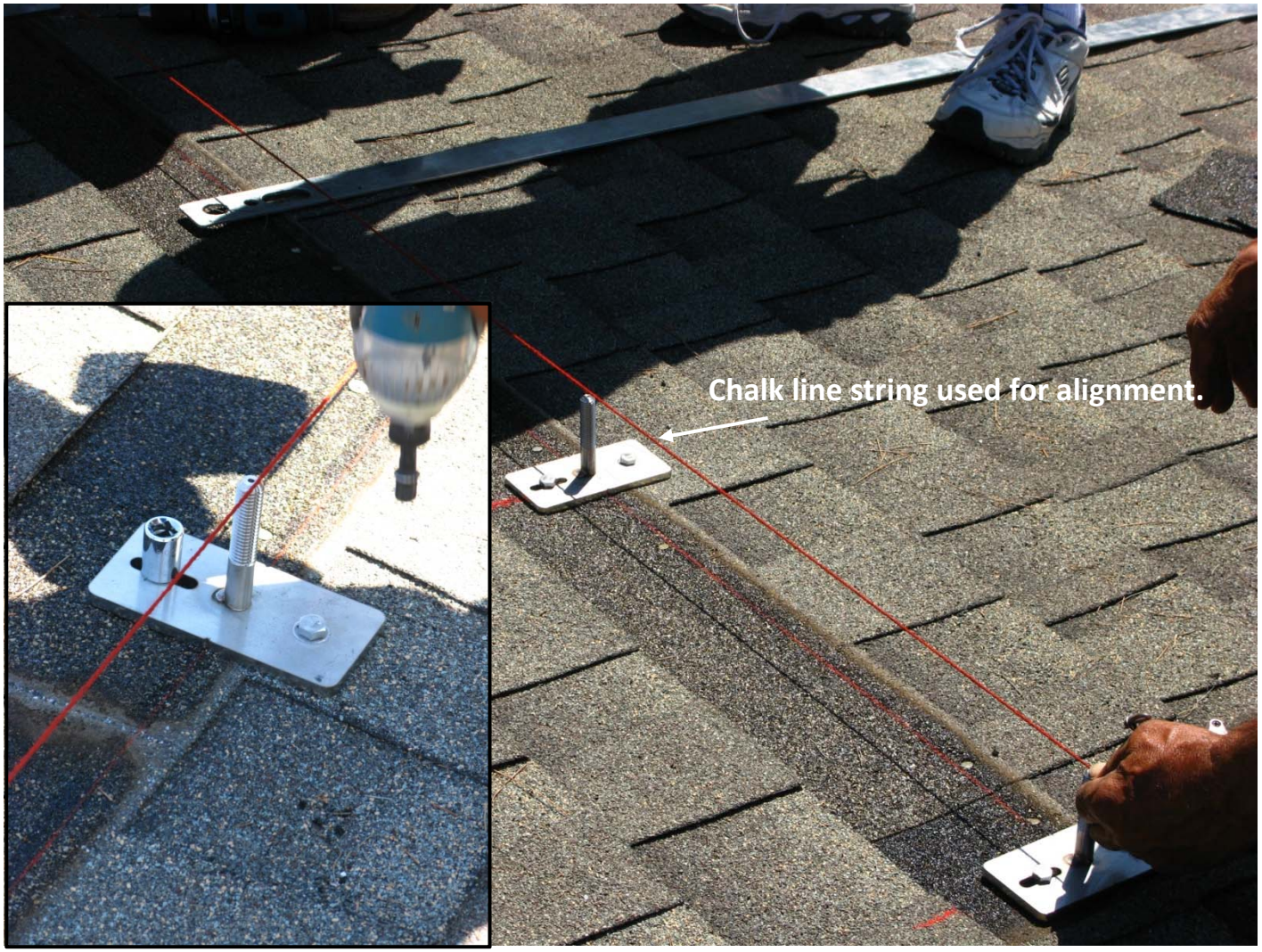
Test Home 3 – El Cajon

Stanchion alignment

All tools the roofing contractors are familiar with + the GE spacing tool



Notes:

Test Home 3 – El Cajon

Flashing installation sequence

Flashing and shingle installation sequence

Shingles laid out and nailed down through nailing strip
this is a Bob Piva roofing choice – not a GE best practice

Preparing a new section of shingles

Cutting in the flashing

Finishing the shingle over-layment

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Test Home 3 – El Cajon

Flashing installation use of a PVC sealant

Notes:

- Staggering the rails to even roof point-loading is a good practice.
  - however with loading < 2 lbs. per square ft the need for staggering is questionable
- Note the lower and upper rails maintain the same stanchion positions and all of the outer stanchions do as well (so the row spacing tool can still be used for the outside stanchions)

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Test Home 3 – El Cajon

Easy movement of materials to the roof and wiring to the load panel

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Use of a three-contractor crew in CA installations

Notes:

- An advantage of a 3-contractor crew is the ability to stagger stanchion row and flashing installations to reduce to total time
- One person can be handling the material (ac modules) while the others complete the installation

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Test Home 3 – El Cajon

Electrical rooftop assembly

Installation of electrical interface and safety cut-off

Notes:

- This system required wiring interconnections be made on the roof
  - the use of flex conduit between the switch/connector box and flashed penetration allows the entire assembly to be prewired and installed by the roofing contractor

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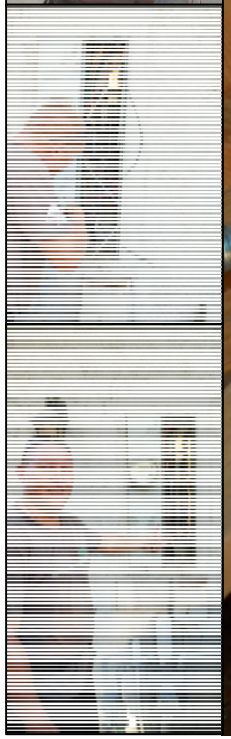
Test Home 3 – El Cajon

Completion of the home run by the electrical contractor



Clean roof penetration – notice the required safety labels
- 4 wires carried through flex conduit AWG10 – 120V, 120V, N;
AWG8 - ground

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Test Home 3 – El Cajon

Clean up

Cleaning up …

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Test Home 4 - Santee

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Test Home 4 - Santee

Delivery of complete installation kit to site

Notes:

- GE kit contains all mounting components including screws, nuts, washers, special alignment tools along with the electrical components.

- components are labeled
- contractor can check off kit components against bill of materials

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Test Home 4 - Santee

Set up for stanchion installation

Notes:

- CA roofer preference to remove a row of shingles where the stanchions are to be installed

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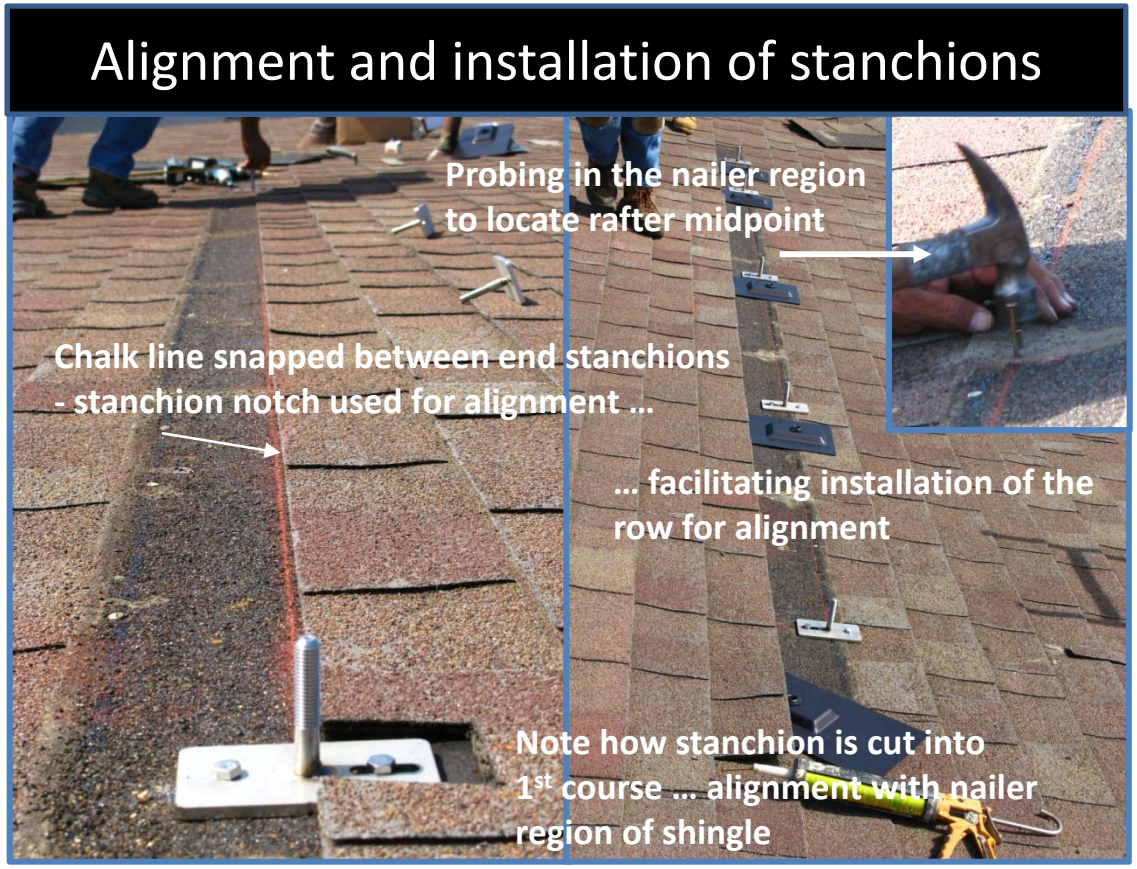
Test Home 4 - Santee

Installation of stanchions



Notes:

- CA roofers are using the special stanchion notch to align their chalk lines
- Critical to locate center of each rafter to avoid split outs – particularly in vaulted ceiling areas that cannot be inspected.

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Test Home 4 - Santee

Stanchion row location

Notes:

- Accurate location of rafter center reduces potential for a split out
  - cannot just snap a line since in CA have found that rafters do not always run true
- Fix before flashing! The inspector will require all split out situations to be repaired.

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Test Home 4 - Santee

Stanchion row location

Use of GE spacing tool for row location

Notes:

- The use of the GE row spacing tool is critical since modules are supported end to end

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Test Home 4 - Santee

Stanchion row installation

Notes:

- In addition to alignment of the stanchions it is important to make sure that the posts are standing straight
  - alignment can be checked by sighting from the edge (if there is room) or using a string as shown

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Test Home 4 - Santee

Installation of flashings - process

Notes:

Application of butyl bead is horse shoe pattern Is a best practice

- CA roofers use nails because they are concerned flashing not wide enough
  NY: not an issue

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Test Home 4 - Santee

Rail installation

Installing the rail

Notes:

- A best practice to look at each clip to be sure the rail is evenly seated on both sides - properly seated rail will require 3,000 lbs. of pull out force
- The rail can still slide (until modules installed) allowing the array to be squared

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Test Home 4 - Santee

AC wire harness

Harness wire dressing

Notes:

- GE uses specially design rail clips to support the ac harness but the Enphase Engage harness has too much slack between connectors
- Next generation product will have a redesigned harness and not require in-field adjustments

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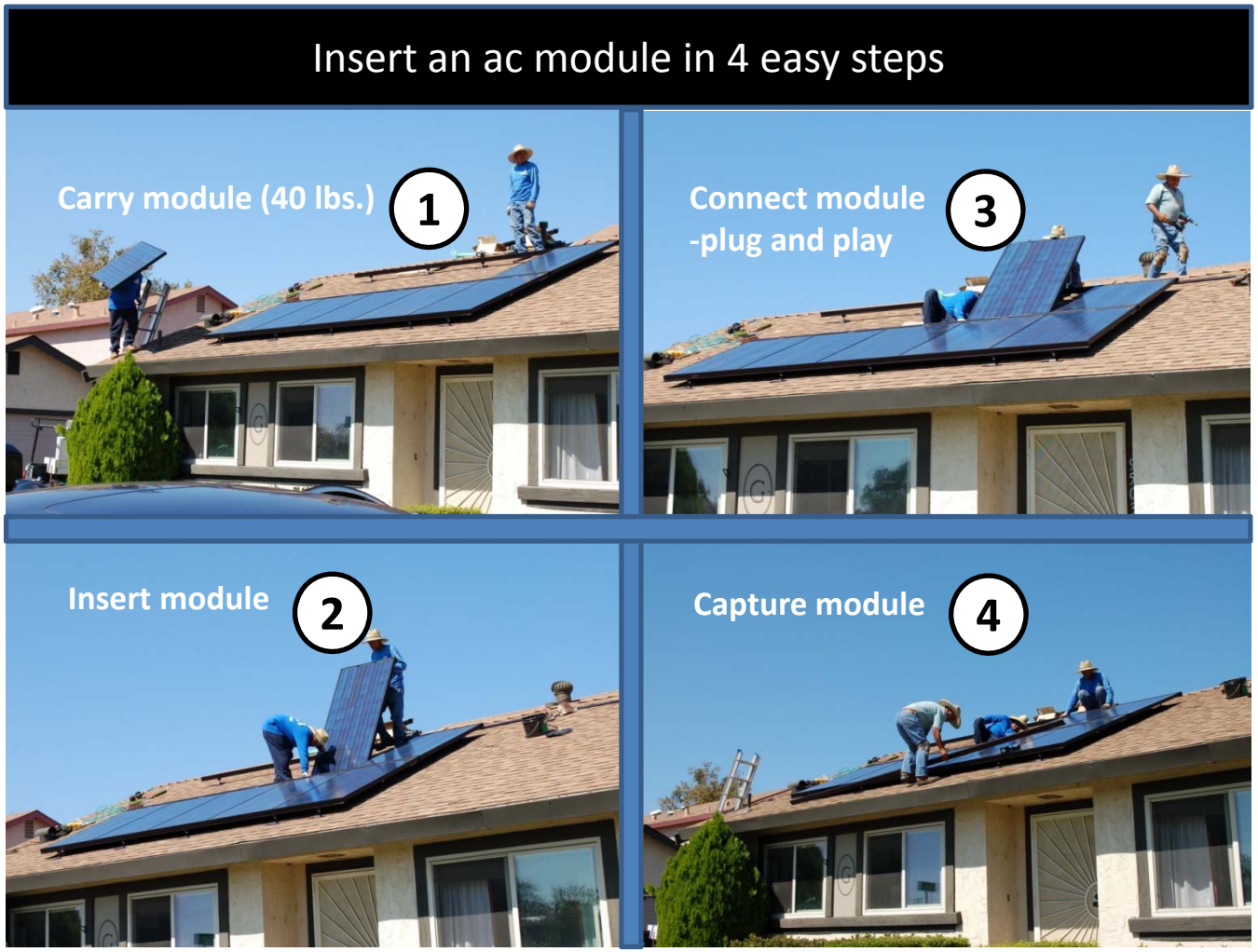
Test Home 4 - Santee

Module insert and capture



Notes:

- It is just as easy to remove a module for maintenance as to insert one

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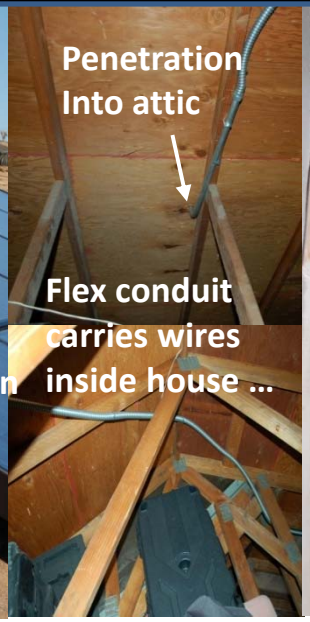
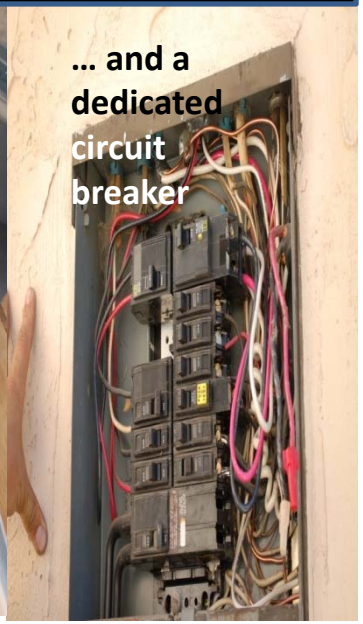
Test Home 4 - Santee

Electrical contractor's work

From the roof to the load panel





Notes:

- CA single story residences provide the simplest wiring scenarios

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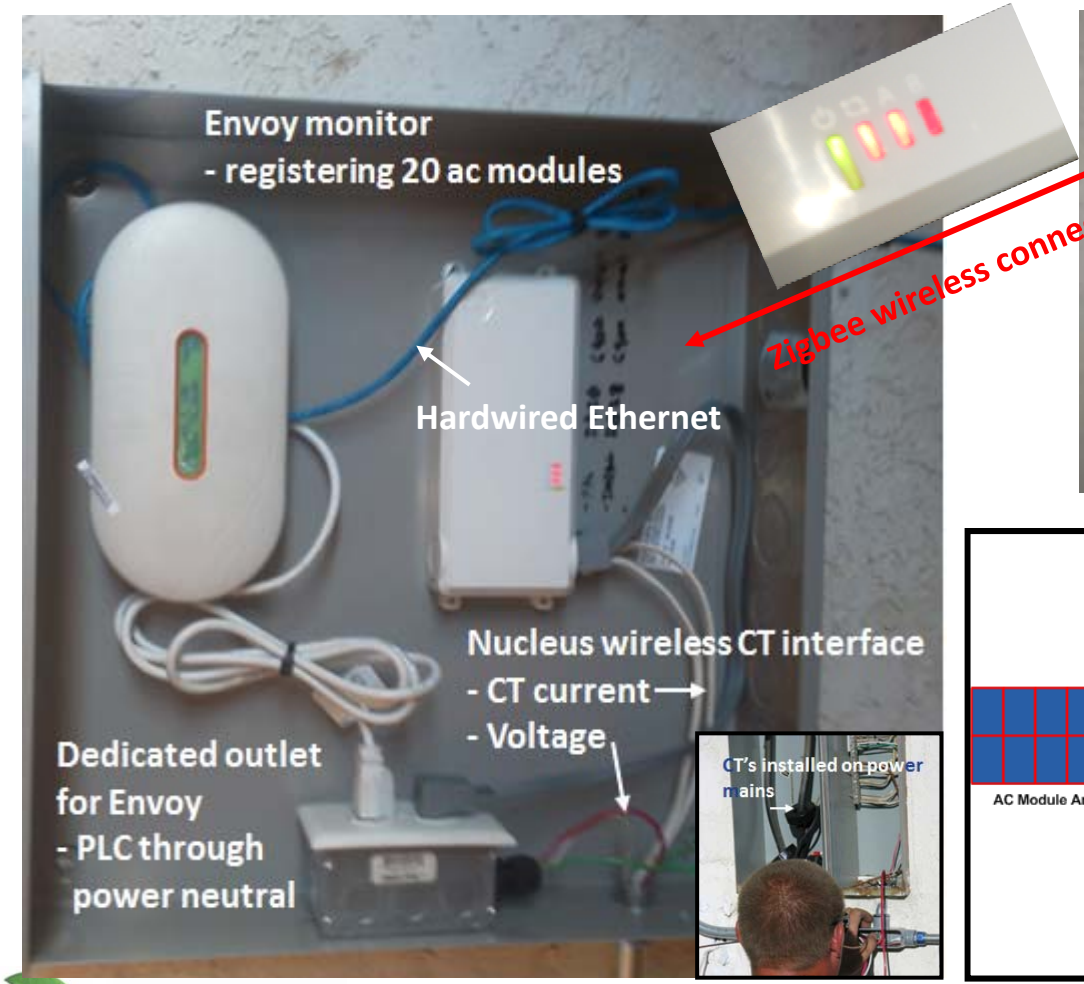
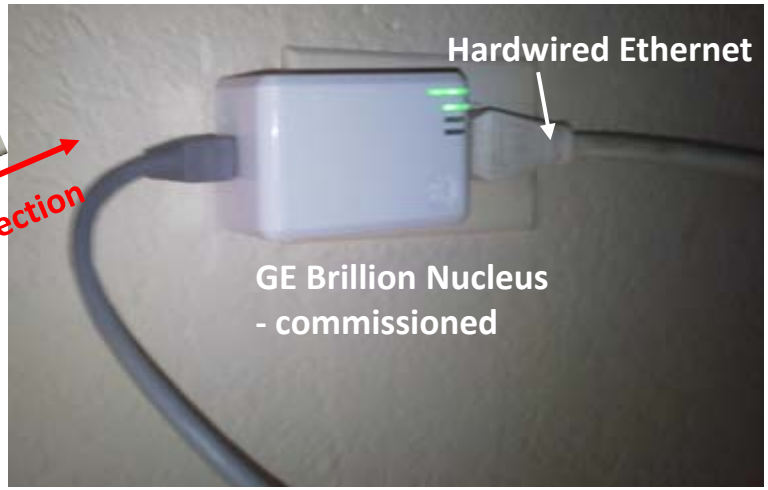
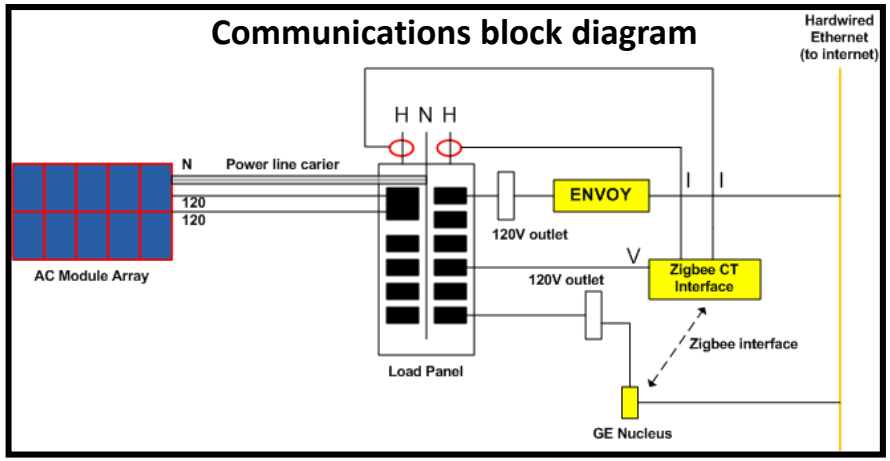
Test Home 4 – Santee

Solar generation and electricity usage monitoring for the Zero Net Energy Home through the GE "Nucleus" that provides energy generation and usage information to the homeowner. The Nucleus also provides Demand Response through GE-DR appliances and DR-module controllers for use at desired electrical outlets (see ZNE Home Report).







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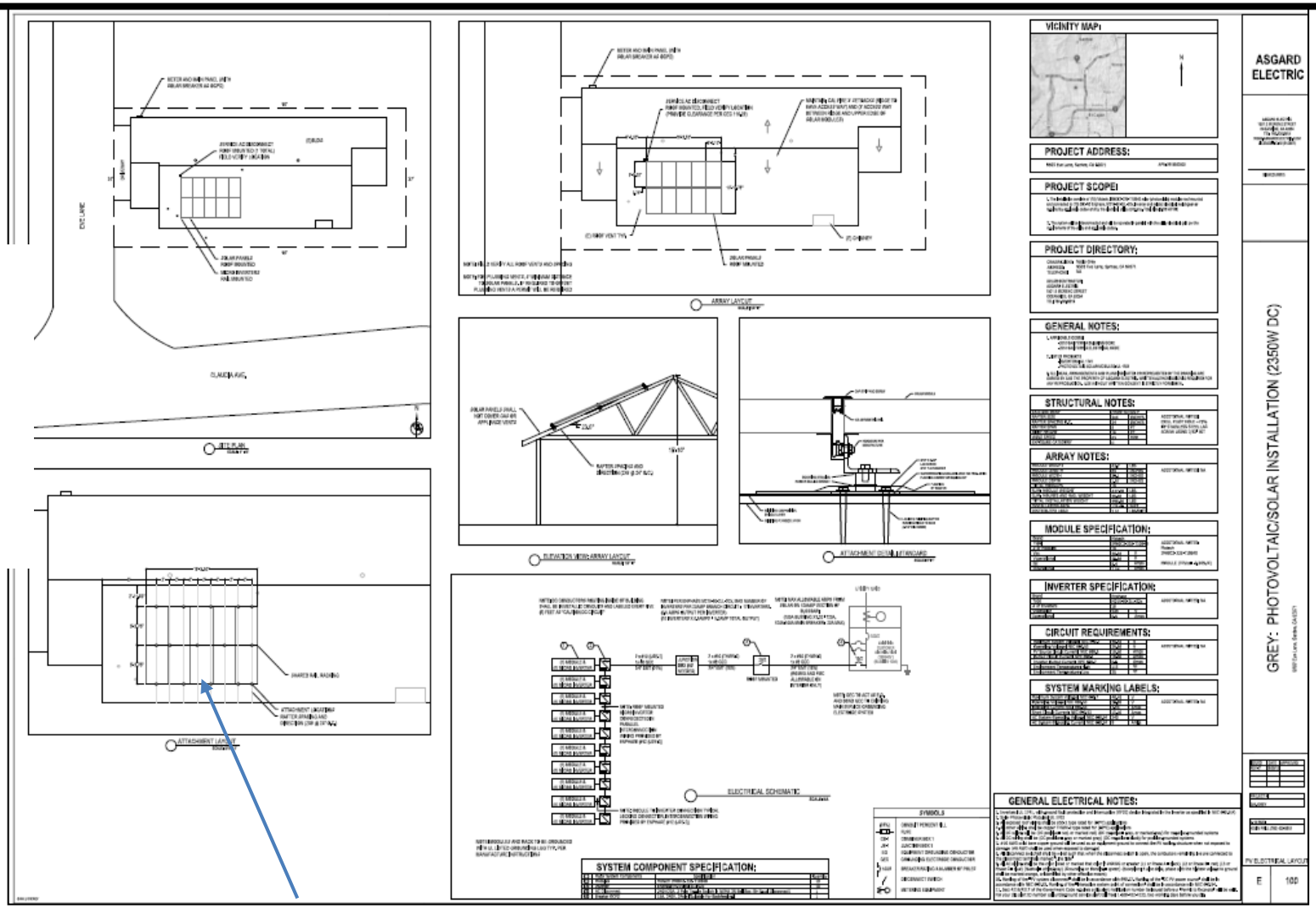
Test Home 4 - Santee

Plan design for local jurisdiction approval

Notes:

- Plan preparation including structural analysis is an element of soft cost



GE baseline design does not stagger stanchion installation. Structural engineer modified the design

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Test Home 5 – Borrego Springs

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Test Home 5 – Borrego Springs

Roofing issue had to be addressed before system could be installed

Home not properly inspected. Best to have been re-roofed, but homeowner declined.
Desirable for project to have home in hot Borrego Springs area.
Decision made to proceed and to place new course of shingles over the top of the nailed shingles

This home stayed as extreme climate test home; dropped as ZEH/ZNE target. Switched to Santee for ZNE.

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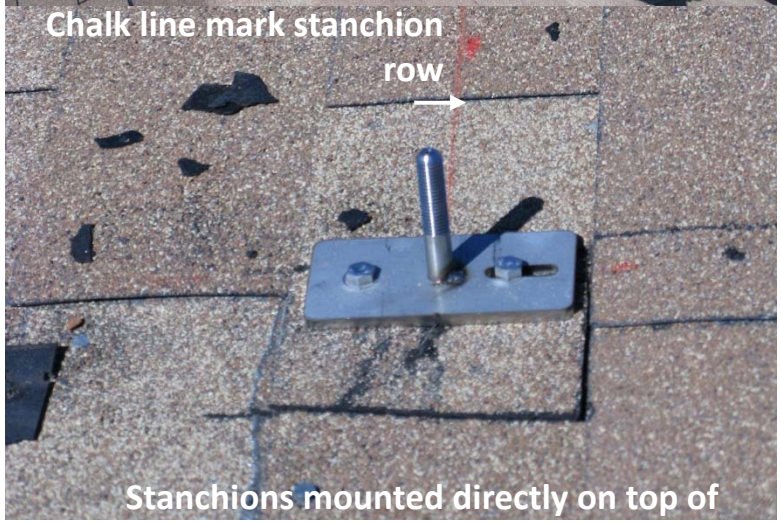
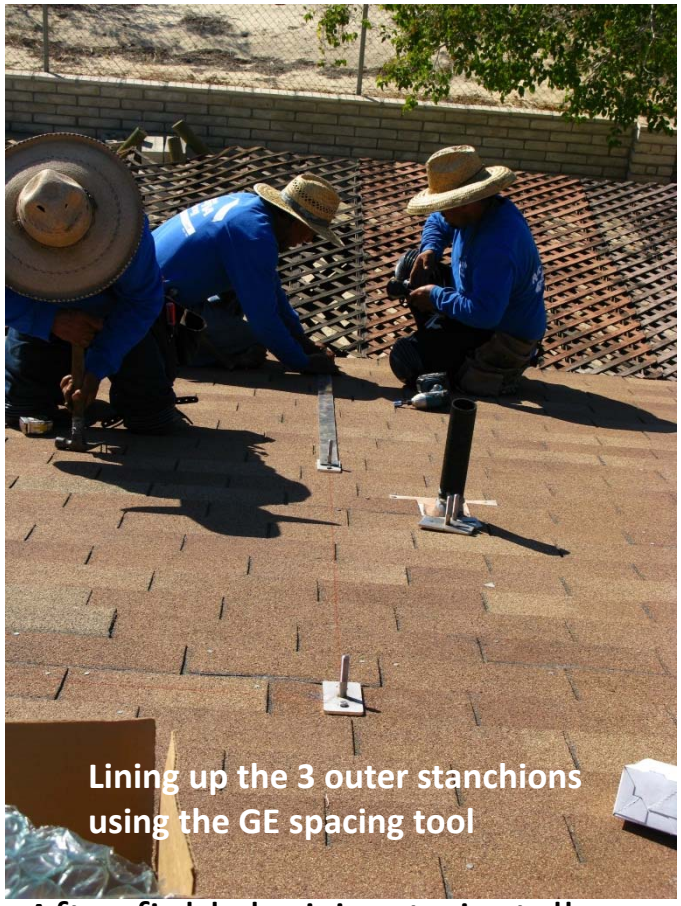
Test Home 5 – Borrego Springs

Stanchion location and mounting





After field-decision to install; proceeded with standard install process.

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Test Home 5 – Borrego Springs

Flashings installed with new roof

Laying down new course of shingles and installing flashings over stanchions

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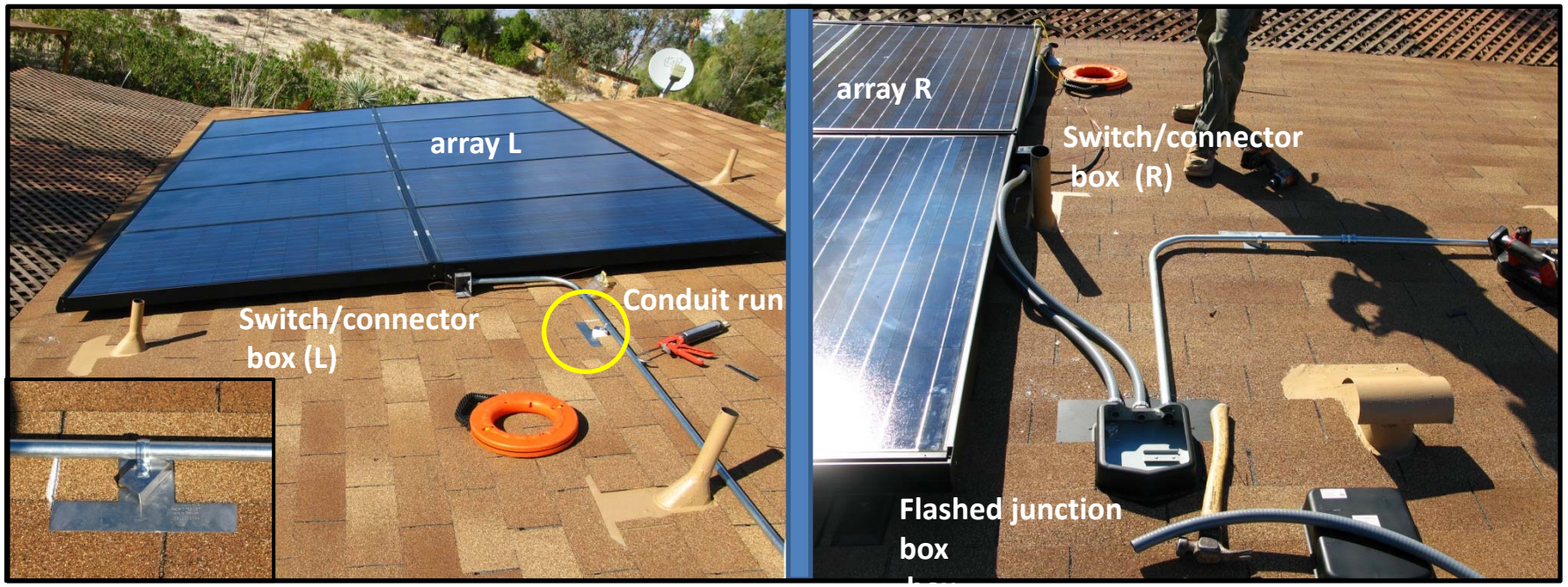
Test Home 5 – Borrego Springs

Rooftop electrical interface



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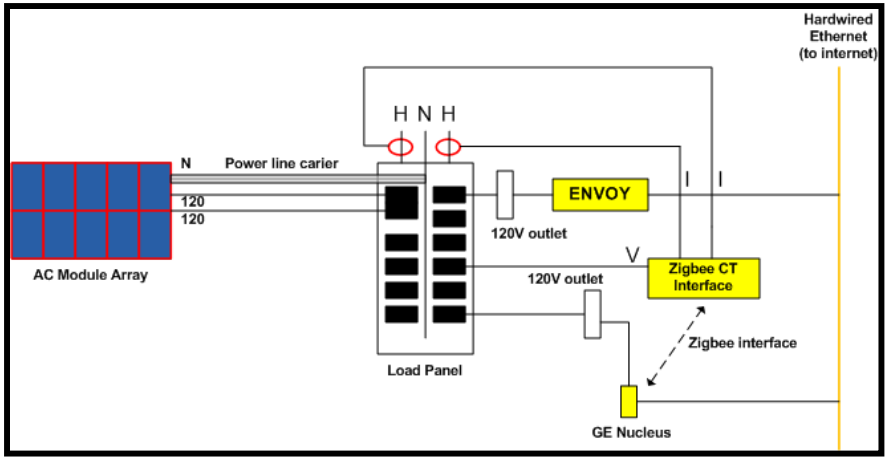
Grid-Ready Plug-and-Play PV Kit

4. PV Systems Commissioning

Once the systems are installed, they need to be commissioned. The commissioning process is designed to make sure that the system and its components are all working and working properly; the process is automated through the Enphase Envoy system, that monitors and can control the Enphase microinverters. Each solar panel, or module, has an Enphase microinverter that converts the DC electricity generated by the solar cells that make up the module to AC electricity. The microinverters also gate the AC output based on signals from the Envoy and their detection of 60Hz (US) line voltage. The Envoy must go through its commissioning process before the microinverters allow current to flow to the electrical panel. Similarly, if the 60Hz AC signal from the meter via the panel is lost, the microinverters close their gates so that generated electricity does not flow into a downed power system, thus avoiding any islanding that could be dangerous to utility linemen who might be working to repair an outage. The figure to the right shows the wiring diagram for the PV modules, to the panel, the connection of the Envoy to the panel. The ZNE home also has a GE Nucleus system, that can monitor electricity generation, house electric loads (through current transformers (CTs) on the electrical mains), and can control Demand Responsive (DR) appliances and electrical boxes via the GE Nucleus.



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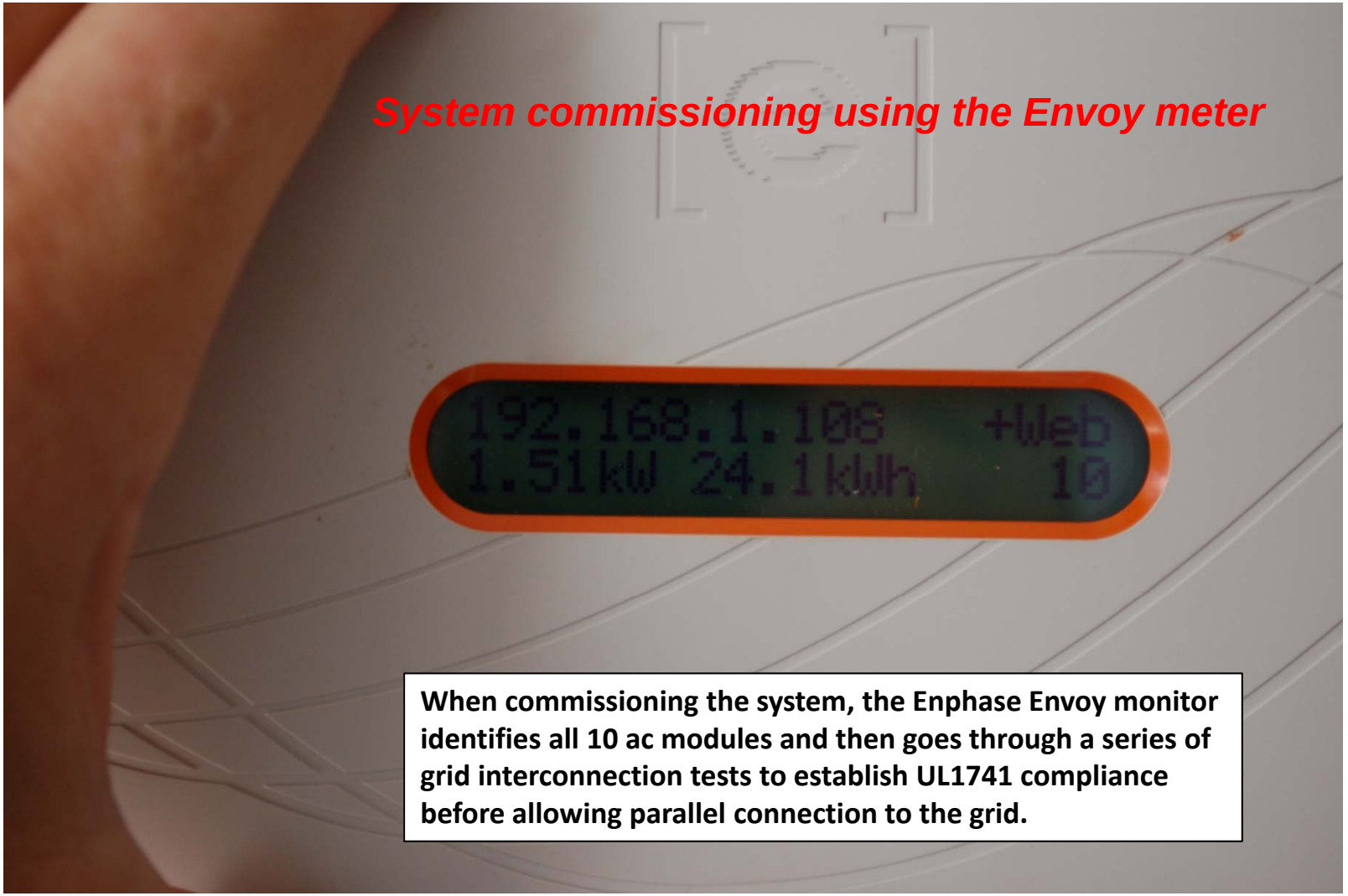
Grid-Ready Plug-and-Play PV Kit
System Commissioning



When commissioning the system, the Enphase Envoy monitor identifies all 10 ac modules and then goes through a series of grid interconnection tests to establish UL1741 compliance before allowing parallel connection to the grid.

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imagination at work

Commissioning Test Home 1 – La Mesa

2.4 kW Pilot Installation – La Mesa, CA

2.4 kW system installation – La Mesa, CA

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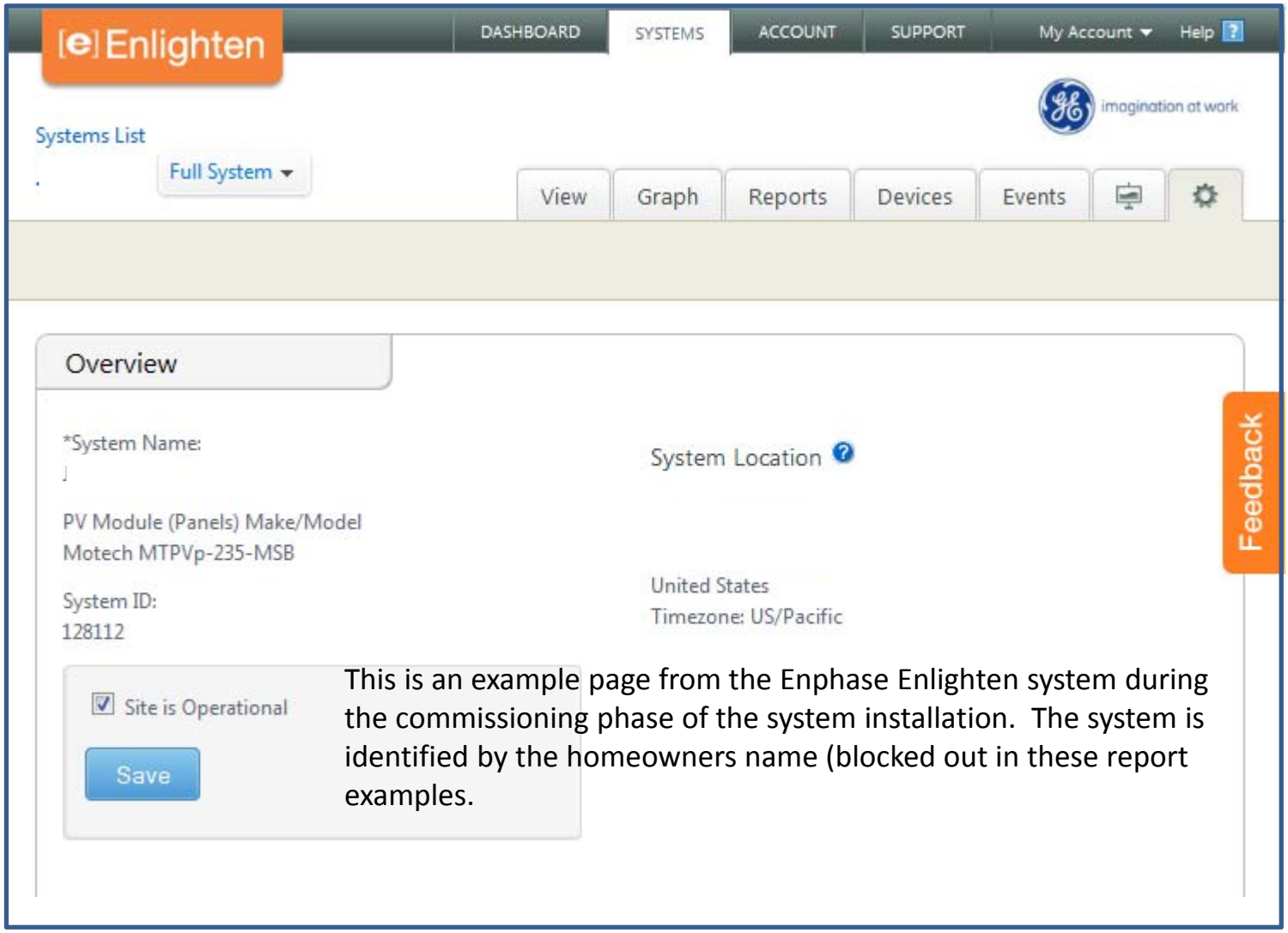
imagination at work

Commissioning Test Home 1 – La Mesa

2.4 kW Pilot Installation – La Mesa, CA



This is an example page from the Enphase Enlighten system during the commissioning phase of the system installation. The system is identified by the homeowners name (blocked out in these report examples.

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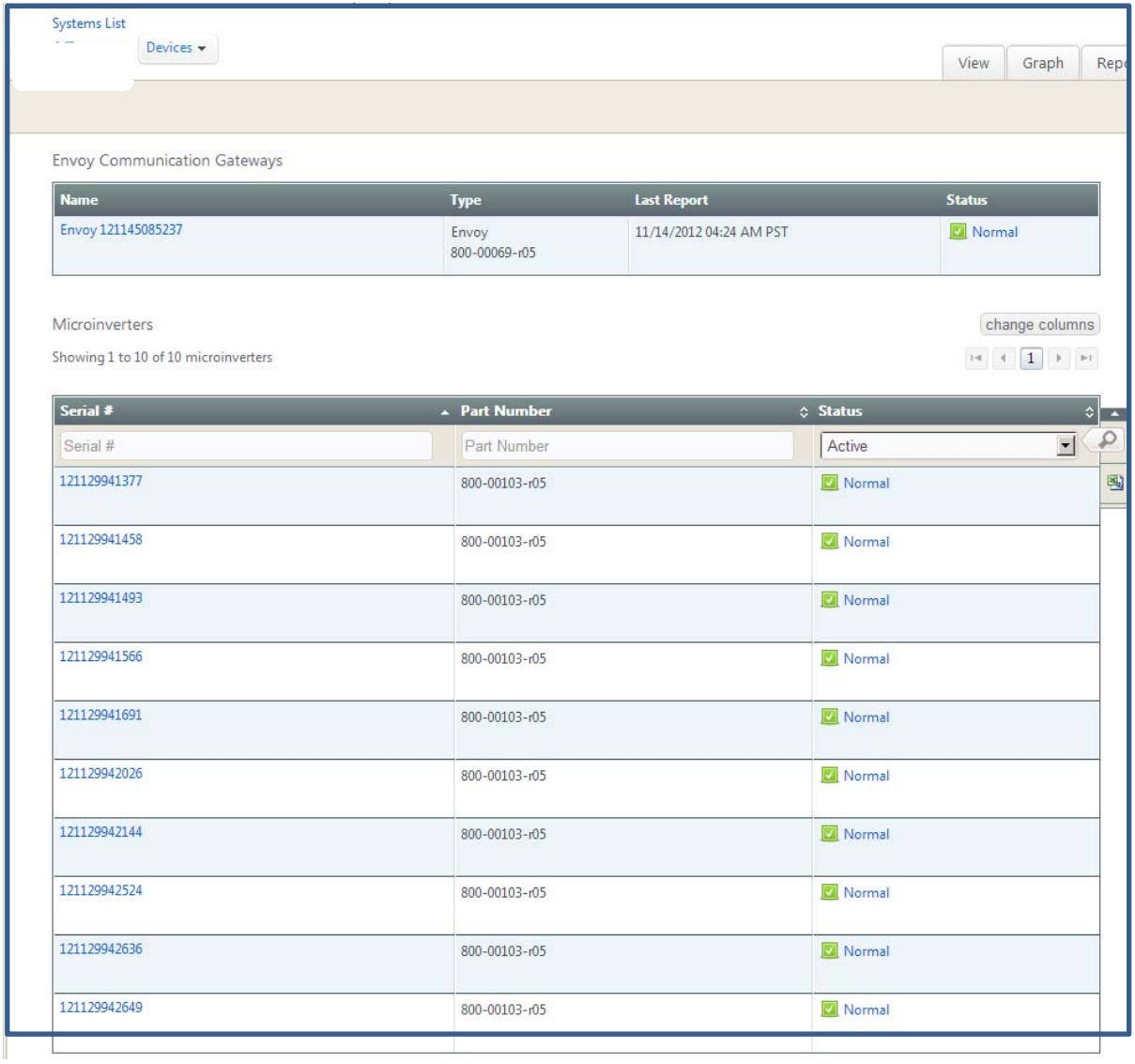
imagination at work

Commissioning Test Home 1 – La Mesa

2.4 kW Pilot Installation – La Mesa, CA



At this stage of Commissioning, the Enlighten system has identified each module and verified that they are all working properly.

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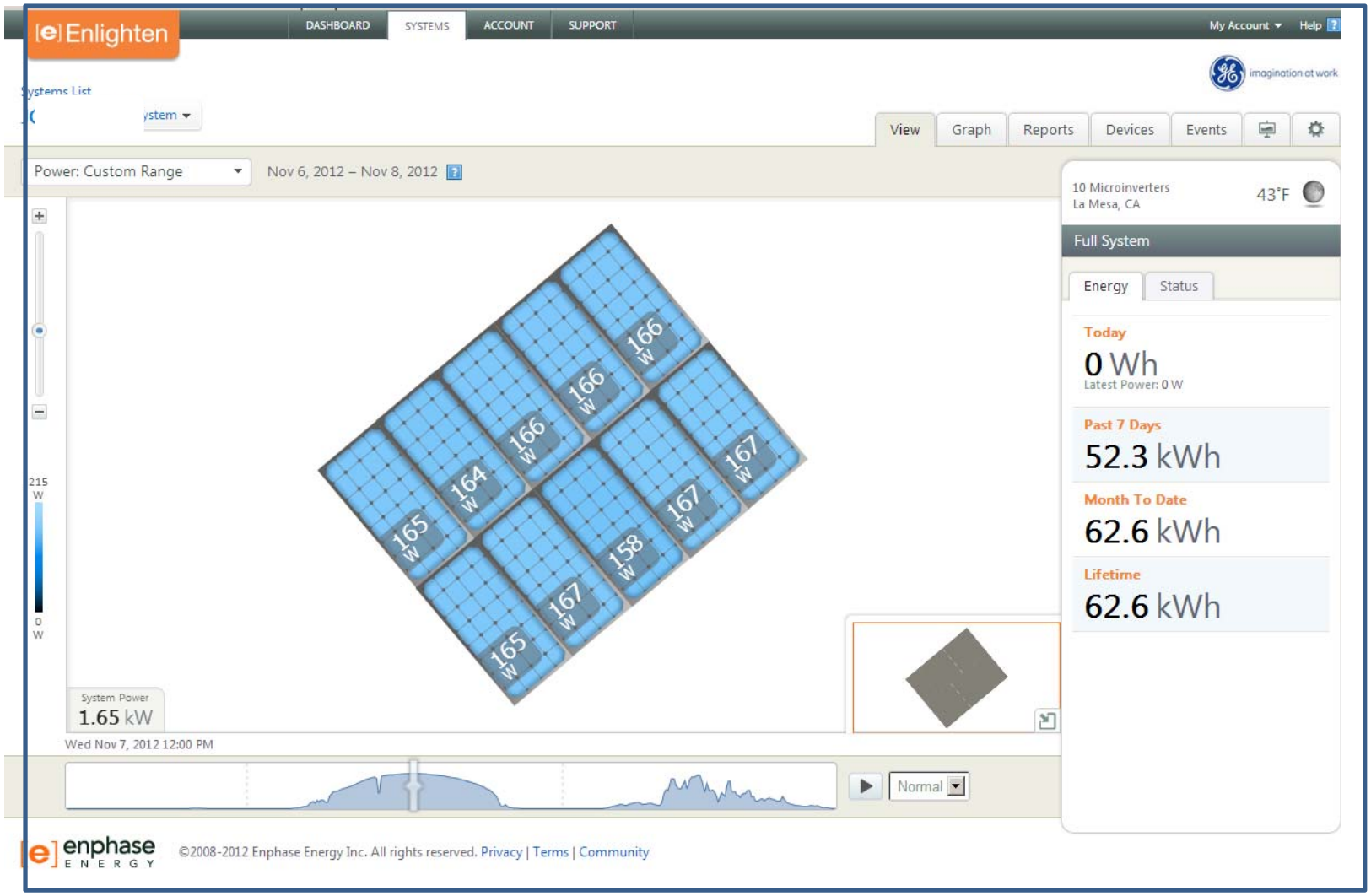
Commissioning Test Home 1 – La Mesa

2.4 kW Pilot Installation –La Mesa, CA



After all the modules have been identified and their operation verified, they are allowed to connect to the electrical box. The Enlighten provides this graphic showing the status and output of each module, as well as system statistics (at the right). Commission-ing is now complete.

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Commissioning Test Home 2 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA

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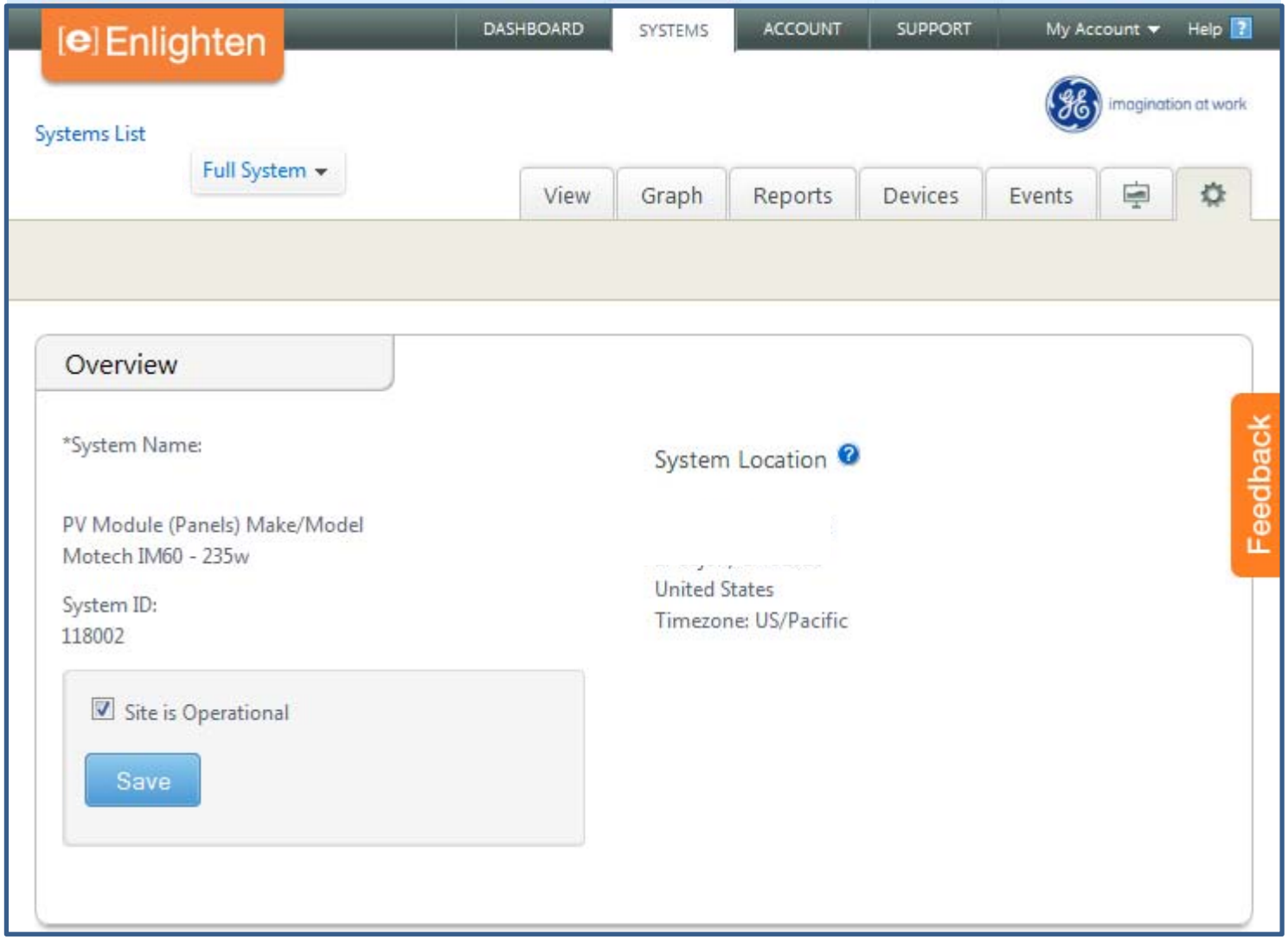
Commissioning Test Home 2 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA



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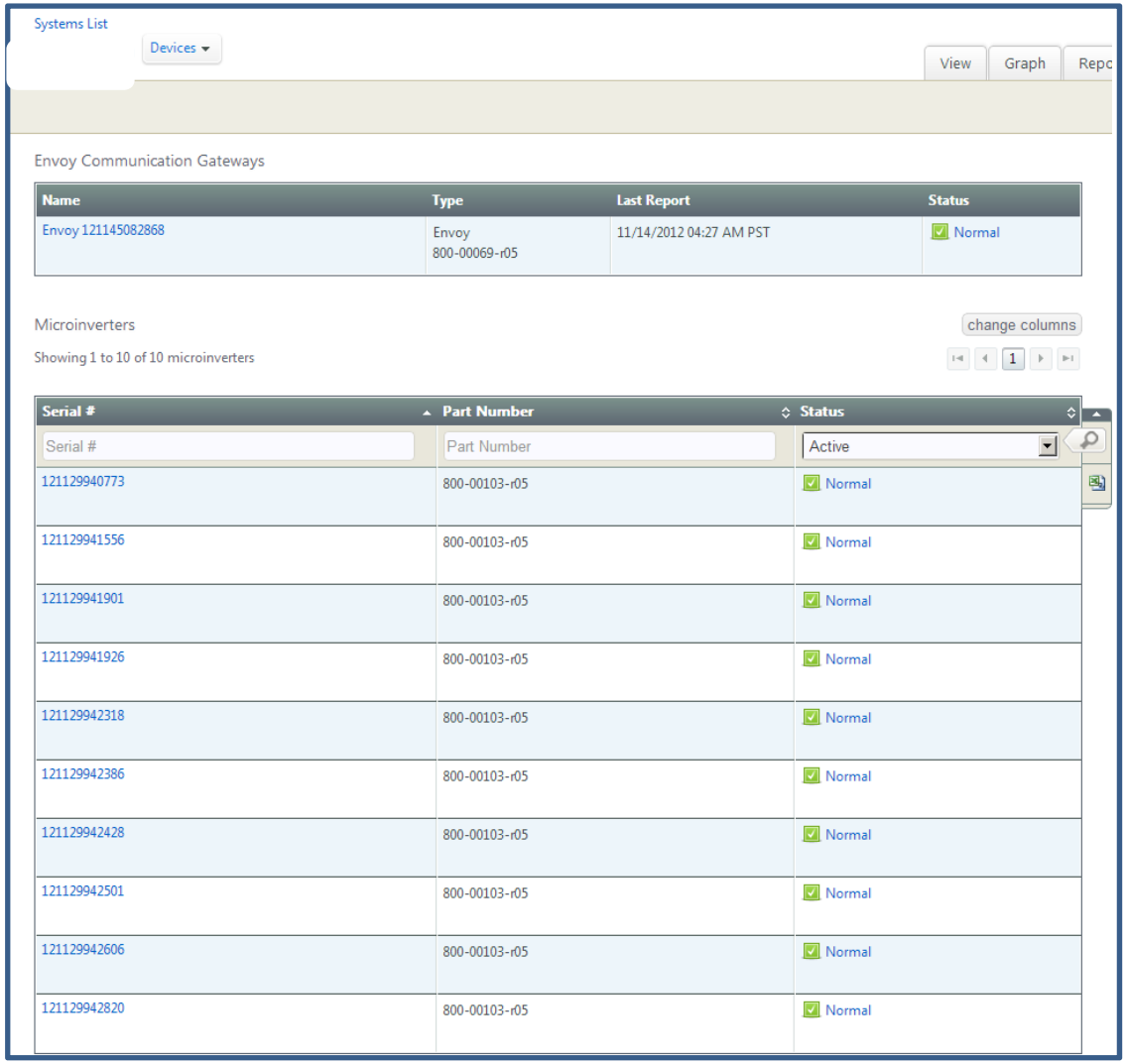
imagination at work

Commissioning Test Home 2 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA



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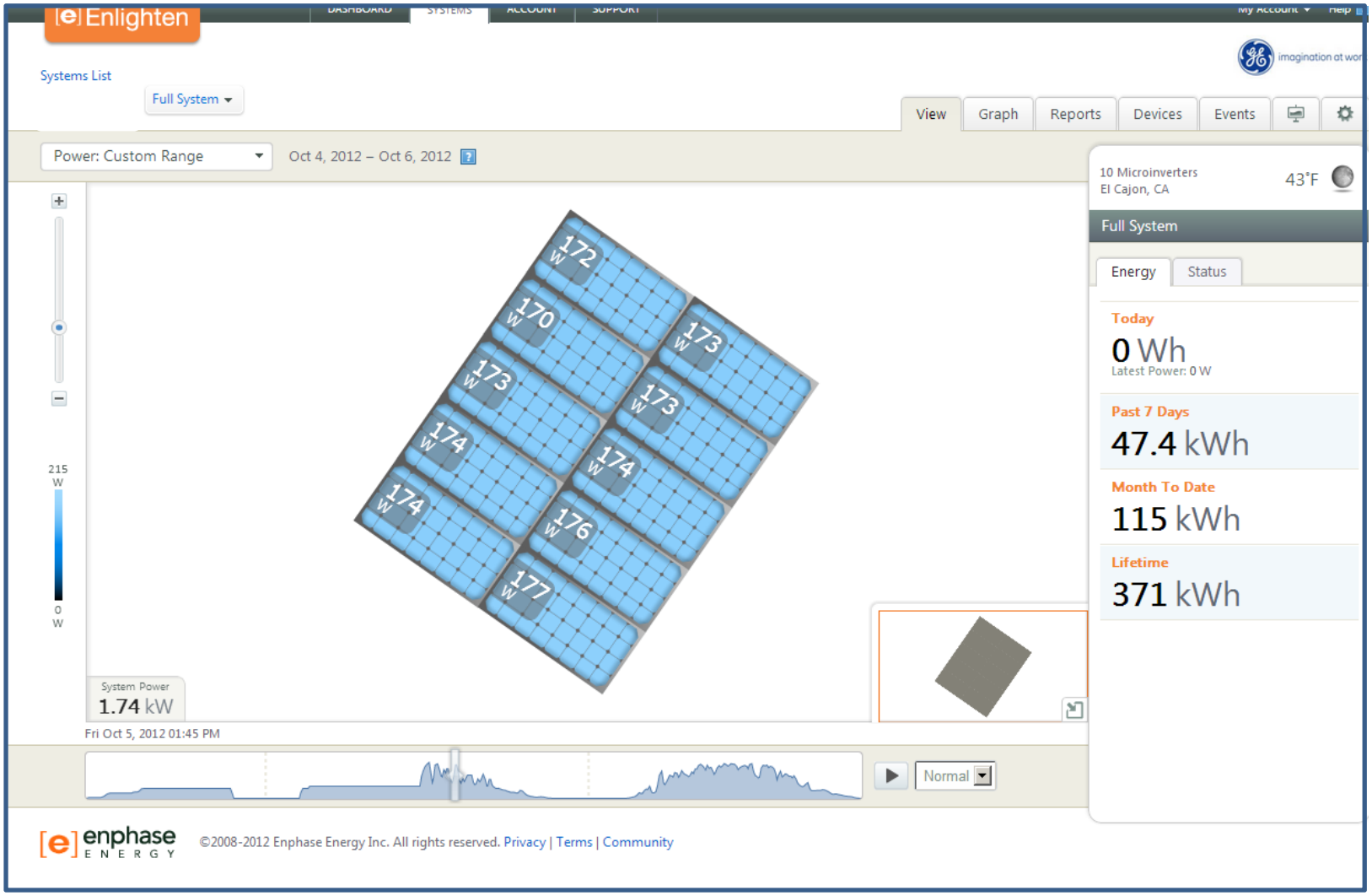
imagination at work

Commissioning Test Home 2 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA



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imagination at work

Commissioning Test Home 3 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA

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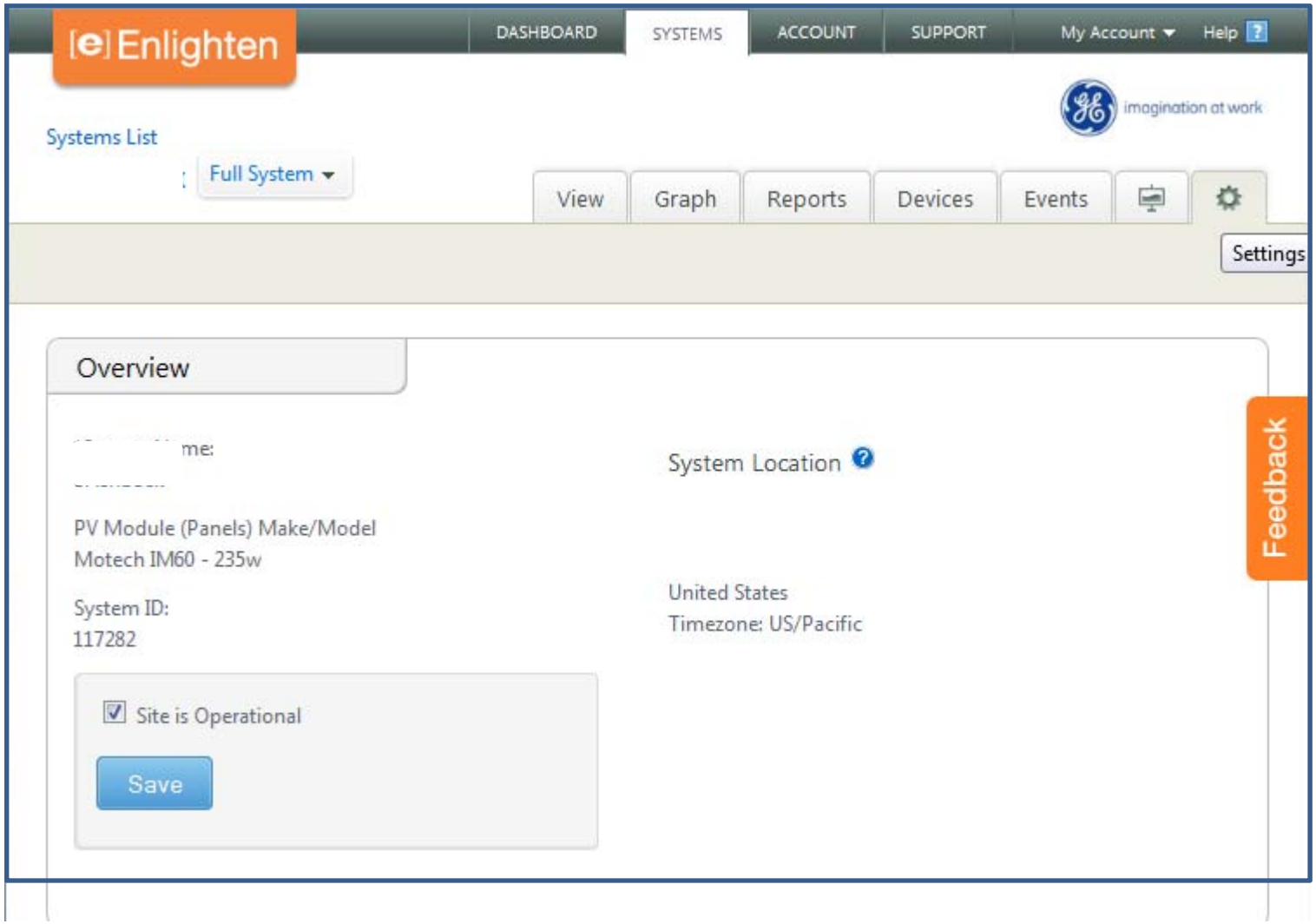
imagination at work

Commissioning Test Home 3 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA



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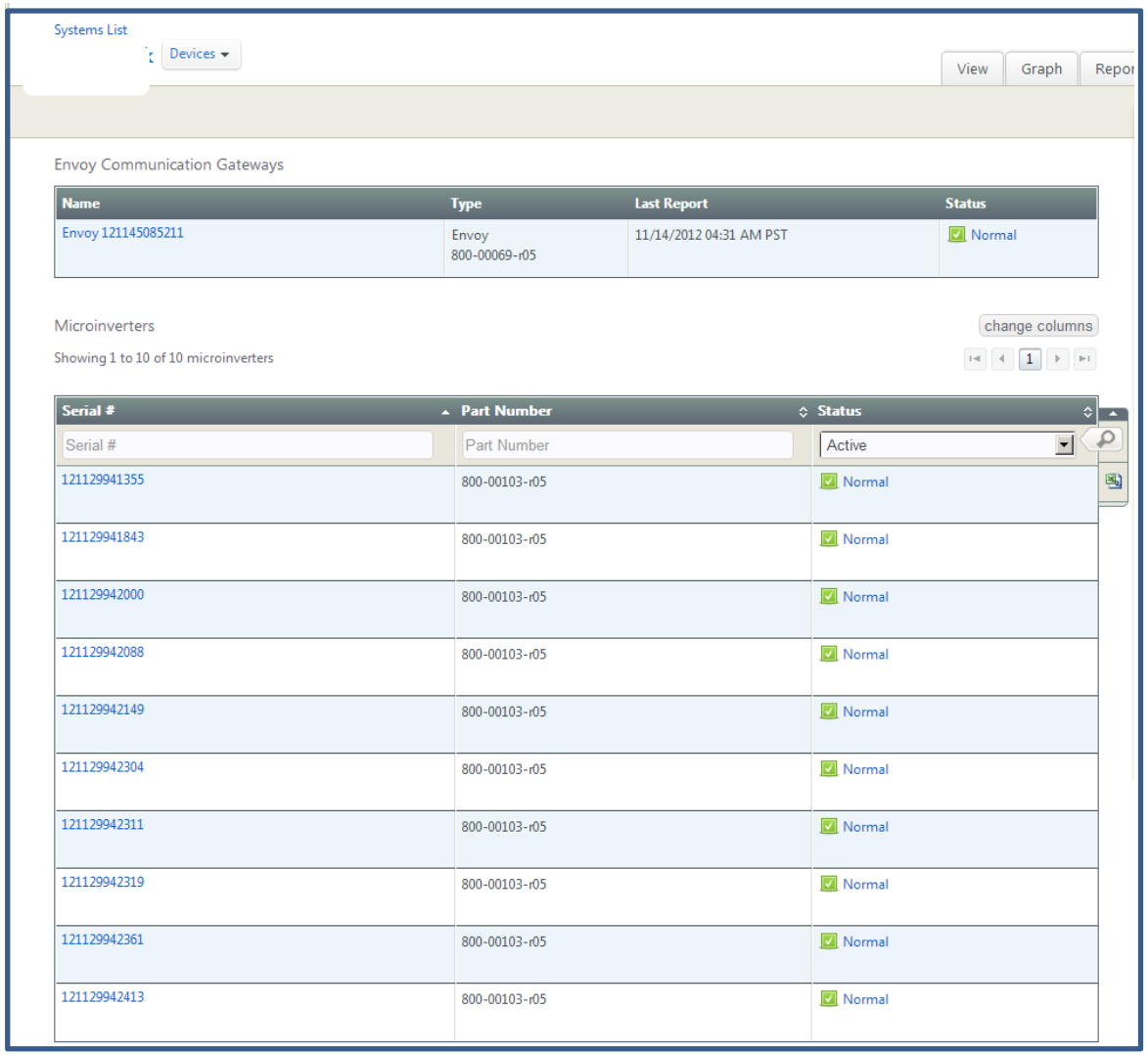
imagination at work

Commissioning Test Home 3 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA

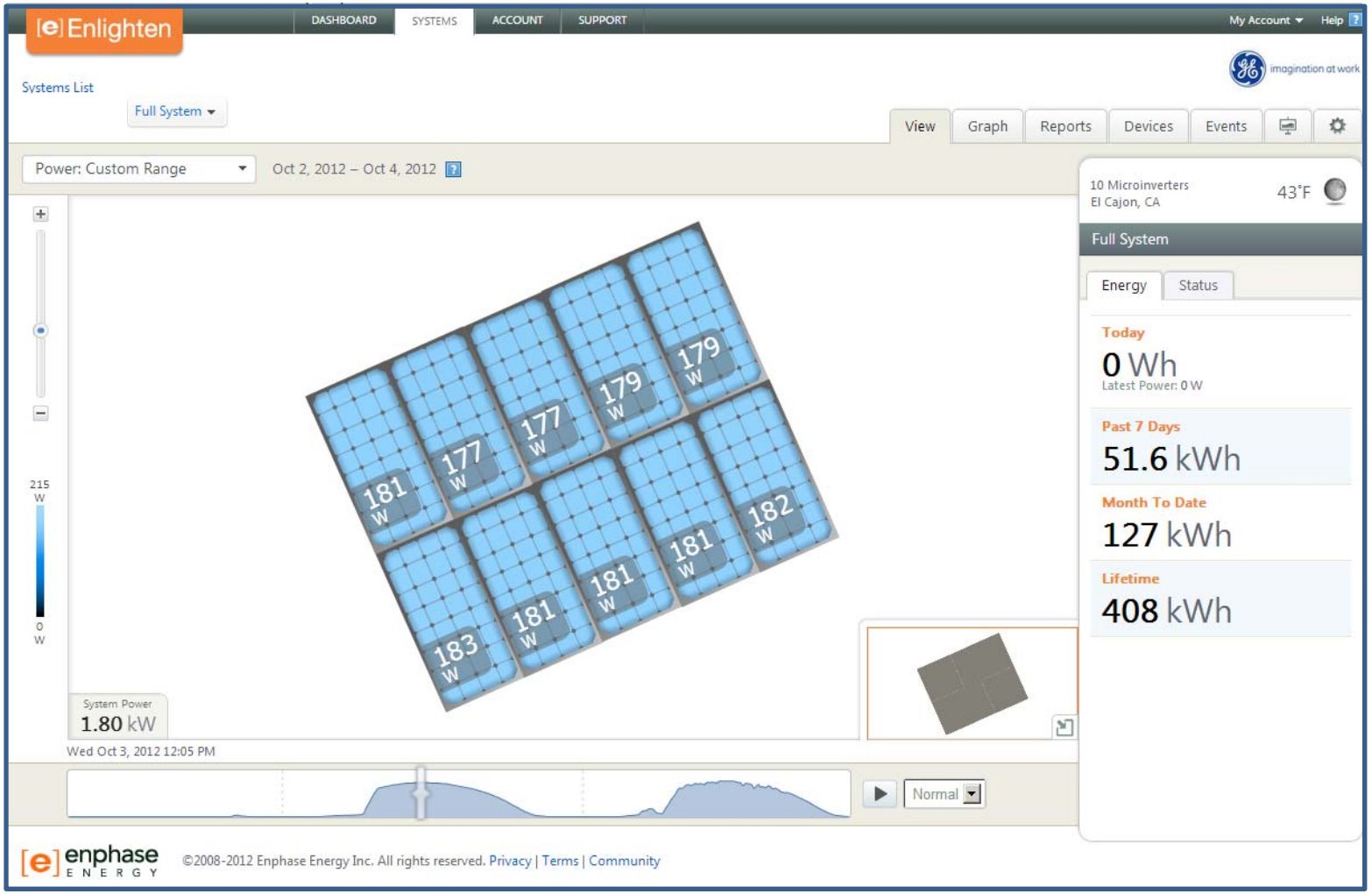


biraenergy

imagination at work

Commissioning Test Home 3 – El Cajon

2.4 kW Pilot Installation – El Cajon, CA



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imagination at work

Commissioning Test Home 4 - Santee

2.4 kW Test Installation –Santee, CA

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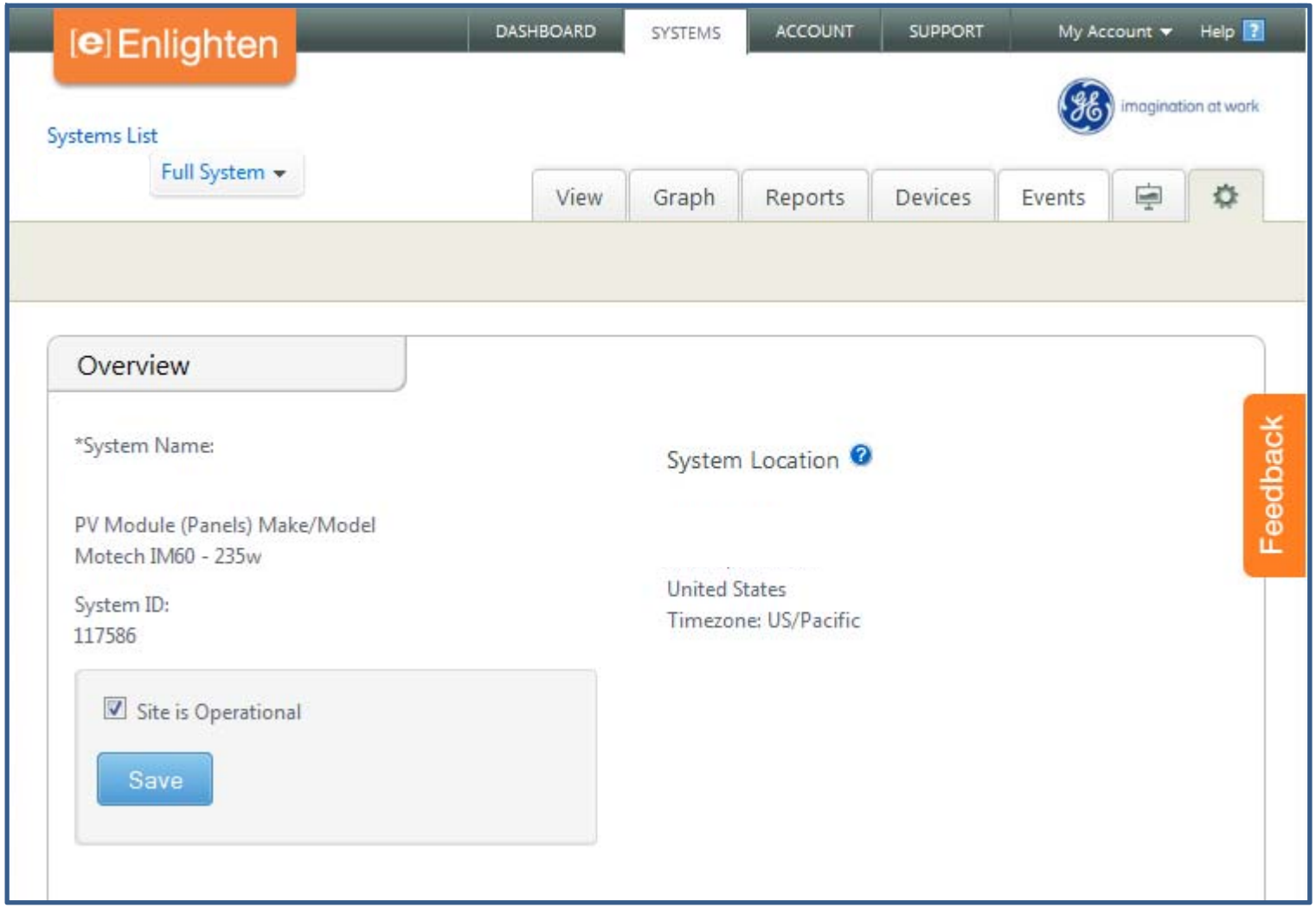
imagination at work

Commissioning Test Home 4 - Santee

2.4 kW Pilot Installation – Santee, CA



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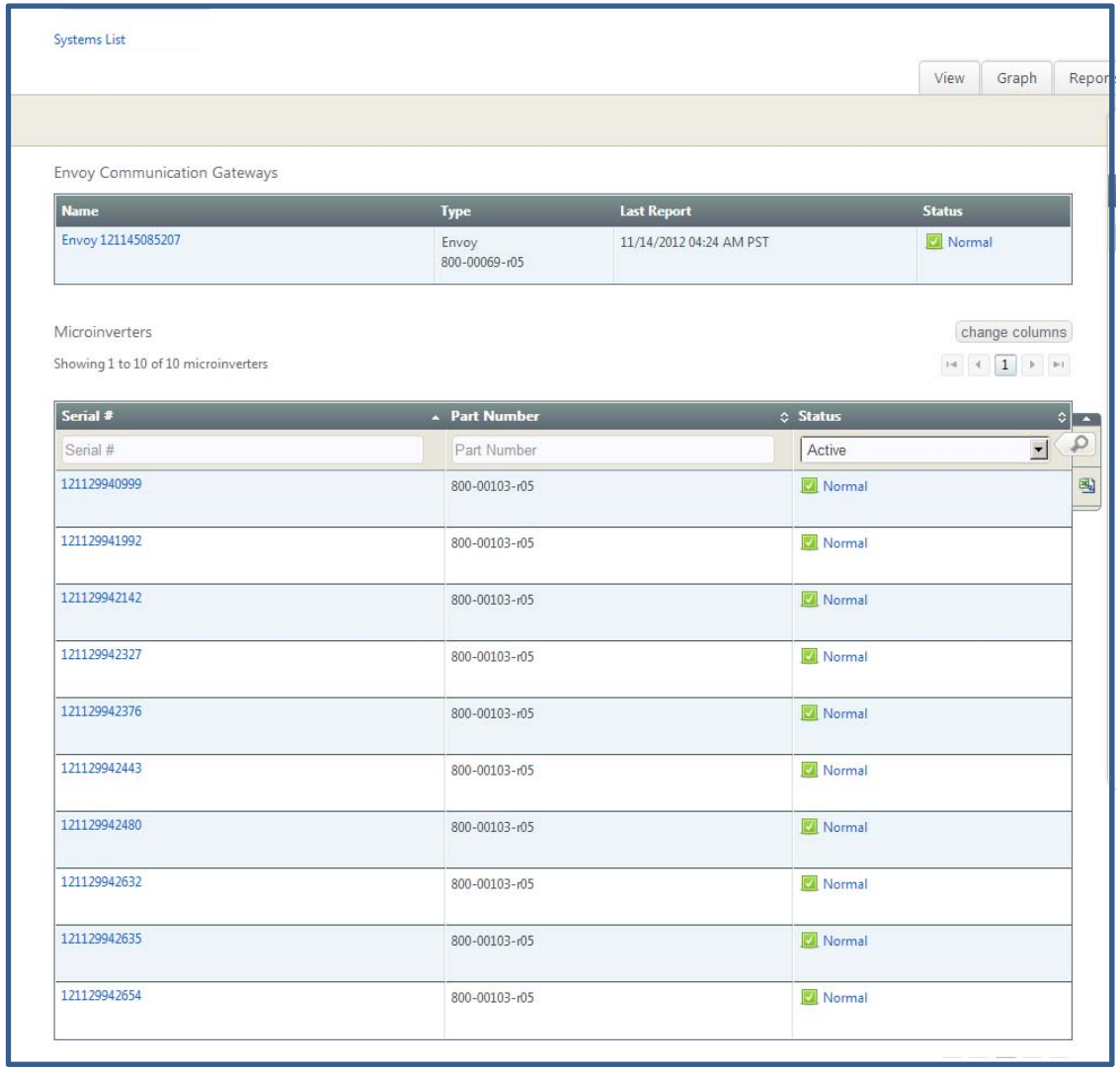
imagination at work

Commissioning Test Home 4 - Santee

2.4 kW Pilot Installation – Santee, CA



Systems List

View | Graph | Repor

Envoy Communication Gateways

Name	Type	Last Report	Status
Envoy 121145085207	Envoy 800-00069-r05	11/14/2012 04:24 AM PST	Normal

Microinverters

change columns

Showing 1 to 10 of 10 microinverters

1

Serial #	Part Number	Status
Serial #	Part Number	Active
121129940999	800-00103-r05	Normal
121129941992	800-00103-r05	Normal
121129942142	800-00103-r05	Normal
121129942327	800-00103-r05	Normal
121129942376	800-00103-r05	Normal
121129942443	800-00103-r05	Normal
121129942480	800-00103-r05	Normal
121129942632	800-00103-r05	Normal
121129942635	800-00103-r05	Normal
121129942654	800-00103-r05	Normal

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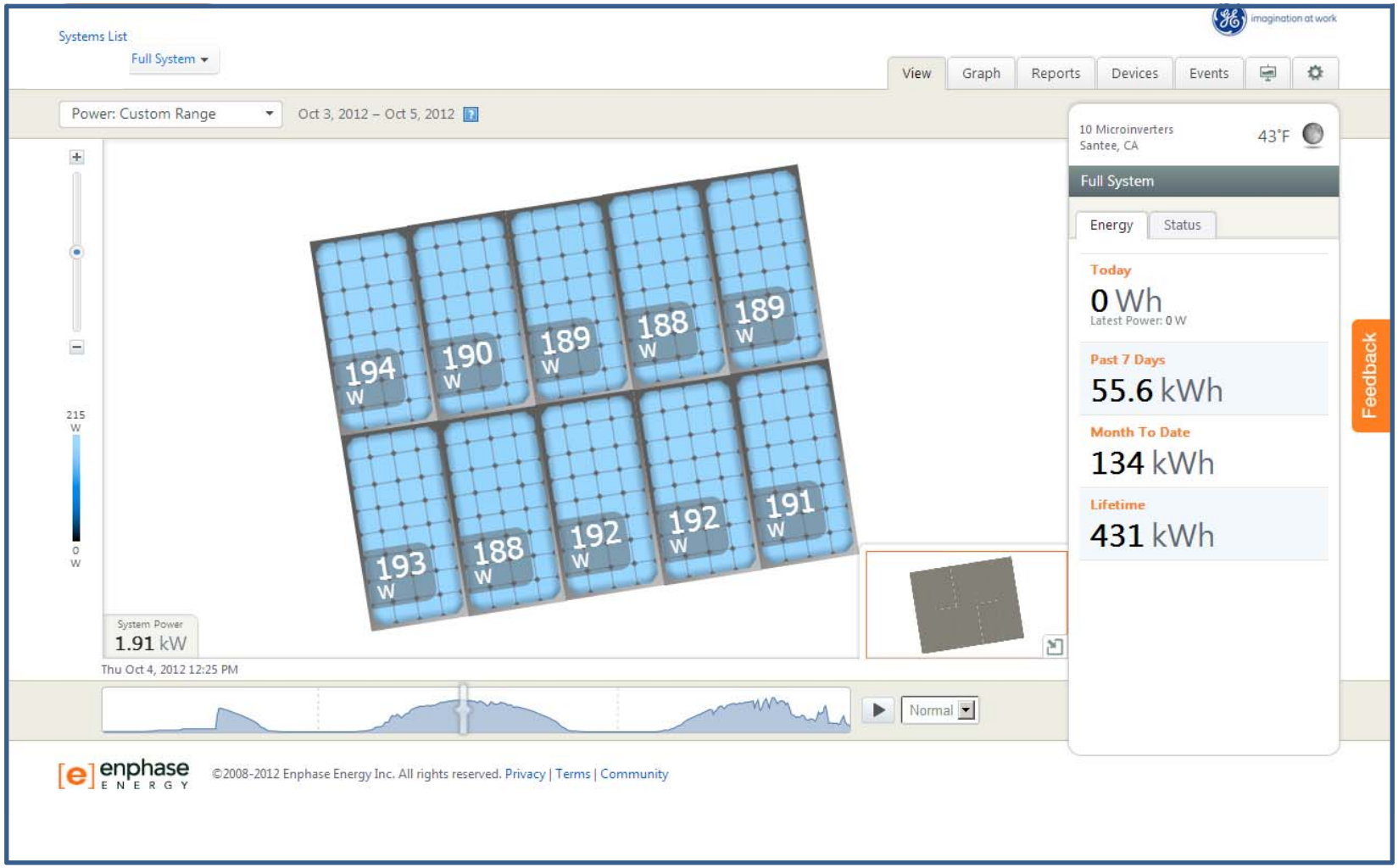
Commissioning Test Home 4 - Santee

2.4 kW Pilot Installation – Santee, CA



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Test Home 5 – Borrego Springs

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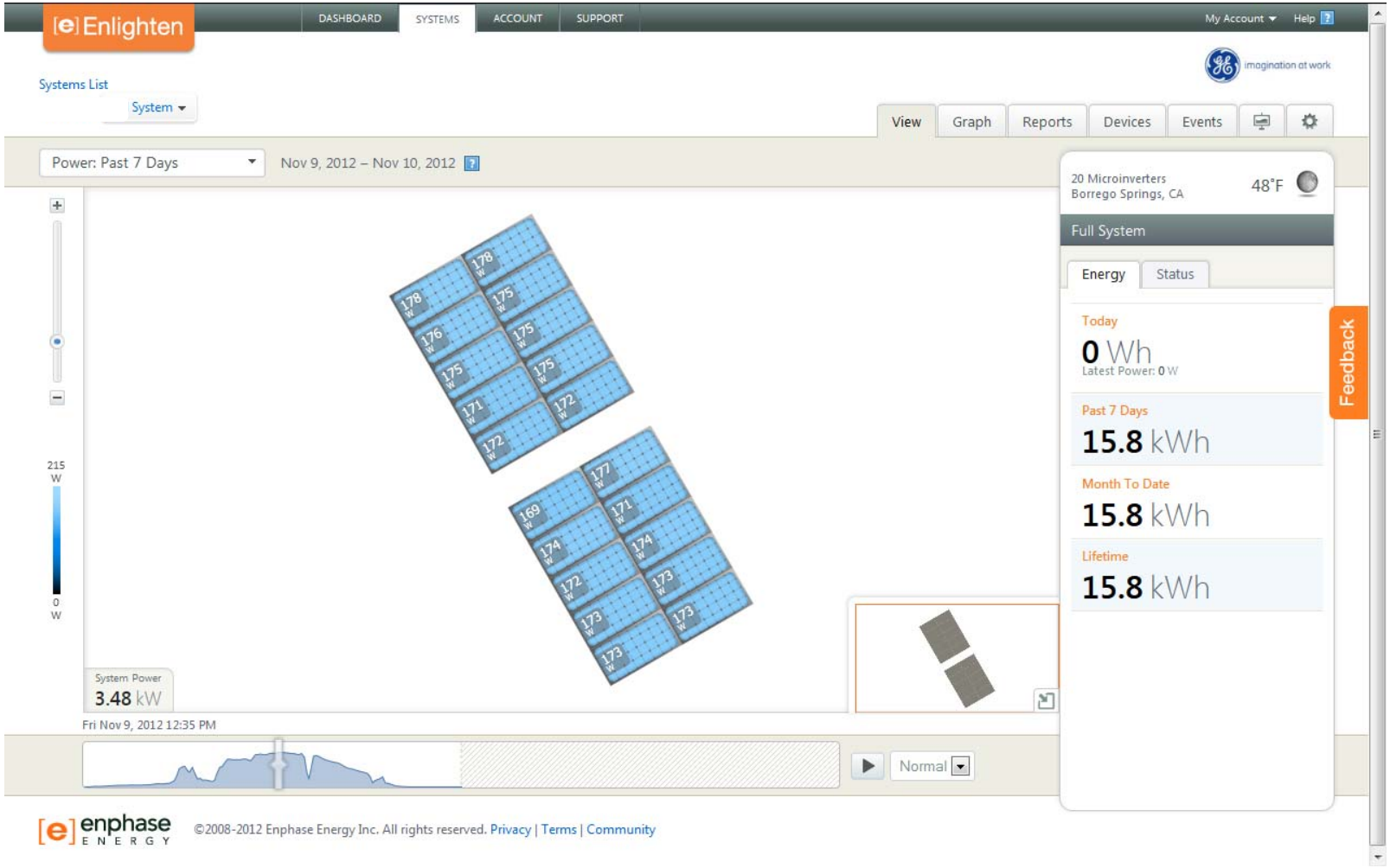
imagination at work

Test Home 5 – Borrego Springs

Enlighten on-line performance data



The Borrego Springs home has two 2.4kW systems, as shown by the Enlighten at Commmis-sioning.

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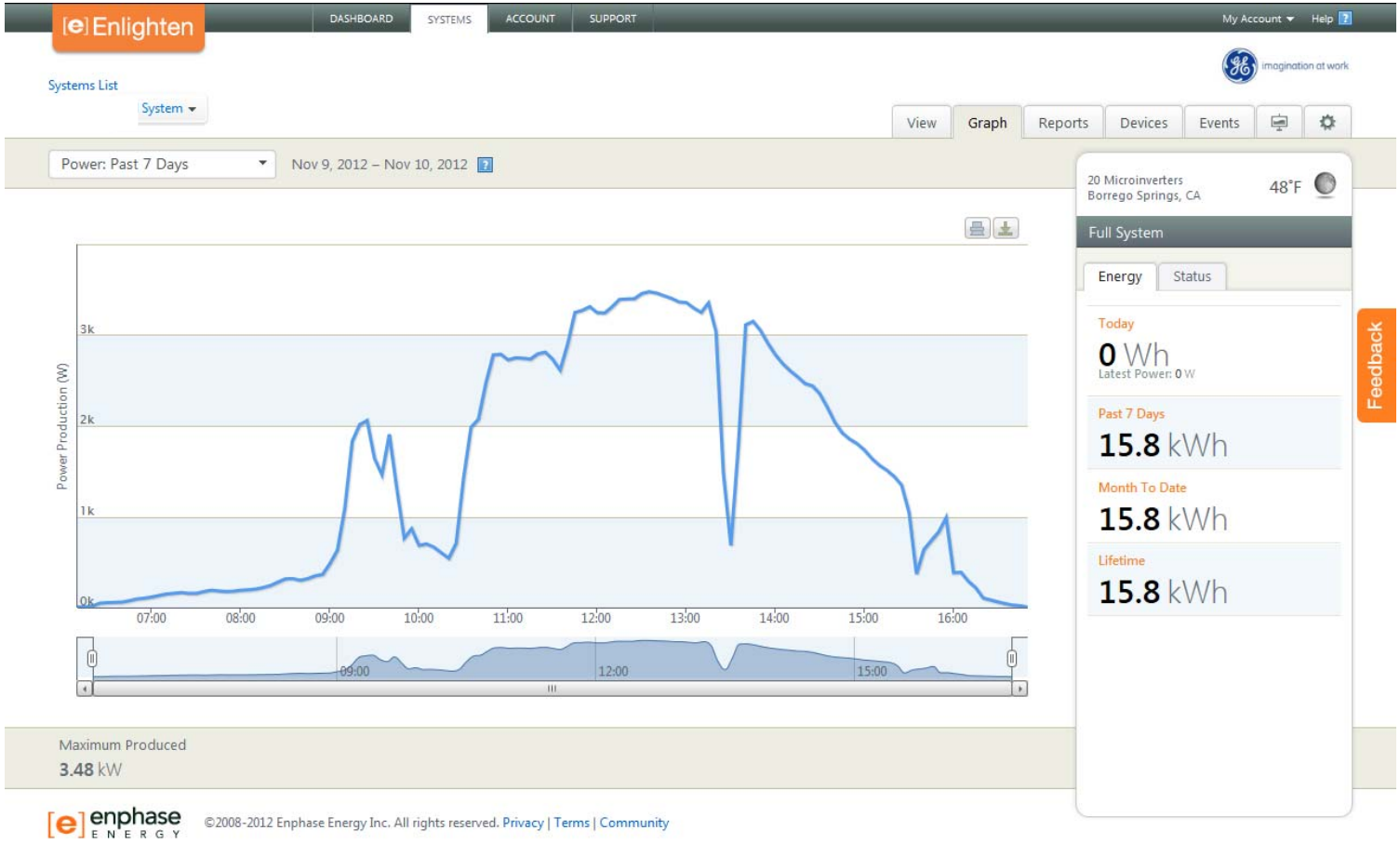
imagination at work

Test Home 5 – Borrego Springs

Enlighten on-line performance data



The Enlighten can provide additional information at commissioning or when desired by the homeowner. This graph was generated after the first full day of operation by the Borrego Springs system. It shows shading events that could be due to clouds, trees, or other obstructions resulting in reduced sunlight on the panels.

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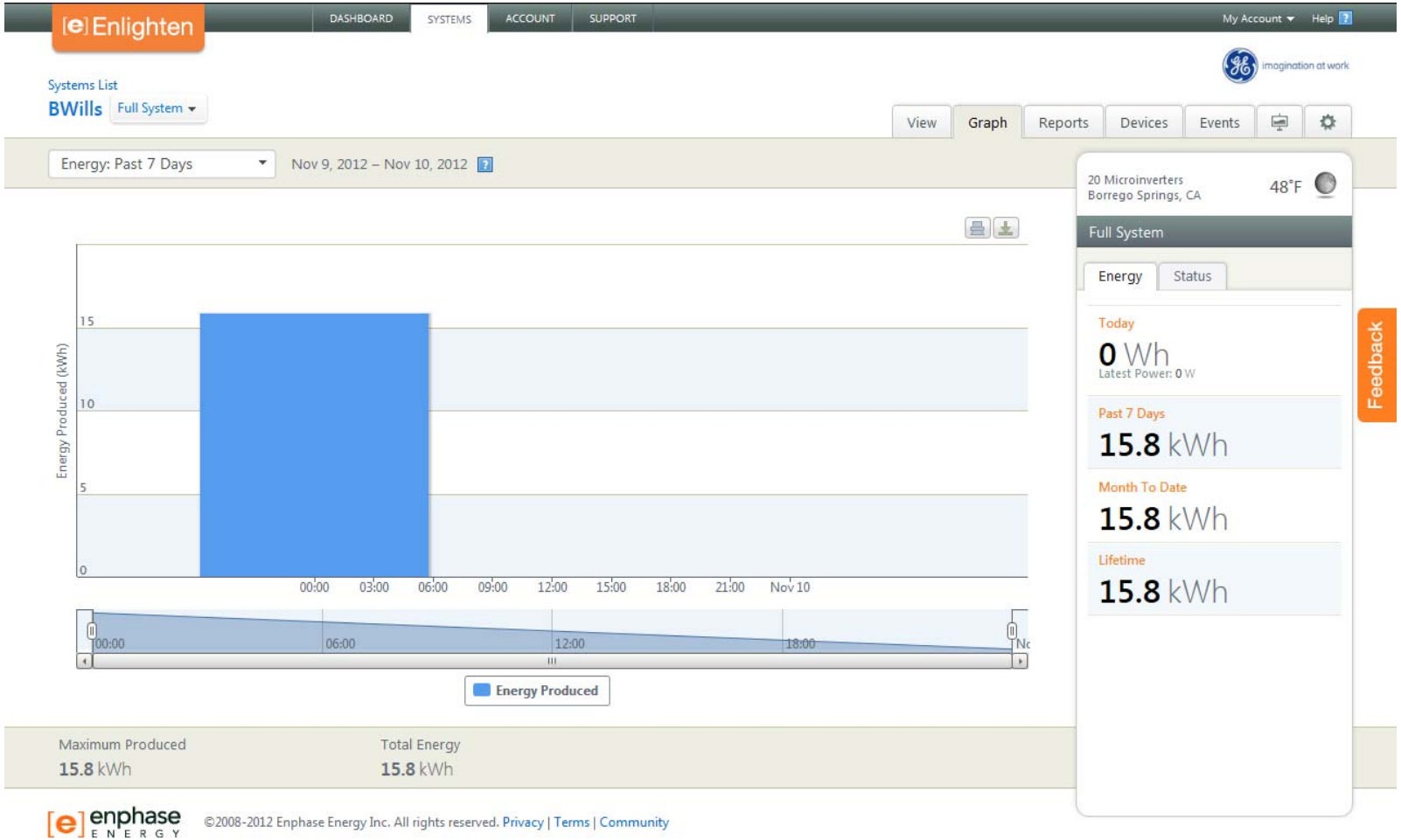
imagination at work

Test Home 5 – Borrego Springs

Enlighten on-line performance data



Another informational graphic available through the Enlighten at Commmissioning. These various graphics from the Enlighten can be produced at any time.

The Enlighten shows power produced, energy generated over various time periods from a day to a week to the life of the system. These can all be displayed numerically (as on the right) or graphically.

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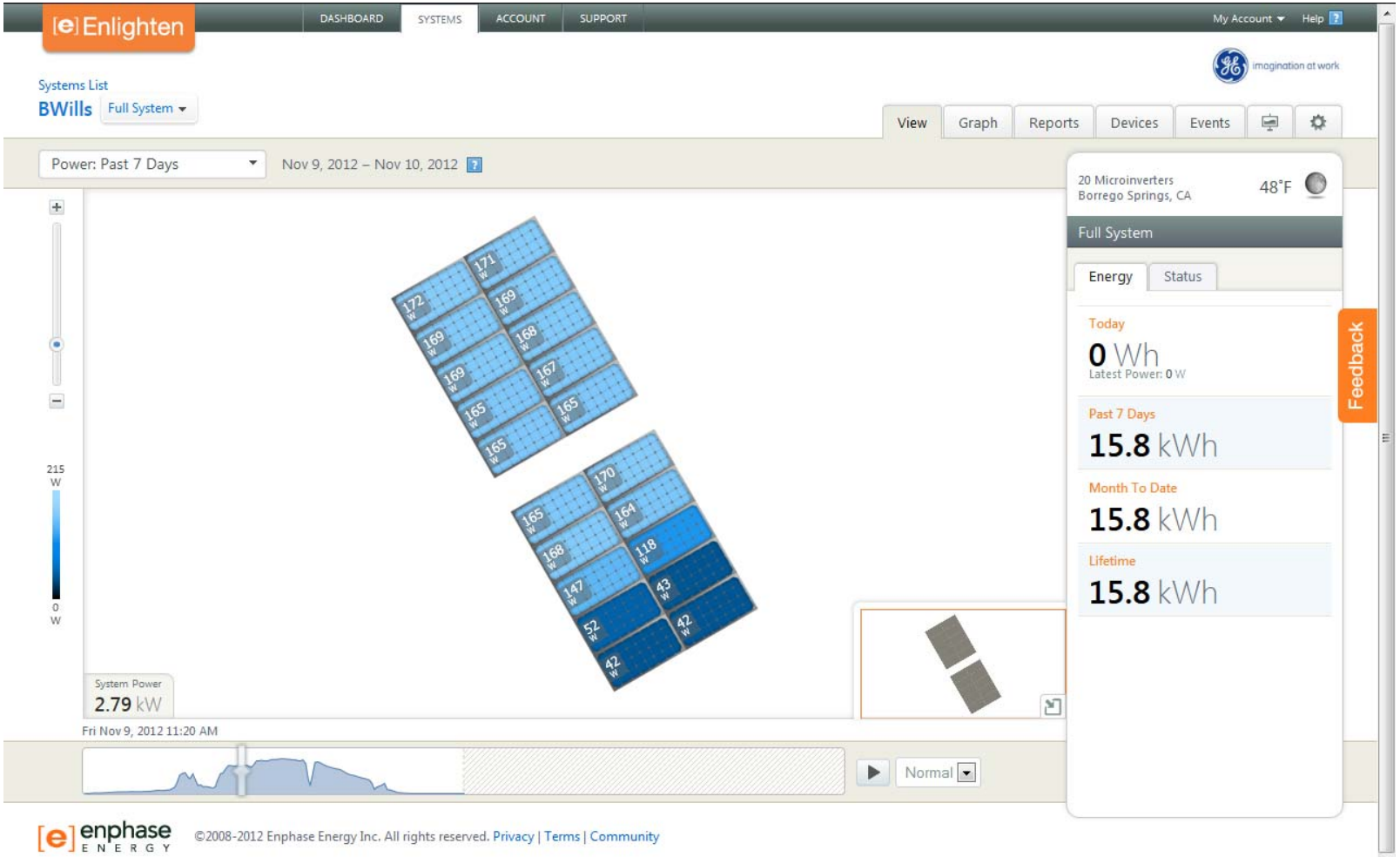
imagination at work

Test Home 5 – Borrego Springs

Enlighten on-line performance data



As the sun moved lower on the western horizon toward the end the day this system was installed, the eastern-most panels started to decrease output due to lower insolation levels. Note that the significant decrease in generation from some panels loosing insolation does not have a large effect on others in the string of interconnected 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 effected.

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imagination at work

Grid-Ready Plug-and-Play PV Kit

Generation Performance

The GE Smart-Grid Ready Insert and Capture Solar Generation System, as the first representative Grid-Ready Plug-and-Play PV Kit have been installed in these test homes for over a year, although the data shown does not contain the most recent month of data, due to a partial month and/or logistic constraints on collecting the data. Nonetheless, there is sufficient data from the six homes to show that they are performing as predicted.

The first step in evaluating the performance of these systems is to establish the insolation on the panels, de-rating factors based on location, azimuth and tilt, and to map the shading on the panels. The insolation levels and de-rating factors are produced from data in the Solar Advisor software model. Shading maps were developed for each system using a Suneye Shading Assessment tool that uses a fish-eye lens to map the shading on a 360° horizon.

When actual generation performance is compared to simulations, the actual generation is generally within the error of the prediction or greater than that in the simulations. For the Borrego Springs home, if the home provided the optimum azimuth for solar generation of 180 degrees the net annual energy would equal 8359kWh, which equates to the high production level of 1777/kWh/kWdc

Another performance note: The calculated performance ratio of 0.87 for the AC module based system is 7% higher than for a typical central string-inverter based DC system. In fact, the actual data for the GE system has shown that in cases where local irradiance approaches 1000 W/m^2 this ratio is actually close to 0.90.

biraenergy

imagination at work

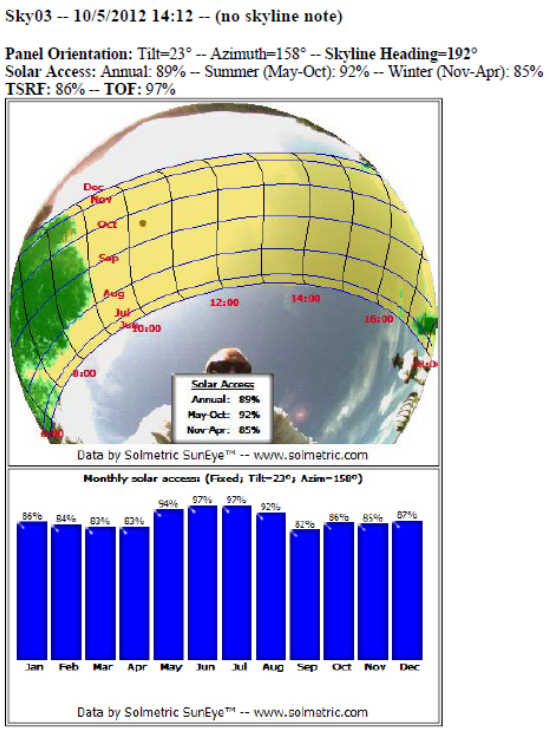
GE Smart Grid Ready Residential PV System

System Simulation – Projected energy yield vs. measured production

erformance Simulation

Address:
Azimuth:
Roof Tilt:

Month	Simulated Energy (kWh)	Measured (2012) Energy (kWh)	Measured (2013) Energy (kWh)
Jan	259.7		
Feb	257.9		
Mar	322.0		
Apr	346.2		
May	359.5		
Jun	354.2		
Jul	370.4		
Aug	366.3		
Sep	309.2		
Oct	310.5	316	
Nov	265.8		
Dec	246.0		
Total Annual Energy:	3766.9		
Energy Yield (kWh/kW):	1601.6		
Performance Factor:	0.866		



Suneye Shading Assessment

AC Module Based System Derating		
Category	***Factor***	***Derating***
	Average Soiling	95%
DC	Mismatch	100%
	Diodes&Connections	98%
	DC Wiring	99.5%
AC	AC Wiring	99%
	Inverter (CEC)	96%

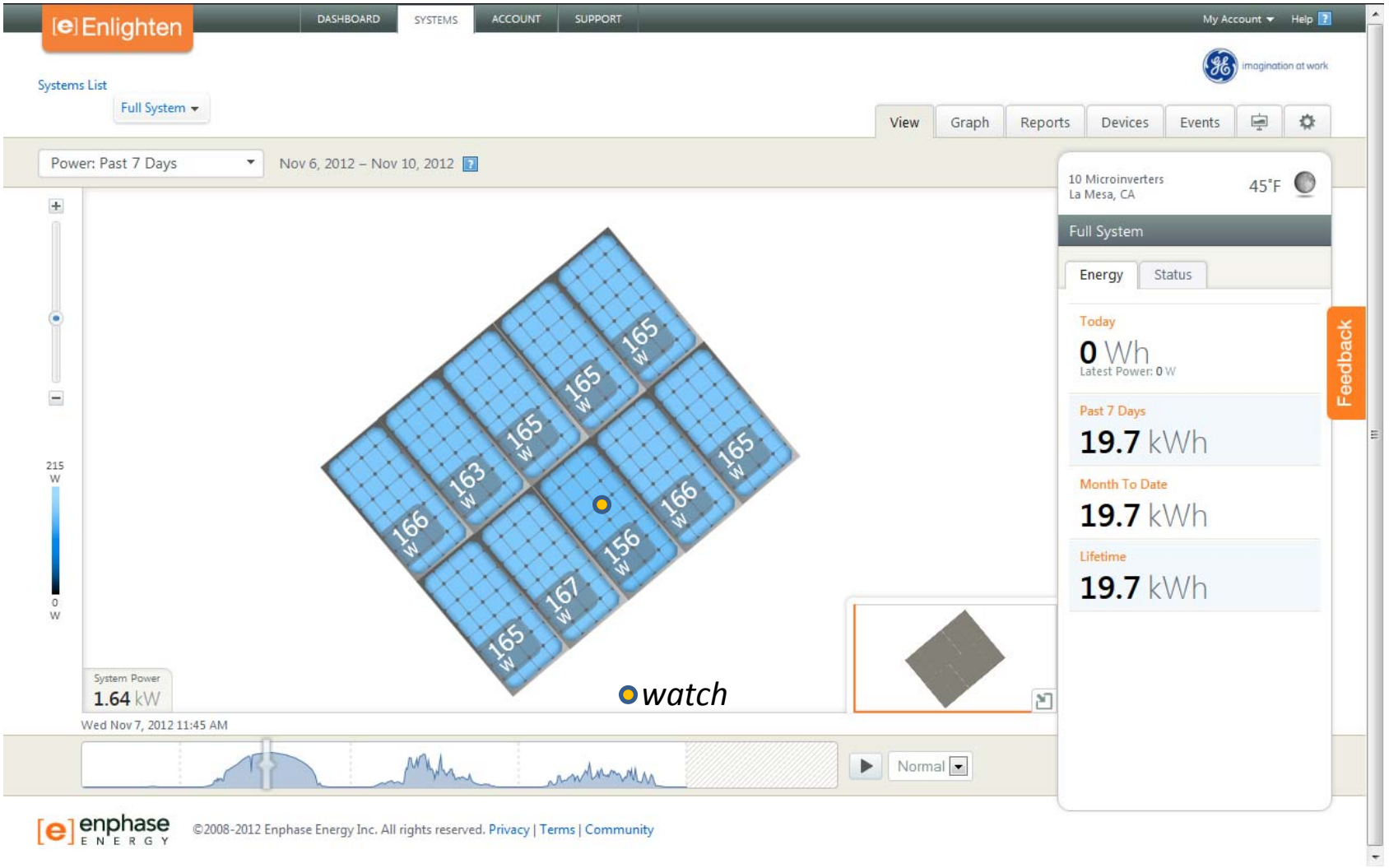
Solar Advisor Model Derating Parameters (electrical losses; based on measurements and analysis)

biraenergy

imagination at work

Test Home 1 – La Mesa

Enlighten map – sunny day in November after commissioning

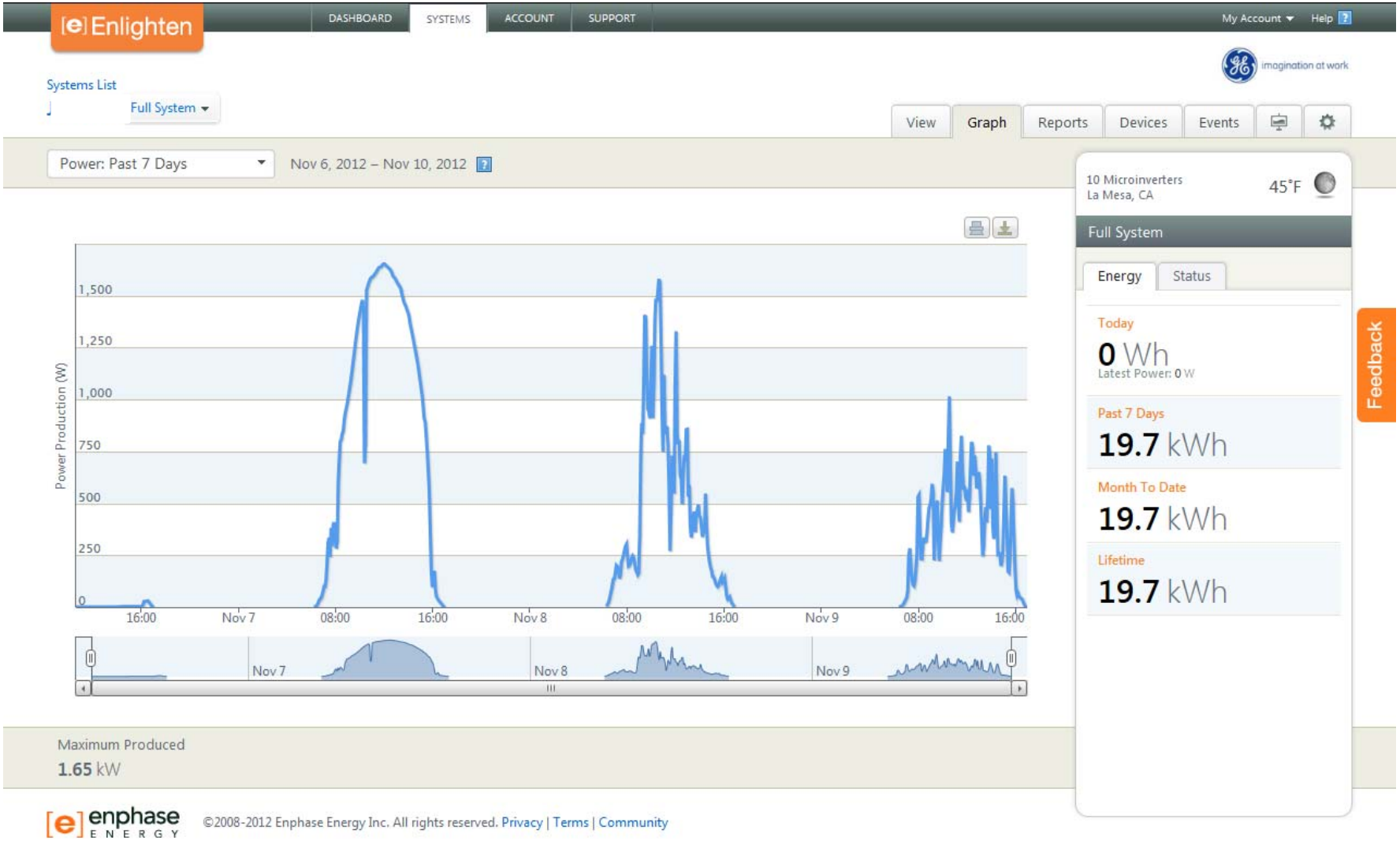


biraenergy

imagination at work

Test Home 1 – La Mesa

Power production after system commissioning



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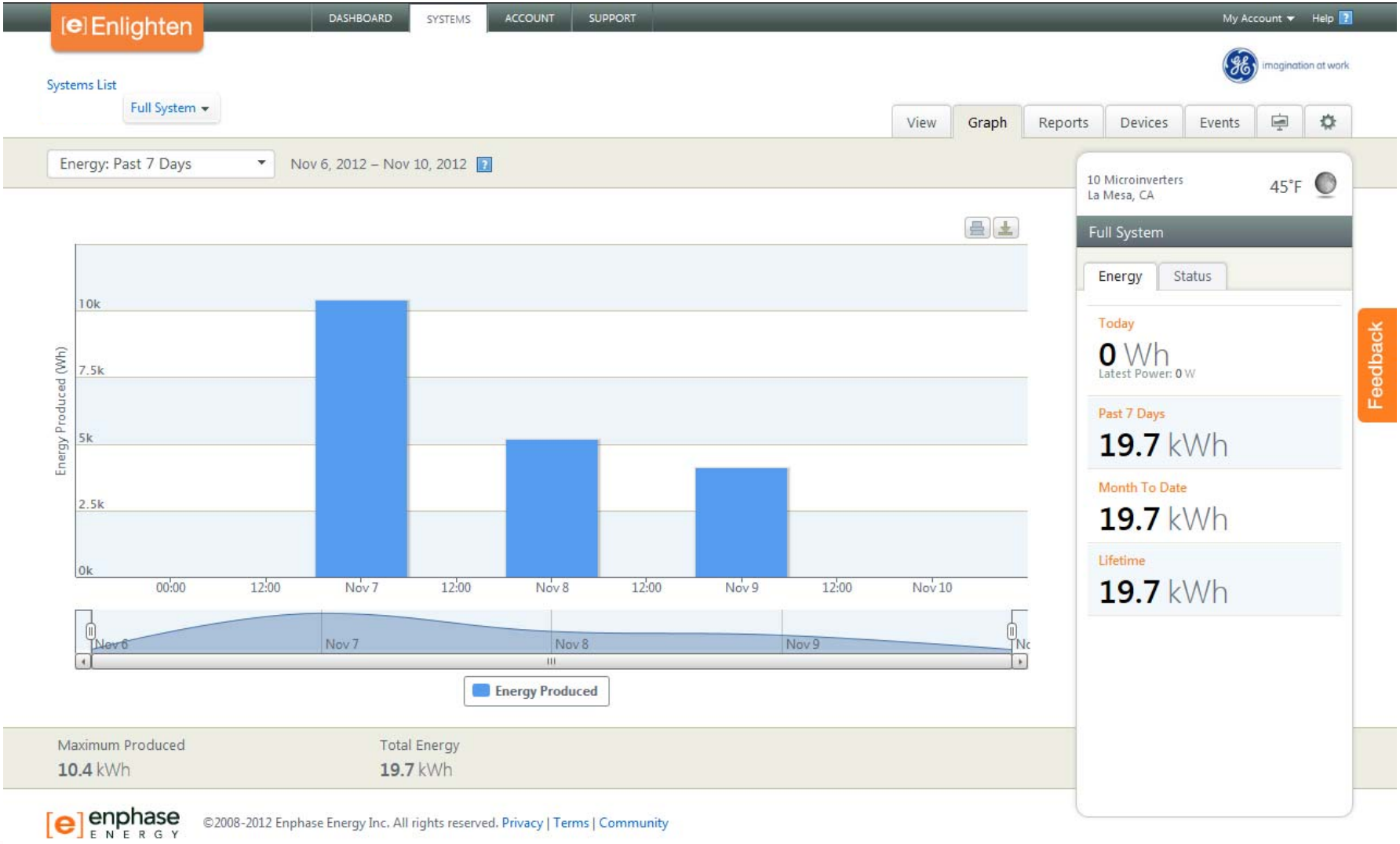
imagination at work

Grid-Ready Plug-and-Play PV Kit

Energy production after system commissioning

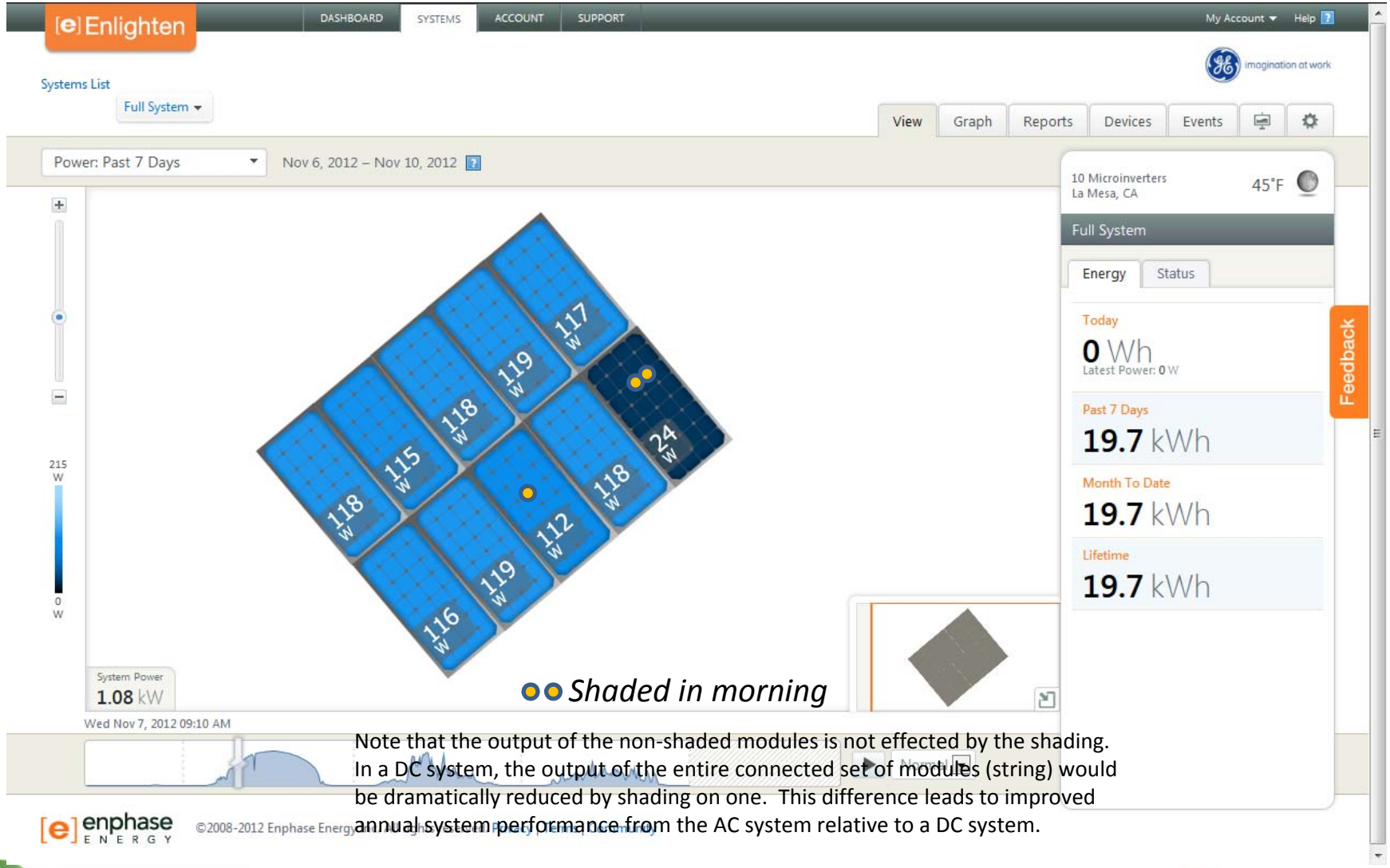


biraenergy

imagination at work

Test Home 1 – La Mesa

Enlighten map indicates period of shading – and minimum effect on total output



Note that the output of the non-shaded modules is not effected by the shading. In a DC system, the output of the entire connected set of modules (string) would be dramatically reduced by shading on one. This difference leads to improved annual system performance from the AC system relative to a DC system.

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imagination at work

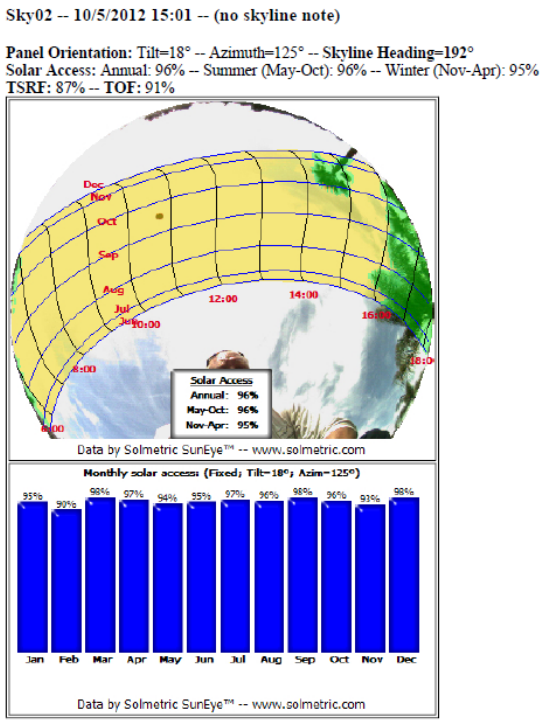
Test Home 2 – El Cajon

System Simulation – Projected energy yield vs. measured production

Pilot Installation Performance Simulation

Address: ajon, CA 92020
Azimuth:
Roof Tilt:

Month	Simulated Energy (kWh)	Measured (2012) Energy (kWh)	Measured (2013) Energy (kWh)
Jan	222.1		
Feb	239.8		
Mar	316.8		
Apr	365.0		
May	367.9		
Jun	365.1		
Jul	379.5		
Aug	372.9		
Sep	316.6		
Oct	286.7	298	
Nov	232.1		
Dec	207.3		
Total Annual Energy:	3665.8		
Energy Yield (kWh/kW):	1558.6		
Performance Factor:	0.865		



Suneye Shading Assessment

AC Module Based System Derating		
Category	***Factor***	***Derating***
	Average Soiling	95%
DC	Mismatch	100%
	Diodes&Connections	98%
	DC Wiring	99.5%
AC	AC Wiring	99%
	Inverter (CEC)	96%

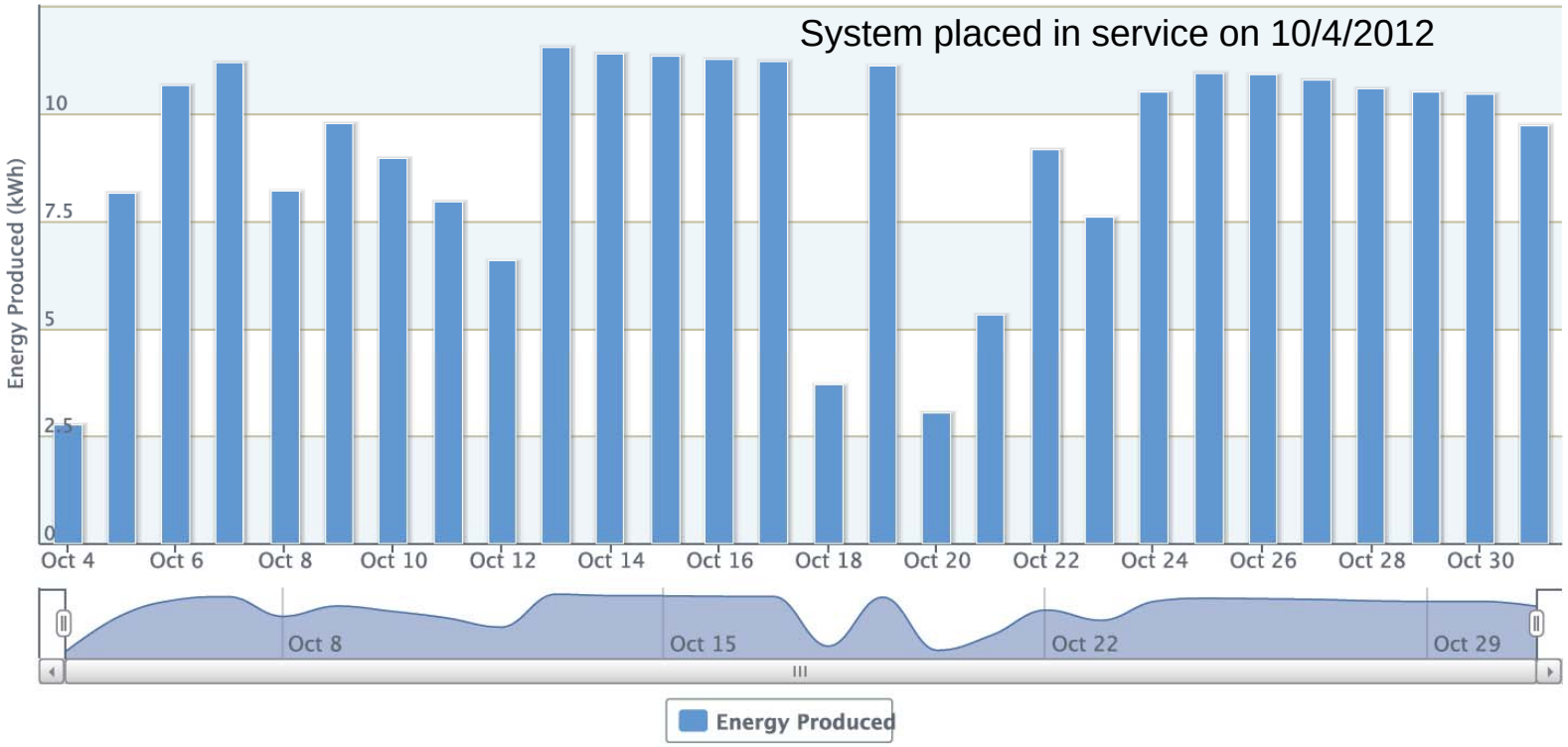
Solar Advisor Model Derating Parameters (electrical losses based on measurements and analysis)

biraenergy

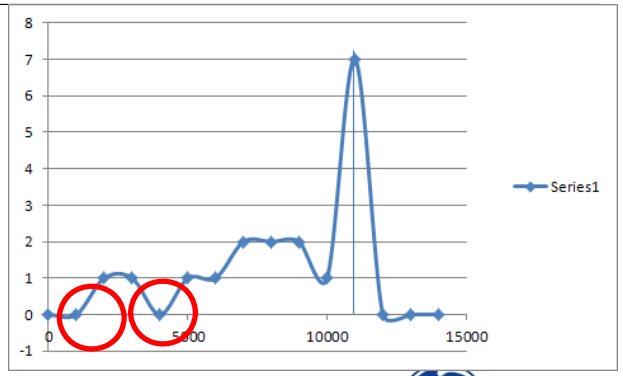
imagination at work

Test Home 2 – El Cajon

Enlighten on-line performance data



Energy produced from Oct 2-Oct 31: 256kWh:
Maximum daily energy: 11.6kWh
Maximum entitlement: 360kWh
Corrected October performance: 298 kWh

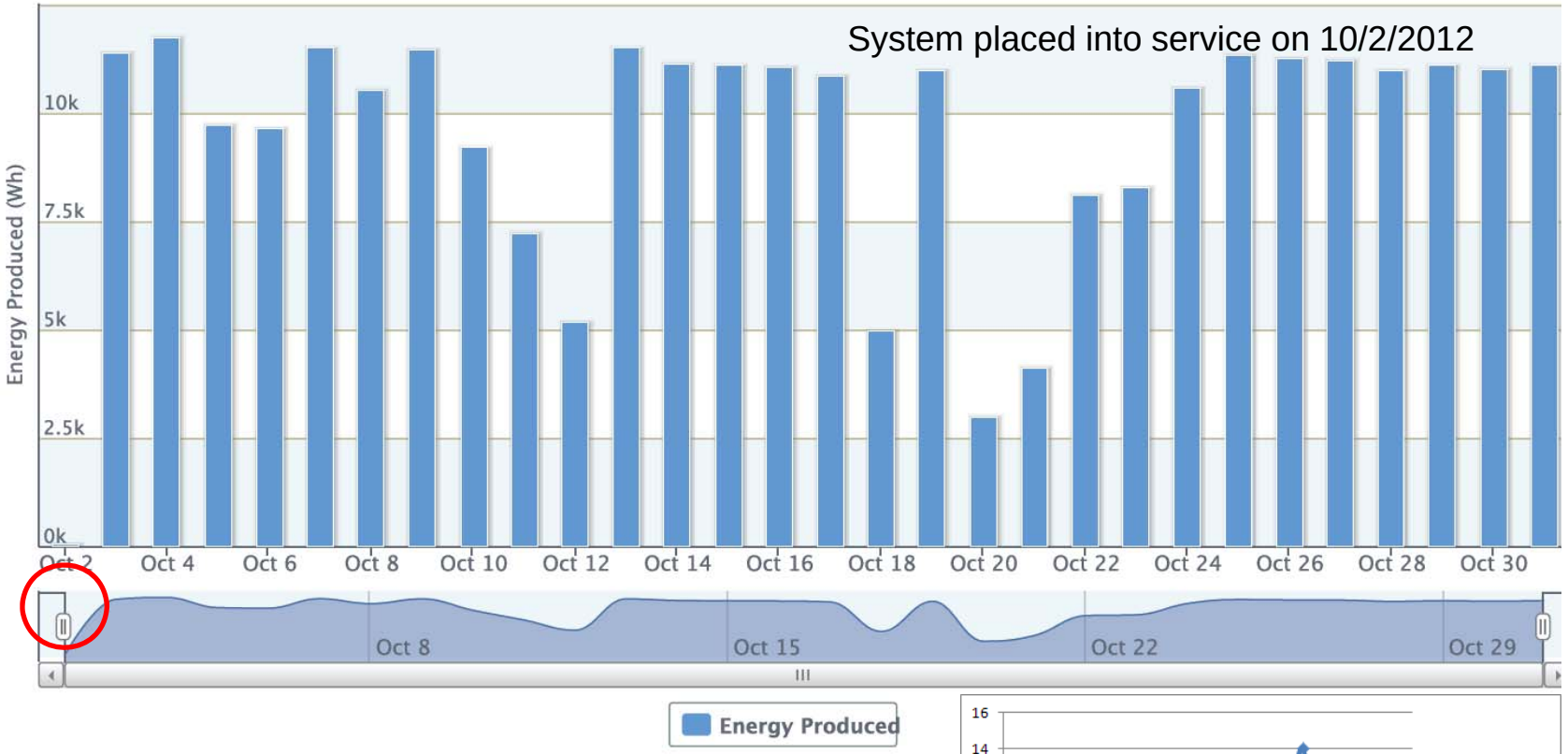


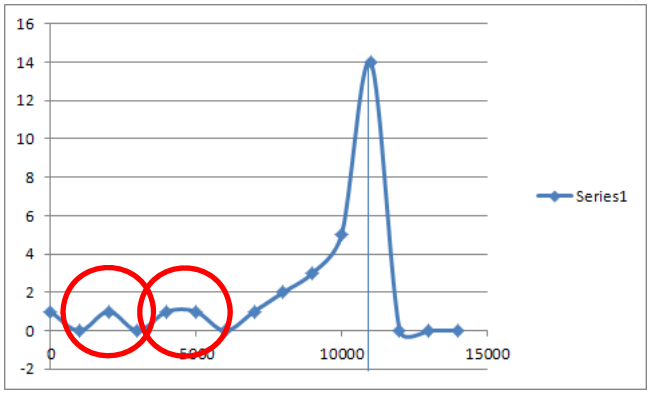
biraenergy

imagination at work

Test Home 3 – El Cajon

Enlighten on-line performance data





Energy produced from Oct 2-Oct 31: 282kWh
Maximum daily energy: 11.8kWh
Maximum entitlement: 365kWh
Corrected October performance: 316 kWh

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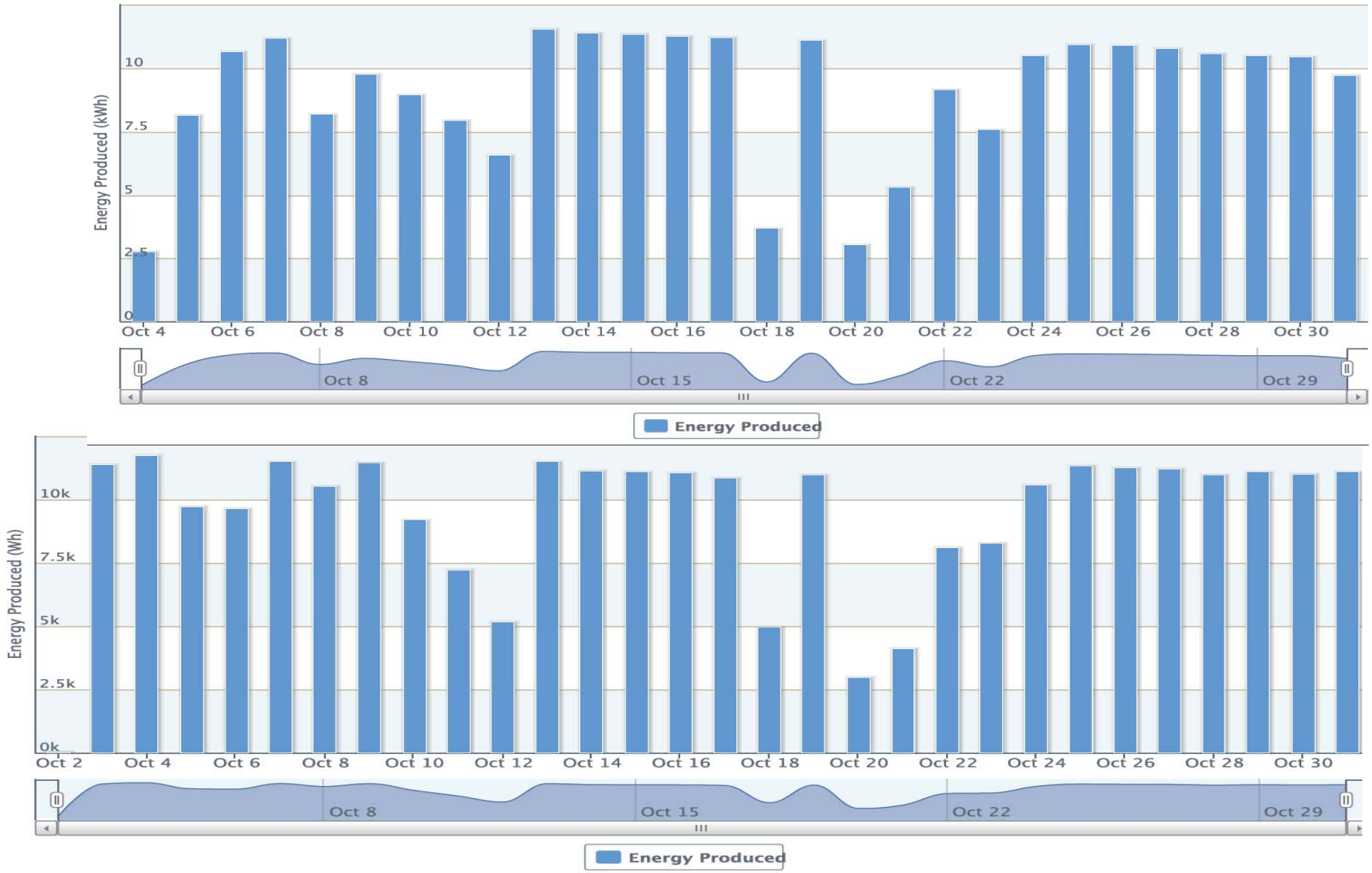
imagination at work

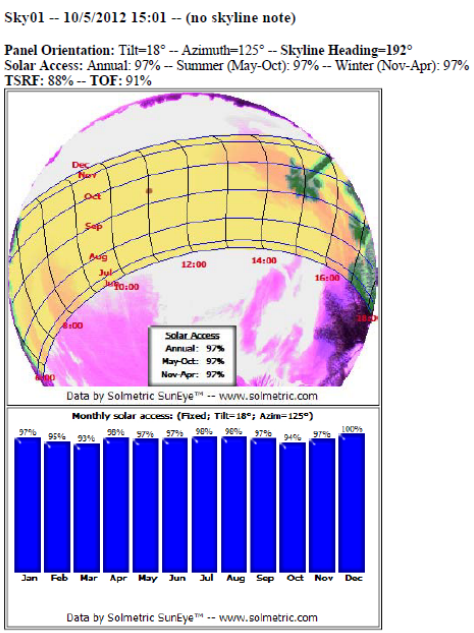
Comparison of daily electricity production of two homes in El Cajon for the month of October, 2012. The systems were installed two days apart: bottom Oct 2, top Oct 4. Notice extreme similarities after 10/8. Both homes' arrays pointed east of due south, with the top about 20deg more to the east, hence the slightly lower overall generation. (both graphs are compressed vertically to fit on the same page.)



Test Home 4 - Santee

Performance simulation

Pilot Installation Performance Simulation			
Address:	[redacted]e, CA 92071		
Azimuth:			
Roof Tilt:			
Month	Simulated Energy (kWh)	Measured (2012) Energy (kWh)	Measured (2013) Energy (kWh)
Jan	273.8		
Feb	277.1		
Mar	353.2		
Apr	374.3		
May	378.8		
Jun	363.3		
Jul	387.1		
Aug	396.0		
Sep	340.6		
Oct	333.8	348	
Nov	281.5		
Dec	261.3		
Total Annual Energy:	4031		
Energy Yield (kWh/kW):	1715		
Performance Factor:	0.87		



Suneye shading profile

AC Module Based System Derating		
Category	***Factor***	***Derating***
	Average Soiling	95%
DC	Mismatch	100%
	Diodes&Connections	98%
	DC Wiring	99.5%
AC	AC Wiring	99%
	Inverter (CEC)	96%

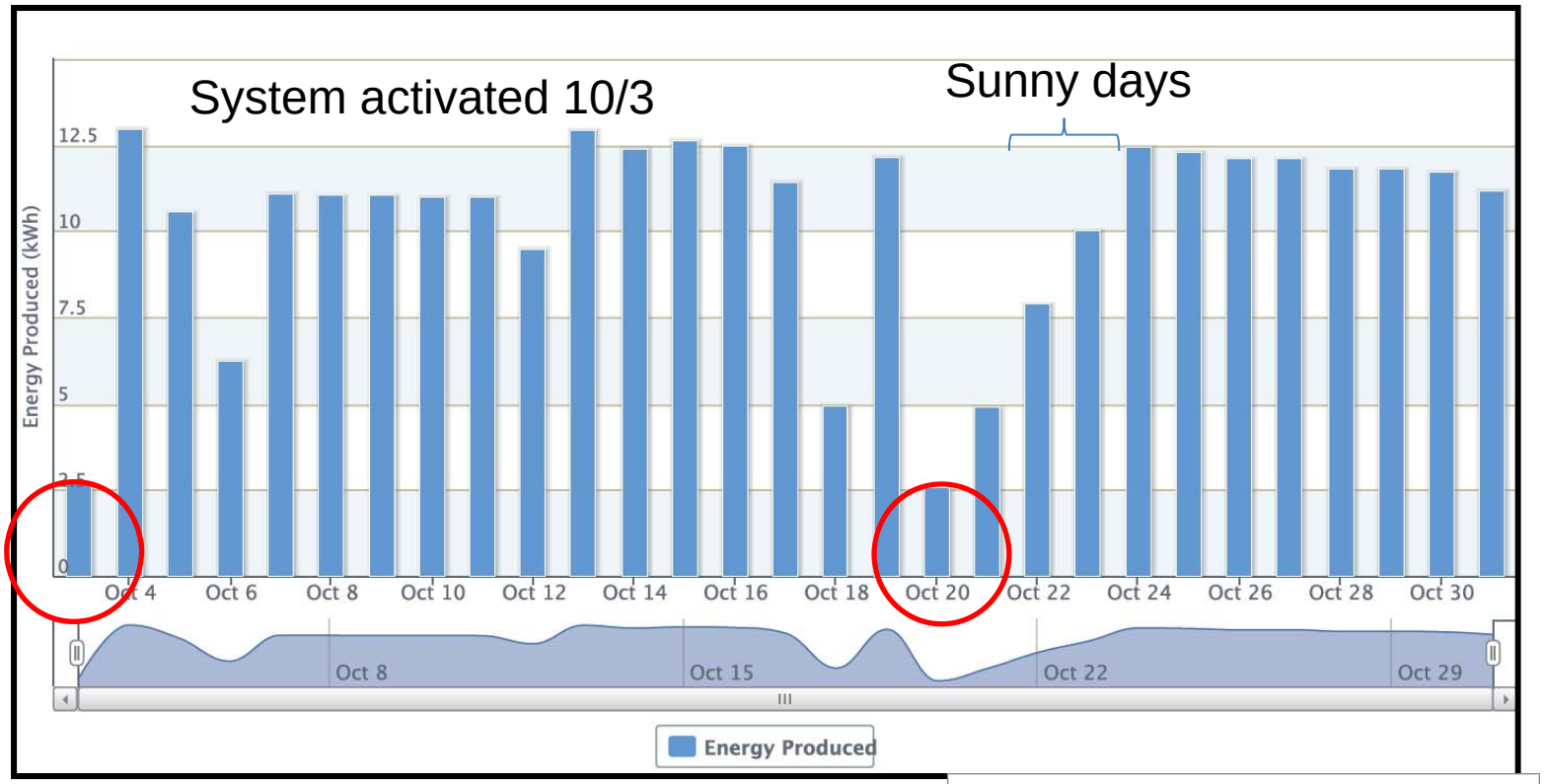
Solar Advisor Model Derating Parameters (electrical losses based on measurements and analysis)

biraenergy

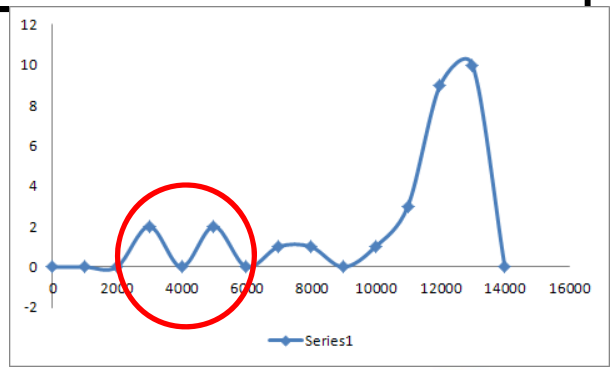
imagination at work

Test Home 4 - Santee

Enlighten on-line performance data



Energy produced from Oct 3-Oct 31: 297kWh:
Maximum daily energy: 13kWh
Maximum entitlement: 403kWh
<u>Corrected October performance: 348 kWh</u>



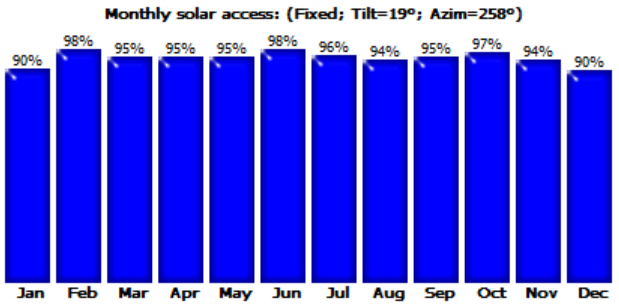
biraenergy

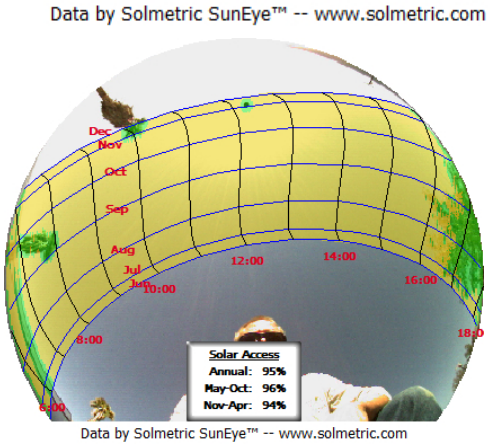
imagination at work

Test Home 5 – Borrego Springs

System Simulation – Projected energy yield vs. measured production

ilot Installation Performance Simulation			
Address:	[redacted] Borrego Springs, CA 92004		
Azimuth:	258 degrees		
Roof Tilt:	19 degrees		
Month	Simulated Energy (kWh)	Measured (2012) Energy (kWh)	Measured (2013) Energy (kWh)
Jan	403.2		
Feb	447.0		
Mar	664.5		
Apr	750.4		
May	848.5		
Jun	839.9		
Jul	786.3		
Aug	718.8		
Sep	647.1		
Oct	572.2		
Nov	418.4		
Dec	381.4		
Total Annual Energy:	7477		
Energy Yield (kWh/kW):	1589.7		
Performance Factor:	0.82		





Suneye Shading Assessment

AC Module Based System Derating		
Category	***Factor***	***Derating***
	Average Soiling	95%
DC	Mismatch	100%
	Diodes&Connections	98%
	DC Wiring	99.5%
AC	AC Wiring	99%
	Inverter (CEC)	96%

Solar Advisor Model Derating Parameters (electrical losses based on measurements and analysis)

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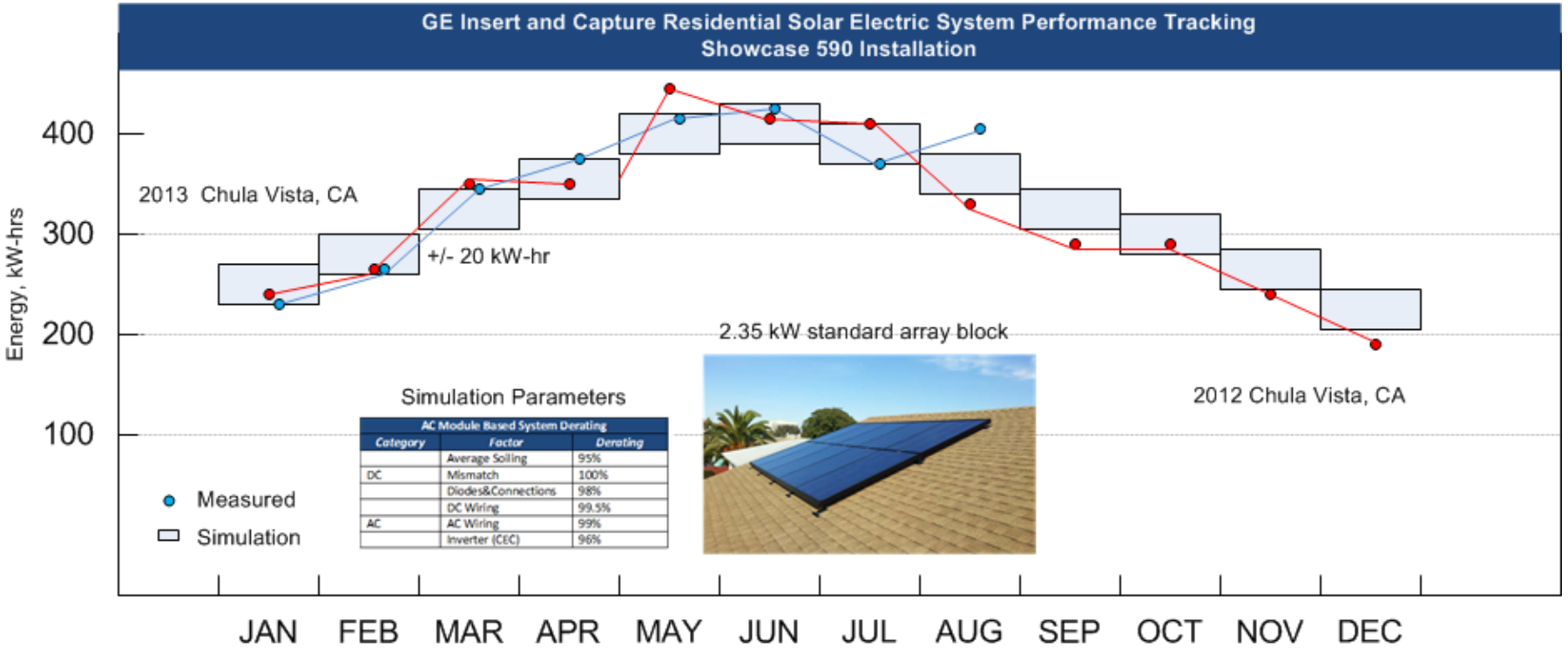
CSI Performance Charts

Chula Vista Showcase, 4.7kW



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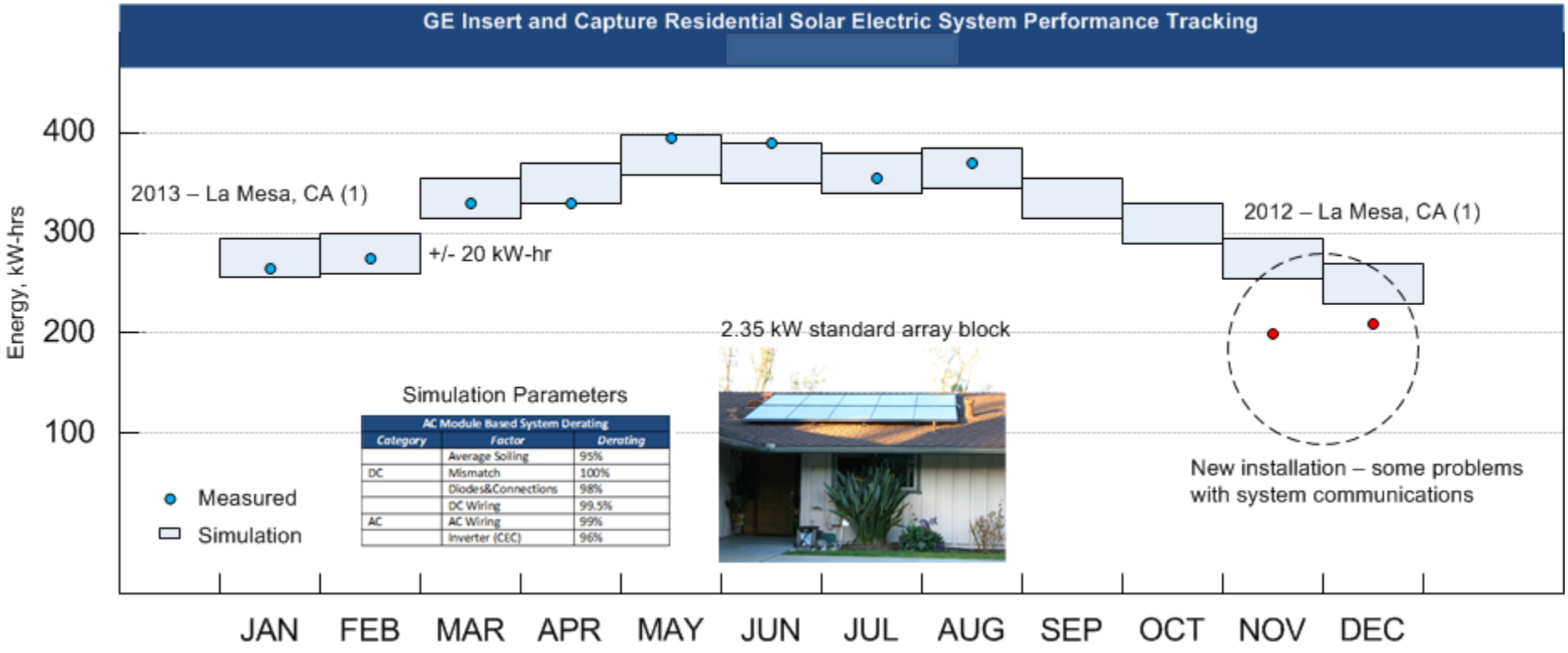
CSI Performance Charts

La Mesa, 2.35kW



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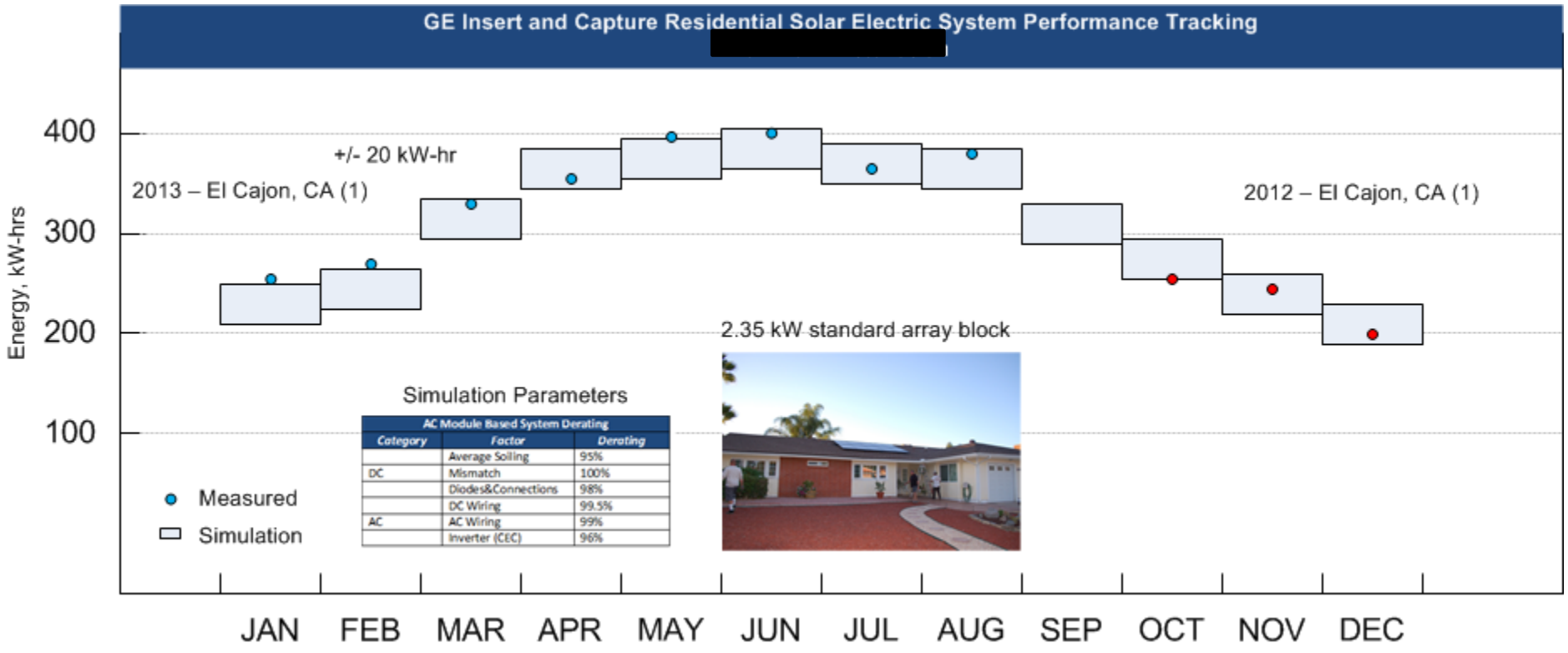
CSI Performance Charts

El Cajon -1, 2.35kW



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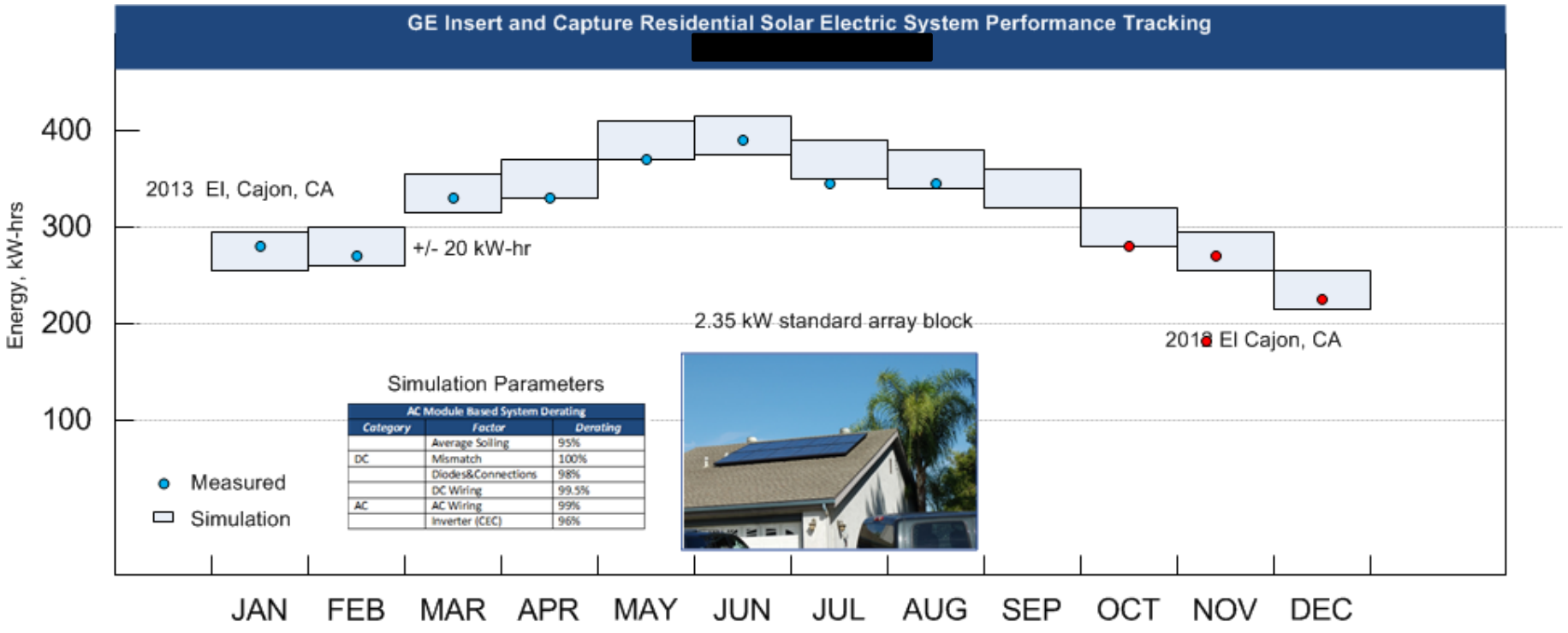
El Cajon-2, 2.35kW



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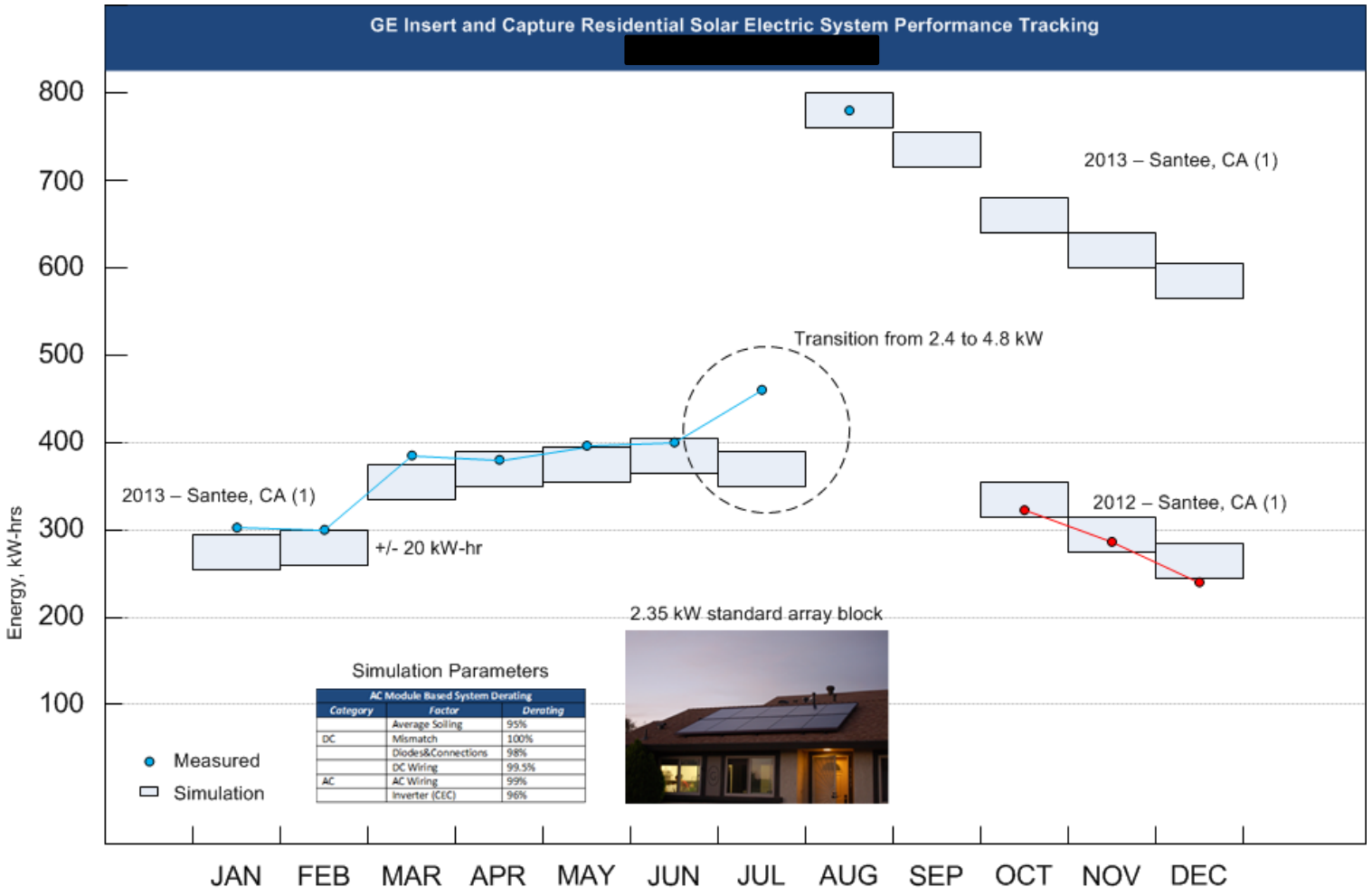
CSI Performance Charts

Santee, 4.7kW



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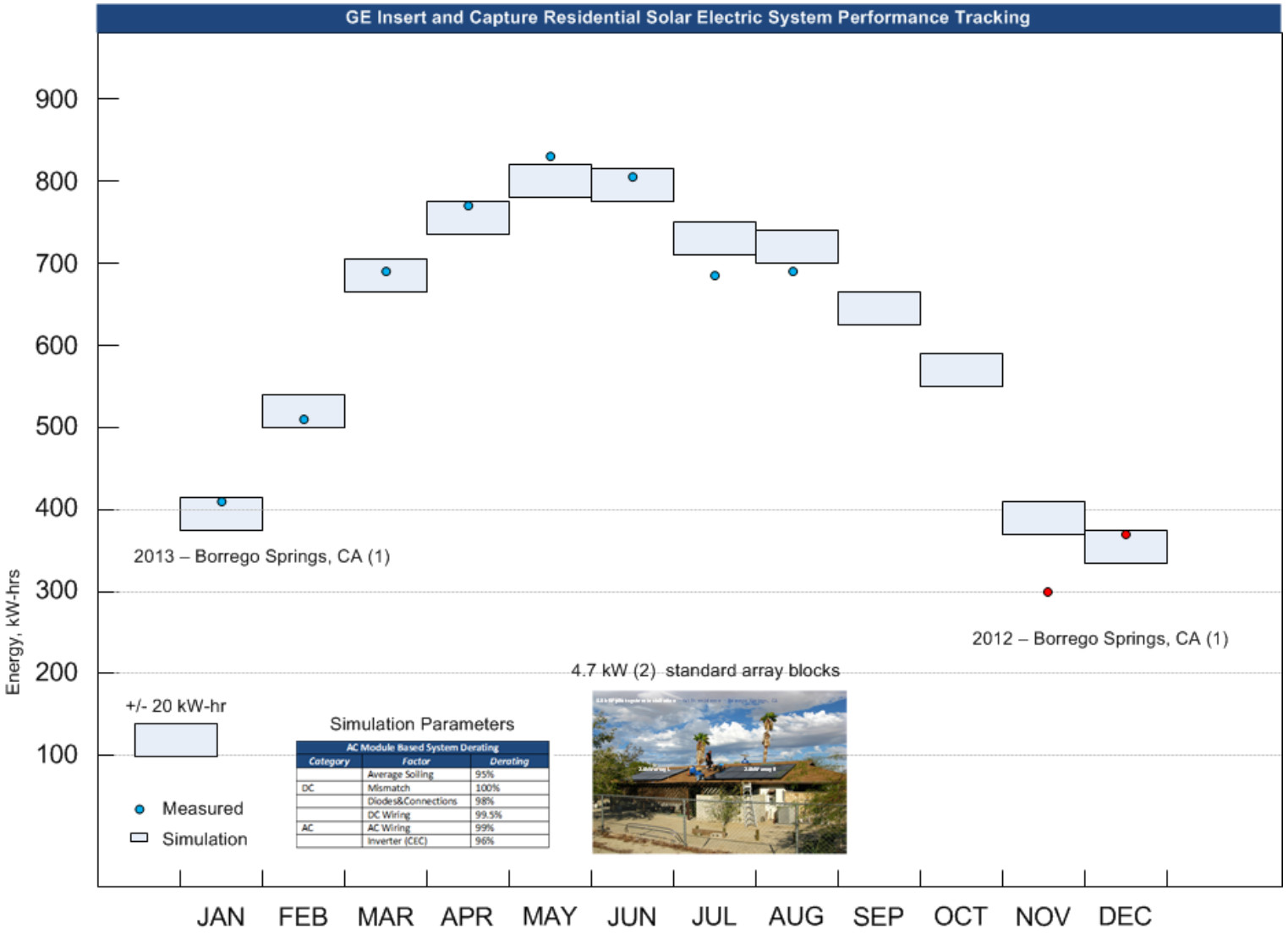
CSI Performance Charts

Borrego Springs, 4.7kW



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Grid-Ready Plug-and-Play PV Kit

Key System Attributes – Importance to Retrofit Market

After some minor shortcomings found in the Prototype installation were resolved, the Grid-Ready Plug-and-Play PV Kit met or exceeded all of the evaluation criteria set for it in this project. In addition, best practices for installation of the system(s) were developed and tested by training two sets of roofers. The system is sufficiently straightforward to install, and the training sufficiently clear and effective that the roofers were sufficiently proficient after a single training/installation that they needed no further training. With additional installations a practice they will be able to install faster, but they know and understand the Best Practices for a quality installation.

Key attributes for this system include:

- Simple to install – crew trained within one installation, based on training two crews and total six installations
- Full installation can be completed in about a half day, with an experienced crew
- There is no requirement nor need for a electrician on the roof. This saves on salaries and insurance costs
- All six systems are performing at or above expectations
- The six systems are out-performing AC systems,
- Except for the module shaded, these AC systems are relatively unaffected by shading.

String-inverter DC-PV systems are quite sensitive to shading, in that the generation from an entire string is reduced even if only one module is even partially shaded. This is an important issue to retrofit, in that the solar potential, at least in Southern California, is very low – only about 11% of homes can accommodate 4kW or more due to shading and physical obstructions[1]. The relative insensitivity to shading of these AC systems compared to the DC-String systems could dramatically increase the market potential for PVs in the residential retrofit market.

[1] Hogan and Hammon: Solar-PV Assessment of Southern California Markets; Posted on BIRAenergy website

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Grid-Ready Plug-and-Play PV Kit

Key System Attributes – Importance to Retrofit Market

As shown in the installation section of this document, and reiterated on the previous page and here, this PV system design is simple and fast to install as a residential retrofit product on asphalt single roofs. Because it integrates a minimum number of parts the manufacturing and assembly costs are kept at a minimum, resulting in an estimated residential customer cost of about $4/Watt[1], installed, assuming manufacturer sales to installers in lots of 1,000 or more.

At less than $4.50/Watt[1], installed, the system is competitive in the residential retrofit market, and, given that the main installation, i.e., that on the roof, can be done entirely by roofing contractors, this potential market entry has an opportunity for a new market niche – being marketed and sold through roofing contractors as an add-on product or an upgrade during a re-roof[2].

The GE system can also be integrated with their Brillion Nucleus system to add Demand Response and Home Energy Monitoring and Management capabilities. This was done on the ZNE home in Santee. The design and results of that ZNE home, integrating energy-efficiency, demand response, energy storage in an intelligent battery system, and PVs are discussed in another report from this project, the CSI-ZNE report, posted on the BIRAenergy and CSI websites.

[1] See Detailed Costs Analysis report for details; this and other project reports are posted on the BIRAenergy and CSI websites (need actual links)

[2] See Business Model report for details; ; this and other project reports are posted on the BIRAenergy and CSI websites (need actual links)

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