Low-Cost Solar Retrofit

Grid-Ready Plug-and-Play PV Kit

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

Zero Net Energy Home Design, Development and Implementation

For
Itron, Inc., Program Manager
California Solar Initiative
Research, Development & Demonstration
Solicitation #2

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CSI ZNE Home Package: Task 8 Project Report

I. Executive Summary

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[1] (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 sqft 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. 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[2]. This IDSM retrofit which is also a zero net energy (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.

This report covers the development of energy efficiency, DR, and storage requirements and design, as well as their implementation in the ZNE home. *The performance of the home is (currently) the subject of another report from this research project (to be integrated into one report after both are written)*

II. ZNE Task Background

Driven at least in part by the California Global Warming Solutions Act (AB 32), the California Energy Efficiency Strategic Plan was developed to provide "Big Bold" goals to reduce energy use in buildings. These include that by 2020 all new homes should be ZNE and the energy use across the existing home market be reduced by 40%. This places substantial pressure on the residential markets to find marketable methods to improve energy efficiency, and to reduce the costs of residential PVs. Efforts are

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[1] A zero net energy home combines efficiency and on-site renewable energy (PVs) such that the PVs produce as much energy as the home consumes, on a net, annual basis.

[2] Korman and Hammon, CSI Task Report: Detailed Cost Analysis of Grid-Ready Plug-and-Play PV Kit (link to report)

ongoing in both the new and existing residential markets to design and evaluate ZNE efficiency packages that are practical and as cost-effective as possible. Although not addressed by these two "Big Bold Goals," a parallel and important effort is needed to substantially reduce summer peak electricity demand. These goals can be achieved through combinations of energy-efficiency improvements, coupled with on-site PVs and significant energy storage, as batteries, thermal mass, or booth.

Electricity generated by PVs both offsets electricity use and can help reduce peak electricity demand; however, rooftop PV electricity generation peaks mid-day, earlier and out of phase with the system peak. During their mid-day generation peaks, efficient homes with PVs frequently produce more electricity than the homes demand, and they feed the excess generation back into the grid when not needed by the homes. When this excess generation is feed back into the grid on community-scales, it can result in reduced grid efficiency, producing increased losses and potentially requiring more infrastructure in the electric distribution system. Alternatively, the excess energy can be stored in the homes as thermal and/or electricity storage (batteries), as well as in batteries in the local distribution system. Thus both utilities and homeowners benefit from a "loading order" of Energy Efficiency measures, Demand Response (DR), Energy Storage and controls all having higher priority in the design process than PV or other on-site generation.

III. ZNE Retrofit Design and Development

A set of efficiency measures or "package" of efficiency features was determined for improving the envelope efficiency, space heating and cooling systems efficiencies, water heating efficiency, and most of the kitchen appliances (which were both DR and high efficiency).

The Energy Efficiency (EE) features packed was the result of iterative EE feature package design and simulation to optimize the features package, based on reaching ZNE with the PV system producing the annual energy needed to be net-zero annually, according to simulation results. Details of the energy-efficiency package design and energy-modeling simulation results follow.

1. Energy Efficiency Package

The first element of the design phase of the development of the ZNE package features was to optimize[3] the natural gas-fueled EE appliances (*i.e.,* heating, cooking, clothes drying, and water heating) in the home. These appliances were chosen because the large source energy savings provided by gas verses electrical, in these specific cases. The final list of EE features includes a high-efficacy range top, gas drier, and 95% AFUE furnace, but not a gas water heater (see attached features descriptions and lists in **Appendix 1**.

[3] The term "optimize" used to describe the development process for the energy-efficiency package components. Optimization was not limited to efficiency only, but also included consumer preference for fuel type (gas or electric), efficiency levels, availability and reliability, and cost.

Following optimizing the gas appliances was to likewise optimize efficiency fuel-neutral and electrical EE technologies. Fuel-neutral EE features included in the ZNE package were insulation, windows, solar hot water, hot water recirculating systems, and various envelope sealing techniques and resulting air tightness levels. The electrical EE appliances that could possibly be used to achieve a desired level of efficiency ranged from simple changes in lighting (LED or CFL, for example), but also included a number of electrical space conditioning and electric water heater options, both in types and efficiencies. The choice of electrical EE space conditioning features includes an 18 SEER AC and a 2.8 COP HPWH (see **Appendix 1**).

The third step in the development of the ZNE feature set was the sizing of the on-site generation (PV), and any resulting adjustments in the efficiency package as a result – attempting to be as close to ZNE as possible without going beyond and becoming a net generator. The PV system was pre-determined by the overall project to be the GE Smart-Grid Ready Insert and Capture Solar PV. The low-cost PV system at the core of this project comes in Kits each of which is sized as 2.4kW. Iterative design evaluations were performed with both 2.4kW and 4.8kW PV system sizes. Through this process it was determined that the most cost-effective EE+PV combination was to sufficiently increase the efficiency of the envelope and appliances such that a 4.8kW PV system (two PV Kits) could provide the electricity needed to offset the remaining energy use, on a net, annual basis. More efficiency improvement could have been made, but it would not have been cost-effective to add sufficient EE to drop the PV to 2.4kW, nor was it desirable to go beyond ZNE.

2. Demand Response Enabled Appliances and Storage

The ZNE retrofit design and implementation under this CSI RD&D program combines efficiency improvements for a very efficient home, including efficient kitchen and cloths washing and drying appliances are both efficient and DR-enabled, and an intelligent battery system was added as well, followed by a 4.8kW GE Smart-Grid ready Plug-and-Play PV Kit. The battery system is programmable and the GE DR-appliances and PV system connect to the GE Brillion Nucleus that can provide energy-use information to the homeowners (occupants) as well as connect to the utility DR system either through the smart meter or via the web.

In addition to the DR modules internal to most of the appliances in the home, GE also provided DR addressable modules that can control appliances plugged into the DR module plugged into the wall. One of the GE plug-control modules is shown in **Figure 1** below. It is an Ethernet-controlled miniature "smart grid" that disengages the power supply to specific appliances during peak hours, if so instructed by the GE Brillion Nucleus home energy management system.

Figure 1. GE Plug Load DR Module. This DR module can disconnect the plug appliance if instructed by the GE Nucleus, an ethernet-adapted electricity usage controller for the Zero Energy Home.

In addition to its DR capability of controlling DR-capable appliances, the Nucleus also monitors and records the energy use of the appliances it can manage, as well as PV generation and whole-house usage (at the meter). Sample Nucleus display screens that can be monitored on a web-connected computer, as shown in **Figure 2**.

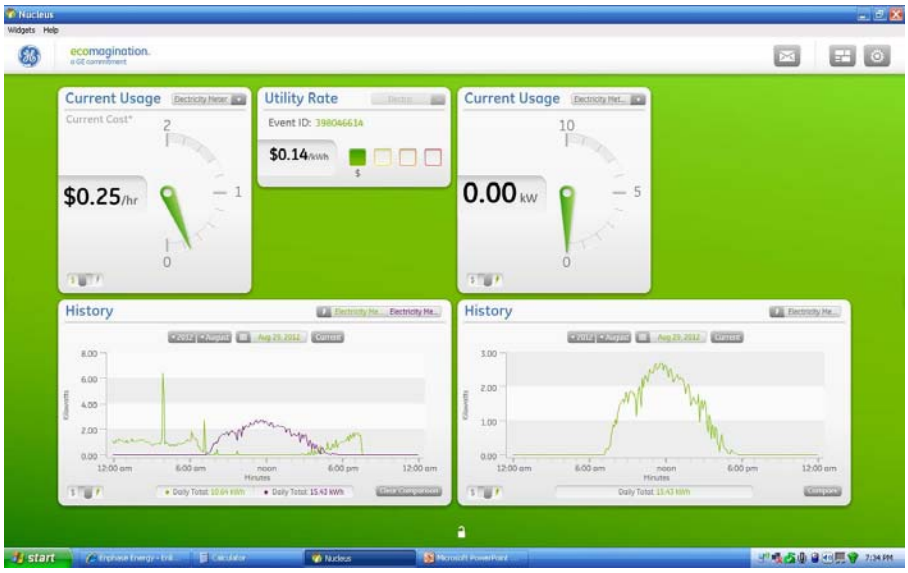

Figure 2. Sample display screen for GE®'s Demand-Response Management System (DRMS). These Home Energy Management system functions of the Nucleus and Sunverge systems were included in simulating the feature package, and set to reduce miscellaneous electric loads (MELs) by 15%, from the Building America MELs benchmark.

3. Building Simulations in Support of Package Development

Building energy-use simulations were performed throughout the design phases of the ZNE package. Once the final package was determined the final building simulation results could be tabulated to show the performance of the home prior to any retrofits, and as expected, post-retrofits. The results of the simulation provide hourly data of the homes end uses, in both kWh and therms, provided in **Table 1**. These values were then used to determine the annual energy end uses and the average daily use profile of the home, as shown in **Figure 3**, below.

	Source Energy Use (MBtu/yr)		Site Electricity Use (kWh/yr)		Site Natural gas Use (Therms/yr)	
	Base Case	*ZNE*	*Base Case*	*ZNE*	*Base Case*	*ZNE*
Misc.	30.39	29.09	2,583	2,469	7	7
Lg. Appl.	18.47	15.54	988	814	65	57
Lights	13.90	9.50	1,211	827	-	-
HVAC Fan/Pump	3.66	0.10	319	8	-	-
Cooling	9.95	0.56	867	49	-	-
Heating	12.28	4.39	-	-	112	40
Hot Water	18.68	14.01	-	1,220	171	-
Total	107.34	73.19	5,968	5,389	355	104
PV	43.98	85.74	3,831	7,468	-	-
Net (Total - PV)	63.35	-12.55	2,137	(2,079)	-	-

Table 1. BEoptE+ v1.3 simulation results for the annual energy end uses of the CSI ITRON ZNE test home, including the base case (before retrofit) and the completed ZNE retrofit package.

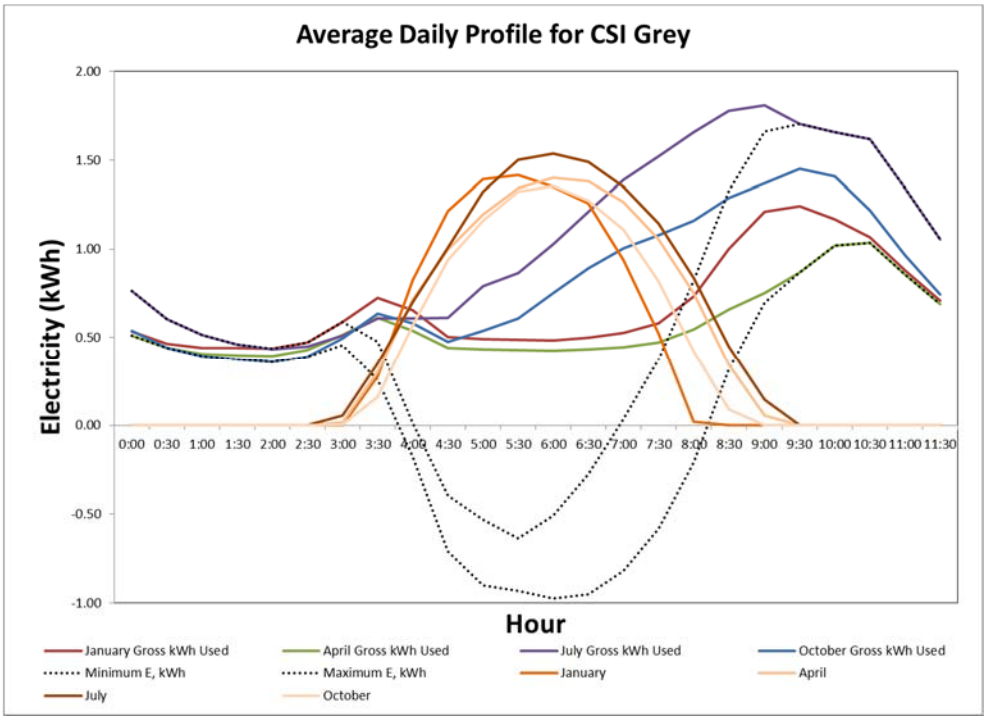

Figure 3. Simulation results of a BEoptE+ v1.3 model of the CSI ITRON ZNE test home were used to determine the average daily electrical use profile, indicating both gross and net electrical consumption. The average hourly solar insolation for the region of California Climate Zone 10 is also shown.

For the purposes of research, BIRA utilized BEoptE+ v1.3[4] (Herein: BEopt) and a custom library of functions created by BIRA. The BEopt library holds information describing the energy attributes for each feature, such as R-values, U-factors, solar heat gain coefficients (SHGC), SEER, and costs, as well as packages of features. The base case features for the CSI ZNE home were the as-built features found in the home before any retrofit by BIRAenergy had taken place. The base case features are summarized in **Appendix 2**.

The library data for each potential EE features for the ZNE package was then verified and updated as appropriate based on manufacture-supplied data. Each unique feature was simulated as a single improvement upon the existing-home base case features (see **Appendix 2**). For each feature, these individual simulation results and costs were used to determine the cost-effectiveness, in source-kBtu saved per dollars cost (units of kBtu/$). A most cost-effective feature from each of the building components (heating, cooling, insulation, windows, PV, etc…) was determined using this metric. Finally, based on cost-effectiveness, availability, and practicality of installation and/or use, a final ZNE package was developed, emphasizing cost-effectiveness and whole-house energy savings.

The as-built base case was simulated first to work out any simulation issues that might occur with the overall input geometry of the home. The geometry proved to be simple, and then initial package features were evaluated, and the results of the intimal tests showed the feature packages were able to achieve the desired level of savings. The final ZNE package savings is about 32% source-energy savings when compared to the as built base case, using BEopt and our custom library (which mirror manufacture's data). The intent was to have a retrofit that, with PVs, would reach ZNE, or "ZNE prep"-similar to the type of retrofit package that could help meet the 2020 goal.

The final ZNE packages will then be installed into the demonstration home. It is a home built in 1979 and located in Santee, CA (Climate Zone 10). The home had not been retrofitted with any modern (2000 or newer) Title-24 features (see **Appendix 2** for as-built base case features and **Appendix 1** for the ZNE package). Pictured below is the test home taken after the start of the ZNE retrofit phase, showing a half of the PV system (2.4kW) already installed.

4. Energy Efficiency Package

The CSI ZNE EE Package is a relatively cost-effective, "ZNE prep" package – producing 32% source-energy savings (as determined using BEopt-EnergyPLUS), each relative to the as-is base-case. Using the default costs in BEopt from NREL, this package would cost the homeowner $34,370. CSI ZNE contains EnergySTAR appliances, R-49 attic (with buried ducts and a radiant barrier), sealing building envelope sealing (to 3.0 SLA), 100% LED lighting, dual-pane low-e windows, and 18 SEER/95% AFUE HVAC. To reach ZNE, this package would require a 4.8 kW PV system, resulting 100% source-energy savings compared with the as-is base case using BEopt, at an estimated cost of $54,770. BEopt simulations and the associated NREL costs showed the 2.8 COP HPWH with D'Mand system to be more-efficient and cost-effective than a 95% EF tankless, condensing water heater.

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[4] Beopt.nrel.gov

Figure 4. The Santee, CA ZNE retrofit test home during the installation phase, showing 2.4kW of the final PV package already having been installed in 2013.

APPENDIX I : CSI ZNE Package Features

Item #	ZNE Package Features	Actual Prices
1	R-49 attic insulation, blown-in cellulose, Grade 1	$ 2,040
2	Radiant barrier, continuous, attic	$ 1,955
3	Low-e/SHGC Milgard windows, U-factor .24, SHGC .27	$ 5,200
	Low-e/SHGC Milgard Patio Doors, U-factor .24, SHGC .27	$ 5,100
4	GE Refrigerator	FREE
5	GE Clothes Washer	FREE
	GE Dishwasher	FREE
	GE Range	FREE
	GE Clothes Dryer	FREE
6	100% LED lighting (indoor, outdoor, plug-in and hardwired)	$ 1,600
7	Hand sealed building envelope, SLA 3.0 or better	$ 2,125
8	18 SEER AC, Rheem RASL048JEC	$ 13,900
9	95% AFUE Furnace, Rheem RGTM07NRBGS	
10	Burrued ducts in attic	
11	Ceiling fans, Generation Brands Monte Carlo Vector Max, models 3SU54PN or 3VMR52TID	$ 750
12	GE Heat Pump Water Heater	FREE
13	ACT, D'MAND hot water recirculation system	$ 875
14	R-2 insulation on exposed hot water pipes	$ 200
15	Low flow sink faucet aerators, 0.5 GPM	$ 75
	Low flow showerheads 1.25 GPM	$ 150
16	4.8kW PV	$ 20,400
17	Energy Management System	$ 400
TOTAL		**$ 54,770**

Table 2. The features used in the CSI ZNE package and their associated actual costs ($54,770, including installation) and simulated energy savings (32% source-energy savings).

APPENDIX II : 2008 Title-24 Base Case Comparisons to ZNE Package

Feature	ZNE Package Features	Base Case
Misc Electric Loads	Home Energy Management System	Building American Benchmark
Wood Stud		R11 Batt-Gr 3 2x4 16"o.c.
Exterior Finish		Stucco
Interzonal Walls		R11 Batt-Gr 3 2x4 16"o.c.
Unfinished Attic	Ceiling R49 Cellulose Blown-In Vented	Ceiling R38 Cellulose Blown-In Vented
Roofing Material		Asphalt Shingles Medium
Radiant Barrier	Radiant Barrier	None
Window Areas		17.9% Grey Homes F46 B28 L0 R26
Window Type	Milguard Windows, Slider (0.27 / 0.24)	1-Pane Clear Metal (0.67 / 0.76)
Infiltration	3 ACH50	10 ACH50
Mechanical Ventilation		None
Refrigerator	EnergyStar Side-by-Side Freezer	Standard Side-by-Side Freezer
Cooking Range		Gas Conventional
Dishwasher		EnergyStar
Clothes Washer	EnergyStar	Standard
Clothes Dryer		Gas
Lighting	100% LED Hardwired & Plugin	40% Fluorescent Hardwired
Air Conditioner	SEER 18 (2-stage), EER 15.5	SEER 10
Furnace	Gas, AFUE 95%	Gas AFUE 78%
Ducts	7.5% leakage, Buried Ducts	15% Leakage, R4.2 Insulation
Ceiling Fans	100% Coverage Eff Smart 4 °F	3 Fans Std Typical 0 °F
Water Heater	Gas Tankless Condensing	Gas Standard
Distribution	Uninsulated TrunkBranch Copper Demand	Uninsulated TrunkBranch Copper
PV System	4.8kW	None

Table 3. A comparison of the as-built base case and the CSI ZNE package features, including 4.8kW, is shown above. The base case features in are on the right. Features indicated under the heading ZNE Package Features include only the deviation from the as-built base case.