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

GO solar CALIFORNIA

Final Project Report:

Grid Integration of Zero Net Energy Communities

Grantee:

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

Preface

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

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

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

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

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

LIST OF ABBREVIATIONS

A/C	air conditioning
AB	Assembly Bill
AFUE	annual fuel utilization efficiency
AHJ	Authority Having Jurisdiction
API	application program interface
ATS	auto transfer switch
BEMS	battery energy management system
BMS	battery management system
BTM	behind-the-meter
CABA	Continental Automated Buildings Association
CAISO	California Independent System Operator
CBIE	California Building Industries Association
CCR	Covenants, Conditions and Restrictions
CEC	California Energy Commission
CES	Community Energy Storage
CSI	California Solar Initiative
CT	current transformer
DERMS	Distributed Energy Resource Management System
DERs	distributed energy resources
DR	demand response
EE	energy efficiency
EEMs	energy efficiency measures
ESS	Energy Storage System
EHA	electric-heating-appliances
EMS	Energy Management System
ETCC	Emerging Technology Coordinating Council
EV	electric vehicle
FAU	forced air unit
FiT	feed-in tariffs
FMEA	Failure Mode Effects Analysis
GHG	greenhouse gas

HEMS	Home Energy Management System
HERS	Home Energy Rating System
HOA	Homeowners Association
HP	high performance
HP-A	high-performance attics
HP-W	high-performance walls
HPWH	heat pump water heater
HSPF	Heating Seasonal Performance Factor
HVAC	heating, ventilation and air conditioning
IBEW	International Brotherhood of Electrical Workers
IDER	integrated distributed energy resources
IDSM	Integrated Demand Side Management
IEPR	California Integrated Energy Policy Report
IGBT	Insulated-Gate Bipolar Transistor
IOU	investor-owned utility
kWh	kilowatt hour
MELs	miscellaneous electrical loads
MEP	Mechanical, Engineering and Plumbing
NASEO	National Association of State Energy Officials
NEM	net energy metering
NEMA	National Electrical Manufacturing Association
NREL	National Renewable Energy Laboratory
NSHP	New Solar Homes Partnership
O&M	operations and maintenance
PCS	power conversion system
PRP	Preferred Resources Pilot
PTO	Permission-to-Operate
PV	photovoltaic
RFI	Request for Information
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SEER	Seasonal Energy Efficiency Ratio
SME	subject matter expert
SMUD	Sacramento Municipal Utility District

SOC	state of charge
SPF	spray-in foam insulation
SSA	System Safety Analysis
TDV	Time Dependent Valuation
TOU	time-of-use
USGBC	United States Green Building Council
ZNE	Zero Net Energy

KEY DEFINITIONS

Backfeed/backflow - Backfeed is a condition when voltage is present on a conductor or associated equipment after it has been disconnected from its normal source. [1]

Duck curve - In commercial-scale electricity generation, the duck curve is a graph of power production over the course of a day that shows the timing imbalance between peak demand and renewable energy production. In many energy markets the peak demand occurs after sunset, when solar power is no longer available.[2]

Load factor - Electrical Load factor is a measure of the utilization rate, or efficiency of electrical energy usage. It is the ratio of total energy (KWh) used in the billing period divided by the possible total energy used within the period, if used at the peak demand (KW) during the entire period.[3]

Needle peaks – A spike on the annual power demand chart, that indicates an extreme demand period[4]

Overgeneration/Oversupply - Oversupply is when all anticipated generation, including renewables, exceeds the real-time demand.[5]

Peakiness – the magnitude of the average absolute deviation of demand peaks in a power demand chart.[5]

Volt/VAR - 1 VAR or Volt-Amphere Reactive is a unit used to measure reactive power in alternating current.[6]

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[1] http://energystorage.org/energy-storage/technology-applications/distributed-grid-connected-pv-integration

[2] http://sustainablecomputinglab.org/wp-content/uploads/2014/09/smartcap.pdf

[3] http://www.demandcharge.com/Web_Pages/Articles/Electrical_Load_Factor.html

[4] http://grist.org/article/adventures-in-the-smart-grid-no-2-demand-response/

[5]CAISO - https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

[6] https://www.nema.org/Policy/Energy/Smartgrid/Documents/VoltVAR-Optimazation-Improves%20Grid-Efficiency.pdf

ABSTRACT

The state of California has a goal to reduce carbon emissions by 80% compared to 1990 by the year 2050. A cornerstone of this goal is to achieve Zero Net Energy (ZNE) in new buildings: residential buildings in 2020, Government buildings in 2025 and commercial buildings by 2030. ZNE is achieved by substantially driving energy efficiency and offsetting remaining energy use (gas and electric) with photovoltaics (PV). ZNE is a near-time (less than three years) practical implementation of high PV penetration, as most new construction occurs in geographically concentrated areas and impacts specific locations of utility distribution systems.

The Electric Power Research Institute (EPRI) led a field initiative to measure actual load profiles of ZNE homes and their impact on electrical distribution systems. This effort led to the first ZNE neighborhood in California, with every home on a transformer designed to ZNE. EPRI, along with Southern California Edison (SCE), worked with Meritage Homes, a top homebuilder in the United States, to design, construct, occupy and monitor these homes.

Energy efficiency substantially reduces energy use in the morning and displaces afternoon peaks until the late evening, with little energy use during times of high solar production. This results in high backflow in the morning and creates steep evening ramps. The load profiles of ZNE homes are similar to the California Independent System Operator (CAISO) duck curve. The load shape will be quite different between spring/fall, winter, and summer. The initiative also electrified the heating loads to eliminate carbon emissions from fossil fuels, required for reaching the 2050 goals. Preliminary modeling and monitoring results show that peaks and valleys of electricity use are driven by the heat pump water heaters and cooling. The distribution system is planned to accommodate an average of 6.5 kW per home. With electrification of space conditioning and water heating loads as dictated by the project and electrification of laundry, cooking and electric vehicles as chosen by the homebuyers, peak loads as high as 15 kW occur in a single home. The goal was to understand if in net, with load diversity, the transformers, laterals, load blocks and feeders had sufficient capacity using today’s planning methods.

To alleviate distribution impact, these homes were set up with controllable loads and with behind-the-meter energy storage. Resource aggregation strategies were developed to connect measurements at the transformer with loads, storage and PV. The results of the testing showed that energy storage when optimized for grid integration (charge in the morning, discharge in the evening) could reduce the peaks and valleys on the distribution network. The connected thermostat could absorb excess solar production through pre-cooling of homes, and a similar strategy is being implemented with water heating. Two important take-aways from the project were that the control strategy of energy storage could either strengthen or in some cases, accentuate distribution problems, and that modeling tools still have a way to go to address the prominent or “needle” peaks that will be more common in future buildings. This report discusses experiences in developing the community, strategies for distributed energy resources (DER) integration, and possible benefits of demand response and energy storage in the future distribution grid.

Keywords

Retail Buildings
Lighting
ZNE
HVAC
Ventilation
Zero Net Energy
Small Business
On-bill financing

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Grid Integration of Zero Net Energy Communities

PRIMARY AUDIENCES: Electrical utility program managers and distribution planners interested in understanding the impacts of high-penetration photovoltaic (PV) systems on the electrical grid. Stakeholders interested in understanding technology packages to achieve zero net energy goals. Interested members that want to better understand opportunities to control and monitor residential communities.

KEY RESEARCH QUESTION

This report details the progress of deploying a residential Zero Net Energy (ZNE) community in Fontana, CA. The community, built to the project's ZNE requirements, served as a demonstration site to understand the impacts on the electrical grid of these ZNE communities and the resultant high penetration PV system scenario.

RESEARCH OVERVIEW

The project details designing, deploying, constructing, selling, and occupying 20 homes built to California Title 24 ZNE standards. Once occupied, research included monitoring and potentially, mitigating grid impacts of these homes on the electrical distribution system. The project demonstrated a combination of new technologies and strategies that resulted in cost-effective ZNE homes and resulting high PV adoption. The project also measured and modeled the impact of concentrations of ZNE homes on the electrical distribution system. Insight was provided into how residential energy management systems can balance solar with loads and support power system needs. The project also evaluated and demonstrated the location of energy storage in high penetration PV settings, and developed an integrated modeling approach to integrate building and distribution models.

KEY FINDINGS

- Achieving deep energy efficiency and minimizing residential PV has multiple benefits that include: (1) minimizing effects on elevations, neighborhood solar planning, and lot offerings, (2) reducing peak backflow back through the distribution system as a result of over generation, and (3) reducing evening ramping attributed to loss of solar plus additional residential electricity usage.
- Improvement and standardization of various construction processes including storage permitting and solar/storage interconnection is still needed.
- Low-cost data acquisition is achievable through connected devices that act as low-cost customer preference, energy performance, and indoor/outdoor environmental sensors. These data were coupled with traditional data sources available to the electric utility to better attribute grid impacts.
- Solar generation and load peaks are not coincident. Preliminary data shows that both transformer and premise-level peaks are driven by coincident usage of electrified loads (heating, ventilation and air conditioning, water heating, ovens, dryers, electric vehicles, etc.).
- Deployment of residential energy storage systems can provide grid benefits if control algorithms are optimized to do so.

- End-to-end models integrating building and distribution models are achievable, and can enable better grid planning. Current building models are not (yet) accurate at predicting peak operation.
- The most reliable path forward in distribution planning is to increase transformer and wire sizing for ZNE and high PV penetration, as this requires a 50-year planning horizon.
- The problem spots for distribution systems are load blocks, laterals where the protection devices lie, and wire sizing.
- Distribution systems will need to manage for load peaks almost as much as for high penetration PV. Passive energy storage, demand response, and energy storage can provide integrated load management techniques, but platforms and controls are currently not available to do so.

WHY THIS MATTERS

The state of California has a goal to reduce carbon emissions by 80% compared to 1990 by the year 2050. A cornerstone of this goal is to achieve Zero Net Energy in new buildings: residential building in 2020, Government buildings in 2025, and commercial buildings by 2030. ZNE is a near-time (less than three years) practical implementation of high PV penetration, as most new construction occurs in geographically concentrated areas and impacts specific locations of utility distribution systems. The research presented in this report provides a possible method of deploying ZNE and other advanced energy communities that are cost-effective to the homeowner and acceptable to the homebuilder, while potentially minimizing the impact to the electrical grid.

HOW TO APPLY RESULTS

The project shows an end-to-end approach for modeling, constructing, and monitoring residential zero net energy communities. Interested stakeholders at various stages of developing advanced energy communities can apply learnings from this report. Historically, residential grid planning was driven by weather-driven loads such as space conditioning. As efficiency and greenhouse gas emission standards drive to deeper and deeper efficiencies, it will be important to understand grid impacts of loads, including electrified end-use loads that can be driven by customer preference and behavior. Actual data at the end-use, premise, and transformer level can inform electrical utilities of the impacts of these loads.

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PROGRAM: Program 170: Energy Efficiency and Demand Response

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1
ZERO NET ENERGY COMMUNITIES AS NEAR-TERM HIGH PV PENETRATION TEST CASE

The State of California has set ambitious targets for greenhouse gas (GHG) reduction goals through landmark Assembly Bill (AB) 32. A key component to meet these targets is the Long-Term Energy Efficiency Strategic Plan, which set a goal that all new homes in California be Zero Net Energy (ZNE) by 2020. As defined by the 2013 California Integrated Energy Policy Report (IEPR), a ZNE home is defined as one where the societal value of energy consumed by the home over the course of the year will be less than or equal to the societal value of the on-site renewable energy generated, measured using the California Energy Commission's Time Dependent Valuation (TDV) metric [1]. These ZNE homes will potentially result in a high PV case combined with a low load case, accentuating the maximum back flow situation from these homes into the grid. Another driver in California is to reduce carbon emissions to 80% below 1990 levels by 2050. To achieve this level, it is predicted that all building end uses must be electrified. However, efficient electric heating and water heating systems today can distort the predicted premise-level load shapes that, when aggregated and deployed at community scale, could result in potential distribution systems issues.

This project demonstrated the impacts of a near-Zero Net Energy home community on the local distribution systems, and mitigation of the impacts using multiple strategies centered around building energy management systems and energy storage. To reduce GHG emissions, California's Long-Term Energy Efficiency Strategic Plan has a "Big Bold Goal" that all new homes in California be Zero Net Energy by 2020 [2]. As ZNE communities become de rigueur, new home construction will become the largest source for distributed photovoltaic (PV) installations. This project evaluated various ZNE approaches to derive PV sizing and interconnection requirements that produce cost-effective and grid-integrated ZNE communities, as well as community solar. Meritage, the homebuilder partner, built 20 ZNE homes in Fontana, California for the field evaluation portion of the project.

The typical ZNE home design is to increase energy-efficiency of the envelope, space conditioning and water heating equipment, kitchen appliances, and lighting, and then add sufficient PV on the roof to attain zero TDV [3]. The load-factor for ZNE homes is expected to be low (<0.3), implying low electric system asset efficiency with mid-day excess net generation and a late-afternoon peak-demand most of the year (waning PV production with evening demand from lighting and air conditioning [A/C]). Examples of energy efficiency (EE) and ZNE packages are shown in Figure 1-1.

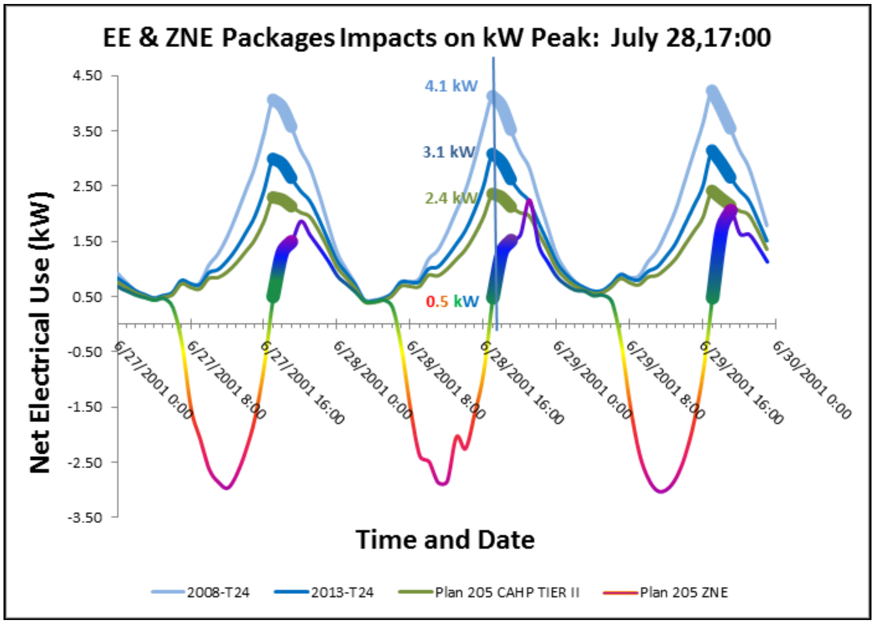

Figure 1-1
Projected ZNE impact on load shape

All the homes in the study have an Energy Management System (EMS) that serves as an Integrated Demand Side Management (IDSM) controller – managing end uses for EE and demand response (DR) in tune with consumer preferences. DR was used for load shaping and power quality management at the distribution level, to manage electric vehicle (EV)-ready requirements and to support electric system needs. The Community Energy Storage system (CES) performed a second level of distribution impact mitigation while also serving bulk system requirements for cost effectiveness.

In addition to low distribution asset utilization, ZNE communities can increase distribution line losses and create power quality issues such as voltage control and harmonics from transients in PV generation and loads. The project developed modeling approaches to predict the impact on distribution systems and the effect of mitigation strategies by integrating building models, energy storage models, and distribution models. The modeling was informed by the measured data from the community. The integrated model can be extended to other locations in California using concurrent research being undertaken to categorize and model distribution feeders in the state. The results can be used by utilities and the building codes to incentivize measures in ZNE communities that will enhance the electric grid. In addition to distribution benefits, the measures evaluated in the project can also address concerns raised by the California Independent System Operator (CAISO) with regards to future requirements for flexibility to address low midday loads and high evening ramp rates on the grid.

The primary goal of this project was to ensure that the **widespread development of ZNE communities and the resulting Grid Integration is beneficial rather than detrimental to the operation of the electrical grid, and the distribution systems.** The homes built and evaluated in this project demonstrated substantial benefits to investor-owned utilities (IOUs) and developers in terms of distribution system architecture, specifications and cost, and interconnection properties. The quantification of these benefits could enable electric utilities to provide incentives for ZNE communities based on business economics rather than societally-based incentive programs.

Data from the ISO, EPRI, and BIRAenergy [4] [5] all show that the load factor of the distribution system is lower for near-ZNE homes than homes built to current code without PV. Reduced distribution system load factor would negate expected benefits for the grid, and possibly require enhancements to the distribution infrastructure for ZNE communities to new homes built to current code. This could make ZNE homes more expensive and the costs will need to ultimately be passed on to the new-home buyer/occupants. This cost hurdle could potentially be avoidable, and ZNE homes that incorporate IDSM, Home Energy Management Systems (HEMS), PV, and energy storage could restore the efficiency of the distribution system and possibly enhance it. Data is needed to predict the potential current and mature-market savings on infrastructure costs, as well as the net costs of adding storage and EMS to a ZNE home. Nonetheless, the predicted reduction or elimination of mid-day over production, late-afternoon rapid demand-ramp, and mitigation of PV transients with EMS and storage has significant value to utilities. The current value of the electricity marginal costs savings from a ZNE that can optimize its load shape could be worth well over $8,000 per home to the IOUs [6]. The added benefits of reduced distribution costs, and GHG reductions could enable IOUs to promote ZNE communities with storage and HEMS, possibly reducing their cost to buyers

The project goal of ensuring that the widespread development and Grid Integration of ZNE communities was beneficial to the distribution systems was achieved by meeting the following objectives:

- Demonstrate technology pathways for ZNE communities that are cost-effective and appealing to tract-home builders and consumers, and that provide a roadmap for distributed PV installations to meet 2020 ZNE requirements.
- Outline how ZNE communities can impact electrical distribution system in an “as-is” scenario. Develop and demonstrate practical approaches to community-scale ZNE, employing storage, HEMS, and DR that make widespread development of ZNE communities beneficial to grid/distribution-system efficiency and stability while maintaining operational flexibility.
- Evaluate and demonstrate DR in ZNE home communities to optimize load shape, Volt/VAR, fast transient events, and to enable greater PV penetration in the bulk power system.
- Evaluate requirements for energy storage in ZNE communities, considering both thermal and electrical storage and demonstrate the effective use of storage.
- Estimate feeder impact of ZNE communities using categorization of distribution feeders.
- Identify additional requirements for ZNE buildings that can be incorporated into utility ZNE programs and/or CA Title 24 code.
- Develop an end-to-end modeling approach for ZNE Communities that integrates building modeling and energy storage optimization with distribution models.

2
DESIGN PROCESS FOR ZERO NET ENERGY COMMUNITY

Design of the ZNE community was a multi-stakeholder process that required coordination between product manufacturers, home builders, trade allies, designers, and electric and gas utility providers. This section discusses the steps taken to develop a practical set of efficiency and renewable energy measures that lead ultimately to the ZNE packages deployed as part of this project. The goal of this section is to detail the process to design the ZNE community as part of this project. These steps included: (1) distribution system planning, (2) neighborhood selection, and (3) ZNE technology package development. This section also touches on cost and financial strategies to deploy ZNE homes at scale and to develop ZNE packages that are acceptable to builders, developers and homeowners. It is worth noting that this section supports the overall goals of the project in that it details: (1) the design and plan to construct ZNE communities that are cost-effective and appealing to volume home builders and to consumers, and (2) roadmaps for large-scale integration of efficient homes with rooftop PV systems, providing distributed, renewable energy to the grid. The work described and performed by the team was to develop an integrated package of energy efficiency and renewable energy measures that would result in the homes being rated as zero net-energy using the California definition based on time-dependent value of energy (TDV energy[7] and ZNE_{TDV} or simply ZNE).

Distribution System Planning

It is important to note that distribution systems for this community were not designed to account for all considerations that a ZNE Community would entail. This includes, but is not limited to: (1) high penetration PV and resultant additional distribution infrastructure requirements, and (2) any electrification of end-use loads that were required to meet other greater project goals. As previously stated, any intervention with distribution system planning would have to be before Community Tract Maps are approved by governing cities, in this case, Fontana, CA. As Tract Maps were approved and completed before project commencement, they were not scoped as part of this project. This resulted in a project that vets current high-penetration PV scenarios with the current distribution system planning practices. Section 7 goes into further detail.

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[7] TDVenergy: Hourly site energy values multiplied by a factor for every hour of each day for a year. TDV energy has been the basis of energy calculations for the State of California since the 2005 Energy Code update. TDV factors are updated every three years, coincident with building and energy code updates. Full-year, hourly TDV factors exist for all 16 CA Climate Zones for natural gas, propane, and electricity. In the future, TDV factors will also be developed for different forms of renewable energy. Calculations. TDV energy, TDV factors, the process to calculate them were developed for PG&E in 2002: *Time Dependent Valuation (TDV) – Economics Methodology,* by Heschong Mahone Group. New TDV values for the 2016 code update have been published: *Time Dependent Valuation of Energy for Developing Building,* Energy+Environmental Economics.

Neighborhood Selection

The project team took multiple factors into consideration when selecting the neighborhood in which to deploy the ZNE homes required to complete the project. The team tried to meet multiple criteria for site selection of the neighborhood. Initially, the project was to design and deploy ZNE homes as part of an entire builder community. However, a community of homes is not necessarily electrically bounded, a necessity for better understanding distribution system impact of high penetration PV scenarios. In addition, completing a full community to ZNE would require starting from the community planning process – before Tract Maps are approved by governing cities. This would be a multi-year process and would not fit in the two-year timeframe of this project. This pointed to a community that was in the early stages of construction with a significant number of homes that were not yet sold or constructed.

Attaining ZNE would require financial strategies for funding the PV systems required to successfully complete this project. Meritage Homes, the partner home builder, planned to offer PV as an option with an incentive for prospective homeowners to add PV to their home purchase. But offering PV as an option would imply that the team could potentially not achieve a high penetration PV scenario as it would rely on homeowner market uptake factors such as economics, building aesthetics and customer preferences. As it was imperative to understand effects on the electrical system, and a larger community would not provide the complete results the project team was hoping to obtain, a smaller subset of a community was chosen for project cost-effectiveness and overall project inclusion. Cost-effectiveness and PV sizing are discussed later in this section.

Measuring the impact of the ZNE neighborhood on the distribution system was a critical objective of this project. The team needed to find an isolated yet measurable control volume to assess grid impacts of ZNE homes and resultant high-penetration PV scenarios. As most utilities do not have any measurement on the distribution system beyond the substation and feeder, the team focused on the neighborhood transformer. The selection process then required overlaying the community map with the electrical distribution map to determine the location of the lots. In turn, ZNE homes were predetermined, adjacent to one another and dedicated to two isolated community transformers to minimize the effects of additional variables such as differing weather conditions. In addition, electrically binding communities at the transformer level helped the project team assign treatment and control groups for specific project research questions. These requirements resulted in the need for a community that was early enough in the sales phase for the team to dedicate a set of contiguous lots to these ZNE communities.

To make a final decision on the choice of community, a meeting of core project team members, was held at the Meritage offices in Southern California on February 6, 2015. The team reviewed all potential Meritage Homes communities that met project timelines. Overall community selection had factors that included, but were not limited to:

- The community being selected would be early enough in the sales phase so that the research team could pick electrically contiguous lots.
- There would be enough flexibility in the selection of the home plans and elevations to be able to account for solar orientation.
- The home sizes would be near market average to keep down the size of PV required.

- The community being selected would have the opportunity for community scale storage.
- With the right type of outreach, the research team would be able to build, sell, occupy and collect data within one year from project launch.
- The community was of interest to the homebuilder.
- The community would not be a high-end community, but would emulate single family, ZNE communities in California as closely as possible.

Based on these requirements, the Sierra Crest home development in Fontana, CA was selected for the project. This residential development has 187 lots, and while sales started in Q3 2014, only 15 homes had been sold as of February, 2015. The homes were divided into three collections (based on home size), and gave the team the opportunity to select the appropriate electrical control volume. There was additional interest by Meritage Homes as this was a first-time homebuyer community. This would be a great opportunity to evaluate how energy efficiency and solar were within reach of everyone and market strategies that drive adoption of these homes at scale.

The team identified two specific community transformers corresponding to two communities for this ZNE project - a total of 20 homes. See Figure 2-1.

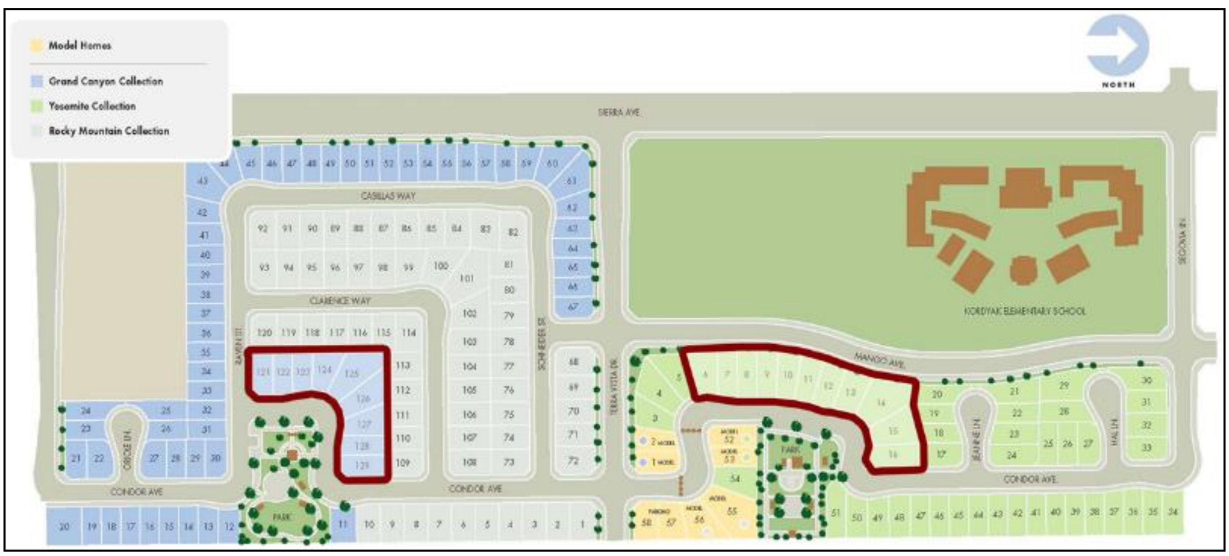

Figure 2-1
The two ZNE community locations as Part of a larger 187 Sierra Crest Home Development

The 20 ZNE homes are clustered in two communities: 11 of the homes (Group 1 or Transformer 1) located on 1 isolated transformer and 9 of the homes (Group 2 or Transformer 2) located on its own separated isolated transformer. Group 1 (Lots 121-129 on Figure 2-1) consists of homes that are 1900-2300 square feet and served by a 50kVA transformer. Group 2 consists of homes that are 2600-2900 square feet and served by a 75kVA transformer. The transformers were sized by Southern California Edison (SCE) based on distribution planning rules, taking into account climate zone and home size.

This ZNE-home siting arrangement was critical to implementation of this project and the team's ability to compare the functioning of these two "ZNE" transformers to other distribution transformers in the Sierra Crest community that are not ZNE and that do not have PVs on their roofs. Each product has three different models and elevations – six home types in total. See Table 2-1.

Table 2-1
Transformer location, and home size of 20 planned ZNE homes

Lot #	Group/Transformer #	Sq. Ft.
6	1	2842
7	1	2888
8	1	2673
9	1	2888
10	1	2673
11	1	2842
12	1	2888
13	1	2842
14	1	2888
15	1	2842
16	1	2842
121	2	2319
122	2	2182
123	2	1936
124	2	2182
125	2	2182
126	2	2182
127	2	1936
128	2	2182
129	2	2182

After home elevations and lots were allocated for the project, energy efficiency and renewable energy packages to achieve ZNE were then considered.

Initial ZNE Technology Package Design

The team developed ZNE technology packages constituting a combination of energy efficiency and renewable energy measures for inclusion in the homes built by Meritage Homes. Building simulations were completed to develop the initial ZNE packages. The team chose to use the energy-modeling tool BEopt [8] for this task. BEopt was chosen both for its relative ease of use

[8] BEopt or Building Energy Optimization Tool is an energy modeling software tool developed by the National Renewable Energy Laboratory to provide accurate residential building energy models that can be simulated with different efficiency features. https://beopt.nrel.gov. The version used for this study was BEopt v2.3.0.2

and its accuracy. While later tasks in this project included collection and evaluation of actual energy use in these 20 ZNE homes, the accuracy of the simulations in this project will not be known because the monitoring period will extend beyond the CPUC CSI Grant period[9]. Two months' worth of data will be assessed vs. modeled data, as discussed in Section 6.

Figure 2-2 is a flow diagram of the generalized process for developing a ZNE-design package:

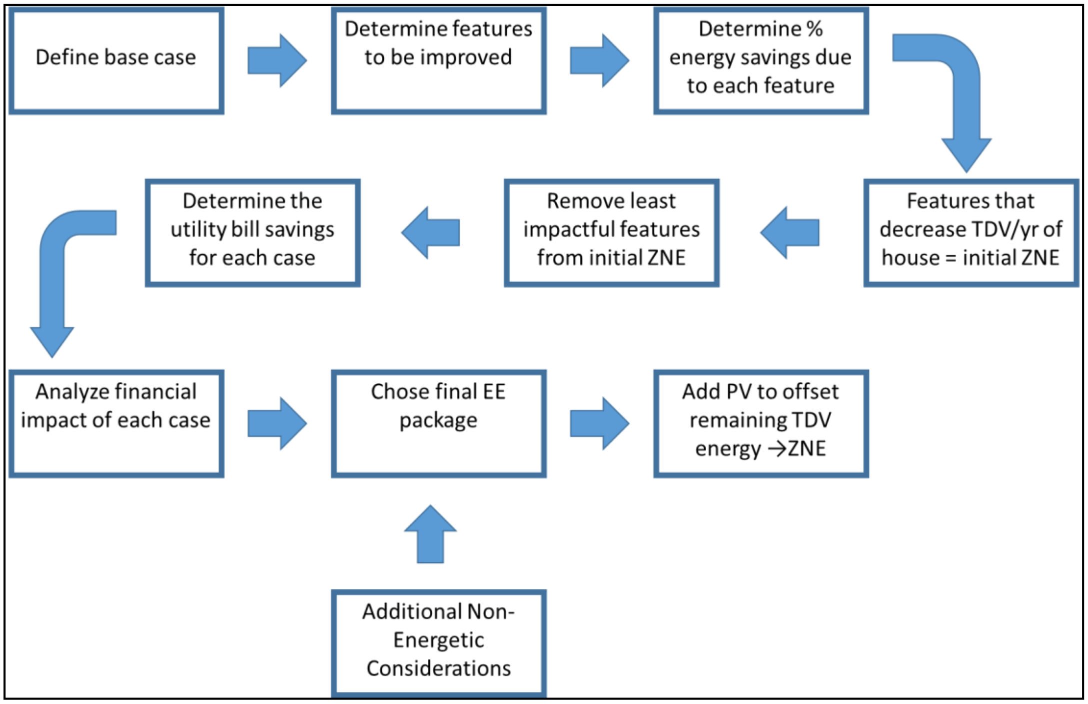

Figure 2-2
Flow diagram of generalized ZNE-features development process used to develop ZNE packages

Defining the Baseline

Baseline information used to develop a BEopt model for each plan-type was garnered from building plans, features specifications, and California residential building energy efficiency standards (Title 24) requirements. California Title 24 baseline conditions are detailed in Table 2-2.

[9] A full year of actual energy use data is required to fully evaluate the accuracy of computer models.

Table 2-2
California Title 24 base case measures (per 2013 Code)

Category Name	2013 CA Title 24 Base Case
Unfinished Attic	Ceiling R-38 Cellulose, Vented
Radiant Barrier	Double-Sided, Foil
Air Leakage	4.9 SLA (9 ACH50)
Air Source Heat Pump	None
Water Heater	Gas, 0.62 EF, 50 gallon located in garage
Water Distribution	Uninsulated, TrunkBranch, PEX piping
Refrigerator	25ft^3, EF = 15.7, side freezer
Cooking Range	Gas, Conventional
Dishwasher	318 Annual kWh
Clothes Washer	Standard
PV System	None

Two baseline conditions were simulated for every plan type: Title 24 minimum efficiency, and the base-efficiency package offered by Meritage as standard on every home. No architectural changes were made to the ZNE homes for the project for efficiency or any other reason, relative to the non-ZNE homes in the larger 187-home Sierra Crest development. Upon review of the 20 homes sited on the designated lots, there were no duplications of plan type, elevation or orientation.

For all analyses (baselines and improved), 20 homes were required to be separately evaluated. As previously stated, architecture was not a variable, thus the differences between the ZNE homes and others in Sierra Crest were EE measures, PV systems, and energy storage systems. The PV systems were sized specifically to meet ZNE. Even though all 20 homes needed to be simulated independently because of differences in floor plans, usable floor area, window areas, orientation of the home and of the roof segments that could hold the PV system, it was important for Meritage, a volume builder, to have no more than two efficiency packages, one for each group of homes. The result was a single package for both product types.

To complete building simulations, the team worked with Meritage to acquire details of the lots for the ZNE homes, including connection and locations of distribution transformers, building plans for all the models and elevations, detailed lighting and window schedules, as well as a complete description of the Meritage Standard Energy-Efficiency package. The amounts of miscellaneous electrical loads (MELs) were estimated based on both the team’s experience in calibrating existing home models, and data published by the National Renewable Energy Laboratory (NREL) [7] specific to new homes built on the west coast.

Developing an Initial Energy Efficiency Measures Pool

The initial ZNE design process drew from a pool of energy efficiency features that, in combination, would typically result in a ZNE or near-ZNE home that could be near the lowest incremental cost, and/or optimized for ease of construction, and would generally be highly effective at improving comfort and quality. EE feature packages were then developed independently for each of the building plans/elevations – 3 elevations per 6 total building plans in the 20 ZNE Home community. Before developing these packages, a list of high-efficiency features that could be used in the final ZNE package was vetted with Meritage and the rest of the team, to make sure that only pre-approved changes would make up the final proposed ZNE package. The features the team eliminated from the list were not recorded, but included materials preferences, such as use of spray-foam in the walls and attic, national vendor contracts, and operational or installation issues attributable to a device, brand, or model of equipment. These reasons for feature removal can be considered representative of considerations when scaling these communities by production-level homebuilders.

Sensitivity and Parametric Analysis

Draft ZNE packages were developed using the interactive, *sensitivity analysis* process. This is an optimization scheme where the home is modeled with minimum-efficiency features that just meet code to provide a baseline condition, then, singly and individually, features are upgraded (e.g., R-value increased) or swapped for a different, more efficient alternative (e.g., exchanging a 90% annual fuel utilization efficiency [AFUE] furnace for a 10.5 Heating Seasonal Performance Factor [HSPF] or greater heat-pump) to determine the impact of each individual feature on the baseline. Results of parametric analysis for a single lot, Lot #127 are shown in Figure 2-3.

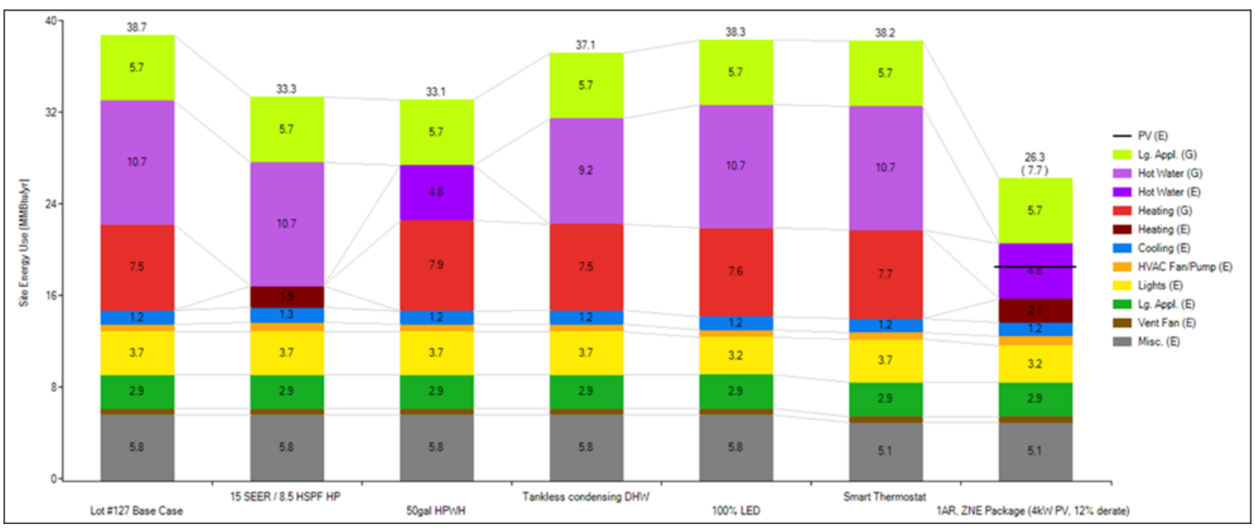

Figure 2-3
Sensitivity analyses results for the development of the ZNE package

Each stacked bar shows the results of a sensitivity analysis of a different feature evaluated for performance in the initial ZNE case. All comparisons were made to the unimproved base case, shown on the left, and to the initial ZNE package, shown on the right. The amount of energy for each end use is represented by the height of each colored band and the value is provided within each band. Energy attributed to each end-use is stacked to visually show the contribution of each end-use to the total home energy use. The total home energy use is represented by the height of the stacked bar, and the total is above each bar. The bar for the ZNE package (on the far right of the figure) shows the contribution of PV, which is represented by the black line across the bar. It is important to note that in sensitivity analysis, the efficiency improvement made by each step up in efficiency of a single feature in either sensitivity test cannot be added to the improvement made by another feature from these analyses. This is due to interactive effects common in application of multiple EE measures.

Each feature was evaluated individually using a parametric analysis, as shown in Figure 2-4. The example in Figure 2-4 evaluates the A/C and forced air unit (FAU) for replacement with a heat pump.

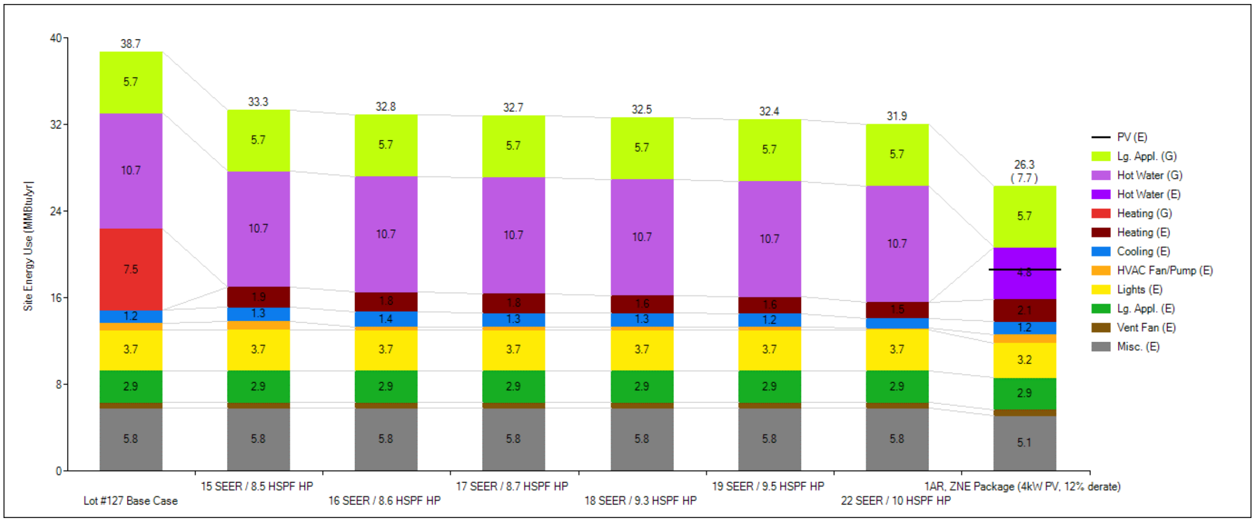

Figure 2-4
Parametric analysis results of replacements of different efficiency levels for a single measure-type

Notice that the base-case has a red bar for gas heating, and the other cases have crimson bars for heat pumps—the different colors indicate both different end uses and different energy types. The ratios of energy savings from these individual features evaluations and their incremental costs were used to optimize cost and performance for each feature.

Table 2-3 shows the actual cost analysis used to make the recommendation for a 15 Seasonal Energy Efficiency Ratio (SEER) / 8.5 HSPF Heat Pump over the existing 14 SEER AC / 92.5% AFUE FAU, including the results of the parametric analysis of the heat pump's performance range, as per the sensitivity analysis of the EE package.

Table 2-3
Actual cost-analysis used to make the recommendation for a 15 SEER / 8.5 HSPF heat pump over the existing 14 SEER AC / 92.5% AFUE FAU

Lot #127 Base Case	Initial Cost	Annual Utility Bill	Cost over 30 yrs	Cost Benefit	Rank
14 SEER AC / 92.5% AFUE	$5,351	$866.60	$31,349	36.17	7
15 SEER / 8.5 HSPF HP	$3,544	$878.90	$29,911	34.01	1
16 SEER / 8.6 HSPF HP	$3,689	$860.60	$29,507	34.29	2
17 SEER / 8.7 HSPF HP	$3,835	$856.70	$29,536	34.48	3
18 SEER / 9.3 HSPF HP	$3,980	$848.70	$29,441	34.69	4
19 SEER / 9.5 HSPF HP	$4,175	$843.50	$29,480	34.95	5
22 SEER / 10 HSPF HP	$ 4,561	$825.30	$29,320	35.56	6

The energy-impact of changing each feature can be compared to the cost to provide a first-order method of choosing the measures to use in the ZNE package. There were other considerations in developing the final ZNE packages, including interactions between different measures, product availability, installation/construction considerations, and consumer/home-buyer preferences. These “sensitivities” were analyzed in a sensitivity analysis that was conducted on each of the 20 homes, as detailed below:

1. Determine a model for Meritage Homes’ standard, unimproved package and compare it to an identical model that just-meets-code for 2013-T24 and 2008-T24.
2. The simulation of the code packages produced a baseline performance of Meritage’s unimproved case, including kilowatt hour (kWh) and therms used per year, home energy rating system (HERS), package cost differences, utility bill savings, and PV sizes needed to achieve ZNE.
3. A set of measures that would increase the efficiency of the unimproved model above the baseline performance was developed and vetted with Meritage and the entire project team.
4. Each possible feature that can be upgraded was individually evaluated in a parametric analysis. A single feature replacement was made to the baseline package, changing one BEopt energy feature from baseline performance levels to a higher-efficiency level, or to an alternative energy feature (such as swapping an AC and a FAU for a heat pump). The models (baseline plus single feature replacement) were simulated to determine the reduction in whole-house energy use due to the single feature replacement. The data from this single feature replacement was recorded in terms of annual energy use, change in annual energy used, and annual utility bill savings.
5. The incremental cost of each single feature replacement was determined using data from members of the project team, and/or RS Means data from BEopt.

6. For each single feature replacement, the cost-effectiveness (a simple 30-year payoff metric) was determined using annual utility bill savings compared to the baseline and the initial cost of the single feature replacement.
7. The ratio of cost of the single feature replacement over 30 years and the annual utility bill savings were recorded in the spreadsheet as a simple ratio (see Figure 2-3). This metric was used to rank the features.
8. The highest-ranking features from this sensitivity analysis were used to make the initial ZNE package.

The result of the sensitivity analysis was an initial ZNE package based on the combination of features that had the shortest paybacks and lowest initial costs, in which the improved measures with the shortest paybacks replaced corresponding lower-efficiency measures in the baseline. An initial ZNE package was constructed for the home on each lot in the subdivision.

The resulting initial ZNE package from the sensitivity analysis then underwent another test, called a "perturbation analysis." This followed the same general scheme, where the ZNE package had each single feature replacement "perturbed." This is where the value of each feature to the final ZNE package was determined incrementally. In this analysis, the starting point is the initial ZNE package that was built up from the sensitivity analysis (see Figure 2-3). An example of the results of the analysis is shown in Figure 2-5.

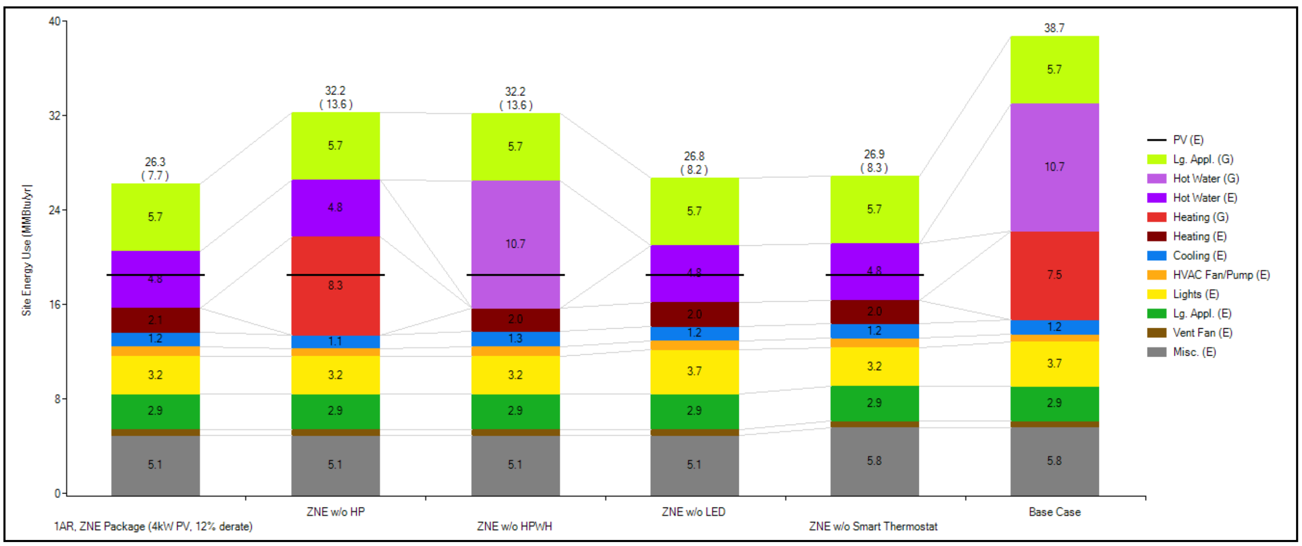

Figure 2-5
Results of the single feature replacement perturbation analysis of the unimproved base case for Lot #127

The methodology used in the perturbation analysis was conducted as follows:

1. The initial ZNE package was simulated and annual energy use metrics were recorded.
2. A single feature replacement was performed and evaluated in the reverse fashion of the sensitivity analysis: each individual efficiency measure that was upgraded from the baseline to the initial ZNE package was individually "perturbed" by reducing it from its ZNE-level performance to its previous baseline performance level, while all the other features of the

ZNE package were held at their performance level. Only measures that were improved for the initial ZNE package underwent single feature replacement and perturbation analysis.

3. In this analysis, the impact of reducing each individual measure selected for the initial ZNE package from the ZNE-level performance to the baseline performance level (while all the other measures are held at the ZNE package level) was recorded. These changes are called "perturbations." These perturbations provide a measure of the contribution of each of the ZNE-level measures, including their interactions, to a final ZNE package. Features eliminated from the ZNE package as a result of the perturbation analysis improve the overall cost-effectiveness of the high-efficiency package.
4. Features in the initial ZNE package that could be reduced to baseline-level performance without a significant change in the annual energy use were removed from the ZNE package. A ZNE package resulted from the perturbation analysis that was then vetted by Meritage Homes, who also made whatever changes they deemed necessary. This became the final ZNE package recommendation.

The results from the evaluation of the ZNE package, arrived at by sensitivity and perturbation analyses included any effects of interactions between different measures. Interactions between measures can reduce the impact of some measures as well as the cost of some measures. The single most important interaction was typically equipment sizing. As the building envelope was improved, the required capacity or size of the heating, ventilation and air conditioning systems (HVAC) needed to maintain desired temperatures decreased. This decrease in system size reduces the cost of the heating/cooling system, and thereby the package. The perturbation analysis resulted in removal of features with large interactions that severely reduced their impacts, and included savings due to updating systems sizing.

The final step in developing the ZNE Package for each home was to size the PV array for each home. For these homes to achieve ZNE, each home required a rooftop PV array sized to produce as much TDV energy as each house needed annually. The version of BEopt used in this project includes TDV-energy calculations, and the output of the BEopt simulation can be used to calculate the CA HERS score for each home[10].

Using *EnergyPLUS* weather files for PV productivity and using roof tilt and azimuth from the building plans, each array size was determined manually. This array size for the final ZNE package was then corroborated with the available roof area on each building, making sure to be mindful of Meritage's preferred aesthetics (no front-facing arrays) and within the range of orientations that qualify for PV incentives (no incentives paid for PV arrays facing north of due east or due west).

Results

As part of this project, detailed specifications were developed for each home in the ZNE community. These specifications provided the requirements for both energy-efficiency measures and rooftop PV systems. BEopt computer simulations of the Meritage ZNE homes showed that the implementation of these ZNE measures should produce a reduction in the annual site energy

[10] The 2013 California Integrated Energy Policy Report defines a ZNE home as having a CA HERS score of zero, produced by the integrated combination of being highly energy-efficient and having a PV array sized to produce a zero HERS, which is defined as producing as much TDV energy as the home consumes annually from the grid.

use (MBtu/yr) in these homes of about 43% compared to if the homes were built to just meet the current energy code. The reduction was about 32% compared with similar homes in the Sierra Crest community that were built to the Meritage Energy Efficiency Standard Package – the set of energy efficiency measures that Meritage Homes includes in its standard models. For BeOpt models for the 20 homes in the community, please see Appendix A.

Packages of integrated enhanced efficiency and properly sized rooftop PV systems were designed and developed to make the ZNE homes meet the California definition of ZNE, $HERS_{TDV}$=0. The ZNE homes at Sierra Crest have specially engineered energy efficiency packages that, together with PVs, reduce net purchased TDV-energy use to approximately zero[11]. As previously discussed, the Meritage Energy-Efficiency Standard Package exceeds Title 24 requirements by an average of about 20%. The Meritage Standard EE package already includes a well-sealed, well-insulated building envelope, high-efficiency lighting, and ENERGY STAR appliances. Some of the key features used on this ZNE project beyond Meritage's typical EE package were a heat pump water heater and 15 SEER efficient heat pump heating and cooling system. See Figure 2-6.

Figure 2-6
Final EE and DER measures used for ZNE community

Figure 2-7 shows the simulation results for all energy end-uses. The height of each section of each bar is relative to the amount of energy for each energy end-use, with the total bar height relative to the total amount of energy used in a year.

[11] Annual net TDV energy is predicted to be zero, provided the assumptions regarding occupant behavior in their use of energy is close to the assumptions used for MELs (see methods). The annual net site energy, upon which the energy bills are calculated, is expected to be low, but not zero.

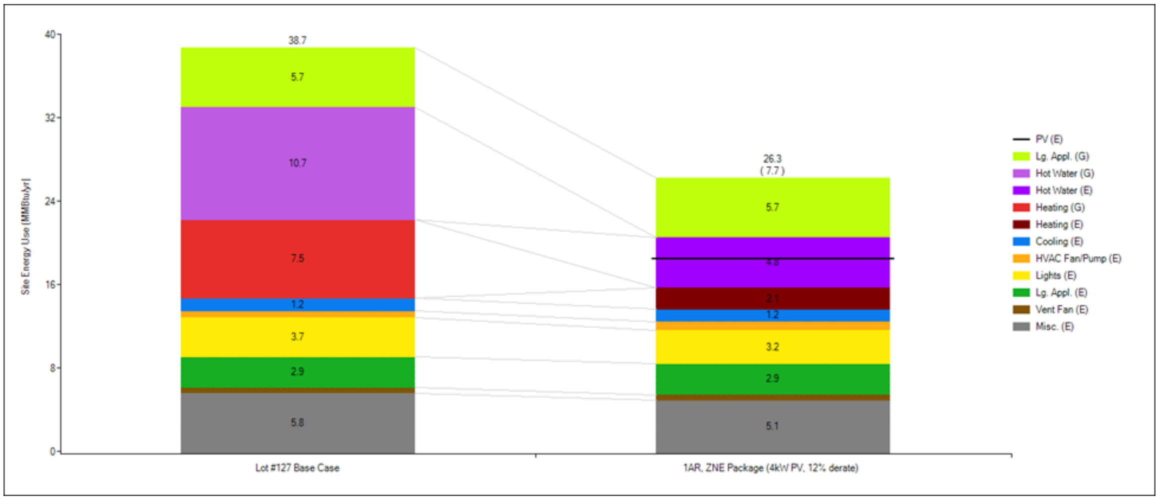

Figure 2-7
Stacked bar graphs of site energy (kWh and therms used per year) showing relative reduction of the base case to the final ZNE cases

These two stacked bars are for the same floor plan: the left with energy-code minimum features and the right with ZNE efficiency measures. The code home would require on average 6kW$_{AC}$ of PV, whereas the same homes with the ZNE efficiency package required on average 4kW$_{AC}$ of PV to achieve an average HERS score of zero for the 20 homes.

As previously discussed, these BEopt simulations resulted in an average annual EE savings of 43% compared to the Base Case. Annual energy savings and PV generation to achieve ZNE is summarized in Figure 2-8.

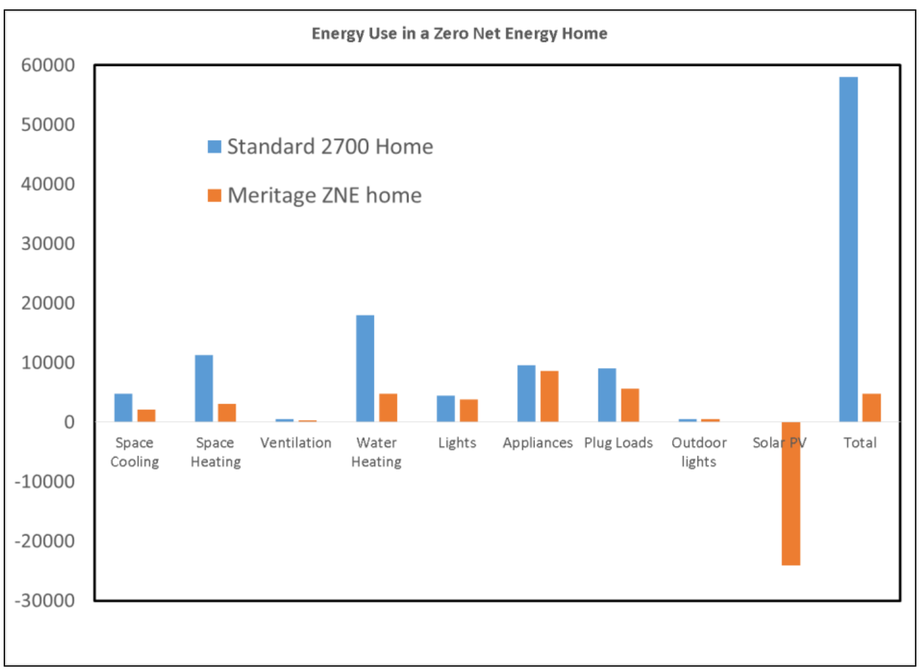

Figure 2-8
Average annual energy used and generated by 20 ZNE homes compared to Title 24 base case

The importance of achieving deep efficiency is shown by the difference in PV sizing of a 2013 CA Title 24 home compared to the PV sizing of an identical home containing integrated EE measurements. Title 24 homes had on average 6 kW_{AC} while the ZNE homes had on average 4 kW_{AC}, a 2 kW per home difference in PV size when implementing integrated EE measures before PV sizing to achieve ZNE. Reduction in PV size typically results in decreased incremental costs and minimized grid impacts attributed to the intermittent nature of renewable energy sources.

Net Metering in HERS Scores and Actual Energy Bills

Utility interconnection agreements detail each utility's net-metering rules, which include an electricity meter that can record electricity used or exported by the home, along with a time-stamp. The electricity net-meter records and stores the amount of electricity either demanded by the home or exported by the home, as a function of time, with relatively high resolution of 1- to 5-minute intervals. This information is sufficient for utilities to net meter either electricity or the cost of electricity, based on usage and time of day and service charges according to the tariff for that home. Most homes in California are charged by their electric utility according to a tiered tariff structure (as of 2016), where the cost of the electricity used in a month is a function of how much was used during the monthly billing period. Under a tiered structure, costs for electricity are accrued at a cost per kWh until a threshold amount of energy is reached. Electricity used above this threshold, or tier, is more expensive than that consumed within the prior tier. There are typically four tiers, where the cost of energy is higher in higher tiers. Each tier has a minimum and maximum amount of kWh accrued over the billing period, with typically 12 billing periods in a year ("monthly" billing periods). Each month, the utility reads the total amount of energy used during the previous month. The cost of the electricity is the amount in each tier multiplied by the cost per tier. That is, the total amount of electricity is separated into the amount for each tier, filling the tier from the minimum (zero for the first tier) to the maximum for each tier, with the minimum for each tier equal to the maximum for the previous tier plus one. Thus, each month the consumer is charged for the total amount of energy used, at prices that escalate in steps (by tiers) until the top tier, beyond which all excess electricity has the same high cost.

Energy bills were estimated for these ZNE homes based on the most commonly used tariff in SCE territory, the tiered-rate. The average annual energy-bill savings for a ZNE home in this ZNE Enclave is just over $1,300, as shown in Table 2-4.

Table 2-4
Utility bill analysis for the ZNE community

Lot	Annual Utility Bills and Savings		
	Title 24 Base Case	**ZNE**	**Utility Bill Savings**
6	$1,634	$223	$1,411
7	$1,786	$388	$1,398
8	$1,618	$182	$1,436
9	$1,786	$388	$1,398
10	$1,612	$338	$1,274

11	$1,598	$206	$1,392
12	$1,765	$199	$1,566
13	$1,653	$248	$1,405
14	$1,786	$351	$1,435
15	$1,639	$240	$1,399
16	$1,615	$220	$1,394
121	$1,498	$121	$1,377
122	$1,490	$404	$1,086
123	$1,455	$267	$1,189
124	$1,486	$257	$1,229
125	$1,512	$310	$1,202
126	$1,492	$227	$1,265
127	$1,439	$173	$1,265
128	$1,477	$324	$1,153
129	$1,477	$387	$1,090

Utilities are increasingly interested in moving residential electricity consumers from tiered rates to time-of-use (TOU) rates. In TOU rates, the cost of each kWh is set according to the season or month and the time of day, typically with a day divided into three of four periods: off-peak, shoulder, near-peak (optional), and peak. The cost per kWh is determined by the season and daily period. Usually the rates are also different between weekdays and weekend days. The electricity charges are determined differently from the TDV values, but TDV does put a higher value on efficiency measures that reduce peak-occurring electricity use. Neither of these tariffs provide for net-metering of gas used by electricity generated, as far as the utility bill is concerned.

The average HERS Index for each home was targeted to be 0. Due to practical limitations of PV sizing, the HERS Index for the 20 homes ranged from +7 to -12, with an average of -3. Modeled HERS scores and annual energy consumption and utility bill analysis are shown in Table 2-5.

Table 2-5
Energy consumption, HERS Index and utility bill analysis for ZNE community

	Annual Energy Used and Generated		
Lot	**Modeled Annual Energy Used (kWh)**	**kWh Needed for ZNE (kWh)**	**HERS Index**
6	6,923	6,099	-7
7	7,485	6,518	2
8	6,882	6,199	-6
9	7,485	6,518	2

10	6,882	6,445	0
11	6,923	6,208	-4
12	7,518	7,213	2
13	6,926	5,956	-3
14	7,512	7,213	2
15	6,902	5,961	-4
16	6,773	5,768	-7
121	6,331	5,801	-12
122	6,550	5,800	5
123	6,143	5,021	-2
124	6,521	5,759	-5
125	6,559	5,560	0
126	6,521	5,568	-5
127	6,035	5,798	-9
128	6,451	5,800	-1
129	6,451	5,800	-1

Table 2-4 shows that the average annual electricity bill for the 20 ZNE homeowners were estimated to decrease by approximately $1,300 per year compared to an identical Base Case home. Since the goal of this effort was to understand the cost-effectiveness of building ZNE homes, it was important to obtain actual, not estimated, costs from product providers and system installers. For these homes, the team tracked the costs at every line item sold to estimate the cost difference between standard construction by the homebuilder and the designed ZNE home. Incremental costs were attributed to the following upgrades detailed in Table 2-6.

Table 2-6
Incremental cost of EE and solar upgrades to achieve ZNE

Energy Efficiency and Solar Upgrades	Incremental Cost	Notes
All LED Lighting	~$300	All interior lighting
50 Gal. 2.3 COP Heat Pump Water Heater	~$300	Note that the project received a $540 rebate that was provided to the homebuilder for not running a gas line. Not included as part of the incremental cost calculation.
Additional Electrical Cost	~$2,900	Additional cost attributed to electrician labor for commissioning the advanced measures for the ZNE home.
15 SEER, 9.0 HSPF Heat Pump	~$800	Incremental cost compared to 14 SEER AC / 92.5% AFUE Base Case

Solar and solar installation	~$13,900	Includes solar array, balance of systems and roofing required for operable residential PV system for each of the 20 homes. Does not include labor cost for achieving permits or permission to operate (PTO) documents.
Total	**~$18,000**	

Economic analysis showed the incremental cost of the ZNE measures to be approximately $18,000 per home, with over 50% of the cost attributed to PV. Incremental energy efficiency measure costs were primarily attributed to labor (the homebuilders' electrical contractors), which can be assumed to decrease as trade practices are implemented at scale. It is important to note the incremental costs were compared to Meritage Homes' standard practice. This included implementation of technology measures to improve the building's thermal envelope, which included spray foam insulation with 2" x 4" staggered studs, R-30 spray foam roof insulation to create conditioned attic spaces and ENERGY STAR appliances.

These 20 ZNE homes ranged in price from ~$370,000 to ~$480,000 USD after additional features were selected by the homeowner. Assuming a 30-year fixed mortgage, this equates to an approximate cost of ~$1,600/month for the homeowner[12] using August 2016 average interest rates for 30-year fixed rate mortgage [8]. Modeling estimates showed that utility bill savings compared to an identical home built to code were approximately $1,300 USD per year or ~$110 USD per month in electricity bills. If the homebuilder invested the $18,000 USD in these ZNE homes and passed on the incremental cost to potential homebuyers, that would increase homeowner monthly mortgage costs by approximately $80 a month using the same 30-year fixed rate mortgage assumptions. This would result in a ~$30 USD cash flow positive transaction for the homeowner per month, or $360 USD per year.

Note that these calculations are from the perspective of the homeowner and reflect current electricity rates. It is also important to note that these calculations do not include the additional costs to procure residential energy storage systems for the nine homes connected to Transformer 2. As the implementation of energy storage did not directly contribute to the achievement of ZNE, it was not included in the calculation. Section 5 details residential energy storage in greater detail.

Lessons Learned from Modeling and Designing ZNE Communities

After the ZNE packages were finalized, savings metrics for each home model were determined, including the utility bill savings per house and the HERS score. These metrics were then used to determine savings metrics for the entire community. These figures were used as part of the sales approach for the homes in the ZNE community. Homebuyers are required to allow monitoring of energy use in their home, with all published or otherwise publicly available results being anonymous. Next steps will be to evaluate the monitored results and compare them to the simulations. Some control homes built to the Meritage Energy-Efficiency Standard will also be monitored for use in the same, later-task analysis.

All new homes in California are projected to be required to meet the ZNE_{TDV} as a standard by 2020. By California law and regulations, this research process is integral to the building industry

[12] Assumes a 20% down payment with a total mortgaged amount of ~$340,000 USD.

as it migrates from current standards to ZNE standards. ZNE homes generally, until now, have been built by high-end builders in luxury-oriented communities, and the process that leads to the development of an entry-level ZNE house was not evaluated at community scale with production-level builders. These homes provide energy-cost savings of up to $50,000 spanning a 30-year mortgage, and cost only $20,000 more than the homebuilders' standard product offering. Once the research team has the energy data from the current and future occupants of these communities, ZNE construction will be one step closer to standard building practice within the building industry.

Solar Planning and Barriers to Universal PV Adoption

Working through the neighborhood planning, one of the biggest question marks with regards to reaching ZNE relates to solar planning. When building new homes, the homebuilder process is to develop a set of "standard" plans for different home models, and create different elevations (as shown in Figure 2-9) for each of the home models. This provides buyers with choices, both on the inside (number of bedrooms, size of the home, etc.) as well as how they want their home to look on the outside (window locations and types, door configurations, roofing planes, etc.). Figure 2-9 shows three elevations of the same home and illustrates how different they look for the same floor plan.

Figure 2-9
Three elevations of the same home

The key characteristic to note is that the roof planes are different for these elevations and Elevations A and B have a highly cut-up roof plane, with probably only the rear roof appropriate for ZNE-scale solar. On the other hand, Elevation C has a large contiguous roof area on the front. Traditionally community planning would define lots before ZNE designs are considered, so this means that there will be home orientations (e.g., front of the home facing south) which will not work depending on customer preference (such as no solar on the front of the home) and lot orientation. This could considerably constrain the lots in which homes with the required PV necessary to achieve ZNE would be required.

Neighborhood solar planning is an exercise that will need to be conducted in detail for ZNE communities. Ideally, in California, PV would be facing west to maximize production in the evening hours, which would minimize over generation in the morning and mitigate excess ramping during the early evenings. However, the lot-model-elevation fit, especially in instances where lot orientation is not planned upfront for ZNE homes, will present questions of enabling

PV in non-optimal orientations, including Northeast and Northwest as additional ZNE communities are implemented. In addition, possible elevations, such as those offering third-floor spaces and/or vaulted second-floor ceilings, could also lead to elevations in which shading will play a role in the amount of usable roof space to achieve ZNE. This will also be an issue that the New Solar Homes Partnership (NSHP) will face in the future. This will also mean that the PV might need to be sized larger than a straight kWh calculation would indicate, which would also impact the community PV production profile.

In this community, there were a total of six plans, each of which had three elevations to choose from. Table 2-7 shows the results of the solar planning for the 20 homes. As can be seen, some of the PV arrays are in a non-optimal orientation, but that is what was required to meet the ZNE requirement.

Table 2-7
Results of the solar planning for the 20 homes

Lot	Plan #	Elevation	Garage, Front Orientation	Front Orientation	PV Roof Orientation	TDV Zero PV Size	PV Sized for Aesthetics
6	2	C	Right	East	West	4.3	4.5
7	3	B	Right	East	West	4.4	4.5
8	1	A	Right	East	South	3.7	3.75
9	3	C	Right	East	West	4.4	4.5
10	1	B	Right	East	West	4.1	4.5
11	2	A	Right	East	South	3.7	3.75
12	3	B	Right	East-Southeast	Southwest	4.1	4.5
13	2	C	Right	East-Southeast	Southwest	3.7	3.75
14	3	A	Left	Southeast	Southwest	4.1	4.5
15	2	B	Right	Southeast	Southwest	3.7	3.75
16	2	A	Left	South	West	3.9	4.0
121	6	A	Right	East	South	3.5	3.75
122	5	B	Right	East	South	3.5	3.5
123	4	C	Right	East	West	3.6	3.75
124	5	A	Left	East	West	3.8	4.0
125	5	B	Right	Southeast	Southwest	3.5	3.5
126	5	C	Left	Southeast	Southwest	3.5	3.5
127	4	A	Right	South	West	3.2	3.5
128	5	A	Left	South	West	3.4	3.5
129	5	A	Left	South	West	3.4	3.5

The final set of orientations was derived after changing a few of the elevations to obtain optimal roof faces.

Summary

This section detailed the process and results to select and design the zero-net energy community. Twenty ZNE homes built within a larger 187 home community in Fontana, CA were selected. These 20 homes were isolated on two community transformers to better understand grid impacts of these communities. Design and modeling of these ZNE homes detailed the process to plan such ZNE homes within the current community planning processes. Energy efficiency and solar measures implemented to achieve ZNE were found to be approximately 4% of the home price in this community. This potentially results in cash flow positive economic scenarios for homebuyers when considering potential utility bill savings.

The next sections will detail the process to construct and monitor this community. Section 3 includes the construction, permitting and commissioning required to erect these 20 ZNE homes. Section 4 discusses data acquisition, monitoring and control using connected appliances and efficient, communicating technologies that are part of this community.

3 CONSTRUCTION, COMMISSIONING AND MARKETABILITY OF ZERO NET ENERGY HOMES

The previous section details the steps necessary and considerations taken when designing ZNE communities at scale. This section of the report details the execution of the plans as laid out by the results detailed in Section 2. This includes:

- **Construction Planning and Design:** Coordination necessary to erect these ZNE homes per homebuilder, code and buyer requirements
- **Community Marketing:** Necessary training and materials required by the homebuilders' sales team for potential homebuyers.
- **Customer Uptake:** Results on sales of homes from May, 2015 to the date when the last ZNE home was sold, as well as sales challenges and solutions to meet project requirements on home sales.
- **Customer Education and Training:** Additional documents and materials necessary to train the homeowners on their ZNE homes, the efficiency packages that comprise the home, and the community in general.
- **Home Commissioning:** Steps required to commission and construct the ZNE communities. Includes any installation, testing, and permitting required to operate all the efficient technology packaging and Distributed Energy Resources (DERs) that comprise these homes.

Construction Planning and Design

In this community, Meritage Homes' process from when a customer buys a home to closing a home sale starts with the Customer Purchase Agreement (conditional) and ends 99 days later, with the closing. Meritage guarantees a 99-day build period, which is not very common among production builders. The construction planning started on the front end, well before the actual purchase of the home.

The first set of activities relate to finalizing the list of measures and appliances in the homes. Since these ZNE homes deviated from standard practice for Meritage, the project team had to rapidly address the list of proposed changes detailed in Section 2. All energy efficiency and PV choices were made within three weeks to meet the construction and community launch requirements. Since one of the main objectives was to minimize the effect on current building processes, adhering to existing processes and timelines was critical in any decisions made by the project team. Rapid choices on many measures starting from LED lights all the way to energy storage are listed below:

- **Lighting:** One of the first decisions was to switch to all LED lighting. This was easily accomplished since Meritage's procurement staff could obtain the LED lights for an increase of a few hundred dollars. See Section 2 for additional details on energy benefits and resultant incremental costs.

- **Space Conditioning** A key part of the project was electrification of heating loads. Current perception is that heat pumps might not be capable of maintaining comfort conditions as defined by the homeowner. This is mainly related to occupant comfort (due to lower discharge air temperatures, air cooler than 100°F feels cold to the skin). However, Meritage had substantial experience with heat pumps in other parts of the country and could mitigate this concern, as the longer run times provide better comfort. In addition, utility distribution representatives were concerned about electric resistive elements found within standard commercially available heat pumps. These resistive elements are enabled in certain climates in temperatures where the heat pump is unable to meet desired comfort preferences of a homeowner. The project team, along with the homebuilder, determined that resistive elements were not required on heat pump installations in this climate region, so they were not included.
- **Water Heating:** Standard practice with all California builders is to use either high efficiency tank or tankless gas water heaters. The existing homes were designed with 50-gallon gas water heaters. To meet several of the goals of this project, the team had to convert over to heat pump water heating. This change required working with the builder to address their concerns about customer satisfaction and space limitations, as garage layout and attribution of space to the water heater was determined beforehand. When switching to heat pump water heaters (HPWHs), the team worked very closely with the water heater manufacturer on sizing. The recommended size was a 50-gallon tank for smaller homes and a 66-gallon tank for the larger floor plans. In addition, as this project aimed to unlock additional grid services, the team determined that 80-gallon HPWHs were optimal to maximize the thermal storage capability made available by connected water heaters. However, as the main limiting factor in the original project plans was the available space in the garage, a 50-gallon heat pump water heater unit was ultimately chosen as this did not require substantial structural redesign. Any sort of redesign would result in additional work that included additional permitting and would not meet the project timeline.
- **Electrical Wiring:** The intent of the project was to isolate appliances, plug loads and lighting. For new home construction, it is standard practice that the remaining electrical end-uses are connected to a common circuit breaker based on location or zone in the home. To attempt to disaggregate premise-level loads for specific end-use types, the electrical contractor was directed to group loads in the home by end-use type and not by location. In addition, since water heating was electrified, the electrical contractor added 240V to the garage for the heat pump water heater, which requires a 240V connection that is normally not wired. The extra wiring had to be added to the electrical plans and re-permitted.
- **Other Electrical Requirements:** It is important to note that other electrified loads were a result of customer preference and not a result of project design. For example, although gas ovens and clothes dryers were considered standard in this building, some homebuyers chose to include electric dryers, ovens and ranges in their home. In addition, two homes, lot 8 and lot 123, owned electric vehicles and could potentially charge their vehicle in the home.
- **Residential Energy Storage:** Energy storage was a big undertaking in terms of the installation process, responsibilities and permitting. As residential customer-sited storage is a

new technology, many of the project partners (permitting organizations, installation contractors, etc.) had no prior experience. The project team therefore managed the storage process from the electrical wiring design all the way to commissioning. The first step was to set up a backup power panel to serve the critical loads using energy storage. The design of the critical loads panel took a substantial amount of time, and more importantly, required re-permitting of the electrical drawings. Another challenge was the skill level and responsibility of the overall electrical installation. As previously mentioned, it is important to understand that an existing solar provider and electrical contractor were used in this project. Each stakeholder—the solar provider, electrical contractor and battery energy storage systems (BEMS) provider—were different entities, so communication and delineation of responsibilities for electrical interconnections was challenging since documentation and installation of residential energy storage was relatively new to each of the providers. In this case, each stakeholder thought it was the other's responsibility to interconnect the battery storage system with the home's electricity service. Close coordination with the project team determined that the electrical contractor was responsible for the installation (the cost was $1,000 USD for each home), with the BEMS provider providing oversight.

These design efforts were critical at this stage to ensure that a properly functioning system would be in place to not only monitor high resolution data sets, but also create a channel to send commands to respond to load management events. The objective was to design a network of smart, connected devices, which would enable a combination of homeowner and utility visibility and control (Figure 3-1). A holistic connection schema illustrates local devices, wireless or hardwired connection, cloud supported and API connected topography (Figure 3-2). It is worth noting that several Ethernet hardwire runs had to be abandoned due to wiring issues experienced in the field. As backup, wireless connectivity made available by many of these connected devices was used.

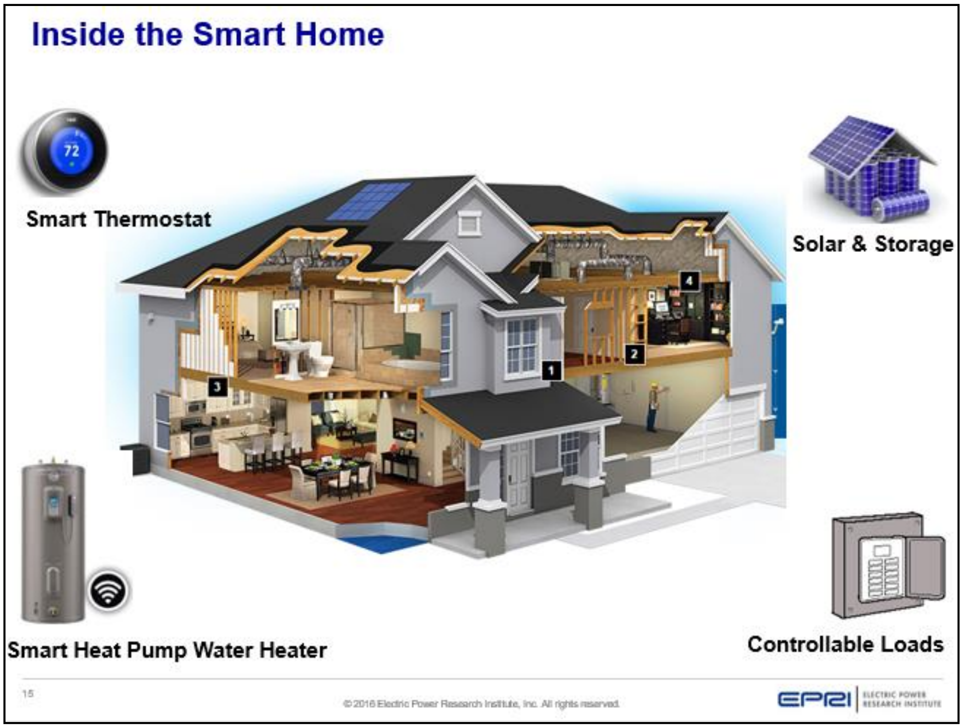

Figure 3-1
Inside the Smart Home

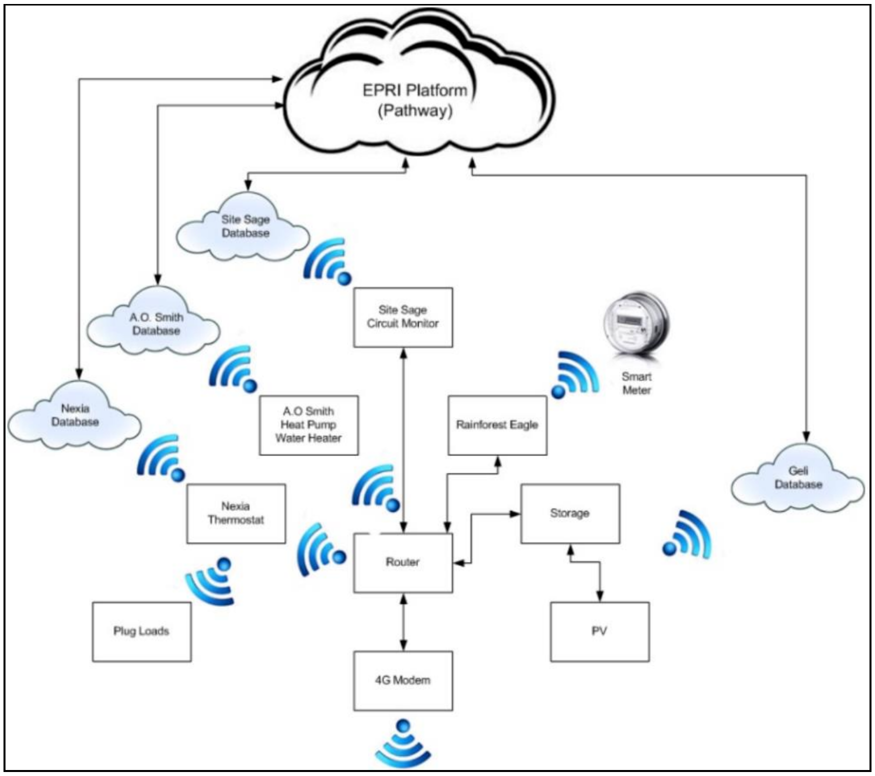

Figure 3-2
Smart, connected device architecture

Residential Energy Storage Design and Commissioning

A substantial effort was required to redesign the original BEMS. A BEMS provider was selected based on experience and ability to support multiple use cases and a robust test plan. This was critical to ensure that the research team could validate several control algorithms as it related to the overall project objective of balancing PV consumption. A notable physical design modification that required a change-order mid-installation was an additional auto transfer switch (ATS), required to maximize customer experience and reduce the risk of service issues related to the battery system. The new externally-mounted ATS provided an interconnection fast-track with a visual disconnect/reconnect feature and provided a grid link to back up a critical load panel in the event the BEMS required service or was fully discharged. See Figure 3-3 for the BEMS architecture.

Since the solar electric system was designed prior to selection of a BEMS, a prominent product feature was determined to be too high risk to be implemented. Despite a provision in the BEMS which allows solar PV to be directly looped into the BEMS (allowing solar to operate in isolation in the event of a grid outage), the O&M agreement with the solar provider suggested that it was best to physically separate the solar and battery products due to different operations and maintenance (O&M) contracts. This was agreed upon due to the relatively early market deployment of the storage provider and to isolate any issues in the event any modifications needed to be made post-installation and operation.

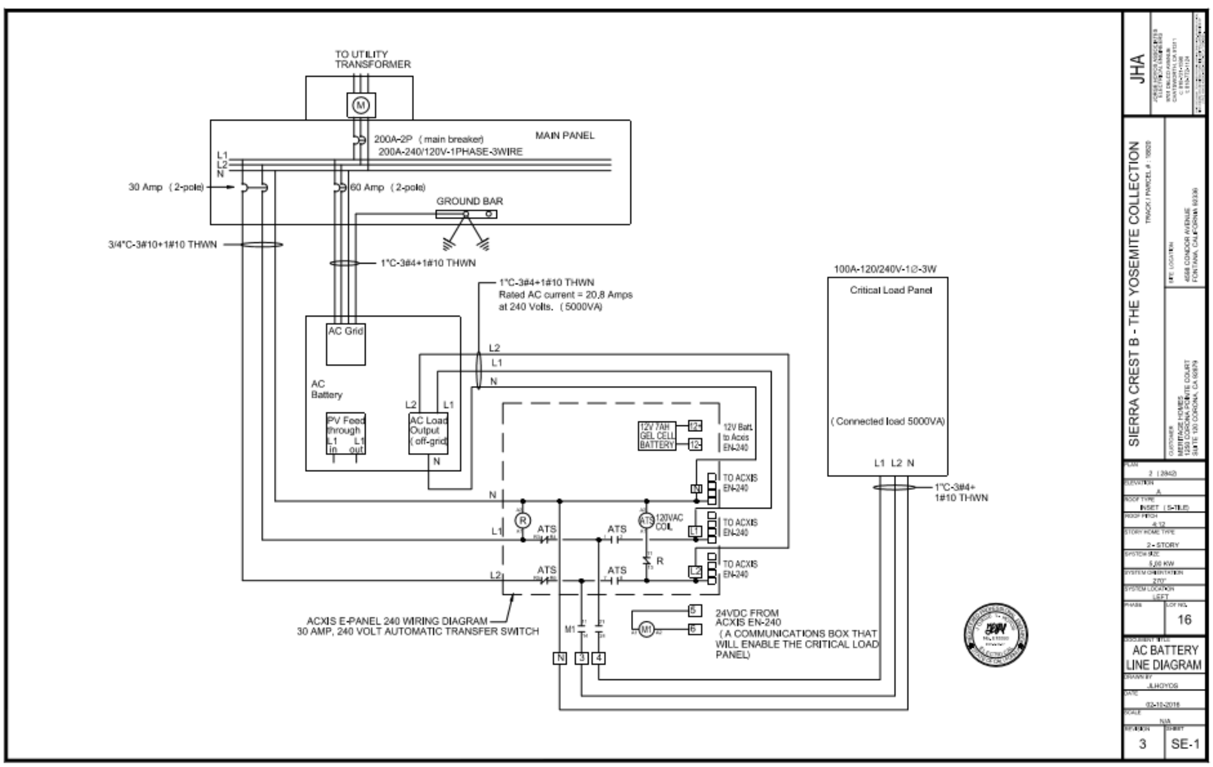

Figure 3-3
Battery energy storage system architecture (as submitted to City of Fontana permitting and SCE Interconnection)

Sales Process and Customer Uptake

While ZNE homes are designed to generate energy that is equal to the energy they consume with help from the grid, they have not been cost-effective to date. Section 2 detailed the opportunity for ZNE homes, in certain scenarios, to be cost-effective to the customer. Since home buying decisions are based on other factors besides energy, however, it is important to understand the marketability of these ZNE homes to typical residential homebuyers.

Sales Process Kickoff

The project was kicked off in early March 2015, with the first major milestone being the community's Ground Breaking event held on April 22, 2015. To market the event, Meritage distributed the flyer shown in Figure 3-4, with language agreed upon by core members of the project team. The groundbreaking event was attended by approximately 70 people that included various stakeholders such as the project partners (SCE, BIRAenergy, EPRI, Meritage Homes) and members of the public. In addition, there were two commissioners from the California Energy Commission (CEC). Other dignitaries included representatives from the City of Fontana and from the Assembly member's office. There was also some significant press coverage of the event, as well as coverage in the electricity industry press discussing the grid integration of the ZNE community. See Section 9 for additional information.

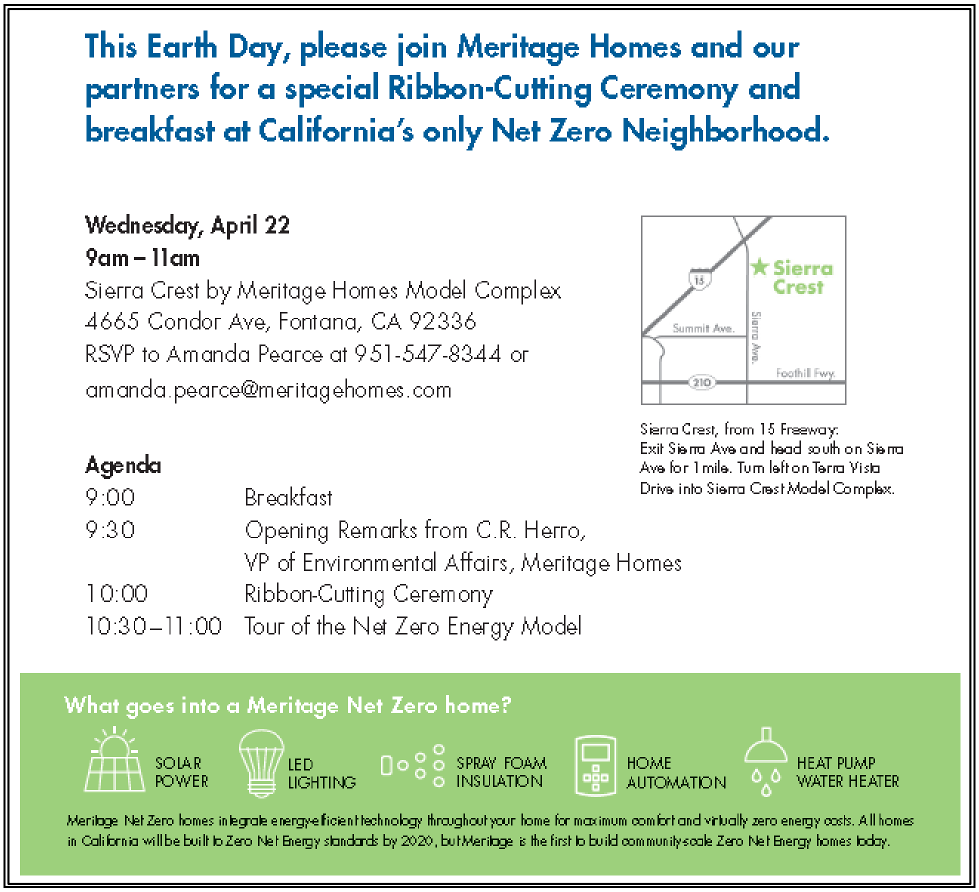

Figure 3-4
Flyer for ZNE neighborhood groundbreaking

Customer Marketing

Meritage Homes began selling the ZNE homes in late May 2015. The homes were sold before they were built, and once the home was sold, the company would then break ground to build it, adhering to the 99-day turnaround schedule discussed previously. Two homes were sold by the end of May, but then no homes sold for the next two months. The team realized that sales were not taking place at the pace expected. The team discussed how to alter the sales processes and improve the messaging around these homes. The main challenge was the prevalence of "greenwashing," since many other home developments in California were also promoting their homes as "green." The challenge was to differentiate the ZNE homes from other "green" homes that were being sold in neighboring communities.

Meritage and the rest of the team took several approaches to accelerate sales of the ZNE homes, since potential customers had a choice to buy a non-solar home vs. a solar home, even in this housing development. EPRI provided Meritage with additional marketing assistance to sell these ZNE homes that were listed at "above" market pricing. Some of the strategies the team used for increasing ZNE home uptake included:

- Evaluating and reporting on the impact of various financial mechanisms for PV, such as zero-down leases, lease buy-down, and builder purchase of PV.

- Assisting with setting up model homes differently to highlight the benefits of ZNE, as well as highlighting the goals of the research project and the California Solar Initiative (CSI).
- Providing marketing collateral, such as brochures, technical documentation and feature highlights that were aimed at the purchasing consumer.
- Financial assistance for additional advertising, such as articles in newspapers and realtor magazines to highlight ZNE features and attract buyers.
- Provide marketing to advance customer uptake of ZNE homes through open houses, advertising and workshops to educate potential customers on ZNE construction and financing.

Customer Education and Home Sales

By the end of July 2015, sales started to pick up. The honed marketing messages, and more importantly, an advertisement by a local television station, resulted in the sale of 10 homes, half of the homes in the ZNE community. As of October 15, 2015, 17 of the 20 homes had been sold. The first homeowners moved into their homes during the first week of October, and six more homes closed at the end of October.

Aligning project needs with new homeowner expectations was a critical aspect of the success of this project. EPRI worked closely with SCE and Meritage to develop a schedule of community workshops designed to inform and educate homeowners on the process associated with these ZNE homes and the project. These town hall-style workshops provided an opportunity for Meritage to further introduce their newly signed homeowners to their new homes (which they had yet to move into). Additionally, they provided SCE an opportunity to introduce the relationship with the utility, and get to know the ZNE demographic better through dialogue and interviews. EPRI was then able to introduce itself as the research organization and project manager of the project, offering a tutorial on the nature and design of a smart, connected home, and why this type of project was so critical to the future of California. The value of having a forum to meet individuals with whom EPRI would work closely for the next eight months was critical. The homeowners were notified that state-of-the-art technology would be deployed to monitor and (to a limited degree) control their loads. They were also advised to use their home as they normally would to ensure that real-world load profiles were captured.

Prior to the customers occupying the home, Meritage and EPRI led a homeowner orientation workshop in September 2015, which included explanations of how the solar, storage and other home energy management technologies work together in the home (see Figures 3-5 and 3-6). This helped explain how the solar and the storage work together and are controlled in unison using a device aggregation platform.

Figure 3-5
Excerpt from the homeowner orientation

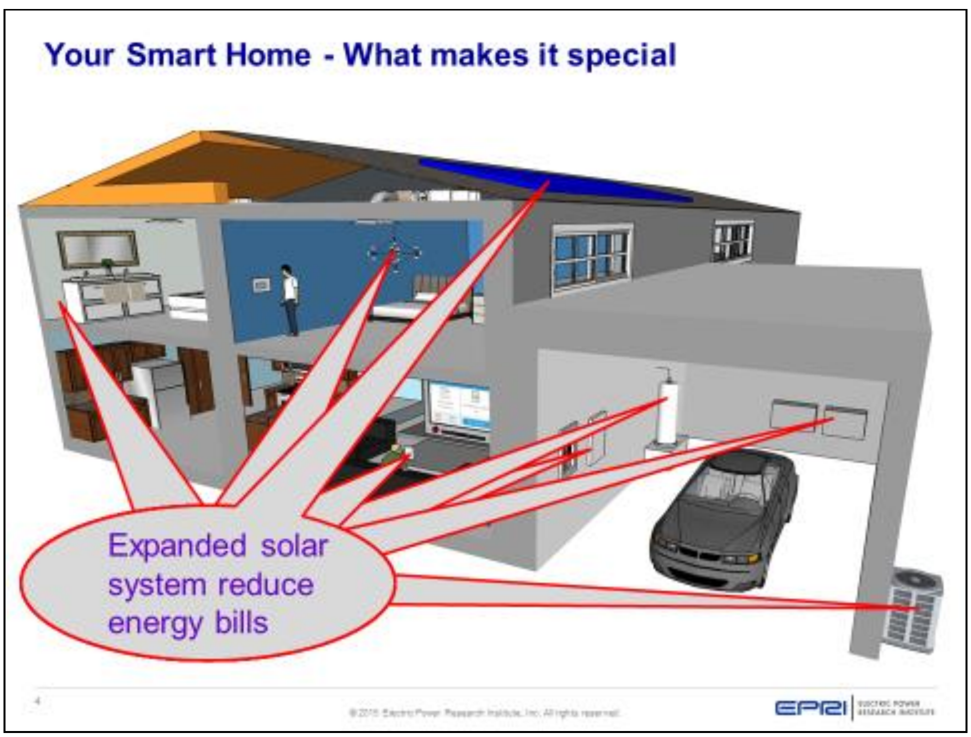

Figure 3-6
Explanation of how ZNE technologies could reduce energy bills

By the end of October 2015, only 16 of the 20 homes had sold. Potential reasons hypothesized by the team for the lack of sale of the four remaining homes were that these four homes did not have model homes that the homebuilder sales staff could use to showcase their floorplans to potential homebuyers. In December 2015, construction began on the remaining four homes so that customers could see the home they were going to live in. As a result, the number of houses sold reached 19.

A second workshop was organized in the local community center and neighborhood elementary school to follow through with the initial batch of homeowners primarily in the initial 9 homes connected to Transformer 2 (Lots 121-129), as well as to provide a forum to meet a new group of homeowners that would be moving in to Transformer 1 (Lots 6-16). A presentation was provided to the group to capture the value, the process and the expectations of the project. This provided a venue to engage with the 40% of those owners attended. For those that did not attend, it was more challenging to engage with them during the construction process.

Preliminary Customer Feedback and Impressions

Initial customer impressions for the ZNE homes has mostly been positive. Several of the customers who purchased a ZNE home knew about the technology components and had a good understanding of the general concept. One customer stated: “The houses were nice but when we were leaving, the (Meritage salesperson) said this was the first net zero home and being in the energy business before selling air conditioning, I knew about ZNE. I knew the amount of dollars they were giving and what we were getting, this is a no brainer. The reason why we bought in this community is because of net zero.”

Initially, several homeowners had a steep learning curve around managing the new technology components in the home, along with questions on maintenance and upkeep. Several of the energy efficient appliances represent state-of-the-art technology and can be controlled through either apps on a smart phone or some form of web portal. However, one of the homeowners was able to help onboard other homeowners with the technologies involved. Once the homeowners fully realized the power of the apps, they could maximize their comfort and minimize their electric bills and are now enjoying their Zero Net Energy home.

During a walkthrough of the community, one homeowner said that now that he’s comfortable with the technology, “Zero net to me, means zero out of pocket attributed to solar energy.” His neighbor agreed, saying, “Because of the features that Meritage Homes provides with the homes, we made the decision very easy. It makes sense with the way the electric company (energy cost) will start going up as time goes on, it makes sense to save $100, $200, $300 a month depending on the size house you have.”

Another homeowner, when asked if she would recommend a ZNE home to her friends and family, said “Energy cost is a big part of our monthly expenses and if they can save like I can, I encourage you to do so. The possibility of not having to pay an electric bill every month is a big deal for us. The possibility of going from $400 plus dollars a month to potentially zero is a big selling point. This is the wave of the future. This is the way to go. And energy bills may be a thing of the past.”

Homebuilder Marketing Lessons Learned

The Meritage marketing team also shared some of the lessons learned during the sales and marketing process. According to the marketing team, initial marketing efforts were centered around Earth Day and drawing parallels between environmental responsibility and energy efficient ZNE homes. The marketing team used advertising techniques such as direct mail, newspaper and radio ads to create additional awareness. The Fontana community groundbreaking took place on Earth Day, driving home the environmentally friendly aspect of the ZNE homes.

The focus on Earth Day helped broaden awareness of the community's development and drove additional traffic to the sales process. However, one of the most fundamental learnings the marketing team discovered was that the focus on environmental benefits and cost savings on energy were not the main drivers for potential customers. The Meritage team realized that the fundamentals on how customers select a home remained the same; future customers were more concerned about the location, price, and floorplan. However, once those key metrics were met, some of the customers were interested in learning more about the potential benefits a ZNE home could provide. The Meritage sales team was also selling other homes that did not have ZNE features, and there were customers who did not see the appeal of the ZNE homes initially.

The Meritage marketing team spent quite a bit of effort on educating customers about ZNE technologies on site. Also, since the ZNE concept is unfamiliar to many potential customers, the Meritage marketing team brought a lot of customers into the site and model home with a softer message, based on the aesthetic appeal of the home. Once the customer was on site, the marketing team educated them about the benefits of ZNE and why they should care.

To properly educate customers, the Meritage sales team had to go through several levels of specialized training to understand how the ZNE homes work, and the ways in which the customer could realize the potential benefits. The Meritage sales team had to be reasonably comfortable with the technology, science, and more importantly, the value of these ZNE home technologies, and explain this in a manner that a customer would understand. If the sales team did not feel comfortable with the technology, they would not be able to explain it to the customer and could lose the sale. Meritage found that properly training the sales force helped with the ZNE home sales. In addition, the model home was structured as a learning center that highlighted the energy efficient aspects of the home and additional signage helped customers tie the physical aspects of the home with the technological benefits of ZNE. Combined with an aesthetically pleasing home, these factors influenced customers to purchase a ZNE home over a non-ZNE home.

Given the increased amount of education required when selling ZNE homes, the sales process for these homes started out a little slower than the Meritage team had expected. However, when customers started seeing others purchase and then move into the homes, the sales momentum picked up. The last three homes took a bit longer to sell as there were no model homes that illustrated that layout, which seemed to be necessary for selling the ZNE homes.

For future ZNE sales, the Meritage team felt that driving traffic to the sales site and model home was important, and could be done using various messages, not just around ZNE and energy efficiency. From Meritage's perspective, there are a small group of people who are early adopters of technologies, and for those people, the ZNE technology is a meaningful addition to the home. Most homebuyers, however, need more education to understand the benefits of ZNE and how it can help enhance their day-to-day lives. For homeowners, it is important for them to fall in love with the house first, and then realize the potential benefits of owning a ZNE home.

Business Model, Agreements and Contracts

This project required a considerable effort to collect and execute business agreements with multiple parties. In this case, the regulator (CPUC) provided funding and requirements, the utility (SCE) supported the customer service and experience component, the builder (Meritage) provided the homes and construction schedule, the solar provider installed and maintained the solar system, the battery service provider designed and installed the BEMS, and EPRI facilitated the project plan and execution among these parties. One of the most challenging aspects was defining the business models between the solar installer and the storage owner and operator. Although the solar installer was considered for providing a storage solution, it was later determined that the predefined storage product offering did not meet the constraints of the project requirements (e.g., product size, footprint, and cost). The project team ultimately decided to use another third party interested in owning and managing a storage asset specifically selected to meet this project's needs. Six months after the storage vendor was selected, this 50-year old company filed for bankruptcy, so a new owner and operator had to be sought. Fortunately, a national independent power producer was identified. This added value to the experiment, allowing EPRI to demonstrate an independent third-party owner/operator business model.

System Testing

Shortly after the initial system design was in place, EPRI evaluated the device integration through a demonstration project close to EPRI's offices in Northern California. The goal was to reflect a near-real-world simulation of an individual home at Sierra Crest, including solar, battery storage, smart thermostat, circuit monitoring, and direct utility smart metering (excluding the heat pump communication). It was important to test against an identical replica of the system installed in Fontana in terms of product selection, design, and implementation to eliminate the risk of any implementation challenges introduced by designs lost in translation (e.g. storage hardware and firmware did not fully match after several months of product iterations). After two months of testing and some unexpected product development related to a power backup feature, the test system was deemed operational, and EPRI moved to the next phase of data collection, transmission, and analysis.

Testing was then moved to an initial home at the project site in Fontana's Sierra Crest neighborhood. Here the team could test against the construction process, validating the system design, operating parameters, and use case scenarios supporting the creation and adoption of the final test plan. This provided the additional real-world project detail that could not be obtained through the initial device demonstration. Constraints like distance from data hub to devices, hardwired vs. wireless connections, cellular signal strength, local weather, and site specific installation criteria could be validated through the coordination with an amiable homeowner. After several weeks of testing the initially deployed system, the design was then deployed to the remaining homes as they matured through the new build construction process. A notable omission in device testing was found in the lack of product development related to the AO Smith hot water heater and heat pump. Although the product was designed to be outfitted with a Wi-Fi module to remotely control set points, this module was not available until the final month before testing was complete. Additionally, a Rainforest Eagle device designed to communicate via wireless ZigBee protocol to the SCE utility meter posed too big a process challenge (see Figure 3-7 for the registration guide for device provisioning), and the group collectively decided to forgo the implementation on the remaining homes. The device worked well in connecting in a plug-and-play fashion to the meter, but the utility verification and data collection and reporting processes had not yet achieved an adequate state of maturity as a commercially viable solution. Finally, a smart plug solution was tested but was abandoned since the product had not been designed to be used with the LED lighting technology deployed in the homes.

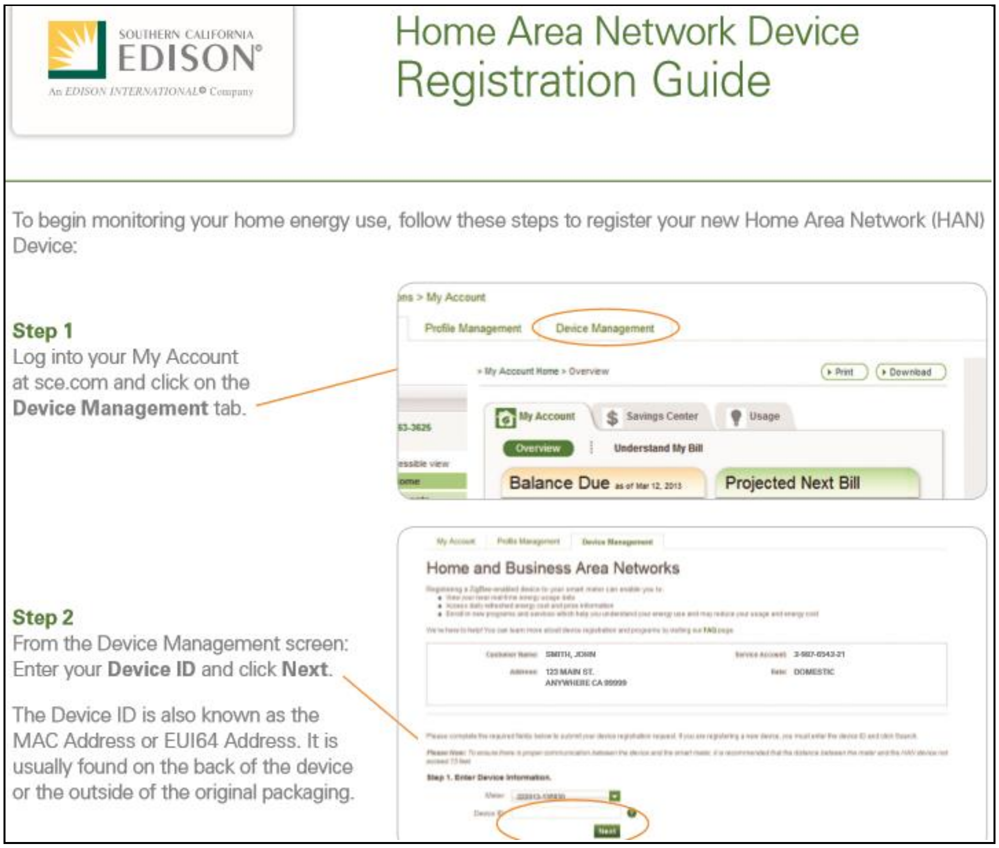

Figure 3-7
SCE Home Area Network device registration guide

Home Energy Management System Installation

In general, the installation of the HEMS hardware was a straightforward process, considering that many devices required throughout the home were primarily located in the homeowners' garage. Commissioning efforts where focused on configuring device software and ensuring connectivity throughout the home and aggregation of homes. In general, commercially-ready products were deployed. However, the environment and concentration of devices introduced challenges that some of the products had not encountered in previous applications. Despite initial intentions to follow through with the installation prior to the homeowner occupancy, various factors prevented this from happening. Product availability and delivery, builder and construction coordination, lack of site security (no locks, doors, open access), and lack of power for testing are some examples of the challenges that made it difficult to fully install systems prior to the move-in date of the homeowner. Overall, the installation process took several months due to scheduling challenges related to coordination with 20 separate households. See Figure 3-8 for a photo of a HEMS installation installed in one of the homes connected to Transformer 2. Note that the integrated HEMS in Lots 6-16 did not contain the battery energy management system, battery auto transfer switch, battery inverter and battery.

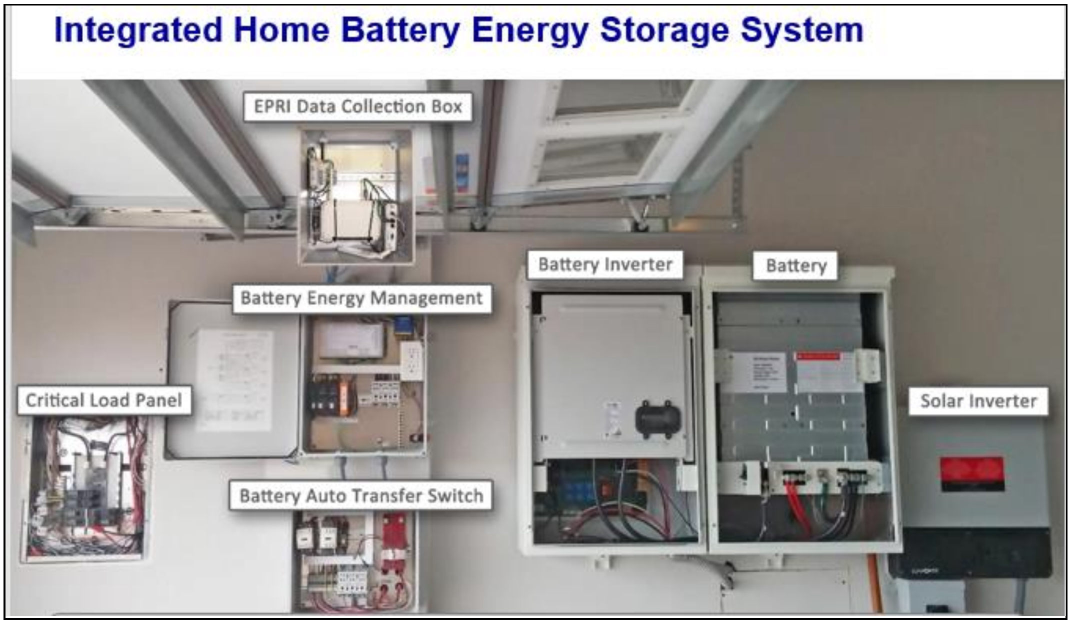

Figure 3-8
Integrated HEMS

Once the initial testing and preliminary installation took place on a model home, a train-the-trainer series of workshops was conducted to delegate remaining installation efforts to contractors. It was a challenge to locate an adequate installer to meet the overarching needs to install, test, and commission new technology. The project team initially settled on the builder's production electrician but concluded that a devoted data technician and electrician resource with a skillset to learn on the fly and install new products and technology was needed.

System Commissioning

It was important to work with product and system vendors to pre-commission where possible, reducing time required in the field. Selecting an Internet Service Provider for the initial commissioning effort was required to set up the smart meter, thermostat, solar and storage, and submetering systems. During commissioning, most of the homeowners had yet to install a home area network usually required to begin connected and DER setup. In addition, to prevent customer service issues associated with customer broadband, it was determined that a dedicated cellular connection independent of customer broadband would be provided to enable connectivity and communication for all the controllable devices and systems. Although the project team's intent was to commission as many of the devices as possible before homeowner occupancy, aggressive construction and project schedules resulted in the need to commission several of the devices once the homes were occupied. During this time, the project staff coordinated with the homeowners in scheduling a time to initialize the system, commission each device with the necessary customer/project credentials, and ensure a reliable communication with the project's backend data acquisition systems. Several homes required multiple visits for recommissioning due to data drop-outs and changes to access privileges/requirements.

Solar/Storage Permitting

In parallel with efforts to identify and validate data channels, the permitting process was initiated with the local Authority Having Jurisdiction (AHJ). Considering the nascent state of some technical solutions (specifically the battery energy storage systems), a high degree of concept education was required to get the AHJ comfortable with a deployment in their territory. Fire codes, environmental studies, and product safety were critical touchpoints, which required a significant amount of communication to clarify the actual risks of the deployed technology. After two months of working with the permitting department and a face-to-face visit with the builder and AHJ, a schedule was developed to physically meet with the construction superintendent to walk-through all nine storage systems, culminating in final, signed permit cards

Interconnection (Residential Energy Storage Homes)

Electric utility interconnection approval was the next event in the construction process. It is best to start filing for a "generating facility interconnection application" (SCE Form 14-957) months in advance of the installation of solar electric and battery storage systems. It is highly recommended that a single entity file, submit, and manage the interconnection approval process (e.g., this could be the dedicated resource noted in the permitting section above).

Due to aggressive project and construction timelines and incorporation of the residential energy storage system, the recommended interconnection project was not feasible. The builder had already agreed to partner with a solar integrator where the PV system cost was wrapped into the final cost of the home, and extended with a warranty to the homeowner. The standard practice for the homebuilder and this solar integrator has been for the solar electric integrator to file their agreements for multiple new homes with the utility. As residential energy storage was included in this project after the agreements had been put into place between the solar integrator and the homebuilder, the battery storage added to this project required an amendment to the original interconnection process.

Additionally, a third-party, independent entity was selected to own and manage the storage asset. This led to design implications that circumnavigated a valuable feature to electrically connect the solar directly to the battery. This would have provided added resiliency in the event of a grid outage, adding value to the homeowner and builder by maintaining system independence through separation of the PV system and residential energy storage system and their respective warranties. As an example, if the storage system connection was defective, it could impact the solar integrator's operations and maintenance agreement and vice versa. Once an agreement was reached between the solar and storage integrators on design, it was decided that the solar integrator would append the storage system to the existing solar interconnection agreement. It turned out that this ad-hoc request was difficult to fit into the existing solar integration processes required by the electric utility. As a result, the project team, with support from SCE, diligently worked together to get the necessary information needed to get the interconnection agreements in the approvals queue to meet the project schedule.

Once interconnection applications were approved, a final field evaluation was required by SCE to evaluate proper interconnection. This test was completed between May and June, 2016, when the homes were already occupied. The project team worked closely with each of the homeowners to ensure that interconnection testing was completed at a time that was convenient to them. After the evaluation was completed, a Permission-to-Operate (PTO) the residential energy solar and storage system was given to the homeowner and the project team. See Figure 3-9.

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PERMISSION TO OPERATE
Self-Generation Facility Interconnected to SCE's Electric Grid
6/6/2016

Homeonwer #1
4788 Condor Avenue
Fontana, CA 92336

Dear Customer:

Congratulations on completing the installation of your self-generation facility. Your application for interconnection has been approved and Permission to Operate your system has been granted.

Project ID	Generating Facility Address	CEC-AC Nameplate Rating (kW)
SCE-59951	4788 Condor Avenue, Fontana CA 92336	3.354

If, at any time, SCE determines that this generating facility is not in compliance with the terms of the Net Energy Metering (NEM) Interconnection Agreement signed as part of you application to interconnect, this Permission to Operate may be revoked. Terms of the Agreement are available at www.sce.com/nem. SCE may inspect your electrical service panel to ensure it meets SCE's electrical service requirements for the generation system you have selected. Electric service panels not meeting SCE's requirement will be required to be corrected in order for SCE to allow continued operation of you generating system in parallel with SCE's electrical system. For further details regarding service panel requirements, please review SCE's tariff Rule 16 at http://www.sce.com/NR/sc3/tm2/pdf/Rule16.pdf.

Service under your applicable NEM rate schedule becomes effective within 30 working days of the date SCE received your completed your completed application to interconnect your generating facility. Once that date has passed, and your system is turned on following receipt of this Permission to Operate, your electric bill will be modified to account for your generating facility's production.

Under the NEM rate option, residential and small business account served under Rate Schedule GS-1 are billed once a year for the "net" energy consumed or generated each month over the previous 12 months, if any. An annual settlement energy bill will come once every 12 months, and payment for your *energy usage charges* for the entire year will be due at that time. Large business NEM accounts are billed monthly for energy usage. It is recommended that you monitor energy usage charges found in the last pages of your bill. All customers must also pay monthly *non-energy charges*, which include utility taxes and city/county fees. If you have paid more than the non-energy charges due, your bill will indicate "Do not pay. Your account has a credit balance."

If, over the course of a one-year billing period, you generate more excess electricity than you use, you may be eligible to receive compensation for net surplus electricity in accordance with Assembly Bill 920, signed into law on October 11, 2009. For more information, visit http://www.sce.com/customergeneration/nem-ab920.htm.

For questions related to billing or rebates, please contact SCE's Customer Service Department at (866) 701-7868 for residential customers or (866) 701-7869 for commercial customers.

Sincerely,

Southern California Edison - Net Energy Metering Interconnection

This is a system generated email.

Automated PTO email generated by SCE

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Figure 3-9
Sample e-mail from SCE giving the homeowner permission to operate self-generation facility interconnected to SCE's electric grid

Operation (Residential Energy Storage Homes)

Once interconnection was received for all nine storage systems, data streams were enabled and analysis performed. See Section 4 and Section 6 for additional information regarding the data collected as part of this project. Post-operation, several site visits were required to adjust, reconfigure, and modify device settings, firmware, software, hardware, wiring, and data communication.

A snapshot of the virtual metering at the 50 kVA transformer for the nine homes is depicted in Figure 3-10. This daily aggregated view is the product of months of validating and verifying data streams for accuracy. This view illustrates the impact the storage systems have on the net import/export (black line) vs. the gross load (red line).

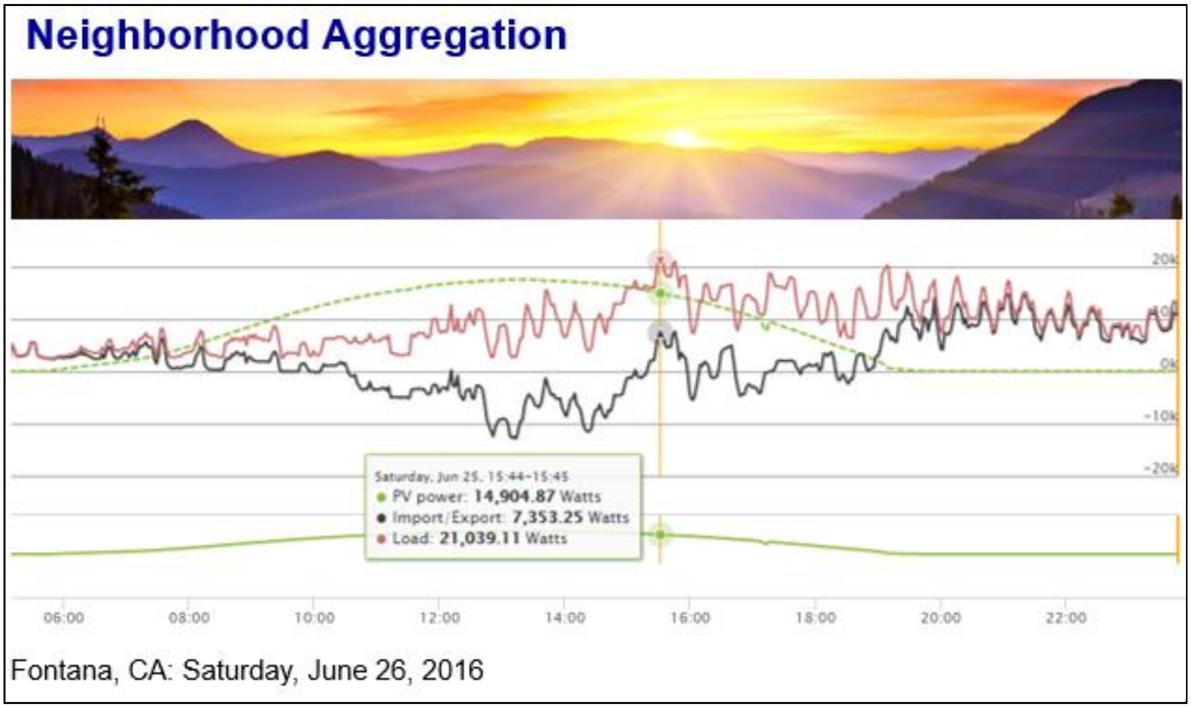


Figure 3-10
Snapshot of the virtual metering at the 50kVA transformer for the nine homes

Summary

ZNE homes are still a nascent technology and are new to many consumers. Education is a key factor in creating a market for ZNE and energy efficient homes. Marketing these homes will require some level of investment in customer education before potential home buyers purchase these types of homes. But once the customer has moved in, they realize the benefits and enjoy the comforts these cutting-edge technologies provide.

After eight months of working through the design and operations phases of the project, many lessons were learned from the deployment of this community of 20 smart connected homes. The 11 homes that did not include storage generally required less effort and impact on the homeowners. The two groups of homes, Lots 6-16 connected to Transformer 1 and Lots 121-129 connected to Transformer 2 proved to be of value to the experiment as Transformer 1 acted as a control to demonstrate the value of storage and the impact that this solution had on the community impact of these zero net energy homes on the local distribution network. Significant improvement in the following areas will be required to get to a point where the building industry can deploy scalable homes in a safe, efficient, and reliable manner:

- Design – Secure all stakeholder approvals at the beginning of the process, which includes the utility, homebuilder, installation and commissioning contractors and product manufacturers staff that will install, commission and support the project.
- Testing – Early system demonstrations enable maximized efficiencies in the field deployment.
- Installation – Properly define teams that can execute on the coordinated critical path timelines necessary to minimize homeowner impact.
- Commissioning – Use fully vetted products in a compatible environment and fully tested connectivity.
- Permitting – As AHJs have more exposure to nascent technologies and education becomes more pervasive, process timelines will improve.
- Interconnection – As examples of deployment are captured, future approval and associated processes will become more streamlined.
- Operations – Cost-effective, reliable, consistent connectivity in combination with a local service team to support any system anomalies related to new products and technology required to minimize potential customer satisfaction issues.

This section discussed general information on the marketability, construction, and commissioning of these communities. Sections 4 and 5 provide details on how two components of this project, data acquisition and controls systems, and residential energy storage were developed.

4
DATA ACQUISITION AND CONTROLS ARCHITECTURE

Community-scale data monitoring has historically been a challenge due to project cost. Traditional monitoring systems that consist of environmental and energy submetering packages can be relatively costly and intrusive to homeowners and operators. Traditionally, customer preference was generally determined using surveys of homeowners and occupants. This too can be misleading; as improperly structured questions could potentially lead to biased responses. Developing inexpensive monitoring tools for these ZNE homes to better understand not only energy performance but also customer preference is preferred since energy usage, especially usage of miscellaneous electrical loads (MELs), varies in these ZNE communities. With increased two-way communication, communicating and connecting technologies are allowing customers the opportunity to demand connected energy resources that enable better management and comfort for these new ZNE communities. In addition, increased market penetration of DERs, such as electrical residential energy storage systems and new methods to connect and control loads such as water heaters [9] and HVAC systems using smart thermostats [10] can now provide additional load management capabilities to mitigate the grid impacts of ZNE homes.

This project applied a method for data acquisition that used data collected from connected devices. Today, common household devices such as thermostats and circuit panel metering log data on customer preference, indoor and outdoor environmental information, and system performance. These data can be readily available to both customers and third parties. This project incorporated a platform consisting of a combination of local and cloud-based data acquisition of multiple end-use devices. As connected DERs and end-use loads are now changing at a rate that requires constant monitoring and verification, understanding how best to leverage data organically collected by these product providers can potentially be an inexpensive way of residential monitoring [11]. Each home is monitored at the premise level, using data collected by the local electric utility. Monitoring through data received from the various end-use devices allows the project to attribute end-use usage specific end use loads, which will vary based on customer behavior. See Figure 4-1.

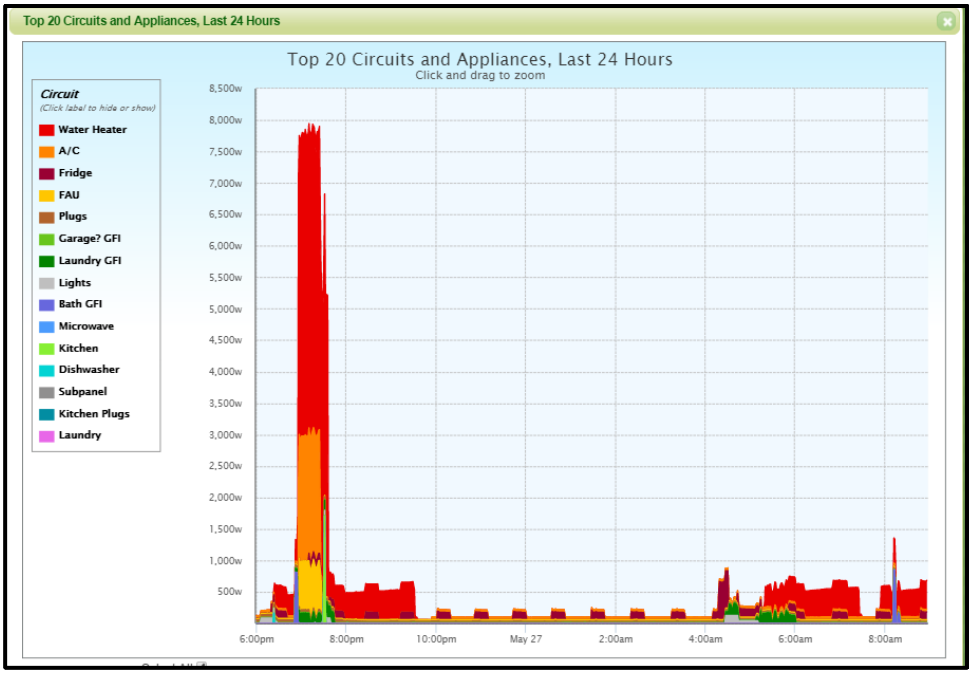


Figure 4-1
Premise-level consumption attributed to end-use loads

Figure 4-1 depicts a user interface screenshot of a circuit level monitoring system installed in one of the homes as part of this project. The figure shows not only premise-level amplitude, but attributes energy consumption to specific end-uses such as air conditioning, water heating, etc. This project deployed a monitoring and control strategy based on connected and smart home devices. The project used the data acquisition capability of each of the devices to collect and transmit the data. The goal was to organically collect more than end points monitored in each home and collected by systems that include, but are not limited to: (1) heat pump water heater data using application program interfaces (APIs), (2) HVAC usage data using APIs from the smart thermostat, (3) PV and storage information using information from the solar and storage energy management system, and (4) end-use load monitoring at the circuit breaker level using a product combining split-core current transformers connected to a communicating gateway.

Integration of all products that can serve as load management systems and load monitoring tools has been of interest to many utilities and third parties. As these product leverage competing standards and ecosystems, the project team attempted to complete the data monitoring task by using a “bottom-up” approach to understand customer preference. The team worked with controls and data that product providers acquire, collect and store organically, and is retrieved from each system. By approaching data collection in this manner, the team developed an inexpensive monitoring system that leverages device data and a controls platform that mitigates grid impacts while accounting for customer preference. The project team will aim to answer the following research questions as part of this task:

1. What are the opportunities to understand end-use load shapes and customer preferences using device data?
2. What architectures are currently available today that can be leveraged to aggregate these different data streams?

3. What are current technology and market barriers to leveraging these data streams in communities of scale?
4. What controls are made available by customer-sited end-use devices that can minimize grid impacts of high-penetration PV scenarios found in ZNE homes?

Approach

The project team used the high-level approach shown in Figure 4-2 to complete data acquisition and analysis.

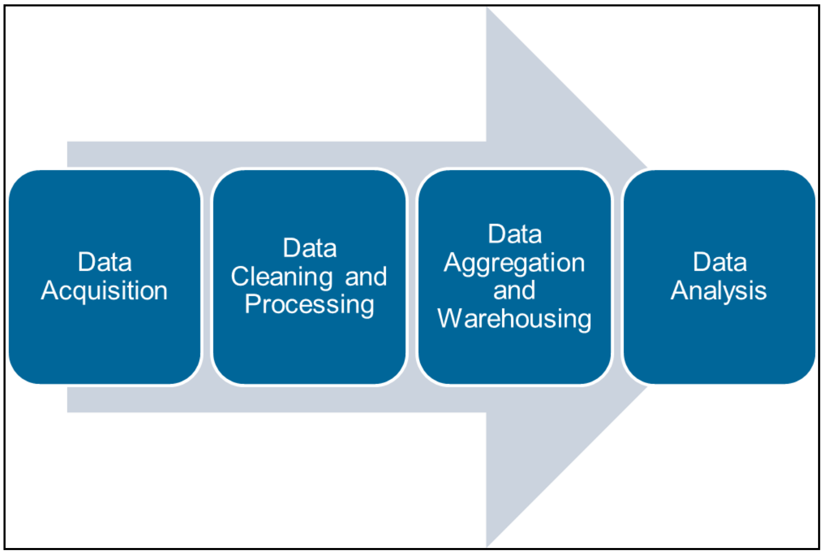


Figure 4-2
Approach for data acquisition and analysis

Each step of the process is summarized below:

- **Data Acquisition:** Steps necessary to install and collect data from the connected devices that will be used as the data acquisition system for this project.
- **Data Cleaning and Processing:** Steps necessary to identify and treat anomalous data values.
- **Data Aggregation and Warehousing:** Steps necessary to store data in an optimized way for data analysis at a later date.
- **Data Analysis:** Analyze the relevant data to provide insights as required by the project.

Data Acquisition and Collection

Data acquisition consists of tasks that allow the project team to collect data from the various connected devices and project partners. This includes: (1) installing connected devices such as circuit level metering and smart thermostats in the ZNE homes, (2) obtaining agreements with product and service providers to obtain data, and (3) developing and collecting customer agreements that grant the project team access to each homeowner’s data collected by the connected devices installed in their home.

The project team aimed to develop a data collection and aggregation system that primarily leverages data from connected, communicating devices that were to be installed as part of these ZNE homes. Although it is implied that data is being collected by these devices, the data parameters that are collected, methods in which data is transferred, and legal restrictions and limitations from third parties regarding what data transfer is permitted by each of these communicating devices may vary. It is important to note that connected device partners were not chosen by the project team for their ability to collect the desired data parameters. Product providers were chosen based on existing homebuilder national contracts to simulate conditions at scale. Devices used as part of the data acquisition system included: (1) a circuit level monitoring system, (2) a smart thermostat and smart plugs, (3) a connected water heater, (4) a home gateway, and (5) a solar/storage Battery Energy Management System (BEMS). To begin the discussion, a set of data parameters was defined based on a combination of previous studies on what data are feasibly collected from each device provider and the core requirements of this project.

The preliminary data acquisition plan listing the communicating devices installed, data parameters collected and method for obtaining data parameters by device is shown in Table 4-1.

Table 4-1
Summary of data acquisition plan

Device	Data Parameter(s)	Method of Obtaining
Circuit Level Monitoring	Main Power, Heat Pump & FAU, Water Heater, EV (2 in community), Microwave, Plug Loads, Light, Solar, etc.	Circuit breakers submetered. Trades informed to connect like loads. API agreement for data collection.
Solar/Storage BEMS	Frequency, Voltage, Main Power, Solar, Battery Energy, SoC, etc	Solar, storage and mains data metered by BEMS and shared via. reports
Smart Thermostat/Plug Loads	Setpoint, Indoor Temp, Outdoor Temp, HVAC Runtime, etc.	API agreement for data collection and device control
Heat Pump Water Heater	Water Temp, Runtime, Setpoints, Operating Mode, etc.	API agreement for data collection and device control

Data Collection Software Architecture: Overview

For this project, it was important to minimize potential customer issues attributed to intermittent and sometimes lost internet connectivity. Therefore, a parallel broadband network was installed to provide connectivity to the devices installed in each of the homes. A schematic of the system architecture is presented in Figure 4-3.

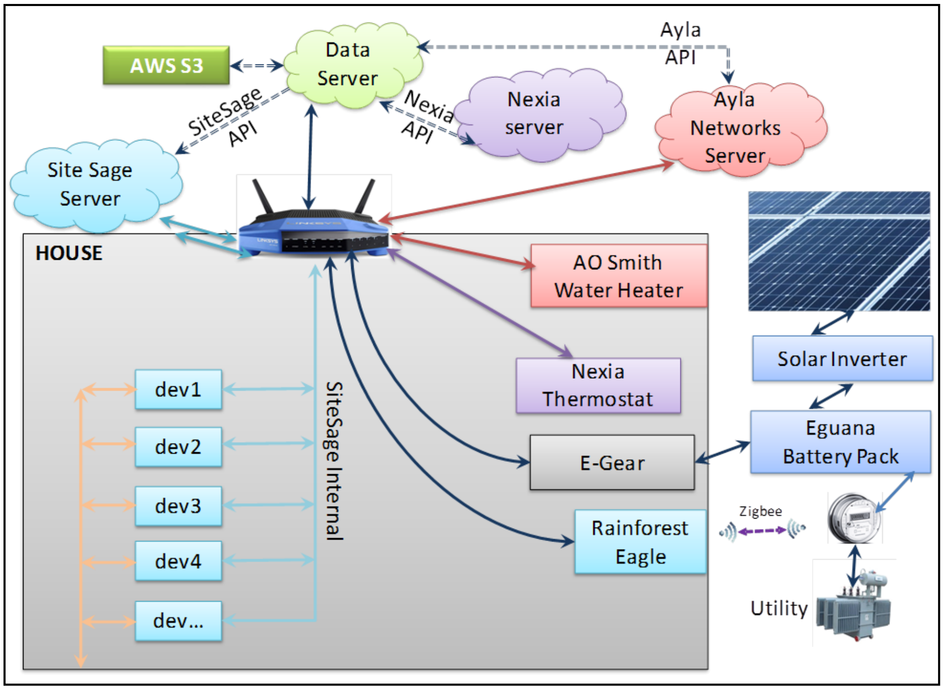


Figure 4-3
Schematic of data collection and controls architecture

The individual layers enabling the functions of the application in the cloud (i.e., the data server system) is shown in Figure 4-4.

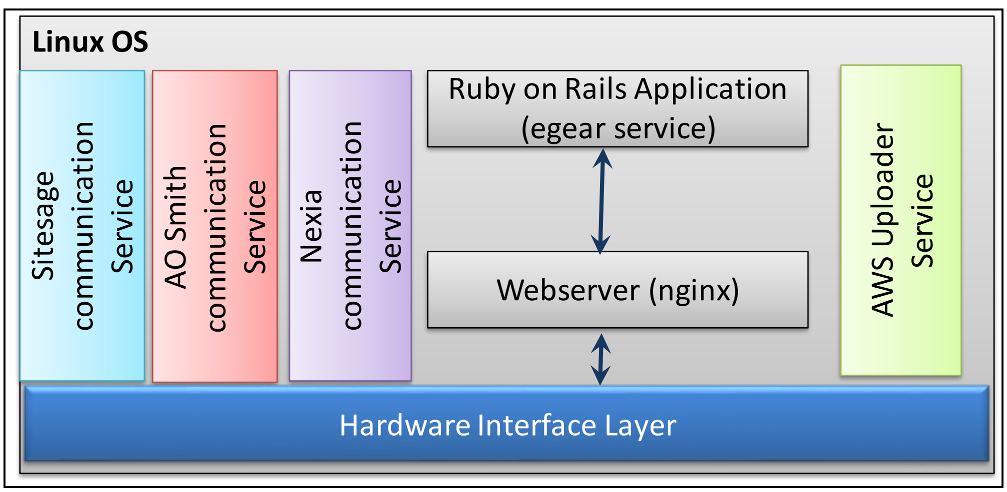


Figure 4-4
Layers of the data server systems

The data server runs a Linux system in the cloud. The fundamental component is based on a Ruby on Rails main application system that is running behind a Nginx webserver. The server is mainly set up to receive POST data from any devices or the system. In addition, this could provide additional information or credentials. All data that is received through the POST or any other method is stored on local file server. Data is sorted based on individual identifiers for each home. This system also provides a portal to set parameters for individual homes, such as setting up DR events.

A web service was used and was responsible for uploading collected files for storage. This storage was used for its combination of cost and its good API access, which allows setting permissions and user details as to who can access, upload, or modify the files in the storage.

For data storage, the service runs once a month and performs the following functions:

- Each file saved by the connected device providers includes information about the time, date, month and year when the data was collected and saved to that file.
- The service looks at files that do not belong to the current month in the folders used by the individual connected device services. The filename includes information about the month and year when the data was collected.
- The service will identify those files that do not belong to the current month and year. Data in the files for the current month are still being updated so they are not touched by this service.
- The service will look at the folders where each connected device service provider stores their data.
- Once the set of files have been identified, the service will perform the following tasks:
  - Zip the file and upload it to a private section of the project database.
  - Encrypt the zip file and upload it to a public section of the project database.
  - Delete the generated .zip and .enc files. Optionally delete the uploaded file to free up space on the server.

As previously stated, the project is attempting to leverage existing infrastructure provided by each connected device provider, and the project team did not want to interfere with existing national contracts with each of the product providers and the trade allies that supported these. The team took a minimum viable path approach to retrieve the data as discussed in the data acquisition plan, limiting the additional infrastructure development from the product providers. The approach for each product provider varied based on data infrastructure maturity for each provider and customer philosophies on data sharing. While some product providers were open in sharing data via APIs, it is important to note that during data infrastructure implementation, delays occurred due to both technical capabilities and company philosophies. Data acquisition methods for each product provider are discussed below.

Circuit Level Monitoring

The Circuit Level Monitoring allowed access to its API for this project. The data API is through RESTful commands to the circuit level monitoring provider’s current server. First-time access to the system requires individual user login details, which are required to get a security key. To separate login access of the individual homeowner in order to minimize the disclosure of personal information, an aggregation portal was provided by the circuit level monitoring provider that grants the user login details for each of the 20 homes as part of the project. See Figure 4-5.

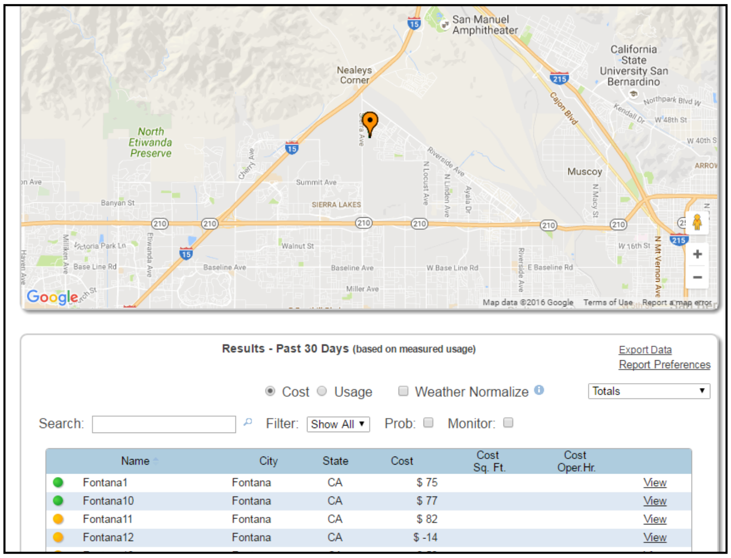


Figure 4-5
Screenshot of aggregation portal provided by circuit level monitoring provider

After authentication, the service repeats RESTful calls to its webserver at predefined periodic intervals (in this project, every minute). Once data is received, it is parsed and stored in the csv files with the following format for data in each line: Time stamp, Variable Name 1, Value of Variable 1, Variable Name 2, Value of Variable 2, etc. Each line of data corresponds to the data received in each call to the server. The service consists of multiple threads. There is one thread for each home in the system. Each thread performs the following steps:

- Access the data for the home through RESTful calls to the server using their API calls.
- Parse the received response for relevant data.
- Store the data in csv files corresponding to the identifier for the home.

In addition to the APIs, the circuit level monitoring provider allows data collection via a reporting function, as shown in Figure 4-6.

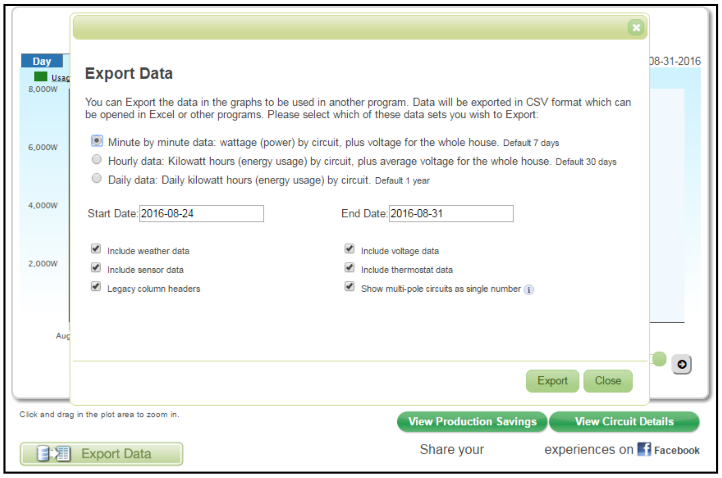


Figure 4-6
Reporting functions provided by the project portal

As Figure 4-6 shows, data is provided on a home-by-home basis in minute, hour or daily resolutions. Figure 4-7 shows an example hourly data report from one of the homes.

		Hourly Sit	2016-08-3	Customer	EPRI															
Column name is Energy Monitor Channel Number-Circuit Name																				
Channel Columns contain energy usage(production) in watt hours for hour																				
Voltage is average voltage for hour																				
Date/Time	CH2-Main	CH4-Wash	CH5-Wash	CH6-Wate	CH7-Oven	CH9-Solar	CH10-Mas	CH11-Mic	CH12-FAU	CH13-Kitc	CH14-Dish	CH15-Gar	CH26-Frid	CH27-Kitc	CH28-Gar	CH29-Gar	CH30-Livi	CH31-Entr	18281/Vol	Outdoor Tem
4/1/2016 15:00	1770	7	8	0	0	0	1	19	1	8	0	0	1	112	16	1	0	0	124.3	75
4/1/2016 16:00	1674	8	8	0	1	0	1	21	1	8	0	0	1	72	16	1	0	0	124.1	74
4/1/2016 17:00	883	8	8	0	1	0	1	20	1	6	0	0	1	106	16	1	0	0	123.2	72
4/1/2016 18:00	378	8	8	0	1	0	72	20	1	5	0	0	1	120	16	1	0	0	122.7	70
4/1/2016 19:00	700	8	8	0	1	0	259	19	2	7	0	0	1	133	16	1	0	0	121.6	65
4/1/2016 20:00	326	8	8	0	1	0	65	20	2	7	0	0	1	117	16	1	0	0	121	62
4/1/2016 21:00	408	8	8	0	1	0	120	20	2	7	0	0	1	97	16	1	0	0	121	59
4/1/2016 22:00	276	8	8	0	1	0	53	20	2	8	0	0	1	61	16	1	0	0	121	55
4/1/2016 23:00	188	8	8	0	1	0	8	20	2	8	0	0	1	64	16	1	0	0	121.4	54
4/2/2016 0:00	182	8	8	0	1	0	8	20	2	9	0	0	1	77	16	1	0	0	121.8	51
4/2/2016 1:00	176	8	8	0	1	0	4	20	2	10	0	0	1	72	16	1	0	0	122.4	51
4/2/2016 2:00	170	8	8	0	1	0	2	20	2	9	0	0	1	144	16	1	0	0	121.9	49
4/2/2016 3:00	170	8	8	0	1	0	2	20	2	7	0	0	1	102	16	1	0	0	121.4	53

Figure 4-7
Data report provided by circuit-level monitoring product provider

As Figure 4-7 shows, data is provided in fixed time intervals. Energy consumption is measured and then provided at both the premise and circuit breaker level. Since loads such as the HVAC and the water heater are connected to an independent circuit breaker, energy usage can be attributed to that end use. For end-use loads that were grouped to a single circuit breaker, special considerations were made to group common end uses (i.e., lighting, plug loads) to common breakers.

Smart Thermostat Manufacturer

For this project, the thermostat provider granted API access to the data. It is important to note that certain data parameters collected as part of this project were only available due to agreements between the thermostat provider and the project team. Like the circuit level monitoring provider, the data API is through RESTful commands to the thermostat's product server. Authentication for data access is based on first time access to the system and requires individual user login details that are required to get an authentication token; any successive attempts to get the data can be obtained using the authenticated token. After authentication, the service repeats RESTful calls to the thermostats webserver every minute for the project (or at predefined intervals). Once data is received, it is parsed and stored in the csv files with the following format for data in each line: Time stamp, Variable Name 1, Value of Variable 1, Variable Name 2, Value of Variable 2, etc. Each line of data corresponds to the data received in each call to the thermostat server.

The service consists of multiple threads. There is one thread for each home in the system. Each thread performs the following steps:

- Access the data for the home through RESTful calls to the thermostat server using their API calls.
- Parse the received response for relevant data.
- Store the data in csv files corresponding to the identifier for the home.

Water Heater Manufacturer

The water heater manufacturer updates data to a cloud service provided by a third-party cloud service provider. This service provides API access to the data. The data API, like the other connected device providers, is through RESTful commands to the Ayla server. The data access steps are:

- The system requires an “Application Id” and an “Application Secret” provided by the cloud service for accessing data from its servers. This is required for each application that requests access to the third-party servers.
- First-time access to the system requires individual user login details and ids, which are required to get an access token and a refresh token.
- The access token is valid for 24 hours and after that if access is required, the refresh token must be used to get a new access token.
  - The access token can be refreshed even before 24 hours has expired.
  - Successive attempts to get the data can be obtained using the access token.

After authentication, the service repeats RESTful calls to the third-party cloud servers at predefined times. Once data is received it is parsed and stored in the csv files with the following format for data in each line: Time stamp, Variable Name 1, Value of Variable 1, Variable Name 2, Value of Variable 2, etc.

Each line of data corresponds to the data received in each call to the water heater server. The third-party servers have a limitation as to how many API calls can be made in a 24-hour period. Generally, only 12 API calls can be made in a 24-hour period. For this project, an agreement was made between the team and the manufacturer to allow for 1440 calls (1-minute resolution) for the 20 water heaters.

Commands to control and manage the AO Smith water heater follow the ANSI CTA-2045 (formerly known as CEA-2045) command set. This command set is inserted into RESTful post data that goes to the servers after proper authentication.

To enable water heater communication as part of this project, a pre-production module was provided. The device acts as a modular communications interface and connects to a pre-existing communications port found on the water heater. See Figure 4-8.

Figure 4-8
Communications port provided by water heater

The module provides Wi-Fi connectivity and allows for data collection and controls based on the water heater manufacturer's existing infrastructure, which is based on the ANSI CTA-2045 data collection and controls command set. It is important to note that during this project, the water heater manufacturer commercialized this Wi-Fi module and it is now sold in retail channels.

BEMS Service Provider

The BEMS Service provider was chosen for its experience in managing residential PV systems coupled with battery storage. Data is provided by the BEMS via JSON posts "pushed" to the project team data server. PV, premise and storage information can be provided via web portal. See Figure 4-9.

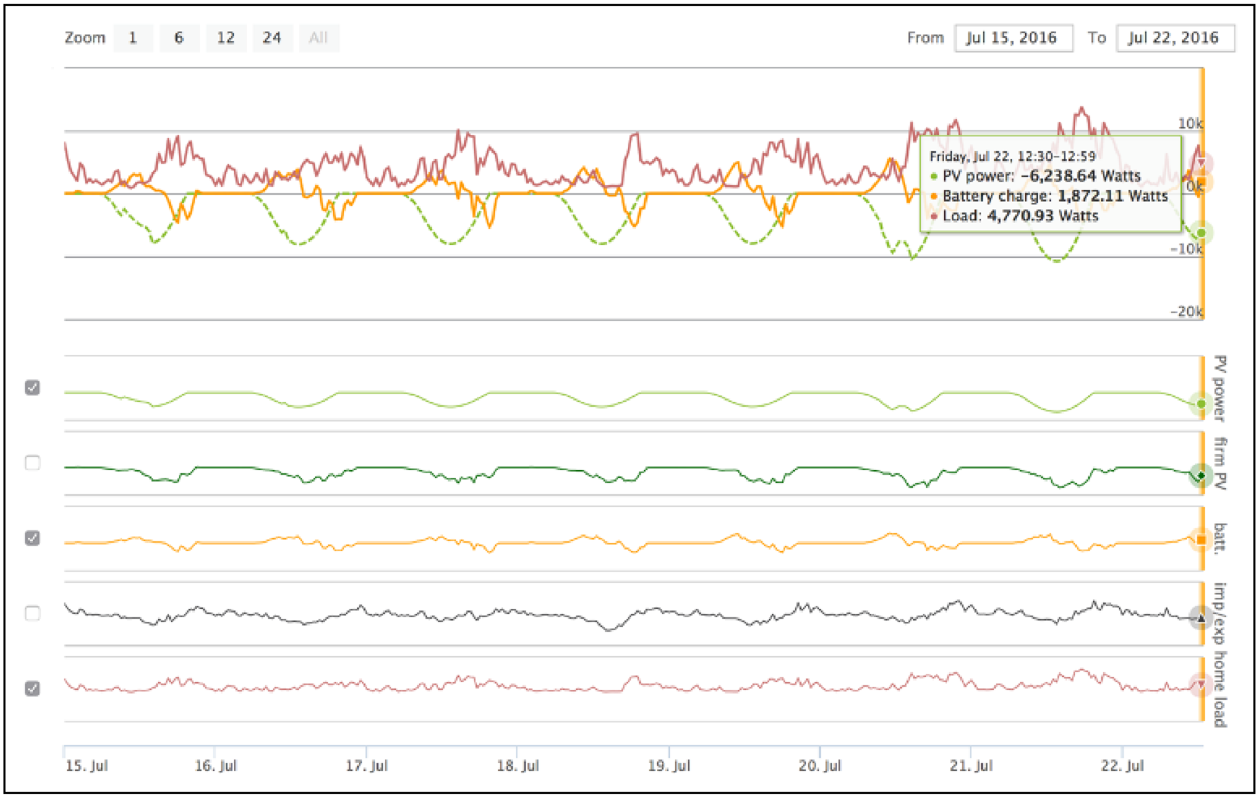


Figure 4-9
Solar, PV and battery information provided by the BEMS

Hardware Requirements

Data collection and acquisition is enabled by a dedicated data acquisition system consisting of two main components: a conventional router and a 3G cellular modem. See Figure 4-10 for a high-level schematic of the 3G cell modem and router enabling data acquisition and local energy management.

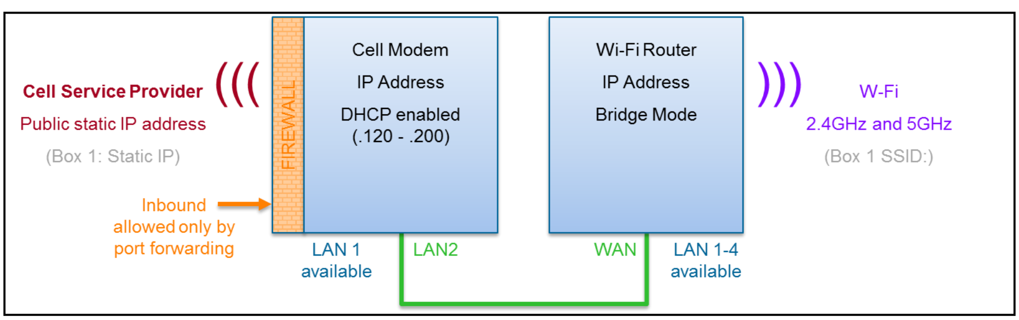


Figure 4-10
Cell modem and Wi-Fi router configuration

The data box consists of a 3G modem equipped with a 1 GB/month data plan and public static IP addresses. A production router that can be procured from a retail store was selected for its ability to be customized for this project's needs. The router can serve as a local Energy Management System (EMS) and can also manage battery storage in conjunction with PV inverter output if provisioned. The router also provides Ethernet ports to connect the circuit level monitoring system and home gateway. The router is also used as a communications hub that provides Wi-Fi access to both the smart thermostat and water heater.

All components are installed in a 15" x 10" x 7" electrical enclosure equipped with DIN rails and an external power supply connected to each home's subpanel. The data acquisition system was installed by the electrical contractor with all the networking connections completed by the project team. See Figure 4-11 for the project team's data box installed in each of the 20 sites.

Figure 4-11
Data box installed in each of the 20 sites

Data Acquisition Progress and Lessons Learned

At the time this report was written, the hardware had been successfully installed in all 20 homes. As previously discussed, delays in data acquisition were caused by the company data sharing policies of the product and service providers. It can be assumed that this barrier would be minimized and potentially omitted completely once these agreements are completed by all parties involved.

In some cases, limitations in current infrastructure limited data collection as part of this project. For example, APIs were not available and JSON posts were not readily available by the BEMS until the end of the project. Finally, through the review of APIs provided by each product provider, it was found that certain parameters were not readily available. For example, tank water temperature from the water heater is not currently provided via the APIs of this specific water heater manufacturer. Table 4-2 shows a data acquisition progress summary table and lessons learned by implementing a novel method for data acquisition.

Table 4-2
Summary and lessons learned from implementing project data acquisition system

Connected Device	Approach	Status	Lessons Learned
Circuit Level Monitoring	- Define and Monitor Critical Loads - Mains - Heat Pump - Water Heater - FAU - Kitchen Plugs - Oven (if electric) - Laundry - EV Charger (if available) - Garage (GFI) - Refrigerator - Microwave - Solar - Battery (if available) - Allocate remaining CTs if available - Train electrical contractors for SiteSage installs - Verify using data	- Most work completed - Some sites offline - Data acquisition completed - Continue to monitor for anomalies	- Requires significant trade training - Commissioning considerations when scaling - Connectivity still issue - Data verification needed and continues
Smart Thermostats and Plug Loads	- Define parameters used to understand device usage/controls capability/customer preference. - Setpoint - Indoor Temperature - Outdoor Temperature - HVAC Runtime - Mode of Operation - Humidity	- API work completed and data collected from thermostats - Setpoint adjustments completed	- Limited usage of smart plugs - Limited transparency of device-level data - No aggregate controls available
Battery Energy Management System	- Define and Monitor Critical Loads - Frequency - Voltage - Mains Power - Solar Power - Battery Energy (Imported/Exported) - Battery Temperature - State of Charge - Fault Codes available for all data parameters - Data acquisition collected as part of eGear BEMS install - Egear and EPRI monitoring data	- BEMS specific data acquisition completed - Continue to monitor for anomalies	- Requires significant trade training (esp. permitting) - Currently no API availability (data read only access)
HPWH	- Define parameters used to understand device usage/controls capability/customer preference. - Temperatures at top, middle and bottom of tank. - Set points and operating mode (hybrid, fast recovery, energy efficiency) as set in the user interface on the water heater. - Run time and/or power usage of the compressor and fans for the heat pump. - Run time and power usage of the back up electric element.	- API work in progress - Not all parameters required are available for PV balancing - Limited API calls available	- API outsourced - API CTA2045-based - Limited technical support - Setpoint adjustment req. additional mixing valve (not std.)

It is important to take note of information provided by electrical and plumbing contractors when installing and commissioning the overall data acquisition system. As previously mentioned, only hardware elements were installed by the electrical contractor due to unfamiliarity with the connected devices – in particular, provisioning the circuit level monitoring system onto the Wi-Fi network. During preliminary data collection, it was also found that although for some homes grouping end-uses to common breakers took place, several homes had conventional group loads by zones due to limited training and communication of this information to some of the electricians that were not part of the original planning events. Possible preventative actions for lack of trade ally knowledge and incentives are increased detail in the data monitoring and acquisition plan that is aligned with electrical circuit schedules. It will be important to understand the cost premiums for this level of detail from both a commissioning and networking perspective. In addition, it was discovered that certain loads were mislabeled as part of the circuit level monitoring. See Data Cleaning and Processing below for corrective actions completed.

Data Cleaning and Processing

The project experienced data anomalies due to a combination of errors attributed to installation, data loss due to lack of connectivity, and anomalies that natively occur in field implementation. It is important to develop systems for understanding and treating data collected by the individual systems before completing analysis.

Resolving Installation Errors

Through preliminary review of end-use data collected via circuit-level metering, the project team found a combination of labeling and polarity errors in preliminary analysis of circuit-level data. To identify the errors, the project team assessed circuit-level data for validity based on a fundamental understanding of the operating condition of each end-use. In addition, polarity issues were identified. To resolve the errors, the project team completed the following tasks:

- Performed on-site reworks of the circuit-level monitoring system. With preliminary analysis, the team verified and adjusted current transformer (CT) location based on data received. Necessary changes made to the back-end infrastructure provided by the circuit level monitoring system were also completed:
  - Circuit level monitoring was reworked for homes 1 and homes 3-9 from May 31 – June 2.
  - Circuit level monitoring was reworked for homes 2, 11-15, 17, and 19 from June 20 – June 23.
  - Circuit level monitoring was reworked for homes 10, 16 and 20 from July 7 – July 8.
- Coordinated with circuit level monitoring product providers to deal with polarity issues and other anomalies detected that could potentially be addressed via software.

It is important to note that this effort is continuing.

Protocols to Clean and Manage Data

Unfortunately, there are no universal, defined industry processes for data cleaning. There are some guidelines that might be relevant but must be adapted based on the data collected and the use of that data.

For this project, the team used a combination of subject matter expertise in end-use energy efficiency and building science to define a set of rules to identify and remove anomalous data prior to analysis. The cleaning/validation strategy depends on the quality of data at hand, which is determined based on preliminary data exploration completed by the home, as well as by each system. Common types of data quality issues that the team addressed were:

1. Anomalous data such as illegal values, including out of range values and/or illogical values.
2. Missing data identified, timestamp present but value missing. Although the connected devices had certain levels of data caching, extensive loss of broadband connectivity resulted

in loss of data for extensive periods, sometimes at the whole-home level. For example, it was identified that the Wi-Fi router was reset in June, resulting in the loss of data for Home 6 for an extended period.

A combination of automated coding scripts and exploratory analysis were completed before data was used and before any analysis was completed.

Data Aggregation and Warehousing

Although data warehousing was described in the data collection section, data aggregation provides additional insight that may be otherwise missed when data is analyzed in a disparate subset. In practice, the connected device manufacturers and electric utilities have historically operated in “data silos,” with limited visibility of other data sources not owned by that stakeholder. It can be assumed that the value of data is exponentially increased when analyzed in aggregate. For example, circuit level monitoring data can quantify energy consumption to an end use. Data analysis from two homes in the study showed similar sized homes consuming different levels of electricity attributed to space conditioning. Evaluation of the thermostat data identified that this was attributed to differences in customer preference indicated by lower daily temperature set-points in one home compared to another. In this project, the team has a unique opportunity to aggregate various data streams that include premise-level data provided by the utility via AMI coupled with several connected device and energy management system data. At the time this report was written, data warehousing was completed but autonomous data aggregated was still in the development stages, so no results can be provided at this time.

Data Collection Example

Data collected by the project provided end-use as well as premise-level information. Aggregation of premise-level data provided the project team with estimates of transformer-level impacts attributed to these ZNE homes.

Figure 4-12 shows a week of aggregated data collected from circuit level monitoring systems tied to Transformer 1. The x-axis represents time period while the y-axis represents total power in kW. This information, along with AMI data collected by the electric utility will be used to monitor impacts at both the premise and transformer level.

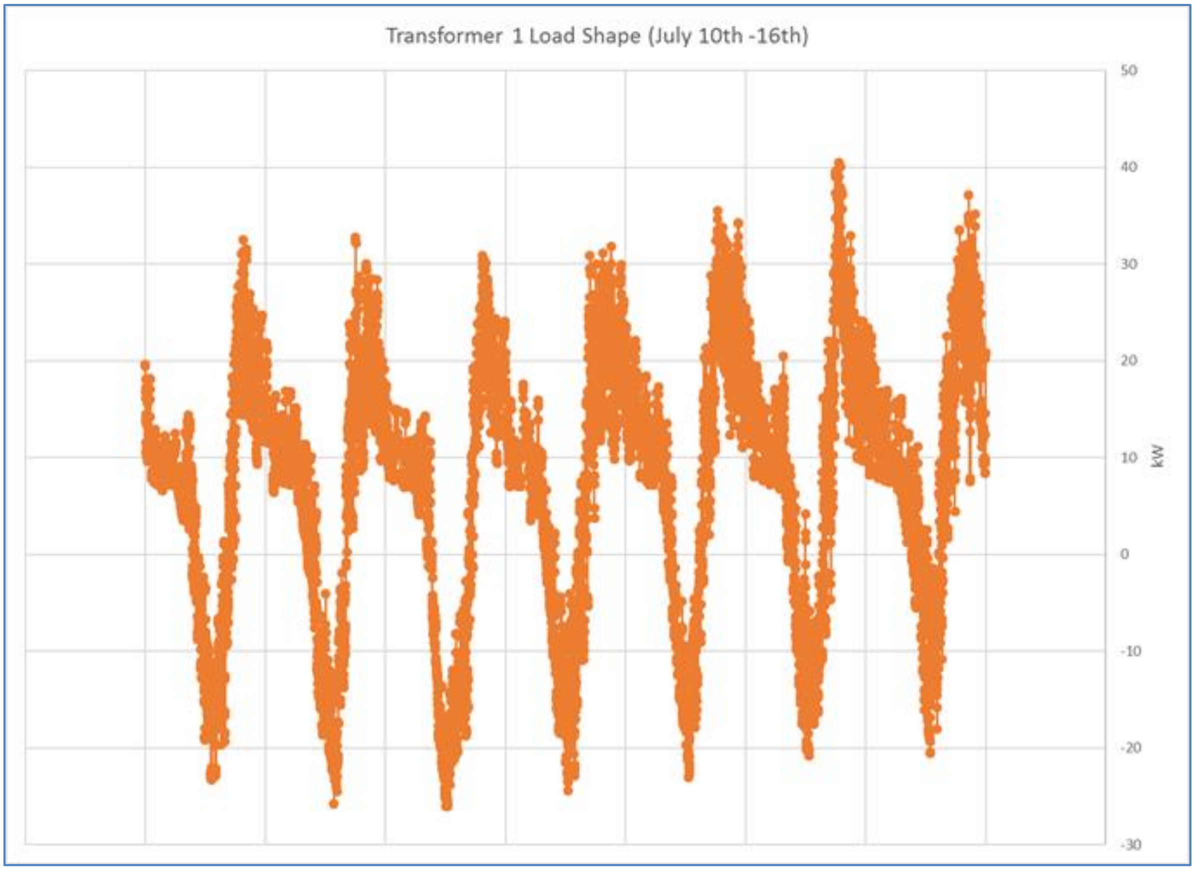


Figure 4-12
Aggregation of premise level data to estimate transformer impacts

Grid Balancing Using Controllable Loads

Connected devices and distributed energy resources provide the user with the ability to change and control end-use loads via mobile applications and/or web portals. For example, smart thermostat set points can be adjusted using third-party provided mobile applications.

In recent years, electric utilities have shown considerable interest in leveraging these devices as part of energy efficiency and/or demand response programs. Utilities use setpoint adjustments provided by these connected devices or load control via communicating switches to minimize energy consumption at desired times. Manufacturers and service providers offer solutions to utilities to aggregate specific devices to achieve this at the bulk level.

Figure 4-13 depicts a representative daily load shape of a “typical” home in this ZNE community for the third week of July. The load shape is like the California Independent System Operator “duck curve.” Premise level data indicates that one can expect over generation attributed to excess solar energy production in the mid-morning lasting until the afternoon, where a combination of increased energy consumption and reduced solar generation results in a ramping effect in the late afternoon until the early evening. The ideal energy management solution would address the “duck curve” using the controllable loads in the home and considering individual customer preferences.

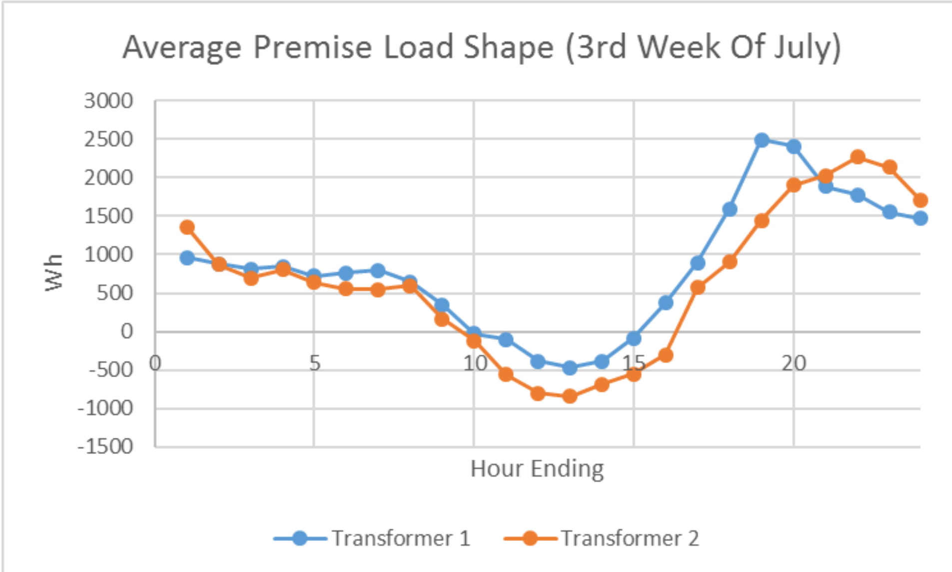


Figure 4-13
Average daily premise load shape (third week of July)

The approach will be to leverage thermal storage provided by the connected water heater and smart thermostat along with electrical storage to balance energy usage. Like data acquisition, the team will use existing controls provided by each of the manufacturers. The team plans to develop a controls platform to provide load leveling capabilities as part of this community. Results of this effort are not yet available as implementation was not completed at the time this report was written.

5
ENERGY STORAGE IMPLEMENTATION AND LESSONS LEARNED

Residential battery storage has been deployed globally for over 30 years. The past five years have seen considerable growth in grid-connected deployment in response to changes in system costs, reliability, safety, energy management features, grid integration, and electricity tariff structures. In some locations, tariff reforms have been implemented to support sustainable growth in markets for residential solar systems and other distributed energy resources.

Expansion of residential battery energy storage is linked to the growth in PV solar installations. Storage can help users maximize the benefits of PV generation by shifting solar energy production to residential load hours. The most effective storage systems incorporate energy management tools to integrate storage with PV and other on-site energy management systems.

Energy storage systems (ESS) consist of three primary components: a power conversion system (PCS), a battery/battery management system (BMS), and an energy management system (EMS)[13]. Many vendors provide integrated systems with all components. Some component vendors offer only one or two of these components, while others form cooperative arrangements with complementary providers to provide complete solutions. With the ongoing developments in energy storage markets and growing emphasis on supporting renewable energy installations with storage, establishing objective metrics for assessing storage systems and components is becoming critical. With many players in the market and product offerings changing rapidly, gaining access to a logical framework for assessment becomes increasingly important. This report proposes one such framework, with example results for real-world systems.

This section discusses a framework for assessing battery energy storage systems in residential applications. The approach incorporates essential elements of value to customers and develops an objective metric-based assessment process. This process relies on understanding the characteristics of complete systems (whether provided by turnkey vendors or assembled by components), so a survey of top-ranked vendors (as of late 2015) was conducted to gather information on system characteristics. Operating experience from a demonstration project is used to illustrate how battery storage integrates with PV systems in residential installations. A logical framework is presented for determining the best combination of components (or best ready-built system) for a set of priorities, needs, and resource availability.

Approach

This section first reviews the global experience in battery storage deployments, including the tariff structures that affect the operation of PV systems and storage. The characteristics of

[13] Certain product providers combine BMS and EMS functionality and provide battery energy management systems (BEMS).

storage are addressed, and the key elements of value to energy storage are identified. A typical case of operation in a well-designed storage system is presented to illustrate key factors in battery system design and management. A survey of top providers of currently-available (or near-available) battery storage components and systems is provided with greater detail in Appendix C. For each provider, the report provides a brief overview of the vendor's product, a table of pros and cons, and (where available) summary information on system characteristics as of late 2015. A framework is presented for assessing available battery storage systems, beginning with the elements of cost for a complete, installed system, factors affecting system cost, and consideration of factors other than cost.

Other EPRI Resources

Other EPRI resources pertinent to these concerns include:

- *Residential Off-Grid Solar Photovoltaic and Energy Storage Systems in Southern California.* EPRI, Palo Alto, CA: 2014. 3002004462. This report focuses on the feasibility of off-grid solar photovoltaic systems supported by energy storage.
- *The Integrated Grid. EPRI, Palo Alto, CA.* http://integratedgrid.com/ This is an EPRI-sponsored online community focused on integrated-grid issues, including information resources and connections to pilot programs.
- *The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources.* EPRI, Palo Alto, CA. 2014. 3002002733. This report focuses on the need for technology and planning approaches for integrating DER into the grid, taking full advantage of distributed energy to support central energy resources while improving the dynamic performance of the system.
- "EPRI Project Update: Zero Net Energy (ZNE) Community with Meritage Homes," *Strategic Intelligence Update: Energy Storage & Distributed Generation*, EPRI, Palo Alto, CA. November 2015. 3002005064. The newsletter covers an array of related topics; this article describes a pilot project involving installation of battery storage systems in a small community of homes.
- "Customer-Sited Technologies and Applications," *Strategic Intelligence Update: Energy Storage & Distributed Generation*, EPRI, Palo Alto, CA. December 2016. 3002007864. This newsletter covers related topics; this article addresses residential battery energy storage systems.

Global Battery Storage Deployment

The global breadth and depth of deployment of residential storage systems is illustrated in Figure 5-1. A significant number of systems are installed in Germany, Italy, Great Britain, Australia, and Japan. In the United States, these installations are most heavily concentrated in California and Hawaii, where PV solar installations may be integrated with storage.

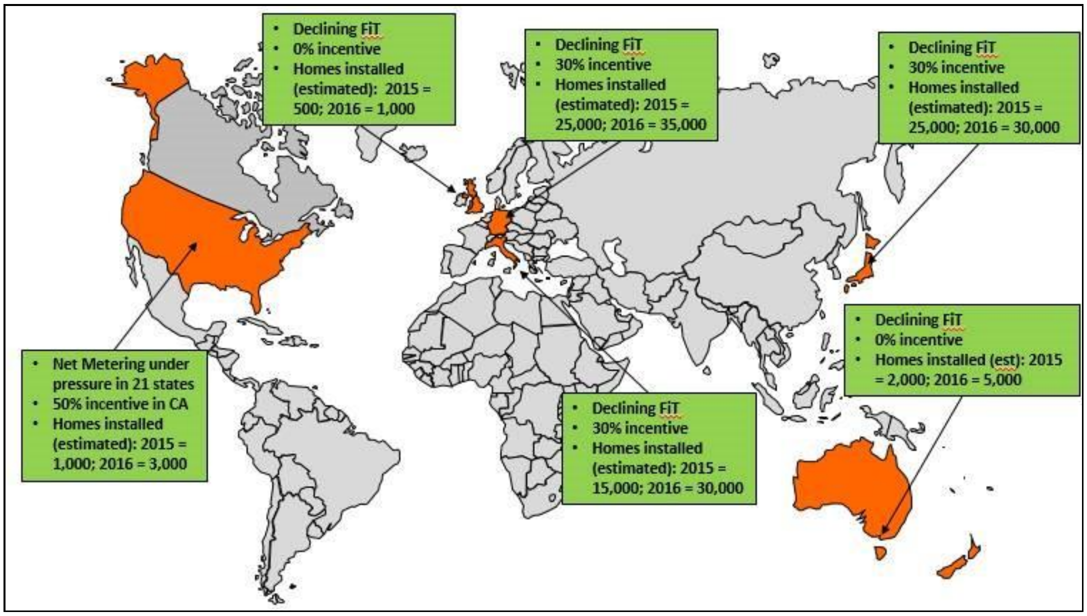


Figure 5-1
Global distribution of battery storage systems, including tariff structure (net metering vs. feed-in-tariff), government incentives, and estimates of installed units

Impact of Storage Tariffs

At the individual customer level, a key factor in the economics of storage is the availability of tariff structures that incorporate or even foster the use of energy storage. In some locations, government agencies have adopted tariff reforms that were designed to support sustainable growth in markets for residential solar systems and other distributed energy resources. The three most widely-used tariff-driven operating modes for residential storage are:

- **Self-Consumption**. Self-consumption customers (sometimes called self-supply users) intend to use on-site all the energy produced by a solar (or other distributed energy) system, and they do not plan to export excess energy to the grid. These systems are designed to use energy management systems to balance onsite production to the grid without needing to curtail production from the PV system. Since self-consumption systems avoid exports to the grid, the impact on the grid of solar production is minimized.

  For example, a PV system rated at 3 kW DC paired with a storage system rated at 6 kWh can provide two hours of continuous charging or discharging. Based on recent test results from EPRI's research project in California, it is anticipated that power ratings will likely shift to a minimum of 5 kW, at least for the U.S. market. Furthermore, a typical household in the U.S. consumes approximately 30 kWh per day. Providing battery storage capacities of approximately 12 kWh balances battery costs with effective capacity for shifting energy production and consumption. When a home power backup application is layered with self-consumption, the designs will be driven to greater than 12 kWh to offer more robust reliability and the resiliency of clean, quiet backup power. Because of these combined forces, designs of home storage systems for the U.S. market appear to be converging towards modules of 6 kWh, combinable to yield 12-18 kWh.

In new construction of solar with storage, design decisions regarding the PV system and the battery components can be coordinated. For instance, the continuous power rating for the battery system can be matched to that of the PV system. In retrofit installations, the available components may not match the existing PV system. EMS functions assist in maintaining the self-consumption operation pattern. To ensure that no exports occur, the system can be designed to be capable of curtailing PV production when solar output exceeds residential load and the battery is fully charged.

- **Grid-Supply Systems.** Grid-supply customers plan to export excess energy to the grid as needed. Under a Net Energy Metering (NEM) program, customers receive energy credits on their monthly bills based on the quantity of energy exported in excess of the customers' load. Note that customers are not directly paid for the energy, but instead earn credits, so tariffs do not include prices for exported energy. Instead, tariffs include credit rates to set the value, per kWh of exported energy.

  Tariff design can encourage or discourage such installations through the credit rate applied to exports. For example, it is often the case that as more customers install grid-supply systems, the credit rate for energy exported to the grid is reduced. In effect, this lowers the overall cost of the utility's renewable energy portfolio, so that the tariff yields benefits for all customers. Depending on network constraints or production by other grid-connected renewable energy systems, some localities may set a cap on the total capacity of grid-supply PV/battery systems.

  Where regulators seek to encourage more grid-supply renewable investments, feed-in tariffs (FiT) may be set. A feed-in tariff rewards producers of a desired type of generation with higher rates for their energy exports to the grid. As Figure 5-1 illustrates, in several countries where battery storage is well established, feed-in tariffs are available.
- **Time-of-Use Operation.** Time-of-use (TOU) tariffs specific to solar customers allow these customers to save money by shifting energy demand to the middle of the day to take advantage of lower-cost solar energy. TOU tariffs encourage customers to adjust their energy use by charging different prices for energy at different times of day. Ordinarily, TOU tariffs encourage customers to shift their energy use to off-peak periods by setting energy prices high at peak hours. For customers with PV systems, TOU pricing can be used to shift loads to maximum PV production hours, thereby diverting these on-site demands away from relying on the grid. By sending the right price signals to customers, utilities thereby reduce overall demand on the grid. To the extent that integrating renewables into the grid might present issues with constraints on the grid, TOU pricing can help alleviate those concerns by directing PV production to be used on-site during peak hours for the grid. In this context, TOU tariffs can also be used to spur investment in new smart home and smart business technologies, encouraging customers to take advantage of the tariff structure.
- When TOU rates are offered, a solar-plus-storage platform needs an EMS equipped with dynamic season, time, rate, tier and forecasting lookup tables to maximize the energy and cost savings available to the customer. For example, the software system can recognize potential cost savings to be gained from coordinated operation of the PV and battery and home energy systems to shifting any net imports from the grid into low-cost time periods. Additional benefits are gained when the EMS can interface with a smart home's home energy management (HEM) system.

- New developments in tariff designs for grid-connected customers with net energy metering are ongoing. In some jurisdictions, utilities are under pressure to increase installation of renewables; in those cases, tariffs may be designed to reward or otherwise encourage such installations.

Residential Battery Storage: Definitions and Values

Defining the Storage Platform

As mentioned previously, an ESS is composed of three major components: the PCS, the battery including its BMS, and the EMS. Turnkey providers offer all components as a complete system, while component providers work on a partnering model.

Turnkey, whole-system providers offer customers a means to enter the market with all components fully integrated to achieve rapid and scalable system deployments. Alternatively, systems may be assembled by selecting from solution providers with core competencies in software, PCS, or battery/BMS capabilities. The component-provider route may be more appropriate in situations where tailored solutions are desired, particularly if one component is a custom design. One example of this would be a custom EMS paired with a high-quality PCS provider and a well-established battery/BMS provider.

Establishing Elements of Value

Value for a home storage solution derives from seven key elements:

1. Safety: For example, designs of components and housings provide fire safety. Grid-connected systems include controls to manage critical loads when the grid is disconnected. Selection of skilled installation personnel ensures safe handling of electrical equipment.
2. Simplicity: A high-value system does not require special solar industry knowledge, but instead relies on the established skills of a residential electrician. This reduces pre-installation design time and costs, and decreases installation labor costs, because specialized solar technical skills are not needed.
3. Fast installation: The target is for installation to require only one or two person-hours per site visit. However, this may be extended in situations where the battery is providing backup power.
4. Reliability: A storage system is expected to be replaced once during the life of the solar system and should operate at its expected rating over 10 years of operation.
5. Efficiency: A key efficiency target is to reduce the number of energy conversion points, with the goal to provide round-trip efficiency greater than 85%. Ideally, no more than two conversion stages are required for a bi-directional system.
6. Customer Experience: A compelling user experience is driven by providing excellent and appropriate system visibility. For instance, the general user desires access to actionable data but prefers to avoid dealing with extensive low-level data streams. When a single company can offer solar, storage, and home energy management, users perceive added benefits by avoiding shopping for services among multiple providers.

7. Cost-Effectiveness: Transparency regarding the components of system costs, particularly installation costs, enables customers to objectively weigh the operating benefits against the system costs and to compare systems based on component and installation costs.

These value elements provide a conceptual background for understanding the characteristics a residential operator seeks in an energy storage system. The process of selecting specific components or systems can be enhanced by inculcating these values into a metric-based framework to objectively compare candidate systems.

Appendix C is a compendium of available residential battery storage technologies.

Background

With the ability to mitigate impacts attributed to high-penetration PV scenarios, the team vetted energy storage solutions for availability and placement. Residential-sited energy storage and distribution transformer sited energy storage solutions were vetted for inclusion in this project. On the residential customer level, one storage system will be installed at each of nine homes (single family residential homes). These homes would be isolated on a single 50kVA community transformer (Transformer 2). The plan was to install a 4 kW energy storage system (or similar size as determined by availability).

On the distribution transformer level, one 20 kW (or similar size as determined by availability) system would be required. This distribution storage system would be installed on the 75 kVA transformer (Transformer 1) connected to the remaining 11 homes. The project was originally designed with community scale energy storage at the transformer. This section walks through the community storage product selection, field implementation barriers, and final choice to not install community storage due to practical considerations.

In both cases, the storage systems will be primarily used to mitigate grid impacts of PV. In the 10-minute timeframe, the storage system will reduce short-term variability from PV; in the 2-hour timeframe, the storage system will reduce evening ramp when PV production falls and load picks up. It is possible that the storage system could provide other benefits in addition to its primary purpose.

For both locations, EPRI was looking for storage system providers that would take responsibility for delivery, installation, interconnection, maintenance, communication and control systems, and installation of monitoring equipment and setting up the controls for the storage unit. Due to the nature of the project (demonstration), the budget was limited for storage procurement.

Energy Storage Evaluation Process

The search for energy storage system(s) started with a list of energy storage vendors developed by EPRI internally. The team conducted initial outreach to determine if the potential vendors on the list could provide the system to meet the project requirements. To communicate with the vendors, the team developed a basic Request for Information (RFI) with basic project information and storage requirements. This document was shared with potential vendors.

For distribution-sited energy storage, due to the specific size requirements, project timelines, and overall energy storage system cost, most of the vendors that the project reached out to could not meet the requirements. The team eventually identified a vendor (referred to as “Vendor 1” to ensure proprietary information is protected) as a potential provider, because it proposed to repurpose its existing units, which would save significant amount of time and cost.

There were three potential ways suggested by Vendor 1 to repurpose its existing units:

1. A few Vendor 1 units were located at the Sacramento Municipal Utility District (SMUD). Vendor 1's units were 30 Kva/34 kWh, pad mount units. These units were owned by NREL. Vendor 1 suggested that NREL might be interested in selling or loaning one or more of the energy storage units to EPRI. For these units, EPRI would need to buy a few battery modules (two to four modules) to replace some modules that were damaged in shipping.
2. There was potentially as many as two units at San Diego Gas and Electric (SDG&E) (30 kVA/72 kWh) that would be in transition from deployment to R&D resource and SDG&E might (or might not) be willing to look at a similar loan or sale arrangement as the units in SMUD owned by NREL.
3. There was one additional unit that might be available that does not have a battery pack in it. To use that unit, EPRI would need to acquire a full battery pack.

Vendor 1 suggested that they could set up an arrangement where NREL loaned the unit to EPRI for the duration of the demonstration or a length of time to be negotiated between EPRI and NREL. The Vendor would help to commission the Community Energy Storage (CES) unit for EPRI. They also suggested that the best course of action would be for the unit to be sent first to the vendor for refurbishing, testing, and an overall configuration update. Then Vendor 1 would send the unit to California for deployment. An alternative plan would be for Vendor 1 to come to NREL to do the rehab and configuration update and then have NREL test the unit to IEEE 1547 compliance. Vendor 1 believed that the CES unit may need up to 4 new battery modules (17 modules are used in each unit) due to damage that may have occurred to the modules in shipping or handling at SMUD or on the way to NREL. Vendor 1 estimated that they could support supplying these modules in a timely fashion at about $2,000 - $3,000 per module. Units of a very similar design are deployed in San Diego on a residential right of way, at the SDG&E research facility, and at a commercial strip mall.

Safety Evaluation

Once it was determined that Vendor 1 could potentially meet the project requirement, the next step was to ensure the safety of the unit. The project team put heavy emphasis on the safety of the unit because the units were planned to be in a residential neighborhood, and therefore close to homes and backyards. The project team requested the following items for safety testing from the vendor:

1. Formal Failure Mode Effects Analysis (FMEA), or at least documentation of the simplified FMEA.
2. Formal System Safety Analysis (SSA), with safety testing to confirm adequate system response in the most critical cases.
3. Formal documentation on the safety mechanisms.
4. A proper fire suppression system incorporated into the device, or recommendations for such a system in a building installation.

5. A manual for first responders in the event of fire and/or explosion.
6. Documentation of 15,000 hours of safe operation (or a number of hours agreed upon by the project team and Vendor 1) with data on how the systems handled failures.

The Vendor was only able to provide the following documentation on the unit (Vendor 1, Unit 1) and a similar unit (Vendor 1, Unit 2):

1. A data sheet on the Vendor 1 Unit 1.
2. A (relatively old) brochure on the Vendor 1 Unit 1as installed in Sacramento.
3. Installation manual for Vendor 1 Unit 1.
4. Installation manual for the Vendor 1 Unit 2 -- which is similar but has twice the battery pack.

Potential Energy Storage Issues Identified by the Project Team

Through the community storage evaluation process, the project team identified seven main issues with the potential community storage solutions available. These issues are summarized in Table 5-1.

Table 5-1
Issues with potential community storage solutions

Requirement	Issue
FMEA Testing for Safety	No formal lab testing for safety. No rigorous FMEA as per an approved standard
SSA	No documentation of SSA provided by Vendor 1
System Certification Compliance Testing and Field Testing	Units were designed per UL-1741 but never formally UL certified
Operational issues during SMUD field testing (minor)	Early issues with inverter bias supply and support electronics failures
Safety mechanism	No safety mechanism documentation or procedures to respond to hazardous failure modes
Fire suppression system	No fire suppression system installed in the battery compartment
Lack of documentation	No manual for first responders and no record or document of safe operation hours

The first issue regarding the product was that Vendor 1 had done no formal lab testing for safety for the unit aside from the field testing with SMUD and SDG&E. Vendor 1 completed a simplified FMEA at some point, but did not do a rigorous FMEA as per an approved standard. The battery vendor provided a significant amount of battery safety background information to Vendor 1, but Vendor 1 was not able to provide any formal documentation of the FMEA.

The second area of concern was the System Safety Analysis. No documentation of SSA was provided. No specific requirements for such an SSA were ever specified and are still not clearly identified.

The third issue was with the System Certification and Compliance Testing and Field Testing. The Vendor 1 units were designed per UL-1741 requirements but were not and are not certified by UL. The SMUD-deployed units were all tested for and passed by NREL for IEEE 1547 compliance, and although NREL would be able to test for compliance, they could not certify equipment for safety purposes.

The fourth issue was that Vendor 1 also had a couple of years of field testing experience at SMUD. During the field testing, there were minor operational issues in deployment. None of these were safety related or necessitated a safety incident report, but they were concerning enough to cause hesitation on the part of the project team subject matter experts (SMEs). The Vendor had some early issues with the inverter bias supply and some other support electronics, such as one Insulated-Gate Bipolar Transistor (IGBT) device failure on a single bridge device on an early unit. All issues were repaired in the field and the unit was returned to service. However, the project team remained concerned about the potential impact in a neighborhood setting.

The fifth area for concern was around the unit's safety mechanism. There was no documentation of the defined safety mechanisms and/or procedures that respond to hazardous failure modes for the Vendor other than the electrical design protection mechanisms employed in the unit. No specific safety specifications had been provided that would guide unit compliance. In an email, the Vendor explained that the safety mechanisms in the unit are the fusing and overcurrent protection devices on the electrical connections (three disconnect means between the battery pack and the inverter, and two disconnect means between the inverter and the AC mains). The unit design is per UL-1741 enclosure requirements (enclosure is NEMA 3R.)

The sixth issue was with the unit's fire suppression system. There was no fire suppression system installed in the battery compartment. SDG&E did install a fire suppression system in their Vendor 1, Unit 2 units on their own initiative after deployment. Information could be provided on the fire suppression system installed by SDG&E; however, it was unlikely that the same or similar system could be fit into the battery compartment of the Vendor 1, Unit 1 unit.

The seventh issue was the lack of safety documentation provided by Vendor 1. Although the specific unit being considered for the CPUC project was deployed in Sacramento in a residential neighborhood in the front yards of three different houses, there were other issues around the safety documentation of the energy storage system. Vendor 1 was also not able to provide a manual for first responders. In addition to the safety concerns in the event of a fire or other emergency, this would have been a significant roadblock in the permitting process for the energy storage system. The Vendor was also unable to provide a record or document of the number of hours of safe operation of any of their units. Given that Vendor 1's only experience in residential unit deployment was three units in Sacramento for SMUD, and three units in San Diego for SDG&E, this made sense, but the project team was not comfortable that Vendor 1 did not have any testing data to share. The vendor was able to provide references from SMUD, as well as from the battery vendor as a point of contact for safety reference.

The project team asked Vendor 1 how they planned to ensure safety of the units. The Vendor suggested that EPRI could either ask NREL/SMUD for a test report from the previous testing or the team could contract NREL to retest the unit after the Vendor 1 retrofit is complete. Vendor 1 also thought that there could be a modification to the system to place a segmenting contactor that could provide an electronically controlled means of dividing the battery string into two separate lower voltage DC strings. If it were required to make sure that no DC voltage above 100 V is ever possible to access, as many as five controlled contactors would be required. However, locating and wiring such contactors would be very challenging in the Vendor 1 Unit 1 battery enclosure proposed for this project.

Although Vendor 1 was willing to undertake more safety testing and analysis, and provide documentation, they needed to do it in coordination with NREL, because the unit was currently owned by NREL. Vendor 1 would also need external funding to undertake the safety testing, that was outside the budget and scope of this project. The project team also requested specific design and performance requirements from this project to ensure the effectiveness of testing, which would have added a significant amount of budget to the procurement of these units.

Community Energy Storage Options:

Due to the lack of safety testing and documentation, the team decided to not select Vendor 1. As a result of the project team's extensive due diligence, the team was unable to procure documentation regarding the failure modes, potential safety issues and a guide for first responders in the event of an incident. In the future, as energy storage becomes more established, more units will participate in standard documentation and testing such as the UL process, which would help ensure a safe outcome. The team felt that at this time, Vendor 1 was unable to provide any assurance of safety and this could represent an unacceptable risk within a neighborhood setting, as any potential issues could have far-reaching and negative consequences.

6
ANALYSIS OF FIELD DATA FOR ENERGY PERFORMANCE AND STORAGE OPERATION

An EPRI demonstration project in Northern California was commissioned in October 2015. The goal of this project was to evaluate a solar and battery storage system operated to demonstrate self-consumption either with or without grid exports, as well as energy arbitrage under TOU tariffs or as a battery backup system without PV. A version of the assessment framework described in Section 3 was used to identify a mix of components appropriate to this project.

The testbed system was composed of a 3.2 kW DC solar PV installation powered by microinverters, with a 5 kW PCS and a 6.4 kWh battery unit for which power throughput was constrained to a 3 kW peak. The integrated EMS provided graphical output tools to view the operation of the battery as well as the PV system serving the residential load, with and without grid support. Figure 6-1 illustrates the relationships among the components of this system.

In the pilot project's location, home consumption information was obtainable via a Smart Meter, but that method is not available in all locales. The project team also tested an alternate method, polling a standard current transformer (CT) meter to obtain the data needed by the EMS. Because latency issues tended to degrade battery and load-management performance, it was determined that in such a case, the preferred design would provide the EMS with direct coupling and a real-time connection to the CT meter.

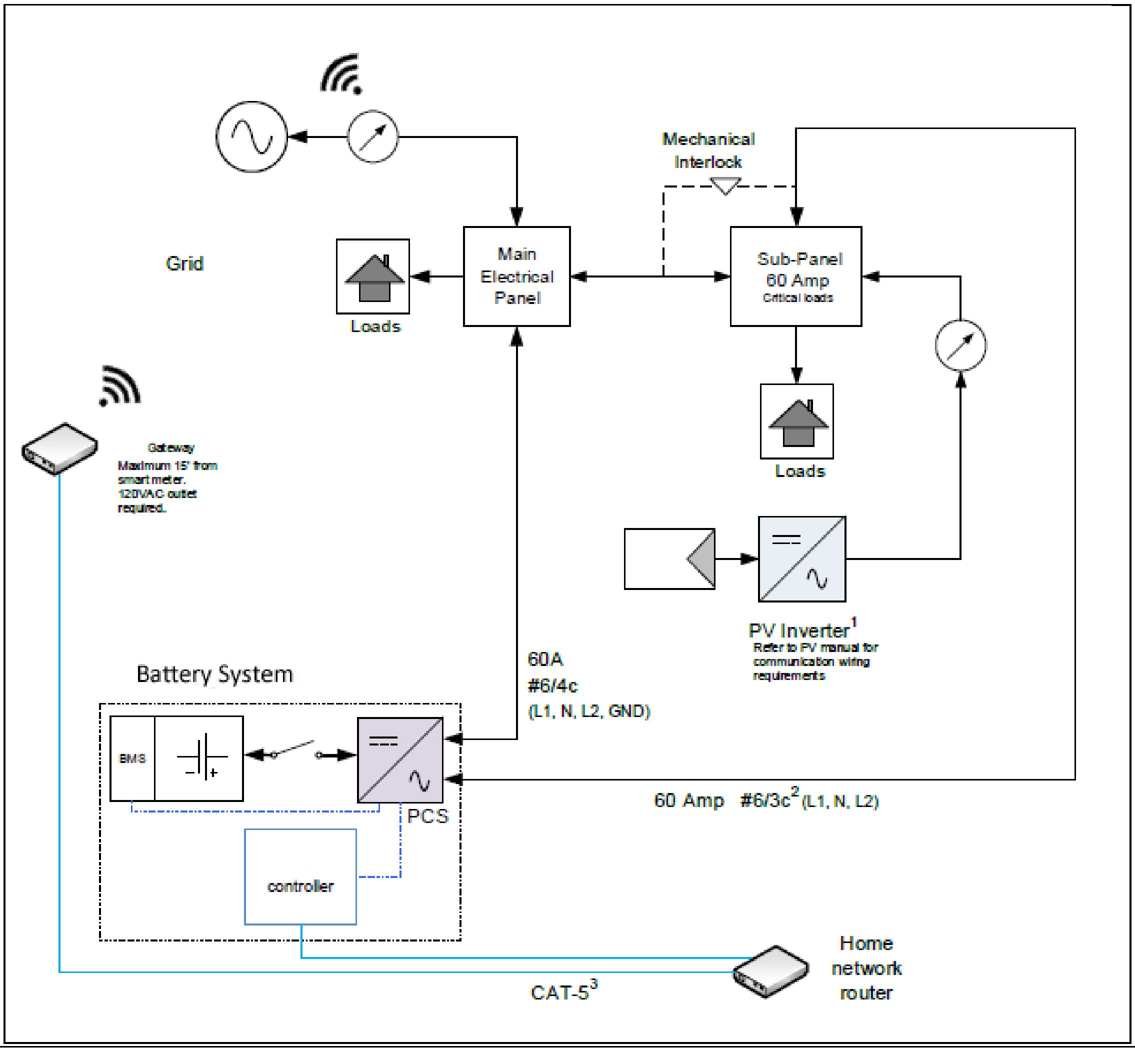


Figure 6-1
Schematic of components of pilot system project

The pilot project yielded a foundation for a larger demonstration project, in which nine homes were equipped with similar systems, allowing data collection for an aggregated total of PV production, battery use, and residential loads. For this demonstration project, all storage systems were grid-connected, but the EMS software is designed to allow a choice of maximum self-consumption or time of use operation.

Figure 6-2 is an example of a single home's storage operation for self-consumption. The home load (red line) is served by a combination of imports from the grid (positive values in black), direct supply from the PV system (green), and output from the battery system (yellow). The EMS operates this system to minimize exports to the grid, so the black line in this case is nearly entirely in the positive range.

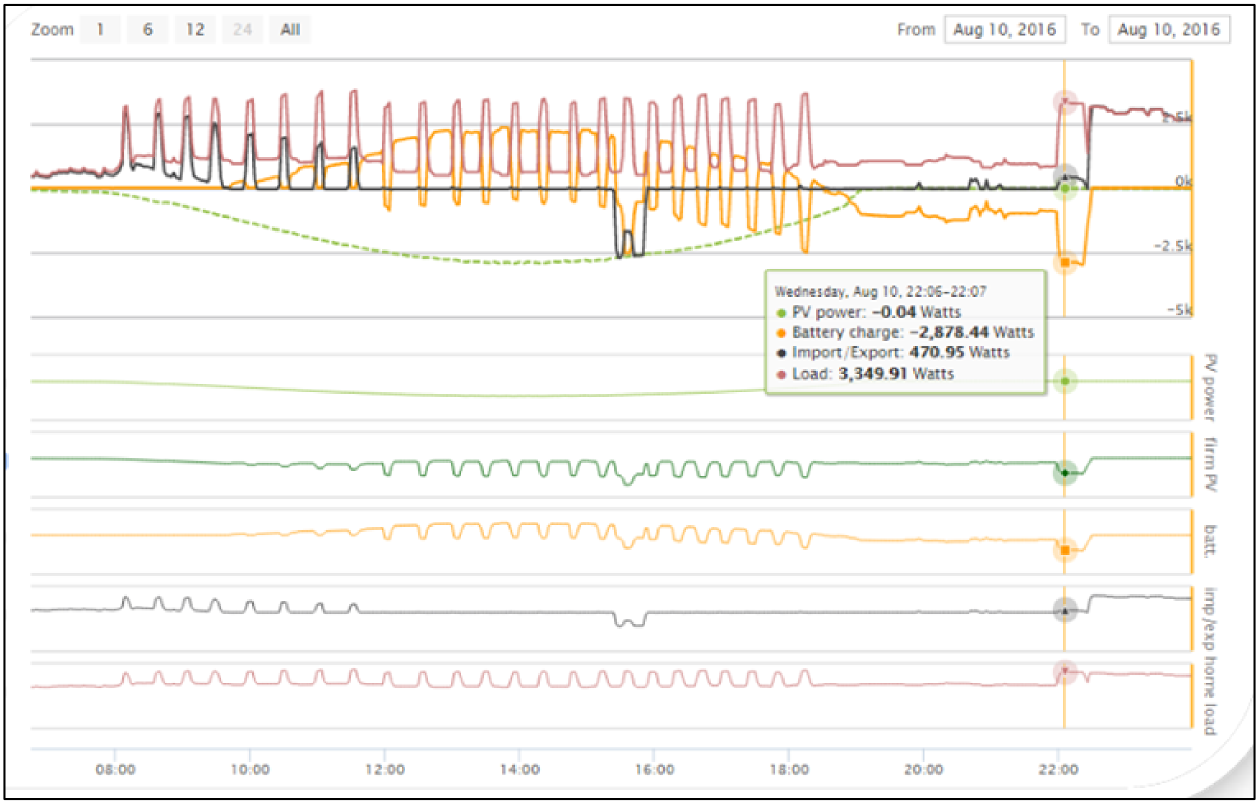


Figure 6-2
A single home's 24-hour operation with self-consumption

In contrast, Figure 6-3 shows the same home operated in load-following mode, guided by TOU rates. On the day sampled, residential loads were dominated by air-conditioning load cycling. In the early part of the day when TOU rates are low, the EMS followed load using grid imports while charging the battery storage. Later in the day, loads in excess of PV production were served first by discharge from the battery, minimizing the total cost of electricity use.

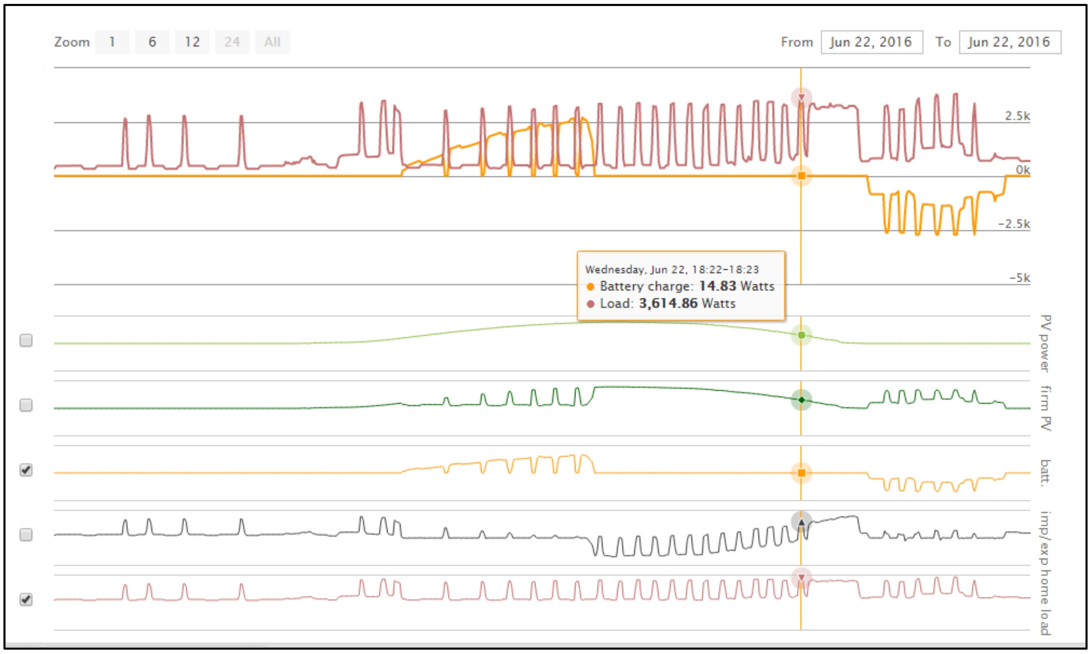


Figure 6-3
A single home's 24-hour operation in load-following self-consumption, scheduled to take advantage of time of use tariffs

When these operations were aggregated over a group of homes equipped with residential energy storage controlled using a load-following self-consumption scenario, the combined profile illustrates key values for energy storage systems. Figure 6-4 presents the combined operation of a group of nine homes operating in load-following self-supply mode. In each installation, solar energy is operated in a "first in, first out" mode with the battery storage. Any excess solar energy is first directed into the storage system, then exported to the grid if the battery is fully charged. Any home load above PV generation is first served by discharging from the battery, then served by the grid if necessary. Solar or battery energy is always the priority over using the grid; grid power is only used when the home usage cannot be met by either PV or battery energy.

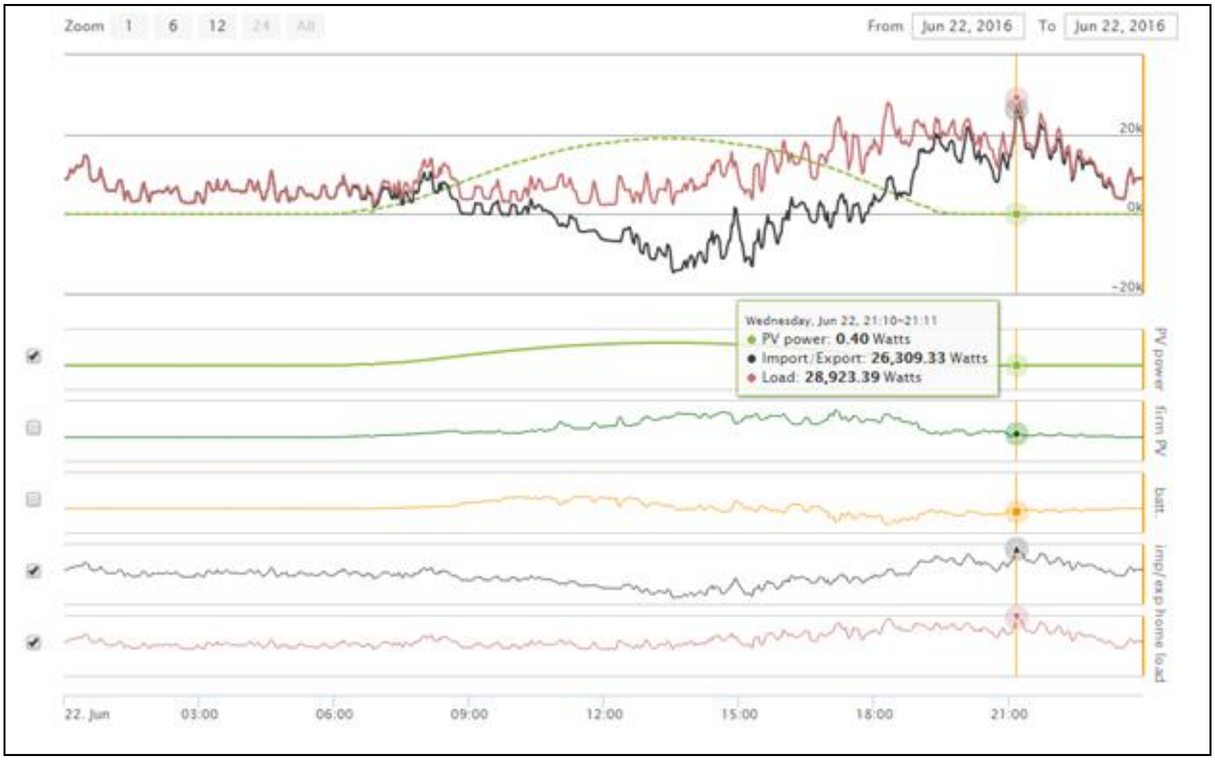


Figure 6-4
Aggregated operation of storage in a group of homes equipped with battery storage

As Figure 6-4 illustrates, with the solar production prioritized to serve residential loads, the impact on the grid from the aggregated group of homes was reduced, while each residence may have its own unique load profile. For example, if a resident is working at home during the day, most of the stored battery energy may be consumed by late afternoon. A household that leaves the home during the day will have low loads during that time and will use the stored battery power when they return home later in the evening. This protocol allows the battery storage to follow each home's energy usage profile.

Preliminary Analysis of Transformer and Premise Field Data

End-use and premise-level data collected from the circuit-level meters was analyzed to better understand when to expect peak energy consumption to occur in each of these homes. It is important to note that because of data collection considerations detailed in Section 4, circuit-level metering data will be presented after the last re-work of the circuit level metering system. Therefore, data presented here was collected from July 10 through October 1, 2016. For this analysis, data collected on October 1 will be included as part of the September data. The team plans to continue to collect data for two years on these homes. Transformer-level analysis was completed by aggregation of data collected at the premise level.

Transformer-Level Data Analysis

Data was collected at one-minute intervals to better understand grid impacts at the transformer level from these ZNE homes. Transformer load shapes were created using this information. See Figure 4-12 in Section 4 for additional details.

Table 6-1 and Table 6-2 detail weekly summaries during July through September, 2016. Times are amplitudes for both peak energy consumption and maximum solar over generation are provided.

Table 6-1
Weekly Transformer 1 data summary

Week	Dates	Peak (kW)	Peak Time	Max. Solar Over Generation (kW)	Max Time
1	July 10–16	40.5	7/15/2016 6:42:00 PM	-26.0	7/15/2016 9:28:00 PM
2	July 17–23	54.3	7/22/2016 9:45:00 PM	-22.2	7/17/2016 12:43:00 PM
3	July 24–30	45.0	7/25/2016 6:46:00 PM	-20.1	7/28/2016 11:56:00 AM
4	July 31-August 6	42.7	7/31/2016 6:53:00 PM	-25.6	8/3/2016 1:54:00 PM
5	August 7–14	45.2	8/13/2016 7:11:00 PM	-25.5	8/11/2016 1:29:00 PM
6	August 14–20	51.9	8/14/2016 9:16:00 PM	-20.6	8/16/2016 12:10:00 PM
7	August 21–27	42.2	8/22/2016 5:58 PM	-25.6	8/26/2016 1:37:00 PM
8	August 28–September 3	43.0	8/28/2016 7:49:00 PM	-20.7	8/28/2016 12:22:00 PM
9	September 4–10	38.4	9/8/2016 6:51:00 PM	-30.1	9/4/2016 11:56:00 AM
10	September 1 –17	35.0	9/11/2016 9:31:00 PM	-25.5	9/13/2016 3:05:00 PM
11	September 18–24	43.5	9/18/2016 6:09:00 PM	-25.0	9/23/2016 1:09:00 PM
12	September 25–October 1	45.5	9/26/2016 8:37:00 PM	-27.4	9/28/2016 12:47:00 PM

Table 6-2
Weekly Transformer 2 Data Summary

Week	Dates	Peak (kW)	Peak Time	Max. Solar Over Generation (kW)	Max Time
1	July 10–16	27.4	7/15/16 9:28 PM	-19.6	7/12/16 12:56 PM
2	July 17–23	33.8	7/20/2016 9:35:00 PM	-20.8	7/18/2016 2:17:00 PM
3	July 24–30	35.2	7/28/2016 8:13:00 PM	-14.3	7/26/2016 1:53:00 PM
4	July 31-August 6	32.5	8/1/2016 8:59:00 PM	-10.7	8/4/2016 2:14:00 PM
5	August 7–14	27.7	8/13/2016 10:32:00 PM	-19.4	8/9/2016 2:10:00 PM
6	August 14–20	32.1	8/16/2016 7:58:00 PM	-16.7	8/15/2016 2:00:00 PM
7	August 21–27	27.6	8/22/2016 5:59:00 PM	-19.6	8/27/2016 1:45:00 PM
8	August 28–September 3	31.7	8/31/2016 6:32:00 PM	-21.0	9/3/2016 1:01:00 PM
9	September 4–10	27.2	9/10/2016 8:42:00 PM	-20.7	9/4/2016 11:56:00 AM
10	September 1 –17	23.7	9/17/2016 7:22:00 PM	-19.3	9/15/2016 1:57:00 PM
11	September 18–24	32.8	9/18/2016 6:38:00 PM	-18.8	9/23/2016 1:54:00 PM
12	September 25–October 1	26.3	9/25/2016 8:07:00 PM	-16.5	10/1/2016 2:57:00 PM

Data from Table 6-1 and Table 6-2 show that generally, peak times can be expected in the evening. To further investigate, daily transformer peaks were graphed. See Figure 6-5 and Figure 6-6.

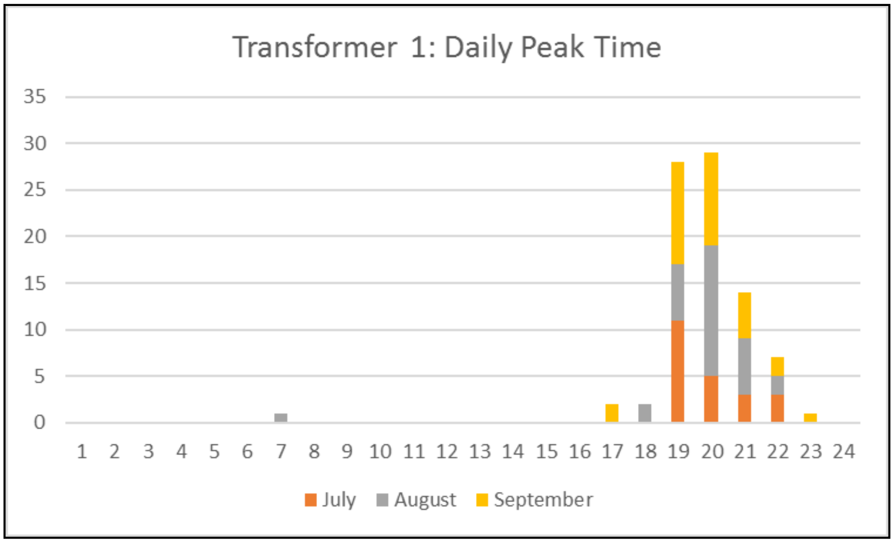


Figure 6-5
Distribution of daily peak from July 10 – October 1, 2016 for Transformer 1

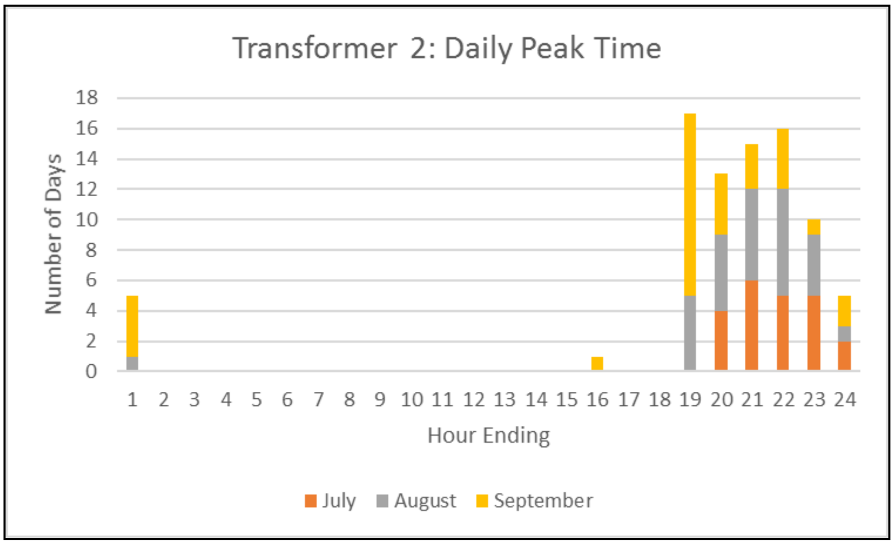


Figure 6-6
Distribution of daily peak from July 10 – October 1, 2016 for Transformer 2

Figure 6-5 and Figure 6-6 show that preliminary data indicates a significant amount of daily transformer-level peaks occur between 6:00 pm and 1:00 am local time. Note that with the preliminary data, transformer-level peaks experienced by the homes with residential energy storage (Transformer 2) appear to have more distributed peaks as well as later evening peaks.

The next step was to evaluate how peak energy consumption at the transformer level was driven by environmental factors such as outdoor air temperature in the summer. The correlation between maximum daily outdoor temperature and transformer-level peaks was assessed using aggregated data from the circuit-level metering systems. See Figure 6-7 and Figure 6-8.

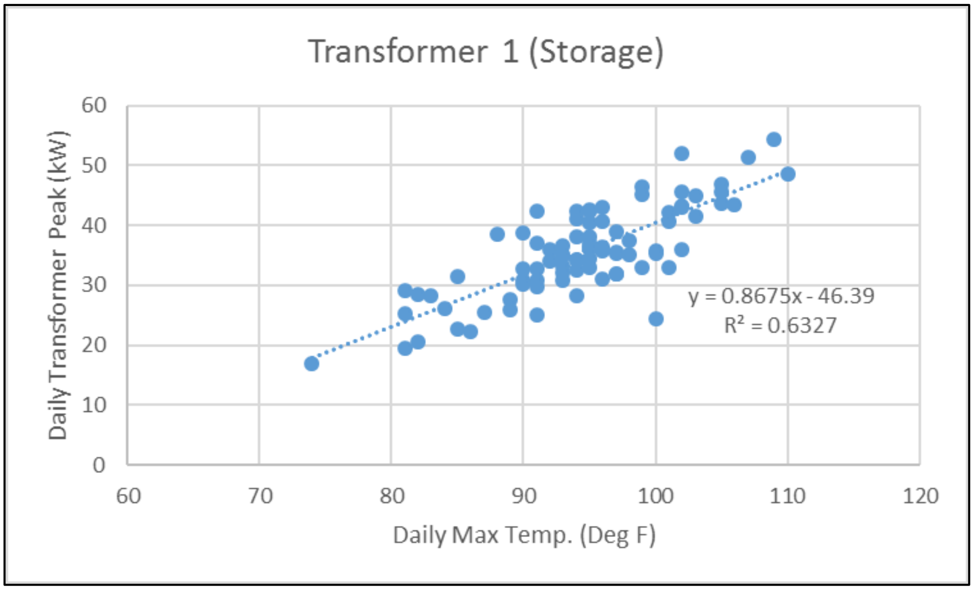


Figure 6-7
Correlation between maximum outdoor air temperature and daily transformer peak (Transformer 1)

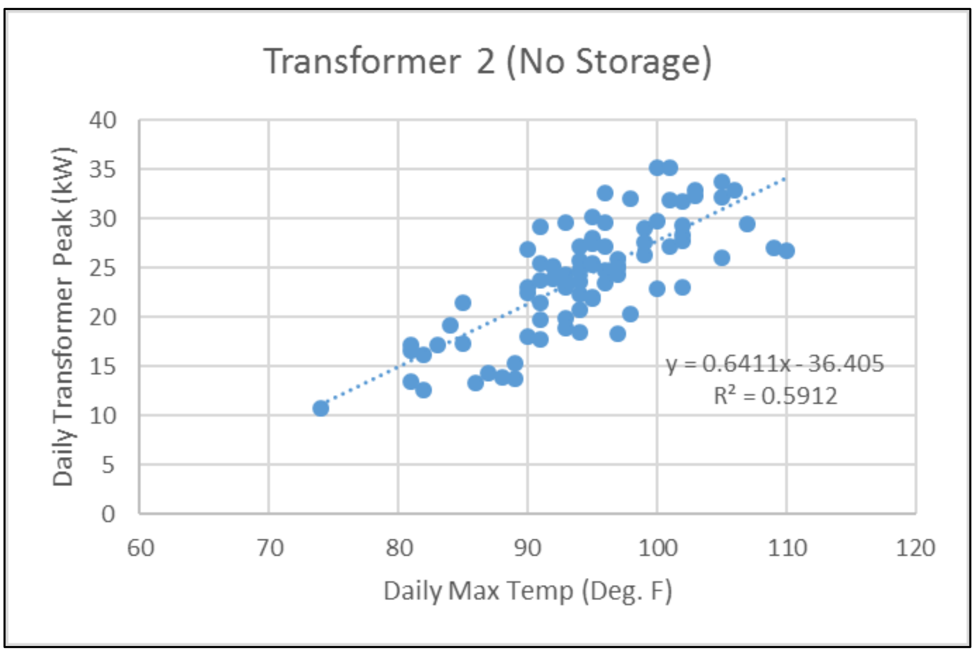


Figure 6-8
Correlation between maximum outdoor air temperature and daily transformer peak (Transformer 2)

Notice that the two graphs show preliminary correlation between outdoor air temperature and daily transformer peaking for both Transformer 1 and Transformer 2. Note that this only details summer months, which have historically been driven by HVAC loads. It will be important to better understand this relationship in other seasons as other electrified loads (water heating, electric vehicles and cooking) could potentially drive transformer peaking.

Premise-Level Data

Additional premise-level data and analysis was completed as part of this project. Premise-level data was used to better understand attribution by home of transformer-level peak energy consumption by day. Summary results at the premise level for 18 of the 20 homes [14] can be found in Appendix B.

Summary

Preliminary transformer analysis shows evening peaking at the transformer level. Summer data analysis at the premise and the transformer level show that variations in customer energy consumption provides a certain level of premise-level peak energy consumption variation, reducing coincident energy usage of electrified loads driven by behavior (water heater, oven, etc.) Further analysis suggested by the project team is the investigation of the correlation between transformer-level peaking and maximum outdoor air temperature during shoulder seasons – where space conditioning is less of a contributor in premise-level energy consumption.

Section 7 details how data collected from this project was used to better understand distribution impacts from both a planning and operations perspective.

[14] Note that Lot 12 and Lot 16 do not have data due to loss of established connection.

7
DISTRIBUTION SYSTEM MODELING AND ANALYSIS

Distribution Planning Overview

The distribution planning process is typically completed on an annual basis. Planning lengths vary between utilities, but the majority plan between 3-10 years out to guarantee ample time for construction of larger facilities. The planning process itself is fine tuned for each utility, but nationwide, most utilities follow the same core steps:

1. Gather field data from Supervisory Control and Data Acquisition (SCADA) systems or other sources.
2. Forecast load growth as granularly as possible (in most cases by substation regions or distribution circuits). Some load growth data sources include customer facilities requests, city or county zoning information, and historical patterns.
3. Compensate load growth for energy efficiency, demand response, and solar PV. The load recorded is from the field, which is the net of any demand side resources. Since the field data are not 100% reliable, some compensating factors are included to compute the expected reliable demand side resources. For example, if the circuit peak is noon during mid-summer, there can be a large portion of the customer-sited solar PV that can be considered reliable during those hours. The unreliable portion is added back to the net load to calculate the total expected planning load.
4. Analyze and compensate for worst-case scenarios (heat waves, winter storms, etc.). This process varies greatly between utilities. Some use historical data from past extremes and establish bounds that planners can use to build resilient systems. Other utilities use regression or other mathematical techniques to compute expected peak load for an extreme year.
5. Plan/size infrastructure as cost-optimally as possible, and ensure load does not exceed equipment ratings. This includes avoiding upgrading shortly after the initial installation. Typically, utility best practices are put into a table with a few input variables, such as number of customers, climate zone, customer type, panel size, etc. These variables help the planner select each element of the distribution circuit.
6. Compensate for contingency scenarios in sizing to allow operators flexibility. Complications arise when planning for contingency scenarios because there is no easy process to follow. The planner must read the circuit diagram and calculate many possible scenarios for circuit switching. Depending on how many neighboring circuits could rely on the primary circuit being planned, there is added capacity in the case of a downed circuit.
7. Ensure proper voltage support and protection settings.

During distribution planning the metric of highest concern is the current, since a conductor's load limits are based on thermal limitations. Overhead lines and cables (underground lines) will deteriorate and eventually fail due to thermal overloading. While voltage is also a concern, the thermal degradation of the system is dependent on current overloads only so planning processes tend to focus on ensuring sufficient ampacity (current capacity) first, and then it is possible to address other concerns.

The fundamental assumption of the distribution planning process is that HVAC systems are the largest loads and therefore temperature drives peak electric load usage. This assumption will be tested by the increased ZNE efficiency's improved thermal envelopes. Better thermal envelopes, which have higher R-values, resist solar heating of buildings. If the solar heating is resisted, then A/C usage should drop as shown in the models. For ZNE, there is also a change with the electrification of gas loads. When gas loads are switched over to electric they tend to be some of the largest loads for residential customers, and therefore cause peaks during usage of hot water and electric heat pumps. As seen in Figure 7-1, for a single residence, switching their gas loads to fully electric results in the following conditions:

- Shift does not only occur seasonally but also to a mid-morning peak, which is driven by morning water usage.
- Peak water usage occurs in spring.
- In summer, the heating load is reduced since the hot water heating system is designed to utilize ambient temperature from the garage.
- In spring, the system will utilize the peak strip heating resistive element inside the unit as opposed to the first lower stage continuous 400-watt heating.

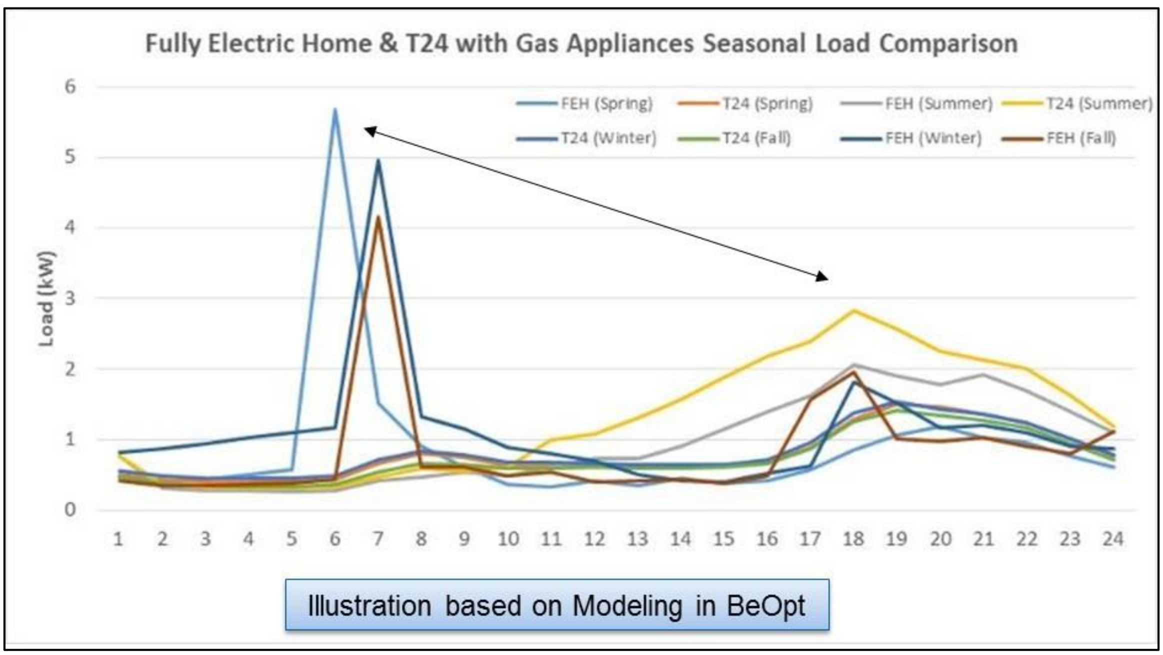


Figure 7-1
Fully electric home and Title 24 seasonal load comparison

This change draws out the weaknesses in using the traditional planning process assumption of a solely HVAC-driven peak for future ZNE communities. Peak concerns should also be inclusive of hot water heating. This is a model-based suggestion for the planning process, but field demonstrations can prove otherwise. There are separate concerns for high concentrations of photovoltaic deployments, which will cause reverse power flow during solar peaking hours.

When new circuits are constructed, each component relies on the utility's standard. Annual planning for most utilities only covers the main line of a circuit and not the single-phase taps (laterals) that connect downstream devices. For ZNE homes, there will need to be a fundamental shift for evaluation of circuits at the lower level componentry.

To fix the deficiency, more extensive research is recommended for larger ZNE communities. The temperature-driven load growth forecasting has worked historically, but since all residences in a load region behaved off the same parameter – ambient temperature – the assumption was effective. In electrified gas appliance homes, the driver for water usage is not ambient temperature, but customer schedules and behaviors. This should be studied further to develop safe and accurate models for distribution planning.

Distribution Modeling and Analysis

Zero-Net-Energy, Title 24, and DER Modeling

To properly evaluate larger communities, the project team began by building accurate behind-the-meter (BTM) load models of both 2013 Title 24 homes with gas heating appliances, as well as more energy efficient homes with electric heating appliances. ZNE is merely a target that aims to achieve zero net energy consumption at the residence level throughout the year. The team achieved ZNE using two methods. The first used higher efficiency, electric heating appliances, and thus smaller PV systems. These were the actual homes built in Fontana and will be referred to as ZNE-EHA (Zero Net Energy electric-heating-appliances). The second used T24 and gas appliances with larger PV systems to account for the decrease in energy efficiency. The T24 models will be referred to as ZNE-T24. There is industry-standard software for creating these models, BeOpt, which outputted 20 models using parameters from the 20 homes with their respective lots/floorplans. Load models are the starting point for a deeper grid analysis. Transformer 1 feeds 11 homes, and Transformer 2 feeds 9 homes. Since the team only had 20 home models in total, but required enough data to analyze up to the distribution circuit (feeder), the team had to extrapolate the home load curves.

The DER models constituted energy efficiency, solar PV, and energy storage. The energy efficiency models were the contrast between Title 24 and a higher efficiency home with electric heating appliances. There were two solar PV sizes applied to the models to achieve ZNE. The T24 homes had on average 6 kW_{AC} PV sites, while the ZNE-EHA homes had on average 4 kW_{AC} PV sites. Solar PV modeling has had an established methodology for some time now. Since the project team was modeling a year and not a short-term few day period in the near future, it used average irradiance over the year instead of specifying specific cloudy days. The irradiance correlated to the performance of the system throughout the year so the summer season had longer daylight hours and higher irradiance than the winter months. Lastly, energy storage was modeled three different ways, as shown in Table 7-1. The system size and efficiencies didn't change, but the control strategy varied.

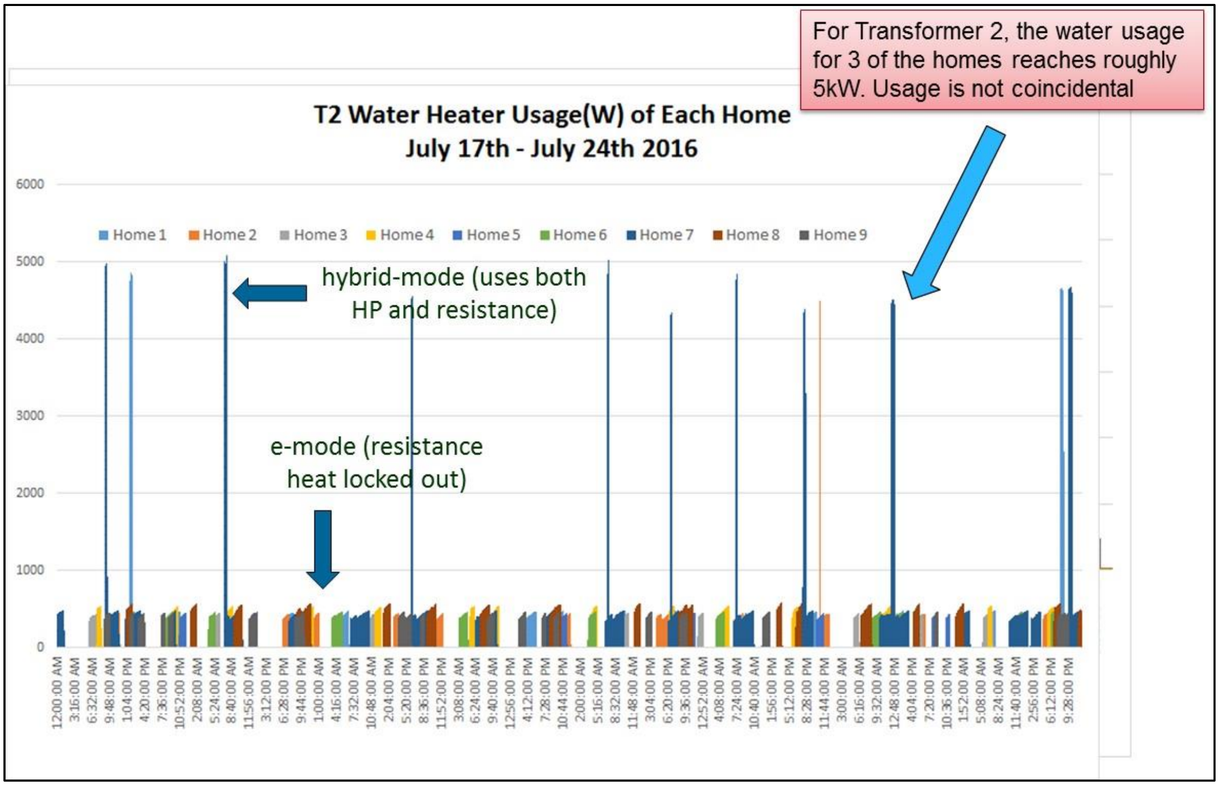
Energy storage (ES) parameters were:

- Capacity: 6.4 kWh
- A/C Power Rating: 5 kW
- Roundtrip Efficiency: 90%
- Depth-of-Discharge: 75%

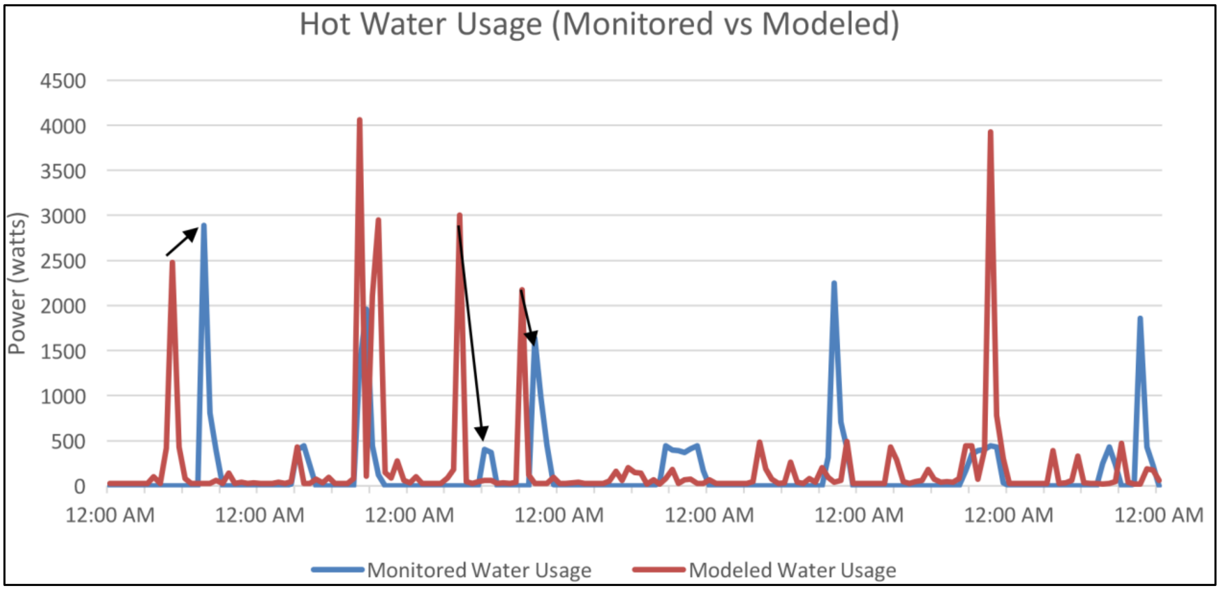
Table 7-1
Energy storage control strategy description

Control Strategy	Description
Self-Consumption	Charges during net export, whenever there is net consumption Maintains 25% state of charge (SOC)
Time-of-Use Peak Reduction	25% SOC maintained overnight Charging begins at 9:00 am and continues until 12:00 pm Discharges at 6:00 pm at constant 2 kW rate
Time-of-Use Rate Optimization	100% SOC maintained overnight Discharges at 12:00 pm at constant rate until 25% SOC Charging begins at 6:30 pm at maximum rate of 4.5 kWh

Individually, most BTM loads, as well as DERs, were accurately modeled in both magnitude and duration. The only load that differed was the hot water heater load. Unfortunately, hot water usage differed in both magnitude and time of day. This is due to the nature of the load being a short duration behavioral-based load. The modeling for the homes assumed that hot water usage would be primarily in the morning, but most usage ended up being in the evening. Figure 7-2 outlines the shift from morning to evening. The models also suffered from an overestimation of the hot water peak demand.



(a)



(b)

Figure 7-2
(a) Measured water usage from ZNE-EHA (electric heating) and (b) monitored vs. modeled hot water usage

The ZNE home models were used to simulate entire distribution circuits of 1000+ homes. While the details of the simulation process are detailed in a later section, even at the individual model level, there is room for improvement. The peak water usage load will end up driving results and concerns for distribution planning if the models are not modified.

Distribution Analysis Methodology

Distribution Planning Zones

In the distribution planning process, there are a multitude of factors to consider for cost-effective and reliable infrastructure. The engineer carefully considers satisfying or balancing cost, time, sizing, electrical compliance (e.g., voltage), reliability, thermal overloading, and protection. To comply with CA Electric Rule 2, the service voltage must be between 1.0 p.u. and 0.95 p.u. for residential customers. This requires voltage regulation devices including capacitors or voltage regulators that can switch/operate on daily cycles to provide voltage support during high load and shut off during low loads. Protection systems are also required in case of short circuit occurrences that can cause fires or wires to melt. This equipment includes fuses, reclosers, and circuit breakers. Electrically, the most important infrastructure that is deployed is the wire or cable itself. There are many different wires with different ratings, but they typically come in four major categories for medium voltage infrastructure: the distribution circuit (feeder), load block, lateral, and transformer. Each serving their own purpose, the distribution planner typically uses a utility-specific “standard” to design each category. The feeder is from the distribution substation bank down to the end customer. The load block is used in emergency situations for circuit sectionalizing and potential load transfers. Protective elements such as fuses and reclosers are often placed at the load block level. The lateral is considered a tap off the main line for a neighborhood. The transformer is to convert the voltage from medium voltage to secondary/low voltage for use within the home. Table 7-2 outlines typical ratings for these four circuit segments.

Table 7-2
Circuit segment and typical rating

Circuit Segment	# Residential Cust. (avg)	Rating* (typical kVA)
Feeder	1200	10,000
Load Block	240	1,500
Lateral	60	375
Transformer	10	50-75

*These ratings are characteristics of the region that was under evaluation and not representative of the range of ratings of California’s 10,000+ distribution circuits.

Figure 7-3 outlines the relationship between a distribution circuit and its components, including load blocks, laterals, transformers, and secondary wires.

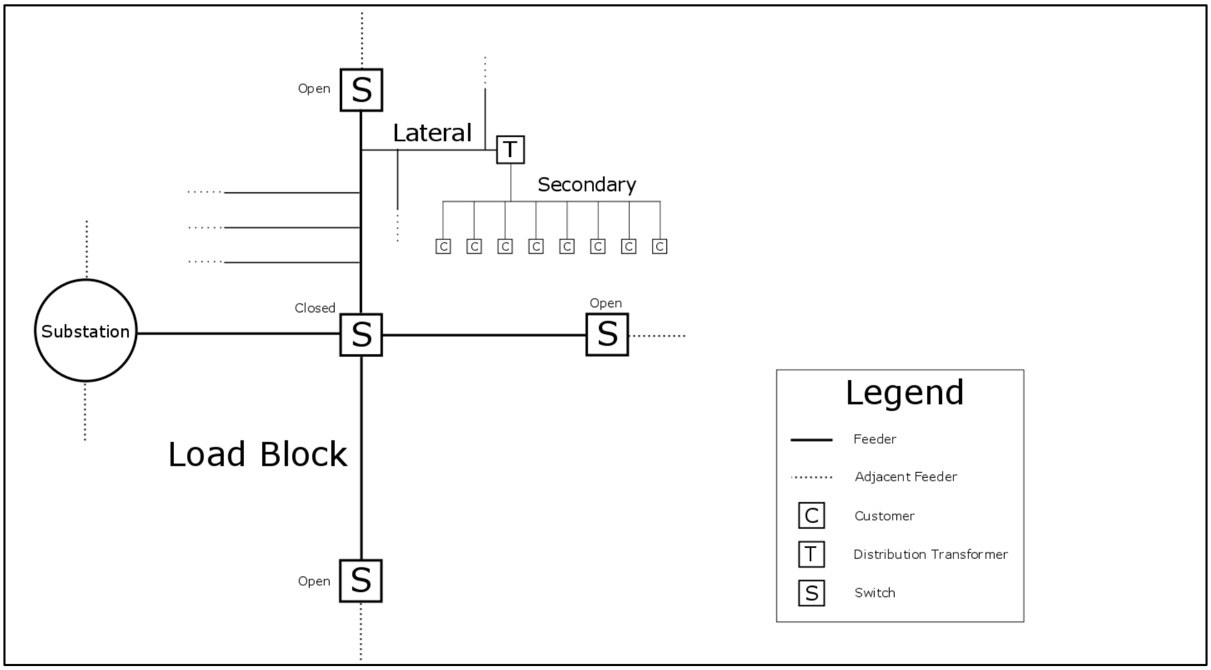


Figure 7-3
Distribution circuit and component diagram

The analysis was done at the four planning levels and only 20 house models were available to construct the larger circuit segments. This required the team to use a creative approach to analyze these larger configurations.

Simulating Large Infrastructure from Small Datasets

Traditionally, residential energy models are not built with a level of granularity that accounts for BTM loads. Traditional models are generated from taking the average performance from an aggregate of hundreds to thousands of homes. The data source is typically a single monitored point (likely the head of the distribution feeder), and the model is comprised of scaling the single load curve down to the size of a residential load. Alternatively, utilities may decide to sample several residential homes and develop a normalized load shape, which is then applied to each residential customer. When using this method, there is no insight into individual customer's behaviors. In the past, this was successful because the peak load concerns had been driven by ambient temperature, which is a relatively uniform parameter for all the customers in the region and is reflected in aggregate load curves. However, for ZNE homes, the load is now driven by temperature and behaviors, which are not necessarily coincidental, therefore peaks might not appear in unison at the feeder head. To capture a wide variety of behaviors for ZNE homes the project team started from individual BTM loads and built 20 independent residential level models. Some of the lots had similar footprints, but the schedules of certain loads (plug loads, heating, cooking, cooling, lighting) were varied. Building 20 individual models allowed the project team to simulate Transformer 1 and Transformer 2.

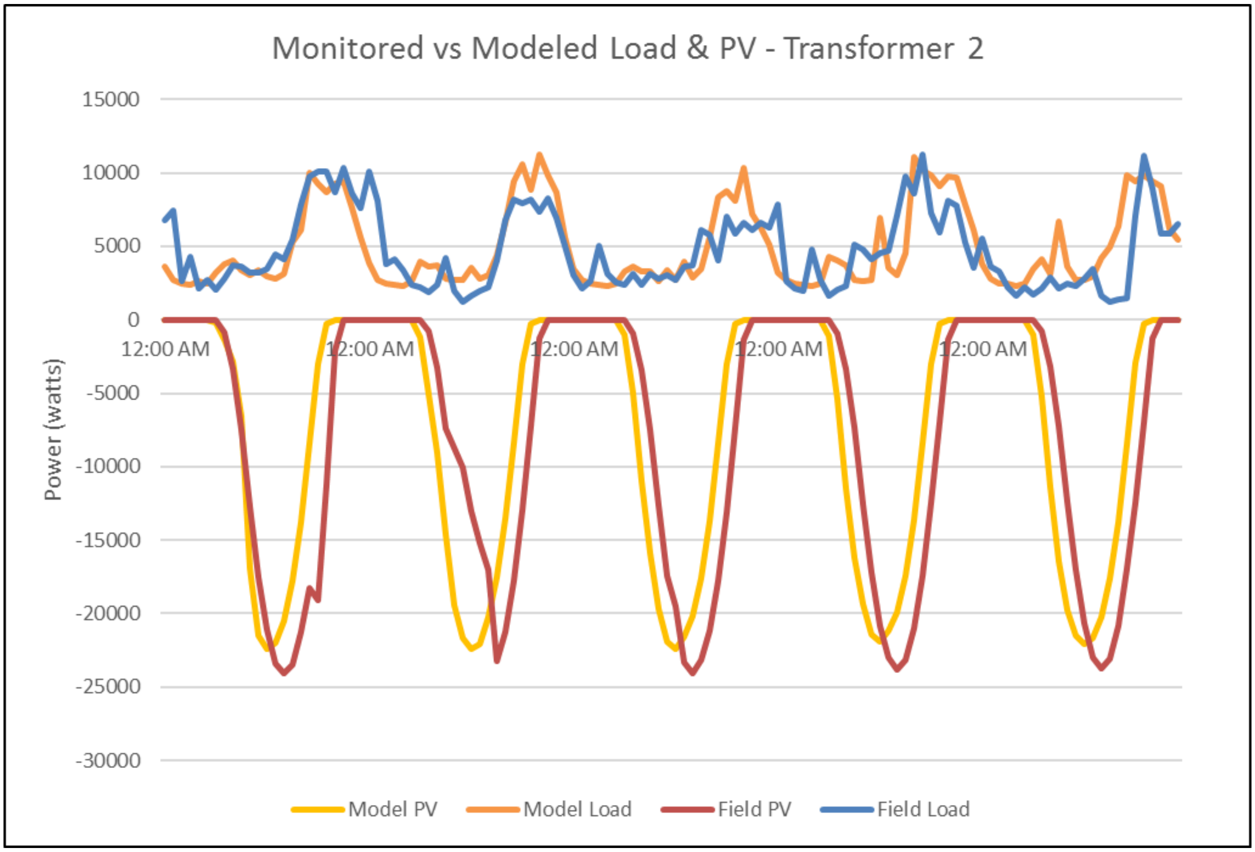


Figure 7-4
Monitored vs. modeled load and solar PV for Transformer 2 (nine homes)

Figure 7-4 compares performance from the modeled data and the monitored data recorded in the demonstration. Note that due to dropped signals, some of the lost monitored data had to be compensated for. A simple multiplicative factor was used for systems that did not report during specific times. While the load performs within an acceptable margin of error when aggregated at the transformer, the solar PV data is misaligned and slightly off magnitude. This is because it is difficult to forecast clouds when modeling solar PV performance, so the industry standard is to average the impact of reduced irradiance due to cloud cover over the entire year. Since this data is from the summer months, the field PV performance is higher than the modeled performance, which is averaged. Also, the modeled data was on hourly time-steps, but synchronized to the 30-minute mark, whereas the actual data was recorded at the minute resolution and synchronized to the 0-minute mark. The hourly resolution also decreases visibility into the impact of loads that are sub-hourly, such as hot water usage.

Figures 7-5 and 7-6 outline two additional issues with the modeling:

1. The minute resolution identifies shorter, sharper peak loads that can cause overloading, which is not observed at the hourly resolution
2. The model data typically uses averaged ambient temperature such as TMY3 (typical meteorological year 3) data as opposed to actual peaks. The July data in Figure 7-5 is from extremely hot days at the Fontana site, whereas the modeled data doesn’t account for extremes.

Figure 7-5
Transformer 2 monitored data (1-minute resolution)

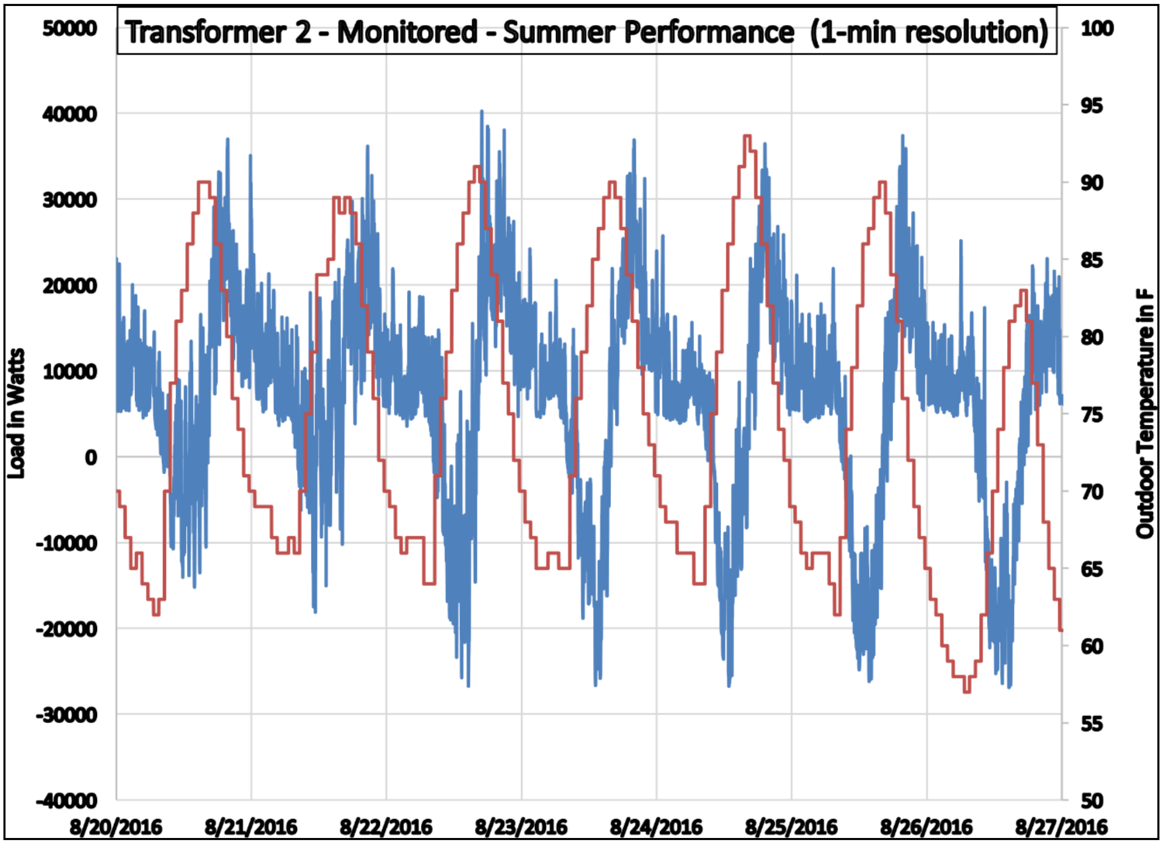


Figure 7-6
Transformer 2 monitored data for summer performance (1-minute resolution)

To evaluate larger subsets of homes, the team needed to produce residential models on the scale of hundreds to thousands. Using BeOpt to produce individual models would be a tedious task requiring months. It is a safe assumption that when simulating larger groupings, there is a decrease in diversity in electric load behaviors as the population increases. As an alternative to BeOpt, the team duplicated the original 20 home models to scale up to larger sets by using a statistical sampling method until a desired quantity was reached. The method batched Transformer 1 homes and Transformer 2 homes so as to not disregard the planning relationship established when the transformers were sized. From each transformer, homes were selected at random until the transformer was loaded equivalent to its original planning specifications. The Median Case is where there is one of each home that is assigned to the transformer, as shown in Table 7-3.

Table 7-3
Transformer 1 simulation example

Lot #	Median Case	Case 1	Case 2	Case X
6	1	0	1	2
7	1	1	2	0
8	1	1	1	1
9	1	0	0	0
10	1	3	0	3
11	1	2	0	0
12	1	0	2	0
13	1	0	2	1
14	1	1	1	2
15	1	1	1	0
16	1	2	1	2
Total	11	11	11	11

The team ran many simulations to ensure the analysis was not driven by a single instance. As the simulations grew in scope from transformer to feeder, there was less variance since the original sample consisted of 20 models, so it was safe to decrease the number of cases run as the scope increased. Table 7-4 outlines the number of cases run per scope:

Table 7-4
Number of simulations per scope

Scope	# Cases	T1 Homes	T2 Homes	Rating (kVA)
Transformer 1	300	11	0	75
Transformer 2	300	0	9	50
Lateral	200	33	27	375
Load Block	50	132	108	1500
Feeder	10	660	540	10000

After running multiple cases to create a distribution of likely scenarios consisting of different customer behaviors, the team selected the worst case, which is referred to as the peak case. The peak case is the result of analyzing many possible configurations and discovering the maximum load throughout the year. This is similar to how a distribution engineer must think about planning. There is a peak when load is coincidental, but the probability of that occurrence lowers since the largest magnitude loads tend to have lower duty cycles. the random selection methodology with enough cases will identify a highly probable peak load. To ensure accuracy of the simulation, the team compared the peak case distribution to the evenly spread or Median Case, where each home was used once per transformer. Figure 7-7 compares the Median to the Peak case for Transformer 1 under the ZNE scenario.

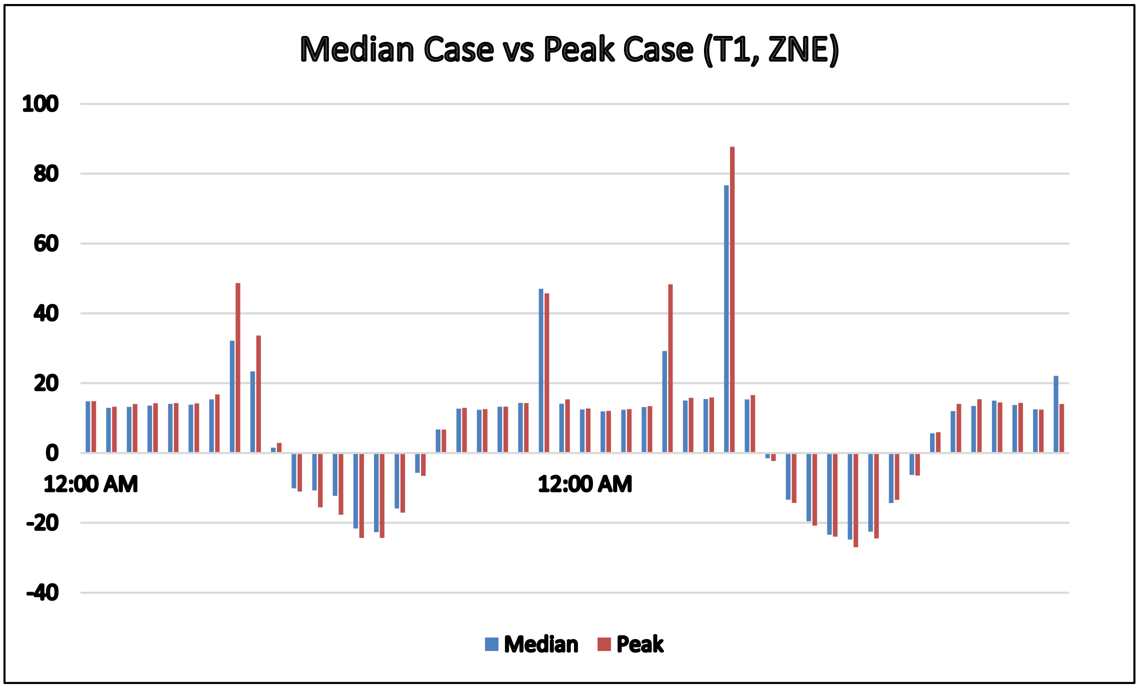


Figure 7-7
Median case vs. peak case for ZNE-EHA – Transformer 1

Results

Distribution Circuit Impacts of Zero-Net-Energy

The rate of transition from Title 24 homes with PV to ZNE-EHA homes has yet to be determined. If building code requirements mandate solar PV installations on all new homes, distribution infrastructure planning might need to consider the following:

- The upgrade of distribution relays to handle bi-directional current
- Better coordination and visibility of customer owned DER assets

The legend in Figure 7-8 will be used for diagrams regarding peak loading (Figures 7-9, 7-13, 7-14 and 7-15).

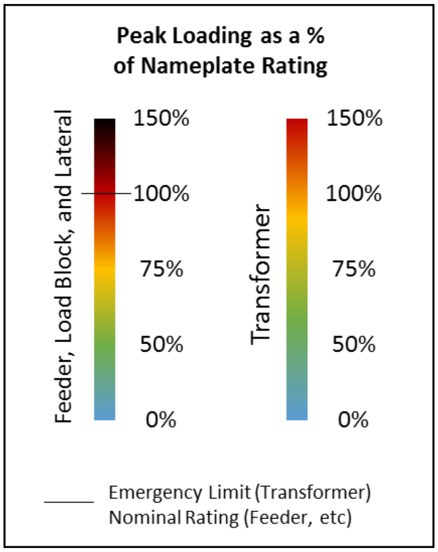


Figure 7-8
Legend for Figure 7-9, Figure 7-13, Figure 7-14 and Figure 7-15

The transition to ZNE-EHA and its impact to the electric distribution system is summarized in Figure 7-9 and Table 7-5.

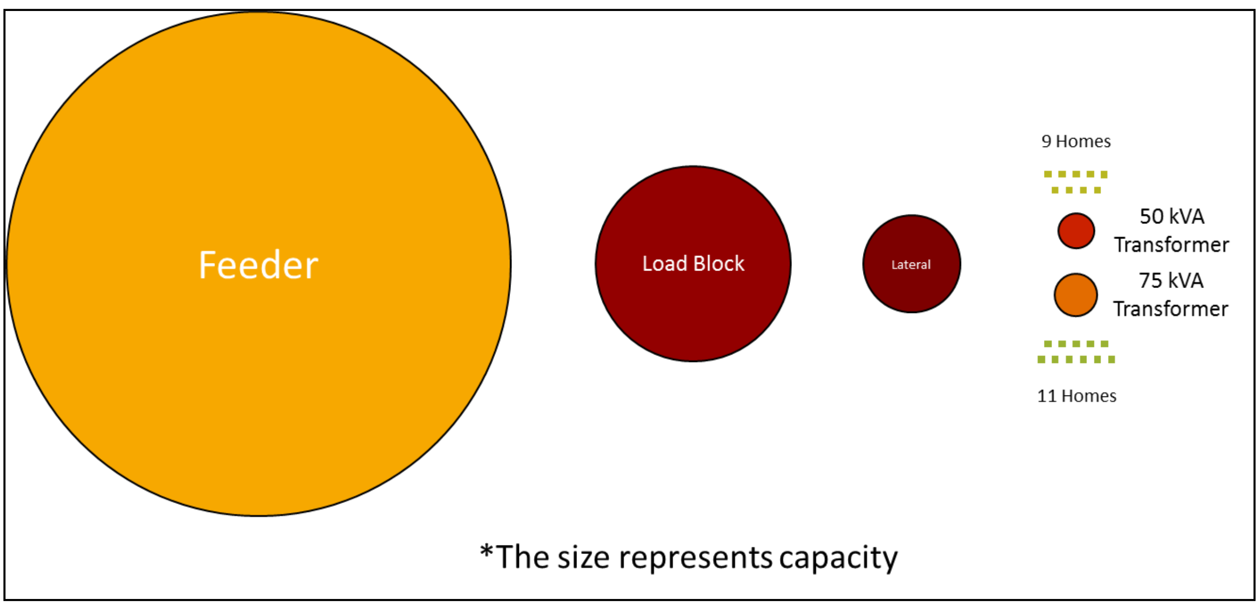


Figure 7-9
Peak Loading ZNE-EHA with no energy storage

Table 7-5
Table of peak loading ZNE-EHA with no energy storage

	T1	T2	Lateral	Load Block	Feeder
Peak kW	87.7	70.0	433	1652	7865
Rating	75	50	375	1500	10000
% of Nameplate	117%	140%	116%	110%	79%

Figure 7-9 and Table 7-5 shows that ZNE could push the limits of the electrical distribution system because of the electrification of heating. Since hot water usage is driving these peaks, further analysis should be done to improve the models. Also, customers tend to use the new electrified heating loads during the same periods, which occur in the morning due to hot water heaters, or in the evening between 5:00 – 7:00 pm. Customer peak usage also tends to be in the spring and winter, as opposed to traditionally summer-driven peaks in warm climate zones. It is important to monitor the usage and customer behavior from a larger dataset. Also, the models will need to be updated.

The load blocks are the portions of the distribution circuit that are rolled over in the case of emergencies and usually carry a 1.5 MVA rating. Design standards should be reviewed to accommodate for the expected overload in the transition from T24 to ZNE-EHA. An increase in PV does not mitigate the overload because PV is non-coincident with load.

The laterals are typically single-phase taps off the main line, and are designed with a 375 kVA rating. Design standards will need to be analyzed for laterals as they are expected to be overloaded by 16% with the transition to ZNE.

Transformers are a vital component to electrical grid design as they allow the safe transformation from a high voltage to lower, usable voltages. Transformers are built to be overloaded for medium durations. They fare better when not overloaded but can maintain a 150% overload. In the transition to ZNE-EHA there are instances where load crosses 100% of the rating of the transformers. The immediate transition to ZNE nears the emergency rating of the transformer, but will suffice for the short term.

Many parties are interested in the performance of energy storage systems to mitigate the negative impacts from ZNE-EHA. There is an important question to answer before deploying energy storage: how should the system operate? Should energy storage systems be called only during emergencies or used only in backup applications? The team tested three popular control schemes as defined previously. The first was “self-consumption,” designed to mitigate backflow of PV systems and discharge in the evening hours. Self-consumption at the transformer level partially prevents solar PV back feed and limits the peak load, but for this demonstration, the systems were undersized. Figure 7-10 outlines a typical 24-hour period at the transformer level.

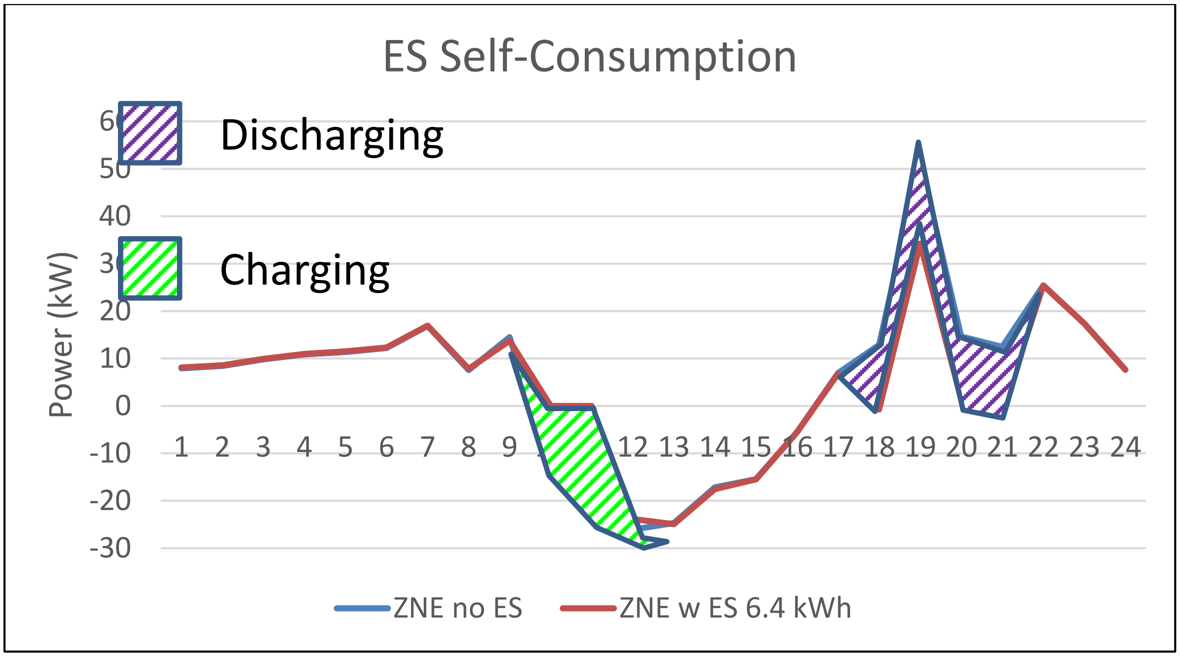


Figure 7-10
ES self-consumption operation at transformer

The second control scheme was a time-based mechanism that aimed at reducing peak. All systems would operate in unison between 9:00 am – 12:00 pm and 6:00 pm – until 25% state of charge. The control system is called TOU Peak Reduction. It operates as shown in Figure 7-11.

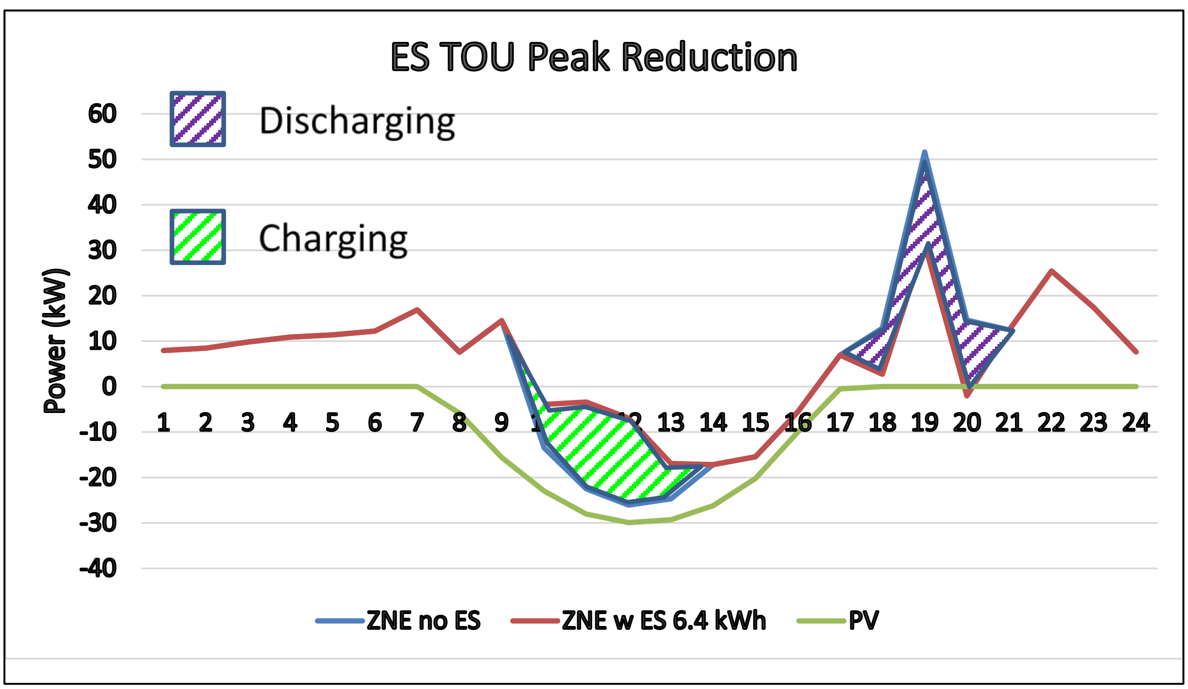


Figure 7-11
ES TOU peak reduction operation at transformer

The final control scheme is called TOU Tariff Optimization and is likely to be the most popular today in California as it is the only one that provides bill savings to the customer. Its basic premise is to charge during periods of low energy charges and discharge during periods of high energy charges. It maintains a high SOC to guarantee backup availability for the customer, and therefore tries to recharge quickly after its energy has been depleted. The parameters are for it to discharge from noon to 6:00 pm and charge at the highest rate at 6:30 pm. This simultaneous charge signal for all energy storage systems causes a spike, as shown in Figure 7-12.

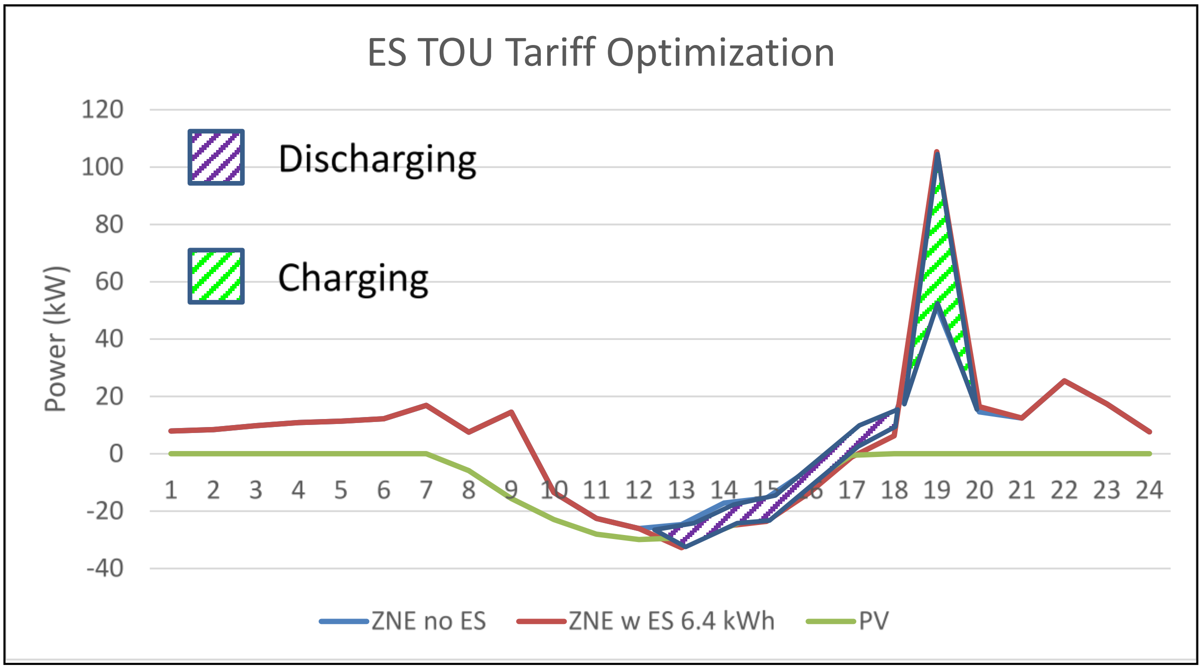


Figure 7-12
ES TOU tariff optimization operation at transformer

These three control schemes comprise most customer-sited energy storage deployments today, but it is expected that more advanced systems that are dependent on pricing or grid power quality signals are possible in the near future. As ES concentrations rise, it will be possible to test the societal benefit of such systems in the applications of acting as spinning reserves, power quality support, and tariff optimization simultaneously. As for the impact of energy storage in mitigating the transition to ZNE-EHA, the self-consumption control scheme's performance is outlined in Figure 7-13 and Table 7-6. TOU peak reduction control scheme performance is detailed in Figure 7-14 and Table 7-7. TOU Tariff Optimization control scheme performance is detailed in Figure 7-15 and Table 7-8.

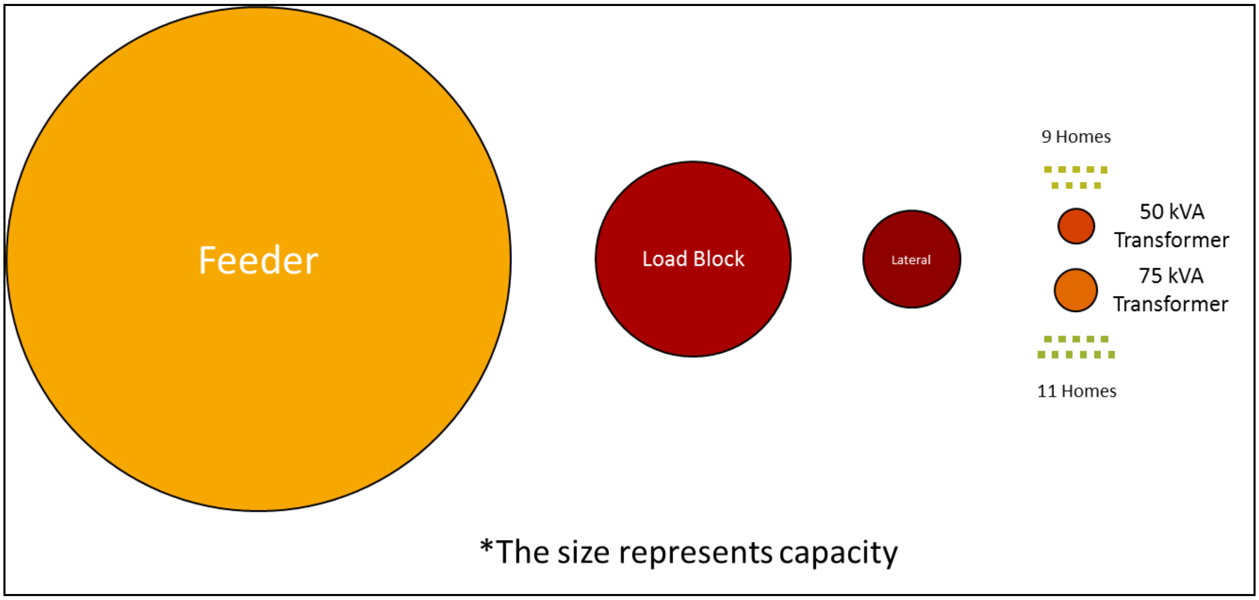


Figure 7-13
Peak loading of ZNE-EHA with energy storage self-consumption

Table 7-6
Table of peak loading of ZNE-EHA with energy storage self-consumption

	T1	T2	Lateral	Load Block	Feeder
Peak kW	85.6	63.3	408	1591	7809
Rating	75	50	375	1500	10000
% of Nameplate	114%	127%	109%	106%	78%

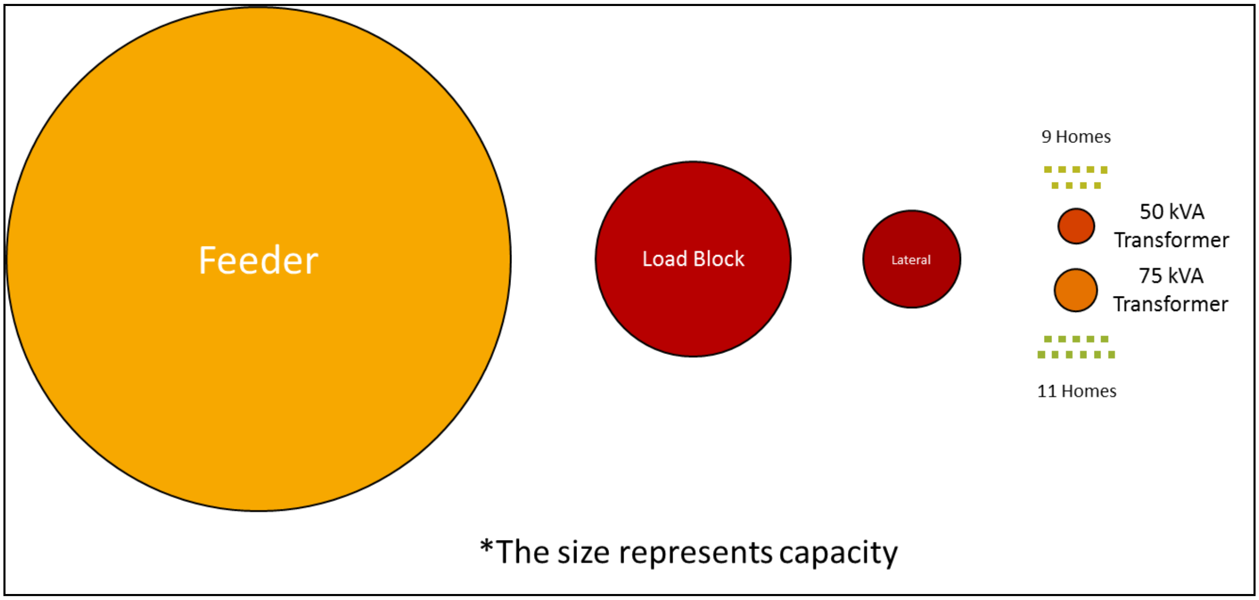


Figure 7-14
Peak loading of ZNE-EHA with ES TOU peak reduction

Table 7-7
Table of peak loading of ZNE-EHA with ES TOU peak reduction

	T1	T2	Lateral	Load Block	Feeder
Peak kW	87.7	63.3	388	1520	7739
Rating	75	50	375	1500	10000
% of Nameplate	117%	127%	104%	101%	77%

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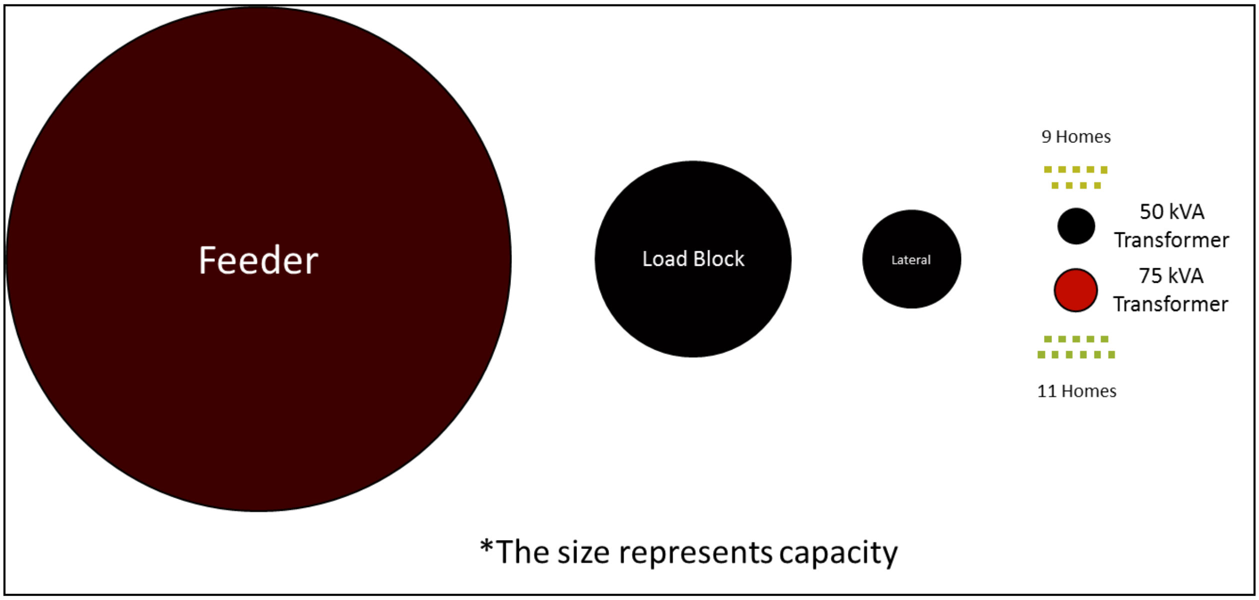

Figure 7-15
Peak Loading of ZNE-EHA with ES TOU Tariff Optimization

Table 7-8
Table of Peak Loading of ZNE-EHA with ES TOU Tariff Optimization

	T1	T2	Lateral	Load Block	Feeder
Peak kW	110	114	727	2826	13735
Rating	75	50	375	1500	10000
% of Nameplate	147%	228%	194%	188%	137%

There is a small reduction in peak load observed at all levels for ES self-consumption. However, the impact is not large enough to bypass distribution circuit upgrades. The energy storage devices would need to be larger. ES deployments at the customer level can contribute to peak reduction, even if the customer-level objective does not align with the feeder-level objective (e.g., self-consumption). The ES just needs to operate within the right hours of the year.

For ES TOU peak reduction, grid level ES deployments that only have to operate a few hours per year are beneficial for the deployed quantity of PV. If ES gets deployed, then customers can be encouraged to install larger PV systems if desired. Even at small deployments, if ES is coordinated under ES TOU peak reduction it can reduce peak load at the load block by 9% of rating.

The ES TOU tariff optimization control scheme can be detrimental if there is a large quantity of customers that are operating under those parameters, which are the most economical today. The load can increase on the feeder to 137% up from the 79% observed with no ES. This is currently the most economical control scheme analyzed under this project.

How Does ES Mitigate Negative Impact?

ES greatly reduces variability, but does not necessarily reduce peak as seen in the three given control system scenarios (Figure 7-16). ES self-consumption greatly reduced variance by 31% compared to ZNE without ES throughout the year. There are outliers that still cause the ES self-consumption feeder to reach the same peak as ZNE without ES. When sizing systems for ES self-consumption, the ES size should correlate to the PV size. In this case, the ES needs to be approximately doubled.

The TOU Peak Reduction control scheme is the most effective in mitigating grid impacts. The ES systems should be sized larger to bring peak load levels down to below nominal ratings. This control scheme is as effective as self-consumption in preventing backflow, at least for small deployments.

The ES TOU Tariff Optimization control scheme can cause great detriment to the grid if customers are incentivized to shift their loads. This scheme's secondary purpose is also backup power, so the requirement to charge quickly to achieve a 100% state of charge is the root cause of the major grid impact. This worsens impact by high rate charging at 6:30 pm during residential peak load.

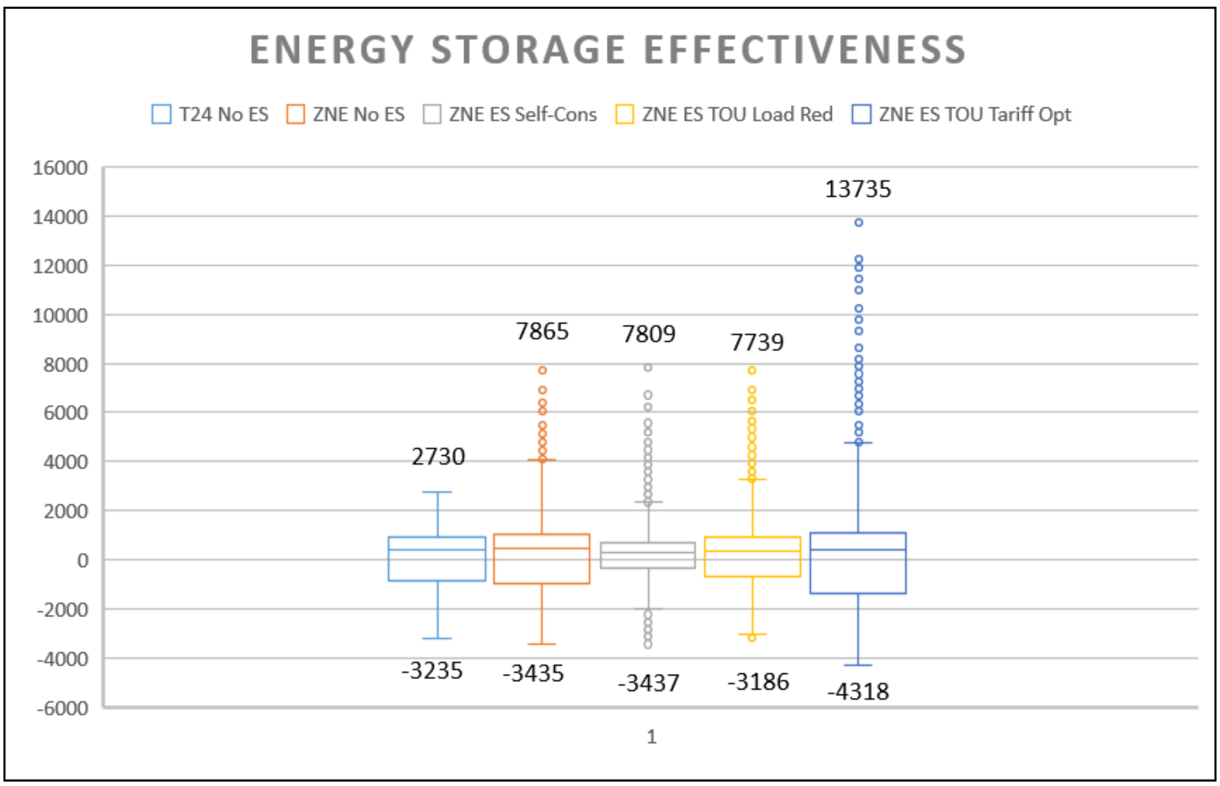

Figure 7-16
Effectiveness of energy storage

Recommendations

To better plan for ZNE communities, the following are recommendations for utilities:

1. Analyze local load profiles and change distribution standards to accommodate for additional capacity at all levels of the grid.
2. Promote grid-beneficial control schemes for energy storage devices via tariffs or programs.
3. Assist customers in sizing correct systems to mitigate grid impact.
4. ES is very sensitive to controls as well as sizing. Be wary of the relationship when designing programs or providing assistance in sizing.
5. Utilities should promote a TOU tariff that is regional and not utility-wide as ES may turn on simultaneously and cause grid issues.
6. ES must have grid awareness to contribute (must be coordinated by the utility) to guarantee net reduction.

Load Control

When analyzing ZNE-EHA homes, there are two dominant BTM loads that drive peak usage: air conditioning and water heater usage. Load control of these two devices would provide mitigation during unexpected peaks, which now can occur during three seasons of the year. It is suggested that the demonstration project look at market-ready A/C and water heating control solutions.

Suggested Further Research

The driving factor of the analysis was the load models. While they were useful for understanding higher penetrations of ZNE, the models were lacking in accuracy. This can be improved by increasing resolution, improving modeling of hot water loads, and using actual weather data as opposed to averaged data. While this demonstration project provided insight into entire transformers being fed by ZNE, there is more opportunity to learn about the emerging technologies. Coupling ZNE, solar PV, energy storage, and electric vehicles would introduce a new dynamic to distribution planning concerns. The electric vehicles would increase the load by anywhere from 10-20 kWh per day per vehicle, further stressing the grid and pushing its limitations. Larger residential- or community-owned energy storage systems offer added understanding of DER mitigation of increased loads. Energy storage devices can also be programmed under new or innovative control schemes that can react more quickly to grid concerns. Including commercial customers is also necessary, as most feeders are not homogenous with only residential or only commercial customers. Lastly, a larger community deployment of 60-100 homes would further validate models of laterals.

8
GUIDELINES FOR DEVELOPING FUTURE GRID INTEGRATED ZERO NET ENERGY COMMUNITIES

The California Solar Initiative funded this project to analyze the impacts of communities of ZNE homes on the distribution grid, and to evaluate whether and/or to what extent energy storage can mitigate problems that ZNE homes produce when connected to the grid. A focus of the project is on grid impacts of high penetration solar and methods to mitigate those impacts, including storage and responsive loads. When developing the guideline, one of the items that kept coming up was the important consideration that the electric distribution grid is designed as a 50-year asset and built around providing a very highly reliable power supply. This section is divided into two main sub-sections:

1. The first sub-section is guidelines for grid integration and distribution planning for ZNE communities in keeping with the program focus. This sub-section also addresses implications of future ZNE community energy use standards and evolution of Net Energy Metering.
2. The second sub-section is guidelines for the development of ZNE communities, including guidelines for all the key stakeholders, including developers, architects, energy planners, city jurisdictions, builders and consumers. The guidelines include a step-by-step process beginning at initial community planning, all the way to home occupancy.

The end of the section has a summary of the key guidelines from both sub-sections.

Guidelines for Grid Integration and Distribution Planning

Frequently the telecom analogy is used to compare the integration issue with the transition from landline to cellular infrastructure. However, as of today, customers have not shown the same level of tolerance to a loss in reliability of electric power as they have towards the lower reliability of cellular networks compared to hardwired landlines. Keeping that in mind, distribution planning should consider two different aspects – planning of the distribution system and operations of the system once communities are developed and occupied. Currently, they are very different considerations, and planning within utilities is a very conservative exercise, especially for distribution planning.

A distribution network such as the one shown in Figure 8-1 has multiple points where planners must ensure reliability for extended lifetimes. The impacts on the various elements of the distribution network such as secondary wires, transformers, laterals, switches (load blocks), feeders and substations could be different. The backfeed from PV mainly impacts protection mechanisms at the switches and substations as well as secondary wire size, while the load variability, system peaks and EV penetration will impact all elements of the distribution system.

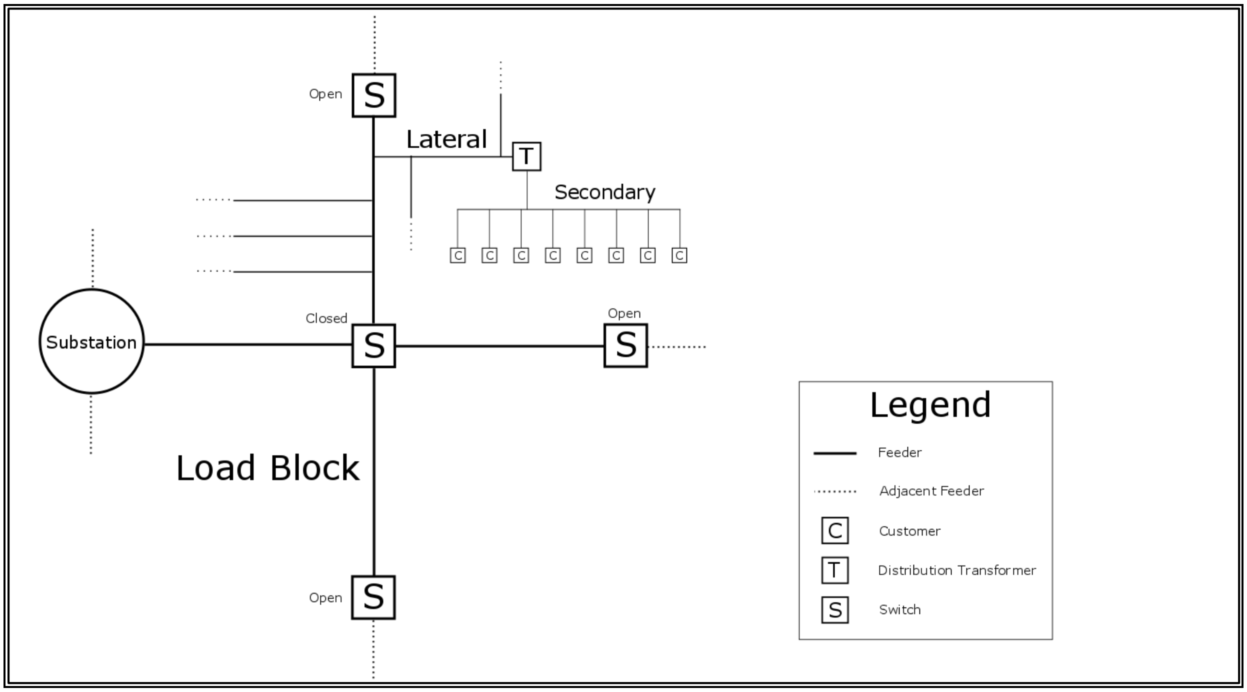

Figure 8-1
Example distribution network

These elements include:

1. **Customer connection/panel/interconnect**: At this point, the distribution system must ensure voltage and frequency stability. The panels and the interconnections must be designed for two-way flows and high draws in both directions. In this project, the possibility of providing backup power using storage required special considerations in the planning process for unintentional backflow, a safety consideration in the event the BEMS malfunctions.

2. **Secondary Wires**: The secondary wire is normally designed for one-way power flow. However, in ZNE communities the design requires two-way power flows with peak flows in both directions. Both heavy loads and high backfeed into the grid can cause reliability issues. In a normal operation, there is a slight voltage decay from the transformer to the last home on the secondary wire. However, in a high PV penetration scenario, if all the homes are coincidentally feeding excess energy back into the grid, the reverse occurs and the voltage is highest at the last home on the secondary wire. In addition, if energy storage feeds power to the grid coincident with solar peaks, it could further accentuate voltage issues at customers' homes. To account for all eventualities, it is recommended that wire sizes be increased based on voltage rise calculations to account for coincident backfeed from solar and storage.

3. **Transformers**: Community transformers, from a utility perspective, are considered to be the edge of the grid. Traditionally, they have not been instrumented or monitored, but are oversized to ensure long-term reliability. Transformers can trip on overcurrent or overvoltage. In worst cases, these community transformers explode when they are heavily overloaded for long periods of time. However, they are not sensitive to the direction of power flow. Typical transformer sizing accounts for at least 50% of overload for two to four hours

and 25% overload for longer periods of time. In this case, the electrification of heating loads adds up to 10 kW of connected load per home[15]. The transformer impact will be based on coincidence of operation between heat pumps and heat pump water heaters in the various seasons. In addition, data from the homes in this project in the summer show that coincident loads can increase due to increased electrification of end-use loads. Electrification of loads such as electric vehicles, clothes dryers and cooking ranges were identified in some of the homes in this project. It can be safely predicted that the increased electrification of loads due to factors such as customer choice and other environmental policies could potentially lead to larger coincident peaks at the premise level. The data from the summer operation indicate that the diversity of loads in the ZNE homes are enabling the transformers to stay below their rating comfortably, both with and without energy storage. However, models of winter operation indicated that there is a possibility of hitting maximum loads on the transformers in the evenings and mornings, primarily due to coincident use of electric heating and water heating. The industry should prepare for the possibility of adding electric vehicles with Level 2 charging[16] at homes. It is very foreseeable that EV charging could add another ~5 kW between 6:00 and 10:00 pm, which coincides with load peaks. Given the uncertainty with electric vehicles and their adoption, it is recommended that the number of homes per transformer be reduced by 50% to account for the uncertainty with electrification of loads and electric vehicle adoption.

4. **Laterals**: Laterals are secondary wires designed to connect transformers to the load blocks. The lateral wires are not normally oversized. Uncertainty in load would increase planning requirements for laterals. Based on the normal size and design strategy of laterals, a utility would be able to plan, design and implement laterals specific to a new home community. Based on observed data, it appears that the PV generation would be limited enough that it would not create a problem for laterals. However, electrification of end loads combined with electric vehicles could significantly increase power draw through the laterals. On the other hand, if ZNE is attained with gas heating loads, then there will be significant over generation in the winter and spring during the day, and in the worst case, over generation will not be different from the electrified heating loads case. The net load shape impact will be reduced peaks in both summer and winter by eliminating the heat pump water heater load. The electric load case is the worst-case scenario for the laterals serve multiple communities.

   Load Blocks: Upstream of the laterals are the load blocks where the protection circuits are located. Load blocks contain relays and are not typically designed for two-way power flow. Load blocks also contain hundreds of homes, so the load diversity shown in this project potentially overcomes the issue of backflow during midday hours. It might also be possible to replace the load blocks or install new protection equipment when permitting ZNE communities. When the load block level with more diversity is reached, it now becomes more an issue of distribution operations. With the current penetration of ZNE homes and communities, it might not be significant enough to impact the laterals.

   From a 20-year planning perspective, electrification of end loads and EV penetration together could require resizing of the load block protection relays. It could also be impacted by the

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[15] 10kW heating loads determined from monitoring homes as part of this project at the circuit-breaker level. See Section 4, Section 6 and Section 7 for additional details.

[16] Currently, level 2 charging stations typically max at 6.6kW.

future definitions of ZNE. If the definition moves to Electric ZNE, this could mitigate impact at the load block level. However, if the definition is based on site or source energy, it could increase the backflow to the grid, resulting in having to replace and upgrade protection mechanisms.

5. **Feeders and Substations**: Feeders and substations typically service a mix of homes, commercial buildings and industrial facilities. When a ZNE community is added to a feeder, the issue is less about planning the feeder and more about managing operations on the feeder. Today, utilities are already addressing issues such as hosting capacity with feeders through better mapping and adding more distributed sensing and distribution automation. In addition, to account for the load changes from solar, EVs and other DERs, these utilities are conducting targeted Integrated Distributed Energy Resources (IDER) programs, such as in SCE's Preferred Resources Pilot (PRP) area to reduce load, add storage and increase feeder capacity. One or a few ZNE communities can be accommodated within the current IDER planning process. However, it is important that the results from this research be directly incorporated into IDER planning groups within the utilities, so they can properly account for the net load changes from ZNE communities in their planning horizons.

Influence of ZNE Definitions

As the research team developed the distribution analysis, it was apparent that two factors could have a substantial impact on the distribution infrastructure: (1) the definition of Zero Net Energy and (2) the Net Energy Metering (NEM) rules. In addition to the evolution of California Title 24 codes from 2013 to 2016, there is also ongoing development of the 2019 ZNE codes. A brief description of each scenario is provided below:

1. **ZNE definition to 2016**: TDV = 0 and the 2016 code increases the value for PV. Initial analysis shows a reduction in PV sizing (~10%) compared to 2013. Getting to TDV = 0 would then result in over generation unless the space heating and one additional appliance were electrified. This would require upgrading distribution planning to increase assets.
2. **2019 Electric ZNE definition**: A proposal by the CEC in November 2016 changed the definition to just displacing electric usage with PV. This was in response to new 2019 TDV values where the highest scaling factors were displaced to late evening, substantially reducing the value of PV and doubling the PV size needed to reach ZNE. If this proposal stands, the least-cost method for builders to attain code (which would no longer attain ZNE) would be to move as much of the end-use load to gas as possible. The result would be that current planning practices would not be impacted, as both the over generation and the peak loads would be reduced because of reduced PV sizing and heating loads switching back to gas.
3. **National Source ZNE definition**: The source ZNE definition would increase the size of PV required for ZNE by about 40% from 2016 Title 24 levels. This would have the opposite effect of the proposed 2019 CEC definition and increase both over generation and evening ramps. If this definition is adopted, initial data does not show overloading at the transformer level, but it will substantially increase the loading at the lateral and load block levels.

Table 8-1 provides some example distribution planning guidelines for ZNE communities.

Table 8-1
Example distribution planning guidelines for ZNE communities under three ZNE scenarios

Distribution Element	2016 TDV ZNE	2019 Electric ZNE	CA Source ZNE
Secondary	Size wiring assuming increase in PV size from 3.7 kW to 4.5 kW/home.	Keep current planning practice of 3.7 kW/home for wire sizing.	Increase wire size by at least 50% to account for increase in PV size from 3.7 kW to 5.5 kW/home.
Transformer	Reduce number of homes per transformer by 25%.	Maintain current transformer sizing guidelines.	Halve the number of homes per transformer.
Lateral (primary)	Increase size of lateral wires to accommodate electrified end loads and EV. Increase sizing to accommodate 25% greater backfeed. Set up lateral drops to maintain balancing of phases.	Maintain current practices, plan for EV adoption.	On load side, plan for coincident electrified load operation with EVs. Increase sizing by 50% for higher PV penetration.
Load Block	Ensure that protection relays are sized for overcurrent situations with electrification plus EVs.	Maintain current practice, along with the already planned EV management.	Ensure that protection relays are sized for overcurrent situations with electrification plus EVs. Plan for 50% increase in solar PV levels.
Feeders	Plan for phase balancing. Likely that electrification could increase phase distortion. Current capacity planning could suffice as high ZNE penetration at feeder level could take time.	Plan for phase balancing. Current capacity planning could suffice. ZNE communities could increase capacity for feeders if there is sufficient building diversity.	The penetration of ZNE might not impact today, but plan for faster impact (15 years instead of 30) and increase capacity. Plan for greater phase balancing problems, add capacitors.
Substations	Plan for load reduction at most times with peaks shifting to late evenings in summer.	Current planning activities for IDER possibly sufficient.	Increase solar penetration level in IDER planning.

It is important to note that the solution most amenable to the distribution grid today is also the least likely to lead to decarbonization of California's energy system, which is the main driver behind the ZNE goals. Given these competing priorities, and the current lack of clarity in the next few years, it is suggested that the industry consider longer-term objectives, which will likely have decarbonization as a central goal. Using this assumption leads to preparing the distribution grid for deeper valleys and sharper peaks by increasing asset density.

Guidelines on the Distribution System Operations for ZNE communities

These guidelines assume that planning recommendations are implemented and will ensure stability all the way to the lateral level, without need for additional controls capabilities at the end of the line. One encompassing recommendation is that new Distributed Energy Resource Management Systems (DERMS) and distribution automation software connect and measure performance of load block protection systems, feeder voltage and phases, and substation performance. Large-scale ZNE and other deep efficiency communities typically associated with high penetrations of DER developments should be prioritized for DERMS connectivity as they will likely have periods of both high over generation and high load draws. It is also recommended that any DERMS develop connectivity to end-use loads and energy storage, which are typically only aggregated for. Table 8-2 shows how load block, feeders, and substations would need to be configured under each ZNE scenario based on the different definitions.

Table 8-2
Changes required to load block, feeders and substations under three ZNE scenarios

Distribution Element	2016 TDV ZNE	2019 Electric ZNE	CA Source ZNE
Load Block	Add distribution automation to measure backfeed at protection.	Add distribution automation to measure backfeed at protection.	Control loads and storage to avoid backfeed through protection mechanism.
Feeder	Connect feeder measurements to capacitors, loads and storage through DERMS. Control loads storage and capacitors to manage phase, voltage, and frequency.	Add additional capacitors to feeders to ensure backfeed (which might be minimal due to lower PV size) can be managed.	Connect feeder measurements to capacitors, loads and storage through DERMS. Control loads storage and capacitors to manage phase, voltage and frequency.
Substations	Expected excursions will be limited. Connect DERMS to capacitors on feeders and energy storage located behind or in front of the meter.	Expected excursions will be limited. Connect DERMS to capacitors on feeders and energy storage located behind or in front of the meter.	Expected excursions will be limited. Connect DERMS to capacitors on feeders and energy storage located behind or in front of the meter.

Another important area for evolution is active distribution planning based on monitored end-use load shapes, evolving from traditional planning practice which is based on connected load. As can be seen from the load data collected from these homes, the load factors are very low, and the peak loads are high and for a very small period. See Figure 4-1. An 8760 hourly load analysis approach, which is being researched by utilities, can possibly reduce the distribution asset size compared to just using connected loads.

Role of Community Solar and Storage

As the discussions around the size of PV and location of storage and their impacts to the grid continue, community scale solar and storage could be very effective in both addressing cost issues as well as grid impacts. For example, one of the newer communities that the research team is exploring for ZNE feasibility in Southern California was platted for solar orientation. A schematic of this community is shown in Figure 8-2.

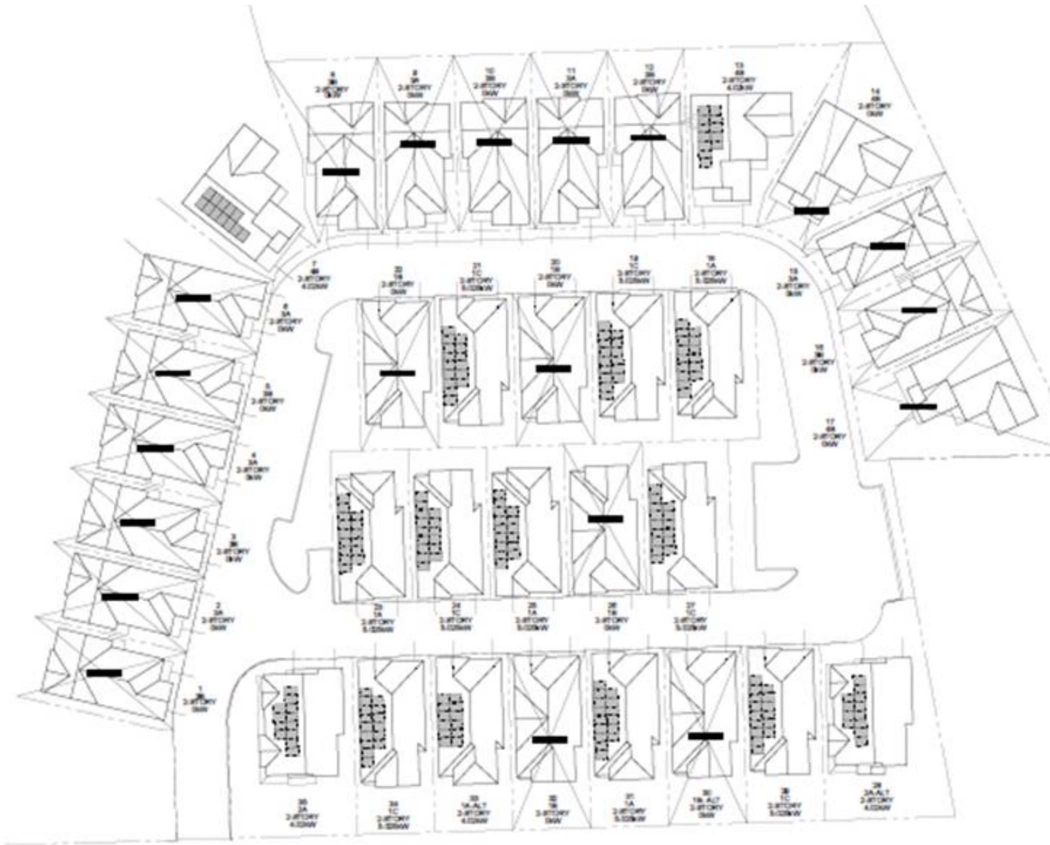


Figure 8-2
Community platted for solar orientation

Figure 8-2 shows that only half the homes are capable of meeting ZNE with the given roof configurations. This is because there is no requirement for rooflines to be solar ready (it is a tradeable option in Title 24), and because many cities and jurisdictions are primarily concerned with home aesthetics. This desire leads to rooflines that cut up roofs and reduce solar potential, limiting the potential to achieve ZNE for all the homes in a community like the one shown in Figure 8-2.

Given these constraints, community solar has the following advantages:

- Avoids cost of solar being assumed by homeowners and builders.
- Provides choice of location and home plans and elevations to homeowners.
- Maintains architectural and visual appeal of communities.
- Moves solar further upstream on the distribution grid and avoids problems at the secondary, transformer and lateral levels.
- Provides utilities with a tool to manage the distribution grid through smart inverters.

- Locating energy storage at the community level would substantially improve grid integration capability as the value of energy storage is insufficient on the customer side of the meter to create enough storage for grid management.
- Reduces storage size requirements through aggregation of load diversity.

Management and planning of the distribution grid would become easier for utilities with community solar and storage. The impact of high PV penetration could be better managed at the community scale and not impact downstream elements, while the transformers and secondaries could be designed for managing load as they have traditionally been designed to.

Although community solar is a potential option, there still remain challenges that include availability of land and the question of who pays for and owns the systems. In many states, utilities plan and own community storage, which enables them to better integrate these systems with the distribution grid. It also enables them to provide financial benefits to homeowners directly on their bill. Another model is to create a Homeowners Association (HOA) that will own the land, solar and storage, and distribute the benefits to the homeowners. A third model is where the solar and storage are third-party owned and operated, such as by solar providers. In California, the payment rates for community solar are less than for Net Energy Metering, which dissuades third-party providers from owning and operating these assets.

As part of the results and lessons learned, stakeholders, including the CEC’s Energy Efficiency Division and New Solar Homes Partnership’s Renewable Energy Division, should be encouraged to consider community solar as a viable option for ZNE communities. This could substantially help in grid harmonization, which means ensuring that benefits to consumers and the system are roughly equal, and alignment of consumer benefits to actions that are beneficial to the overall grid. For example, new standards could incorporate ways to encourage and incentivize the development of community solar over other alternatives. Business models to address how community solar developments should be owned, managed and maintained should also be investigated.

Guidelines for Development of ZNE Communities

Developing a Zero Net Energy community should be a process that includes multiple stakeholders. Decisions should be made early in the land development and acquisition process as these early choices required to get necessary permits to build and develop these communities can have substantial long-term impacts on performance, customer satisfaction and grid impacts. This section details guidelines that apply to each step of the process and of relevance to one or more stakeholders in the process. Figure 8-3 illustrates an overall ZNE project development process.

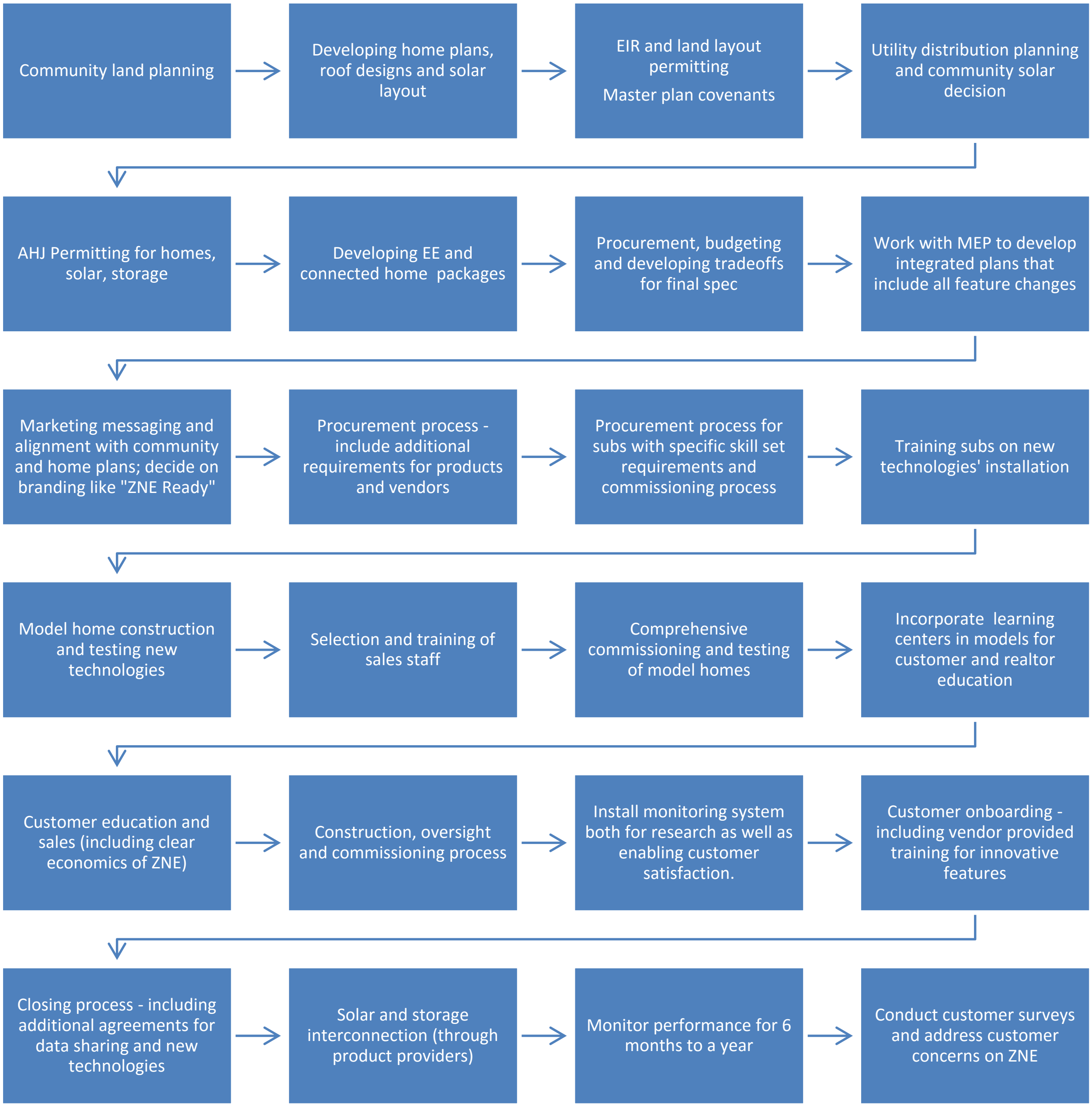


Figure 8-3
Development process for ZNE Communities

In this case, this project was not a greenfield development, since it began after the project community was already permitted and in development, which meant that the research team was not able to impact certain key variables at the start of the project. However, the lessons learned on solar orientation and distribution grid impacts provided the insights below for other projects on how to conduct upstream planning.

Stakeholder Guidelines for Developing ZNE Communities

The guidelines outline suggestions for optimizing each step in the ZNE community planning, design, construction, review and approval process. Through this process, the stakeholders involved include land developers, home builders, architects, energy modelers, solar partners, city planning officials, Mechanical, Electrical and Plumbing (MEP) firms, subcontractor trade allies, realtors and finally homeowners. This sub-section focuses on special guidelines and considerations for developers and homebuilders when planning, designing, constructing, commissioning and ultimately selling homes in ZNE communities.

Guidelines for Developers

Developers looking for property to build a new ZNE community need to consider traditional criteria such as location and cost, but they also have additional considerations to minimize the cost of developing these communities. Table 8-3 below includes typical developer considerations as well as special considerations for a ZNE Community.

Table 8-3
Guidelines for Land Developers

Current Developer Considerations	Special Considerations for a ZNE Community
• Location • Cost • Access to public transit • Access to amenities • Land size • Zoning requirements • Any property Covenants, Conditions and Restrictions (CCRs)	• Energy infrastructure requirements (electric and gas distribution systems) based on ZNE definition • Access/opportunity to site solar/DERs • Land amenable to renewable energy and water conservation • Site plans that account for solar orientation • Environmental factors that may affect DER energy production • Home designs with elevations that have roof planes/locations necessary to achieve ZNE • Additional permits, interconnections and regulations from AHJs required for DERs

Guidelines for Homebuilders

Homebuilders looking for property to build a new ZNE community need to consider the additional requirements and tasks required to construct and commission a ZNE community. Table 8-4 includes the standard homebuilder considerations as well as those for building a ZNE Community.

Table 8-4
Guidelines for Homebuilders

Current Homebuilder Considerations	Special Considerations for a ZNE Community
• Overall tract map approval for building go-ahead • Cost • Elevation designs for aesthetics • Trade ally partnerships and preferred contractors needed • Construction schedules and requirements • Interconnections and other requirements from energy providers • Home marketing strategies • Procurement timelines and schedules	• Coordination with energy utilities on intent to build ZNE community with high penetration of DERs • Understanding of special interconnection and permitting requirements and regulations • Special incentives offered for efficiency/renewables to drive down building costs • Any special inspections required that may affect building/development timelines • Coordination with energy subject matter experts to develop technology packages • Solar provider coordination to develop cost-effective business models • Special equipment procurement requirements • Special trade-ally and contractor training required • Additional commissioning requirements • Additional considerations when marketing these communities

Although energy providers, developers and homebuilders have special considerations when constructing ZNE communities, it is important to note that the process for developing these communities involves significant coordination between these stakeholders. The overall process guildelines for developing these ZNE communities are detailed below.

Process Guidelines for Developing ZNE Communities

Following are process guidelines for developing a ZNE community. These guidelines include all of the steps from land planning and development to homeowner occupancy.

Land Planning and Development

Many new home developments occur through master planned communities that have their own covenants that can either detract or support the goals of attaining ZNE. In fact, a very large master planned community of nearly 13,000 homes in Santa Clarita finally received approval for development by promising to build ZNE homes. For these communities and land developers, the following guidelines assist in developing ZNE communities:

- Avoid any architectural or visual effects covenants that would create barriers such as “no solar on the front of the home.”
- Plan for locations within the development (e.g., retention ponds, etc.) for community solar and possibly storage that could be used to create ZNE communities. Early in the process, work with utilities to identify options and compensation mechanisms for community solar integration. This will relieve builders of the burden of planning and paying for solar and storage if the developers or utility can directly contract with third parties for installation of community solar and storage.

- Implement covenants for energy efficiency, especially for high performance envelopes that can drive builders into adoption energy efficiency and zero energy features.

Builder Land Acquisition

In many cases, builders have limited control over which properties they will be acquiring. However, if there is control of land acquisition, it would be preferable to acquire land that can provide flexibility in layout as well as opportunities for beneficial infrastructure development such as community solar.

Architectural Development

In many cases, builders utilize a standard set of plans that can be implemented in multiple communities across a region. House plans that consider needs to incorporate solar or "solar-ready homes" would substantially help in scaling ZNE across multiple subdivisions. However, completely reworking rooflines to accommodate ZNE considerations often does not happen because the reworked rooflines do not align with customer perceptions of an attractive home. In addition to consumer perception, the rooflines would also need to accommodate multiple orientations of the same plan. One option for builders is to develop orientation specific elevations which could then be used based on lot orientation. For example, the New Solar Homes Partnership (NSHP) could provide additional incentives for integrated neighborhood design.

Another challenge that builders must address is the prevailing covenants and city planning requirements. Many cities have architectural requirements that require multiple architectural rooflines for visual appearance. Ultimately, builders must find a balance between consumer preferences, city planning requirements and solar design. It is recommended that research organizations work with builder associations like California Building Industries Association (CBIA) to develop consensus guidelines for builders and architects.

Utility Distribution Planning

Utilities also need to take a proactive approach to planning ZNE communities. Distribution planning guidelines for utilities was addressed earlier in this section. However, in addition to planning guidelines, it is important for utilities to participate in the planning process as soon as first contact is made regarding a ZNE community. Ideally, utility distribution planners meet with builder representatives to understand end uses, solar and storage sizing and can make appropriate sizing decisions on the front end of the process before overall community development is approved by the local jurisdiction. Currently, permitting and interconnection requirements, especially regarding customer-sited DERs, are completed after community development. It is recommended that utilities revise timing to include considerations for ZNE and other high-penetration DER communities before overall community approvals, but at the same time ensure that this does not negatively affect builder timelines and customer options.

Authorities Having Jurisdiction (AHJ) Permitting

The AHJ permitting processing is also undergoing significant change with the evolving Title 24 requirements, accelerated technology evolution and the lack of experienced staff dating back to the housing downturn that started a decade ago. It is imperative that AHJ officials receive regular training that includes new regulations and emerging cutting-edge technologies. It would also help to work with organizations like the National Association of State Energy Officials (NASEO) to provide additional education on how to permit technologies such as energy storage.

Areas where new rules should be developed include energy storage, connected homes, panel level metering, and structured wiring. More training is required for understanding how to set up critical load panels for backup power, as well as advanced HVAC and heat pump water heating systems.

In addition to AHJ education, another barrier is the reluctance of solar and storage companies to collaborate (especially if they are competitors in one or both fields). This could be overcome through regulatory or statewide requirements that specify data (such as permit drawings) to be shared by the vendors to enable faster and more seamless permitting for energy storage.

Finally, builder representatives who work directly with AHJs also need training on new technologies and how to work with the AHJs on enabling these technologies.

Developing Energy Efficiency Packages

Another important guideline is how to best develop a package of energy efficiency measures and solar PV for achieving ZNE. A primary focus should be on developing a high performance envelope since it has multiple benefits. Moving ducts into conditioned space substantially reduces the amount of cooling and heating loads, which provides the opportunity for cost savings on heating and cooling equipment. Along with a focus on water heating energy use reduction, this can substantially reduce the amount of PV required. This also helps to develop a better fit for PV installation, given the limited amount of roof space that might be available.

It is important that the mechanical and plumbing contractors and Title 24 planners understand the implications of equipment selection on both energy analysis and net energy metering (NEM) credits. For example, using both natural gas and electricity to heat the home might require the same size of PV to reach ZNE. However, the mixed fuel home could have substantial over generation in electric usage over the course of a year, since natural gas is also being used. The over generation is credited at the wholesale rate, which in turn reduces customer cost benefits. It would also be helpful to factor this into the Title 24 or EnergyPlus software to accurately model customer benefits.

Procurement

It is recommended that the homebuilder purchasing managers and/or procurement directors be directly involved in the technology package selection to ensure that measures and equipment are fully integrated. Procurement managers are able to quickly plan and calculate the cost and timing tradeoffs between the different packages and are the primary interface with the trade allies that have the responsibility for implementation of the new technologies. Another issue procurement managers must deal with is the question of lease vs. buy for solar.

ZNE communities require procurement managers to better understand the necessary skills required by their subcontractors and tradespeople (electrical, plumbing, etc.) before they initiate the Request for Quotation (RFP) process. Emerging technologies and appliances that are typical in these ZNE communities require an advanced level of knowledge to make sure that these technologies are operating as intended. The selection of capable skilled trades such as electricians and HVAC installers is critical when working with newer technologies. For example, emerging technologies now are able to provide customer connectivity via broadband. There will be a need in these communities for trades that not only understand electrical commission, but an understanding of basic home and/or community networking. This need for additional skillsets may require training existing contractors or hiring additional contractors to ensure proper implementation of new technologies.

Training of Contractors and Trade Allies

Training contractors and trade allies is a critical part of the process for developing ZNE and other communities that require high levels of DER penetration. Contractors sometimes have to deviate from house plans in order to meet timelines and project budgets. In addition, homebuilder contractors are more likely to using journeyman or minimally licensed staff for keep costs down. As previously discussed, emerging technologies and homebuilding practices required for ZNE community development require additional skillsets for overall home commissioning. It is recommended that a combination of classroom and on-the-job training be provided with new technologies such as connected home systems, energy storage and advanced electrical wiring practices. The classroom training could be provided through organizations such as the National Electrical Manufacturers Association (NEMA) and International Brotherhood of Electrical Workers (IBEW).

Residential commissioning and site inspections should also be completed to ensure that the design intent was met and the measures and technologies are fully integrated. As the energy impacts and benefits of ZNE communities will be more affected by construction and commissioning-related details, increased consistency in the building commissioning approach to these details is important. Building commissioning should be an integral part of the homebuilding process. For example, examining the framing to ensure that there are no possible holes that are left by insulation will have an effect on the overall space conditioning needs and, in turn, the overall customer comfort in the homes. In addition, current practice requires commissioning tests in only 1-in-10 or 1-in-20 homes. It is important to scale the commissioning tests to cover every home until there is assurance of consistency throughout construction, as is done in other industries.

Technology specific training should be provided through product providers such as energy storage system integrators and heat pump water heater manufacturers. In many cases, new technology vendors have a network of “certified” contractors, which may not overlap with the builders’ current contractors. It is also important that subcontractors be trained onsite during installation by the product providers and these providers also must commit to providing installation and troubleshooting resources to assist builders and their contractors.

Model Homes as Test Sites

Builders place a high level of importance on long term customer satisfaction, warranty claims, and avoiding legal issues. Implementing new technologies into the construction process can elevate the level of risk for builders. One way to address this is using model homes as locations to test new technologies and “debug” construction and commissioning processes. Model homes can also be better tailored for orientation and solar planning. Based on past experience, significant labor and cost savings can be achieved by designing and building the model home to be ZNE. Finally, the builder should also implement energy monitoring in the model homes to understand and provide guidance to customers on how the technologies work.

It is recommended that builders implement the full ZNE package in model homes instead of only adding a few ZNE features, as it will help identify early any challenges with permitting, technology and installation. It will also provide a showcase to exhibit innovations and increase customer traffic and sales potential. To support this, it is recommended that learning centers be set up in model homes to both explain the technologies as well as the benefits in terms of convenience and comfort that accrues to new homeowners from the new technologies.

Selection and Training of Sales Staff

It is important to remember that homebuilders' sales staff are customer facing realtors without specific training in new technology. Their strength lies in understanding what customers want and providing them with the relative information for making an objective decision. It is important to have top performers for the sales staff in ZNE communities as the sale is inherently more complicated with the possible addition of solar leases and "smart" appliances. It is recommended that builders provide training to the sales staff on technologies and how they add to the homeowner experience. Training for the sales team could include how to incorporate the integration of technology and energy as an additional benefit during the new home sales process.

Customer Education and Feedback

Customer Education

In addition to focusing on the planning, design and execution of a ZNE community, it is important that the customers be educated on what Zero Net Energy communities mean and that they understand the value proposition. This should be done by the building community, local utility and other sustainability advocates interested in increasing awareness of the environmental and societal benefits of ZNE construction. In addition, it is important to understand the continued relationship that the customer will have with their utility in ZNE communities. Consumer education is required on cost and comfort tradeoffs of various methods and approaches to achieving ZNE in a manner that resonates with the customer's lifestyle needs.

A potential opportunity is for product and service providers of the emerging technologies and DERs to conduct events at new home communities that help new homeowners understand and received the benefits of these new technologies. These events can be coordinated between the various stakeholders to ensure consistent messaging to the customer. Additionally, a statewide education and media campaign could be implemented so builders would have assistance in addressing customer education barriers. An organization or a group of organizations with a holistic understanding of the various facets of ZNE communities could undertake this customer education and outreach effort.

In addition to educating the homeowner, it would be valuable for builders and the research community to conduct customer surveys after a year of operation to gather information about customers' experiences and satisfaction with the technologies in their ZNE homes. This survey can provide valuable feedback on technologies that work well, ones that require a lot of customer engagement and ones that are causing customer dissatisfaction with their home.

Summary of Guidelines for ZNE Communities

Grid Integration and Distribution Planning

- Focus on deep energy efficiency as it substantially reduces the size of PV systems and reduces grid impacts. Energy efficiency has much greater capacity value compared to PV due to the preponderance of loads in the morning and evening hours, non-coincident with PV generation.
- Explore the possibility of a community solar system to attain ZNE at community scale, including:
  - Land availability (example, share in parking lots).
  - HOA or utility ownership.
  - Utilities can explore the possibility of community scale storage for grid management.
- If solar is at the home level:
  - Allocate fewer homes per transformer to enable electrification for decarbonization and additional electric vehicle penetration.
  - Increase size of secondary wiring to accommodate up to 50% higher solar penetration than is currently configured.
- Incorporate connectivity for loads (e.g., smart thermostats and water heaters) and storage. This will enable the end-use devices to provide future flexibility to grid operations when connected to the distribution infrastructure through distributed energy resource management systems (DERMS) or other distribution automation.

Community Planning and Energy Efficiency Measures

- Incorporate high performance walls and envelopes and ensure ducts are in conditioned space. This reduces PV sizing and enables better grid integration.
- Work early with the architectural firm on solar design and planning. Roof layouts are very important to attaining ZNE home designs with flexible orientation.
- Work closely with the AHJ early in the process. Spend extra time with product providers to educate the AHJ on new technologies and integration of new technologies into construction.
- Analyze tradeoffs of energy efficiency measures. For example, variable capacity HVAC systems might not necessarily be required as they might not provide enough value for the incremental cost.
- Focus on the actual performance of unregulated behavioral loads. Consider methods to incentivize builders to incorporate high efficiency appliances into the design of the homes as they could substantially affect the ability to attain Zero Net Energy.

9
TECHNOLOGY TRANSFER AND OUTREACH

This section summarizes the technology transfer and outreach efforts conducted by the project team as part of this research project. General residential construction requires involvement from multiple stakeholders. As data from Section 6 and 7 show, achieving ZNE communities will require additional stakeholder input and earlier intervention when it comes to the technology selection, community development and electrical grid planning.

The multi-stakeholder team worked and continues to work through design, deployment and monitoring of these ZNE communities. Successfully serving a shared customer (in this case the homebuyer) and achieving a "win/win/win" scenario for the customer, the homebuilder [17] and the electric grid may require input and data from various stakeholders to meet ambitious Title 24 ZNE goals. The technology transfer activities included education and information that was passed on to several groups, including materials and collateral to accurately portray the customer value proposition of the ZNE homes.

Close coordination with the many stakeholders in the project was one method to complete the technology transfer needed to successfully complete this project. Stakeholders that contributed included:

- Homebuilder staff members, including the sales, marketing, operations and construction management departments.
- Manufacturer and service providers of the emerging technologies and distributed energy resources, including the trade allies that help install, maintain and commission these products and systems.
- Homeowners and homebuyers.
- Permitting jurisdictions.
- Building modeling community.
- Electric utilities and energy providers.
- CEC Title 24 codes and standards groups.

Since the project continues past the grant funding timeline, technology transfer that has been completed as well as future technology transfer activities suggested by the project team will be presented.

In addition to technology transfer completed to various stakeholders that were a part of the completion of the project, additional outreach included:

- On-site public events such as community groundbreaking events

[17] This includes manufacturers, service providers and trade allies that support the homebuilder in residential construction.

- Media articles
- Technical papers, journal articles and publications
- Presentations at builder events and builder publications
- Presentations and speaking engagements to electric utilities and energy provides outside of the California investor owned utilities
- Future research projects conducted by the project team

Technology Transfer

Homebuilders

Homebuilders and the building industry are the primary beneficiaries of the technology transfer from this project. A summary of the key technology transfer provided to homebuilders includes:

1. Models and analysis of technology pathways to attain Zero Net Energy homes
2. Implemented cost-effectiveness of ZNE homes
3. How to sell ZNE homes to consumers and public
4. Sizing solar PV for ZNE
5. Managing roof plans and elevations for community scale solar fit.
6. Marketing benefits of ZNE homes and increasing foot traffic for ZNE homes
7. Implementation of air source heat pumps as a pathway to ZNE
8. Implementation and customer experience with heat pump water heaters as a new technology
9. Understanding of energy storage for customers and a permitting and integration process for energy storage
10. Long-term performance of solar PV systems
11. Customer perception, satisfaction and support with regards to ZNE homes
12. Better commissioning process

Throughout this project, it was important for the project team to work closely with the homebuilder. As the previous section states, to better understand and comply with scaling conditions that would need to be considered, the team attempted to minimize intervention with the homebuilder from both a scheduling and a supply chain perspective.

Although trying to be minimally invasive, the team did work closely with various members of the homebuilder’s team to market, sell and construct these homes. In the early marketing stages, the team worked with the homebuilder’s marketing team to carefully formulate the customer value proposition of owning a ZNE home. Although these homes were designed to achieve zero net energy goals as defined by Title 24, it was important to note that the tern zero net energy did not mean that these home could be marketed as homes that are constructed so that the homebuyer would no longer pay an electricity bill. It was important to communicate to the homebuilder’s marketing team that although these homes are designed to reduce energy bills of home occupants, actual energy bills may vary due to customer behavior. In the beginning of the project, the team worked closely with the homebuilder's sales and marketing team to identify customer value propositions that could be expected by the ZNE homebuyer.

As one of the leading production homebuilders in the United States, the homebuilder sets up learning centers in which customers can learn about the technologies and features offered as part of their model homes. See Figure 9-1.

Figure 9-1
Customer education center found in model homes showing ZNE technologies

Sales staff training for this community was completed to provide customer education on energy efficiency and ZNE features and practices. The sales staff received individual training on all the key efficiency improvements in the ZNE homes. Technology terms were not the necessary driver for most homebuyers and preliminary feedback indicated that efficiency improvements training needed to be refined. As a result, individualized refresher training was conducted to help properly represent effective value propositions of the ZNE homes. This training was found to increase customer adoption from 2 homes in the first 2 months to 19 of 20 homes within 5 months.

To minimize overall intervention and vet scalability, the project team coordinated with the homebuilder's operations and purchasing teams. Coordination with these groups was completed to vet the feasibility of leveraging existing national contracts that the homebuilder had with technology suppliers. Through these efforts it was found that the homebuilder's existing national contracts could be used to support emerging technologies required to complete these ZNE homes. The value of some of the technologies selected for this project, the heat pump water heater and the 15 SEER heat pump, were defined as great enough by the homebuilder that they now are the standard offering in Southern California single family developments.

The building industry obtains technical information through several channels, including their annual conference, their consultants, *California Builder* and other trade magazines, and training programs. This project will be of importance to builders as they approach 2020 and the requirement of ZNE homes. Builders will need to learn how to build new, high-performance attics and walls, PVs, and other efficiency measures that will vary across markets and builders. They and their teams of vendors, engineers, and consultants will need to learn building techniques, computer modeling approaches, PV sizing, and other aspects important to building ZNE homes that are likely new and different to them.

This project has developed informational pieces that can either directly inform industry members, and/or guide them to locations where more or specific information can be found. The homebuilder, as part of this project, has presented results and feasibility pathways to cost-effective ZNE community development in speaking engagements to other homebuilders. In addition, the project has transferred marketing, technical and customer engagement materials to the homebuilder. In turn, the homebuilder has then used the ZNE community as a ZNE community showcase to others in the homebuilding community through events sponsored by the United States Green Building Council (USGBC) [13].

Although progress has been made, there are still additional technology transfer activities to consider for the homebuilder community. For example, although driven by aesthetics, elevation plans and lot orientations will play a considerable role in achieving ZNE goals. For example, some current home designs have limited roof space for solar panels, and in addition, these roof designs may not be in the best orientation to maximize solar output. For an individual home, this could increase the size and cost of the solar installation, and lead to a less compelling business case for ZNE. Another concern among the homebuilder community regard ZNE is that varying elevations of houses can cause solar shading effects that can make it very difficult for certain elevations to size enough solar in a home for it to be ZNE. There are other options, such as community solar, that can be utilized to make the community ZNE ; however, this may also present certain challenges around integration, community and utility requirements.

Other technology transfers activities to think about are how to improve strategies to transfer maintenance and operational responsibilities of the integrated solar/storage and HEMS packages in each of the homes. The maintenance and operational responsibilities are not just limited to the warranties for each of these devices, but also how to transfer the right information and technical expertise to the homeowners as well as to other individuals such as electricians that may need to address issues once warranties are expired. Education around the best way to maintain and operate these systems should ideally be done on an ongoing basis, as the solar/storage industry matures and the technology becomes more robust.

Technology Manufacturers, Service Providers and Trade Allies

Technology manufacturers, service providers and trade allies play a key role in developing, distributing and supporting the emerging technologies required for ZNE development. A summary of the key technology transfer provided to this stakeholder group includes:

1. Achieved buy-in for deployment, installation and training with trade partners on EE/DER packages
2. Communicated opportunity of leveraging DER and connected device data streams to better understand and attribute energy consumption in ZNE communities
3. Developed an evaluation process, including a method to vet the safety of installation and operation of the community storage system
4. Researched implementation gaps of energy efficient setting as the default setting for emerging technologies, but keep customer comfort in mind as one of the highest priorities.
5. Investigated ways of integrating disparate behind the meter offerings to provide win-wins for both the customers and the grid.
6. Developed planning activities best practice thought leadership for homebuilders, community planners and customers to leverage.

Although the homebuilder's preferred suppliers were not changed as part of this project, the supply of certain emerging technologies required to achieve ZNE for this community was limited. For example, the homebuilder historically uses gas furnaces and gas water heaters for space and water heating, respectively. Although the team was able to use the same manufacturer to supply 15 SEER heat pumps and heat pump water heaters respectively, there needs to be a shift in standard offerings provided by manufacturers to distributors and trade allies in these service territories.

As previously discussed, comfort and reliability are easier to tie into customer satisfaction and therefore, are the primary drivers of technology manufacturers and supporting trade allies. For example, to prevent "no hot water" scenarios, heat pump water heater manufacturers will err on the side of caution and default to more risk averse, higher energy consuming modes when the product is shipped from the manufacturer's facility to the distributor. The installer, in turn, will install these systems in less efficient modes as comfort and not energy is the first priority. Intervention is needed, either to the manufacturer, installers, or standards and code bodies if mass deployment in which these efficient settings are the default setting is required. Another possible solution could potentially be improvements in technology that reduces the need for less efficient settings and/or improved system algorithms that minimize the use in less efficient settings.

In general, data collected by connected devices and DERs is still in its infancy. The current focus is on enabling customer convenience and control, so typical connected appliances provide data via user interfaces or performance reports to the customer. With limited standards and requirements and verification of these data streams, the project has leveraged existing data collection infrastructure of these connected device and DER manufacturers. See Section 4 for additional details. Through the project, the team was able to communicate the opportunity of leveraging DER and connected device data streams to better understand and attribute energy consumption in ZNE communities. Data specifications were created and communicated to participating technology providers that support monitoring and possible mitigation of grid impacts of ZNE communities and high penetration PV scenarios.

Finding individuals with the skillsets to install, commission and operate the integrated technology packages found within the ZNE communities was a challenge for this project. The project team, which includes manufacturers and service providers, provided training to local contractors on how to properly install and commission the technologies and systems. In certain cases, there was a skillset gap to complete proper installation of the technology packages that were part of the ZNE community. For example, as appliances and devices become increasingly connected, a reliance on broadband communication is necessary for communication and control. As baseline technologies are typically non-communicating, installers and contractors are not equipped with the networking skillsets required to properly commission these connected and communicating systems. In addition, although there have been improvements in ease of commissioning of connected devices, installation and especially integration may be a bit complicated for the common user. As a result, the project team spent considerable effort training the trades on installation and commission as well as performing rework efforts to troubleshoot and recommission improperly provisioned connected device equipment. Simplification of the onboarding process and/or training trade allies on the fundamentals of commissioning onto broadband networks is suggested. This becomes increasingly important if the attempt is not only to monitor grid impacts of these ZNE communities, but to mitigate and manage these impacts with load leveling strategies using controllable DERs.

Although the project did not install a community storage option, the work conducted led to the development of an evaluation process, including a method to vet the safety of installation and operation of the community storage system.

Current and future technology transfer activities that the team is working on are to continue efforts around buy-in for deployment, installation and training with trade partners on EE/DER packages. This will help them understand where they could focus their research and development to best address the needs of ZNE and other highly energy efficient homes while not compromising on customer comfort, a key metric for the industry. Technology transfer efforts in this space is not only limited to the trade-allies; the team is actively working with vendors who can help trade allies incorporate better capability for energy efficiency through platform and API development.

As mentioned earlier, there can be a disconnect between customer comfort and energy efficiency settings. The team is researching implementation of the energy efficient setting as the default setting for emerging technologies, while keeping customer comfort in mind as one of the highest priorities. This requires working closely with the manufacturers, the installers and the appliance repair technicians, so that everyone is aligned on how to manage emerging technologies in the most energy efficient manner.

Other technology transfer activities that the team is working on are continuing to investigate ways of integrating disparate behind the meter offerings to provide win-wins for both the customers and the grid. This includes “smart” appliances that can interact with HEMS and other demand response enabling technologies. It also includes different types of customer sited energy storage technologies, such as ice or lithium ion-based energy storage, and how these technologies can integrate with appliances such as hot water heaters and refrigerators. Other technologies such as home management software like Google Home are also starting to participate in aggregation and coordination of behind the meter resources and will also play an important role in the home of the future.

The trade allies who work in solar and storage assets continue to partner with the team on how to best determine the optimal location for these assets within the home, especially as customer's demand "custom" homes with unique designs. This can lead to inconsistencies in solar/storage installation. The team is working with its trade allies to come up with best practice thought leadership for homebuilders, community planners and customers to incorporate in planning activities. The team is also continuing its efforts with trade allies to determine the impact of these assets on the home, the neighborhood and the larger grid, to understand how to optimize the larger effects as more homes and communities become ZNE.

Homeowners and Homebuyers

Homeowners and homebuyers are the ultimate customer in the ZNE value chain, and any ZNE offering needs to meet their expectations and desires. A summary of the key technology transfer provided to homeowners and homebuyers includes:

1. A schedule of community, town hall style, workshops were developed and designed to inform and educate homeowners on the process associated with living in the ZNE homes.
2. Communicating the data collected from the ZNE homes to help home owners and occupants better understand their energy choices and make compromises between bill savings and comfort.
3. Continue to perform research on customer and occupant preferences and how they drive customer choices and ZNE home effectiveness on a large scale.
4. Understand the valuation of ZNE homes and how these technologies add to a home's property value.

Aligning project needs with new homeowner expectations was a critical aspect of making this project a success. The project team worked closely to develop a schedule of community workshops designed to inform and educate stakeholders, particularly the homeowners, on the process of living in the ZNE homes. The town hall style workshops provided an opportunity for the homebuilder and the project team to further introduce the newly signed homeowners to their new homes, since some of these homes had yet to be occupied. Additionally, this provided the partner electric utility an opportunity to introduce the relationship with the utility and get to know the ZNE demographic better through dialogue and interviews. The value of having a forum to meet individuals EPRI would then work closely with for the next eight months was critical. The homeowners were notified that state-of-the-art technology would be deployed to monitor and (to a limited degree) control their loads. They were also advised to use their home as they normally would, to ensure real-world load profiles were captured.

A second workshop was organized in the local community center and neighborhood elementary school to follow-through with the initial batch of homeowners (primarily in the initial 9 homes attached to Transformer 2), as well as provide a forum to meet a new group of homeowners that would be moving-in to the 11 homes attached to Transformer 1. A presentation was provided to the group to explain the value, the process and the expectations of the project as it involved many collaborative parties. Again, this provided a venue to engage with the 40% of those owners who could attend. For those that did not, it was more challenging to engage with them during the construction process. A member of the project team was assigned as a primary contact point to the homeowner to minimize project touch points. Product and contact information were distributed to provide the homeowners a method to communicate questions, comments and concerns during the project.

Continued support throughout a two-year data collection period (April 2016 – April 2018) is planned as part of this project. The team has used these data streams as educational tools to not only understand grid impacts associated with high penetration PV scenarios, but as an educational tool for the homeowners to better correlate lifestyle choices with how they impact energy bills.

For example, the project team was notified by one homeowner of an unexpected high electricity bill. Data was collected from this home to attribute high energy consumption to larger HVAC usage compared to the homeowner's neighbors. See Figure 9-2.

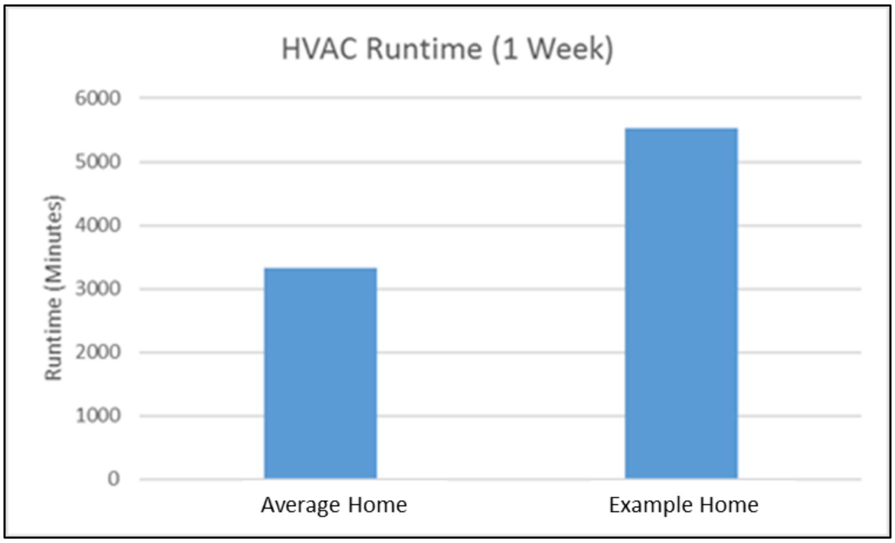


Figure 9-2
HVAC runtime comparison for high-bill home

Data like that shown in Figure 9-2 was used to communicate that the homeowner used two times as much energy to cool their home than other ZNE homes. Once attribution to end use was completed, the project team was able to create messaging that provided suggestions on how the homeowner could reduce their electricity bill moving forward. For example, increasing temperature set points using the homeowner's thermostat can be used to reduce energy consumption attributed to cooling a home. Data from connected and communicating devices that are part of these zero net energy communities, when communicated properly, can help home owners and occupants better understand their energy choices and make compromises between bill savings and comfort.

The team continues to perform research on customer and occupant preferences. Homeowner and homebuyer preferences drive the industry and the choices of each homeowner contribute to how effectively a ZNE home can drive energy efficiency on a large scale. Current research indicates that most homeowners are only peripherally cognizant of how their choices impact their energy usage and the energy efficiency of their home. As the team learns about homeowner and occupant preferences, it can develop strategies and technologies that allow for both homeowner comfort and energy efficiency.

Another question the team continues to work on relates to the valuation of ZNE homes and how they add to a home's property value. As indicated earlier, the addition of ZNE capability and technology was not a main driver of purchasing a home. However, as more homeowners are empowered to make their own choices to impact both their comfort level, their utility bill, and the environment around them, the addition of ZNE technologies will be a valued addition to the property valuation of a home.

Permitting Jurisdictions

The permitting jurisdictions that oversee the local community where ZNE homes are built need to understand how to handle the emerging technologies in these homes. A summary of the key technology transfer provided to permitting jurisdictions includes:

1. Educated the permitting jurisdictions on the concept of the technical solution, such as the battery energy storage systems to help them become comfortable with a deployment in their territory.
2. Communicated critical touchpoints around fire codes, environmental studies, and product safety were critical touchpoints to clarify the actual risks of the deployed technology.

The permitting process was initiated with the local AHJ. Considering the nascent state of some technical solutions (specifically the battery energy storage systems), a high degree of concept education was required to get the AHJ comfortable with a deployment in their territory. Fire codes, environmental studies, and product safety were critical touchpoints that required a significant amount of communication to clarify the actual risks of the deployed technology. After two months of working with the permitting department and a face-to-face visit with the builder and AHJ, a schedule was developed to physically meet with the construction superintendent to walk-through all nine storage systems, culminating in final, signed permit cards. At this point in the process, it became increasingly apparent that there was a bottleneck in the construction process. The builder's construction superintendent is the gatekeeper and relationship manager of multiple entities, and the dependency on this resource added excessive delays in deployment. A significant and potential improvement to mitigate this issue would be to designate a dedicated coordination resource to support unique efforts such as this custom new construction development. An entity approved by the builder to manage these "out-of-box" R&D efforts would benefit multiple stakeholders (i.e., builder, homeowner, research, and integrators). A lean building entity is designed to handle the coordination of manpower, scheduling of materials and equipment, and managing homeowner walk-throughs. Depending on this function to support new and oftentimes complicated design, installation, and approvals adds risk to the project schedule and budget.

Future technology transfer activities include continuing to help municipalities refine, streamline and extend the permitting process. The team also plans to work closely with other builders who are interested in ZNE to help them avoid some of the delays experienced during this project.

Building Modeling Community

The building modeling community builds the models that simulate the energy consumption of the ZNE homes, helping to enable the planning process before construction. A summary of the key technology transfer that was provided or will be provided to the building modeling community includes:

1. Actual field data that was collected and was given back to the building modeling community to improve and/or expand building modeling capabilities.
2. Additional field data will be collected at both the premise and end-use level for two years.

The ZNE homes were designed using building models that simulate the energy consumption of these homes. As this project is collecting data at the circuit-breaker as well as premise level, field data can potentially be fed back to the building modeling community to improve and/or expand building modeling capabilities. See Figure 9-3 as an example.

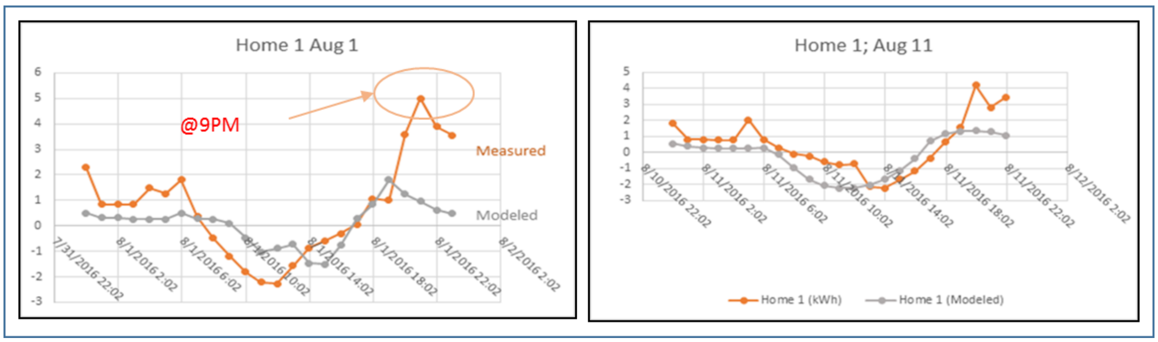


Figure 9-3
Measured vs. modeled data on a single ZNE home for two summer days

Data from Figure 9-3 contain preliminary evidence showing similar load shapes between measured and modeled data, but it is important to note that peak amplitudes were not captured by the modeled data. Preliminary hypotheses on this home show that this can be attributed to the water heater operating in “hybrid” mode.

Figure 9-4 indicates that although modeled data shows coincident peak energy consumption attributed to water heater usage of all nine homes, measured data show variations in both time as well as amplitude. These differences can be attributed to variations in customer behavior and preference.

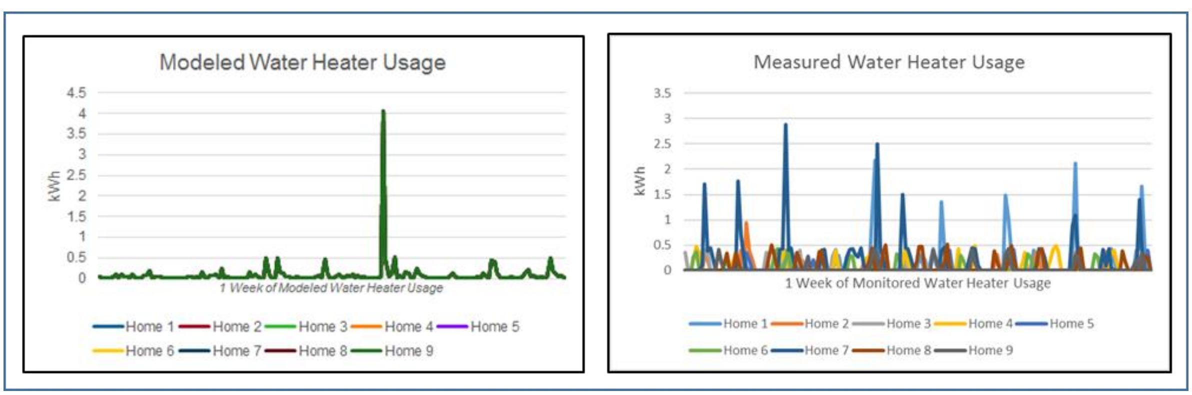


Figure 9-4
Modeled (left graph) vs. measured (right graph) data for one week of water heater usage from homes connected to Transformer 2

Although the end of the grant period was reached with only summer (and some fall) data collected, the project teams plans to continue to collect data at both the premise and end-use level for two years. It can be hypothesized that especially during shoulder seasons where space conditioning loads are usually less, customer behavior and preference will become a larger driver of residential peak energy consumption. The team plans to feed this information back to the building modeling community as well as interested energy providers such as electric utilities. The goal is to extend or enhance the applicability of building models for both grid planning and operation that will become increasingly important as deterministic models will need to be replaced with stochastic evaluations.

The team also plans to help transfer the collected data to the building modeling community to continue to refine the models.

Technology Transfer to the Utility Industry

The utilities who serve the ZNE communities need to understand the impact that these communities have on both the local and the larger grid, so that they are better able to plan for growth and shifting customer priorities. A summary of the key technology transfer provided to the utilities serving ZNE homes includes:

1. Close coordination with the utility project partner's distribution planning group showed how resultant end-use electrification efforts would require a slight adjustment in the current distribution process.
2. Results from this project provided deeper insights with real world data on how a combination of building modeling tools coupled with considerations for variation attributed to customer behavior would need to be used to better plan for ZNE communities at scale.
3. Provided the partner utility with great insights into driving factors for why homebuyers would purchase these ZNE homes, especially as end-uses become electrified, especially electric vehicles.
4. Derived potential data collection methods to better understanding of the utility customer, new value propositions to these customers, and resultant business models to service these customers are of interest to the electric utility industry.

One of the components of this research project was the study of the impacts that ZNE homes in volume can have on the utility distribution system. There is evidence that large numbers of homes with PVs can have a negative effect on distribution systems, as well as increasing CAISO challenges in providing optimal energy to the grid at certain times of day. There is also limited information on how battery storage could provide support to the distribution system. Utilities and energy providers have shown a keen interest in this project because of the data on PV impacts and possible mitigation using battery storage and controllable loads in ZNE communities.

To complete this project, close coordination with the utility project partner, Southern California Edison, was necessary. As discussed in Section 7, SCE's distribution planning was supplemented with data from this project to better understand how the resultant deep efficiency, high penetration PV scenario that is required to achieve ZNE at scale would affect the various levels of the electrical distribution system. Subsequent efforts also showed how resultant end-use electrification efforts would require a slight adjustment in the current distribution process.

Historically, environmental drivers such as outside temperature were primary indicators of peak capacity. This project provided deeper insights with real world data on how a combination of building modeling tools coupled with considerations for variation attributed to customer behavior would need to be used to better plan for ZNE communities at scale. This will be even more important as end-uses become electrified, especially electric vehicles.

The project has provided the partner utility with great insights into driving factors for why homebuyers would purchase these ZNE homes. In the 2016 Annual Shareholders Meeting, Edison International's Chief Executive Officer (CEO) referenced this project and mentioned that as DERs and advancements in technologies are becoming less and less expensive, achieving advanced energy communities, such as the ZNE community designed in this project are making more economic sense for the electric utility customer. He introduced this project as an example of how the business model of the electric utility industry is changing and how a better understanding of the customer is needed to usher in these changes [12].

In addition to project partner SCE, several other electric utilities across the United States have shown interest in the results of this project. With interest in community-scale demonstration sites, emulating the conditions of this project is proposed to investigate and evaluate real-world conditions of advanced energy communities such as this ZNE community. Although interest is not necessarily in ZNE, topics such as high-penetration PV impacts, load balancing and management using residential thermal and battery storage and electrification are of great interest to other utilities in the United States. In addition, better understanding of the utility customer, new value propositions to these customers, and resultant business models to service these customers are of interest to the electric utility industry.

As a result, several utilities have visited the project site to better understand the lessons learned from this project and how they can possibly emulate the work completed in this project to investigate DER aggregation, utility service models to the customers and assessment of achieving similar advanced energy community goals such as ZNE using demonstration site.

The team plans to continue the assessment of DERs and how their operation could better complete grid planning and operations. Utilities can use DERs to control and increase flexibility to better manage available resources for an increasingly distributed grid. The resources can be a variety of technologies—such as solar generation, energy storage, demand-response resources, and electric vehicles—that supply or consume energy on the order of magnitude of tens or hundreds of watts to tens of megawatts. Understanding how DERs operate and how to manage ZNE homes on the grid could help utility grid operators plan for and support local capacity targets of DER while also achieving objectives for improved resiliency.

The team is also continuing to monitor the real-world impact of ZNE homes on the grid. Current project results are highlighted in Section 7 of this report, but the team plans to continue to monitor and assess the impact of these ZNE homes on the grid as more data is gathered. The team will also share its findings with others who are interested in the real-world impact of ZNE homes so that utility planners and engineers are prepared as ZNE homes increase in popularity. Ideally, ZNE homes and communities can become tools that help utility planners and engineers improve the grid, as stated earlier.

Technology Transfer to Codes and Standards Groups

Codes and standards for various technologies help define industry codes that help clearly delineate the market for emerging technologies that go into ZNE construction. A summary of the key technology transfer provided to different codes and standards group include:

1. Informed codes and standards groups about limitations encountered by developers, planners and homebuilders. Also, introduced strategies for coordinating lot planning and architectural design that could mitigate some of the issues identified by this project.
2. A significant amount of time was spent with the CEC Title 24 staff to discuss grid impacts. This has led to an increased focus on grid harmonization aspects of attaining ZNE, with one proposal to modify the definition of ZNE to electric ZNE, thus reducing rooftop PV sizes, which in turn would help with distribution planning.
3. Documented the high performance (HP) construction materials costs, benefits, and construction basics and issues in the design and/or construction task reports for this project, which are readily available to industry. The information has also been distributed broadly by the CEC, as well as by CEC contractors providing training to the building industry, specifically for them to adopt these HP building practices.

The "Big Bold Goal" set by the California Long Term Energy Efficiency Strategic Plan [2] for the 2020 update of the Energy Efficiency Standards (Title 24) requires all new homes to be ZNE_{TDV}. This goal is achievable, but may be daunting to the residential building industry.

The homes built under this project span the three code updates between 2013 code and the declaration of the 2020 ZNE goal. The ZNE homes built as the core of this project started construction in 2015, and were permitted under the 2013 code. Although permitted under the 2013 code, they surpass the 2016 code efficiency requirements (effective January 1, 2017) and meet the 2020 code (as it was defined in August, 2016). Thus, with two code updates between those under which the ZNE community was built (and that are still in effect through the end of 2016), and those that will bring the residential Title 24 code to ZNE_{TDV}, this community of homes demonstrates what can be done now to meet the 2020 ZNE goal. This ZNE community demonstrates how to build to the 2020 ZNE_{TDV} today. Builders, code officials, and other critical stakeholders have an example of what they should expect to be required in 2020.

As previous ZNE projects focused on single home deployment projects, this project demonstrated feasibility and scalability of a community of ZNE homes using technologies and building practices available today. Twenty ZNE homes were constructed in a manner that was feasible to homebuilders and their current supply chain and appealing to the homebuyer. This community was constructed, sold and occupied over a period of less than 18 months and with minimal effect on standard construction schedules.

This project informed Codes and Standards Groups about limitations encountered by developers, planners and homebuilders. These factors included designing ZNE homes after lot orientations had already been defined and building requirements from municipalities suggesting preferred elevations based on aesthetics. For example, lot orientations are planned ahead of time in order to get permission to build from local municipalities coupled with municipalities requiring homebuilders to provide aesthetically-pleasing elevations to improve and increase the valuation of these communities. These customer-chosen elevation offerings can contain cut-up roof plains, minimizing roof space or shading rooftop solar space required to meet ZNE goals. For example, although this project intended to develop 50 ZNE homes, a set of 20 homes within the 187 home community was chosen due to factors that included locations where elevation offerings made it unfeasible to achieve a ZNE community. Space consideration issues are potentially exacerbated when considering that much of California new construction will occur in dense areas and focus on multifamily buildings. Strategies for coordinating lot planning and architectural design could mitigate some of the issues identified by this project. In addition, solutions such as community solar and storage are potential options if DER costs and benefits can be appropriately distributed so it makes sense for all stakeholders involved.

CEC 2016 Code Addition for High-Performance Attics and Walls

The 2016 Title 24 code update introduces High-Performance Attics (HP-A) and High-Performance Walls (HP-W) to builders and supporting industry members. There are both prescriptive and performance allowances for HP-A and HP-W in the 2016 energy code, and there are two methods that builders can use to avoid one or both HP-envelope measures.

The homes built for this ZNE community all incorporate HP-As, but not HP-Ws, as directed by the builder. They are very comfortable with using spray-in foam insulation (SPF) for the walls and attic. They have found that using SPF eliminates the need for other time-consuming methods for air-sealing the envelope, saving costs for the time and materials others spend on air-sealing. They have also been using SPF applied to the underside of the roof-deck for several years, which both seals and insulates the attic simultaneously. This sealed, insulated attic is one of the approved HP-A construction approaches. Using this approach, this homebuilder, and other builders who construct HP-As can put the HVAC system and ducts in the attic and get code compliance credit for doing so.

Ducts in an HP-A are much more efficient than in a typical attic that is not air-sealed, and is insulated from the conditioned parts of the home by insulation on the attic floor. Significant reduction in ducting losses results in less need for additional cooling and higher efficiency HVAC systems, resulting in reduced costs to achieve 2020 ZNE goals. HP-As and HP-Ws are new construction techniques for most California builders.

Outreach Activities

In addition to technology transfer activities that happened organically to complete the ZNE community as a result of coordination between the various stakeholders that comprised the project team, other outreach activities were both sought and provided as a result of considerable media coverage of this project. These outreach activities are described below.

ZNE Community Groundbreaking

The first public event of the project's ZNE community was the groundbreaking event on Earth Day, April 15, 2015. Guest speakers included CEC Commissioners and representatives from the homebuilder, EPRI and BIRAenergy. The event was attended and covered by local print and TV media, and attended by local building planning department leads, members of the homebuilder sales and operations staff, members of the partner electric utility, partner product and service providers as well as potential homebuyers. The attendees were provided with tours of a model home retrofitted to be ZNE as described in the homeowner/homebuyer portion of this section. This model home included a dedicated space for interactive displays and efficiency measures installed in the ZNE homes. The displays are depicted in Figure 9-1. These ZNE displays were available to the public, special visitors and the sales executives who sold these homes.

Media Articles to the Public

This project has received substantial attention from both technical and general media. The media has raised the visibility and increased the public awareness about ZNE and that these homes are becoming available to all prospective homebuyers throughout California. Local television coverage by the local weatherman detailing the value and opportunity of owning a ZNE home assisted in the marketing and education of potential homebuyers. Members of the homebuilder sales staff credit this local advertising for some of the success in selling these ZNE communities.

This project has played a role in providing widespread exposure to builders, developers, local jurisdictions, utilities, and other ZNE stakeholders. The project has raised the profile of both ZNE construction and grid integration of ZNE communities. The list below details a portion of the articles from this report. Please see Appendix D for a more extensive list of media articles that have been published about this research project.

- D. Caldwell, "A Suburban Experiment Aims for Free Energy" *The New York Times*, June 3, 2016. Retrieved from http://www.nytimes.com/2016/06/04/business/energy-environment/solar-power-energy-efficient-net-zero.html.
- I. Penn, "Zero-Net Energy Home Pilot Set to Open in Fontana," *The Los Angeles Times*, September 16, 2015. Retrieved from http://www.latimes.com/business/la-fi-net-zero-home-pilot-20150915-story.html.
- "Meritage Introduces California's First and Only Net Zero Neighborhood," *The Orange County Register*, April 10, 2015. Retrieved from http://www.ocregister.com/newhomes/meritage-657529-neighborhood-zero.html

Technical Papers, Presentations and Journal Articles

In addition to informing the public, the project has generated several technical reports and has also been cited in technical reports and papers directed at technical stakeholders. Elements of this project such as the integration of solar and storage and aggregation of DERs including controllable loads have been presented at several technical workshops and forums. These presentations include in-depth reports regarding the methods and tools used to perform the analyses required to develop the ZNE measures and design as well as panel representation on lessons learned on the grid impacts of these communities. Some of the reports can be found, below. A more complete list can be found in Appendix D.

- B. Clarin, R. Narayanamurthy, R. Hammon, I. Hammon-Hogan, and W. Vicent. "Establishing Feasibility of Residential Zero Net Energy Community Development - Learnings from California's First ZNE Neighborhood." In *Proceeding of the ACEEE 2016 Summer Study on Energy Efficiency in Industry*. Washington, DC: ACEEE, 2016.
- R. Narayanamurthy, N. Tumilowicz, R. Handa, and C. Herro. "Grid Integration of Zero Net Energy Communities." In *Proceeding of the ACEEE 2016 Summer Study on Energy Efficiency in Industry.* Washington, DC: ACEEE, 2016.

- "Paving the Road to Zero Net Energy Buildings," Navigant Research, June 18, 2015. Retrieved from https://www.navigantresearch.com/blog/paving-the-road-to-zero-net-energy-buildings.
- "Gov. Brown Ramps up GHG Goals; EPRI, SCE, CPUC Support Zero Net Energy Units." *ElectricityPolicy.com*, 2015. Retrieved from http://electricitypolicy.com/News/gov-brown-ramps-up-ghg-goals-epri-sce-cpuc-back-zero-net-energy.

Builder Events and Publications

The building community has been informed about the project through a combination of technical presentations and builder community publications. The homebuilding project partner has done significant outreach on various ZNE and green building practices and their impacts to the grid in forums such as the USGBC. Members of the project team have also been invited to speak in forums such as the Continental Automated Buildings Association (CABA). Some of the articles can be found below. A more complete list can be found in Appendix D.

- L. Chow, "California's First Zero Net Energy Community is a Model for Future Living." *Professional Builder*, April 25, 2015. Retrieved from http://www.probuilder.com/california%E2%80%99s-first-zero-net-energy-community-development.
- S, Gibson, "California Project Tinkers with a Net-Zero Future." *Fine Homebuilding*, June 5, 2015. Retrieved from http://www.finehomebuilding.com/2015/06/05/california-project-tinkers-with-a-net-zero-future.
- K. Burger, "A Net Zero Neighborhood Sets a New Standard." *Green Home Builder*, March 6, 2016. Retrieved from https://greenhomebuildermag.com/a-net-zero-neighborhood/.

Outreach to California Investor-Owned Utilities and other Utilities Across the United States

This results of this project have been published and have drawn interest from all California IOUs. Members of the project team have been invited to present some of the research findings in forums such as the California Emerging Technology Coordinating Council (ETCC). Southern California Edison has featured the project in media articles and publications. As previously stated, the project was featured in Edison International's 2016 Annual Shareholders Meeting as an example of the effects that large-scale DER deployment would have on the utility and its business models. Articles released by the California IOUs, in particular Southern California Edison are listed below. Additional articles are a part of a more complete list that can be found in Appendix D.

- "Helping California Meet Goals for Zero Net Energy Homes by 2020," Edison International website. Retrieved from http://www.edison.com/home/innovation/energy-management/zero-net-energy-homes-buildings.html.
- R. Gales, "Helping California Make Zero Net Energy Buildings a Reality," June 12, 2015, Edison International website. Retrieved from http://newsroom.edison.com/stories/helping-california-make-zero-net-energy-buildings-a-reality.

In addition to the California IOUs, the project team has presented results of this project to electric utilities and energy providers across the United States. Sessions at EPRI Advisory Council meetings and presentations to utility sustainability managers through EPRI's Energy Sustainability Interest Group are some examples of presentations made by project team members to electric utilities and energy providers. Although not all these utilities have zero net energy goals like California's, the utility industry is interested in how customer-sited DERs and connected appliances and loads will have an effect on the electric grid once scaled. These utilities are interested in issues that include: (1) understanding utility customers and how to provide additional services that improve customer satisfaction, (2) the impacts that DERs such as high penetration EVs and PV will have on the electric grid, (3) mitigation of grid impacts using granular data from these devices coupled with DER aggregation and (4) how data from customer-sited resources can support grid planners on the distribution side of the power system.

Future Projects Influenced by this ZNE Project

In addition to the continuation of data collection and analysis for this ZNE community, results of this project have influenced the creation of similar projects targeting zero net energy communities and DER aggregation. Interested parties include the California Energy Commission and other electric utilities across the United States. A summary of a few of the projects initiated that leverage this project includes:

- A CEC commissioned project demonstrating the affordability, scalability, customer adoption and grid integration of ZNE communities. The project, led by some members of this project team attempts to design, construct, market, sell and occupy over 100 ZNE homes using 2-3 different homebuilders in 3-4 different California climate zones. This project commenced in 2016 and plans to run until 2020.
- A CEC commissioned project demonstrating a customer-centric resource aggregation platform that plans to aggregate multiple end-use loads including EVs, thermostats, water heaters, solar and storage to respond to rate signals from the utility while understanding customer preference. This project plans to commence in 2017.
- An east coast electric utility working with the project team members to design ZNE homes constructed with high performance walls with high thermal mass. The goal of the project is to not only showcase ZNE, but show how advanced building envelopes can be used for their high thermal mass properties as passive storage systems. Coupled with controllable devices such as smart thermostats, these residential buildings provide an opportunity for the electric utility to investigate how load-leveling or peak shaving can be achieved without compromising residential customer comfort.
- A southeast electric utility looking at investigating DER aggregation through demonstration of a similar advanced energy community such as the one in this project.

Summary

The complex nature of developing residential communities has led to various technology transfer activities targeting various stakeholders involved in the project. Key messages that continue to affect all parties include:

- Although ZNE communities are feasible and cost-effective for the customer today, scaling zero net energy communities will need to involve stronger coordination between stakeholders such as municipality permitting organizations, electric utilities, homebuilders, product manufacturers and trade allies. Not only increased coordination between stakeholders but advanced coordination is needed to best understand the ideal scenarios for achieving ZNE throughout the community while still providing residential homebuyers with the home features they prefer.
- Although monitoring the effects of zero-net energy communities is technically feasible with technology and techniques available today, improved aggregation methods and data collection models will be necessary for advanced controls of distributed energy resources to mitigate impacts of scaled residential PV deployments without adverse effects to the customer.
- Considerable training is still required for trade allies that support DER products and integration systems in a manner that mitigates impacts to the grid.
- Refinement of the customer value proposition and appropriate messaging is still needed to accurately portray the value of zero net energy communities to potential homebuyers.
- Valuation of these communities is also still required to better understand the value of the ZNE home to the customer.

The team has conducted several outreach efforts and has publicized the development, data and results of this projects through various media channels to various stakeholders. Projects addressing zero net energy community development, DER aggregation for grid benefits and a general understanding on how customer-sited resources can achieve “win-win” scenarios to a utility and its customer have been initiated as a result of the learnings from this project.

10
CONCLUSIONS

Project Summary

In California, the distribution systems are designed for gas driven heating and appliances with protection mechanisms designed for one-way power flow. As we move to ZNE, the increasing electrification of end-loads could stress distribution circuits through excessive loads. The protection mechanisms are not typically designed for two-way flows, and ZNE communities could at times have significant two-way flow. The project focuses on a near-term high penetration future in California, when the goal to attain ZNE in residential communities could lead to every home on particular distribution systems having significant amounts of PV.

The design of the community was based on models of home performance. Each home was modeled using BEopt software to understand energy performance of these homes. These models provided the energy use of the homes, which was then used to develop PV sizing to attain zero TDV (California Title 24 code definition). The models illustrated that the residential peak loads in ZNE homes occur around 8:00 pm in the summer and at 6:00 am in the winter. In neither of these cases is PV coincident with peaks, so it cannot help with mitigation.

The actual measured data validated the models at the individual home level. Example data streams are shown for four weeks stretching between the spring and summer (Figure 10-1). The measured data emphasizes the non-coincidence of peaks between the PV production and load peaks. Thanks to deep energy efficiency, the data also shows that the transformer capacity limits were not tested over the summer. The impact of energy storage is shown in moving the peak from 7:00 pm to 9:00 pm on the transformer and reducing the net peak load at the transformer.

Figure 10-1
Average daily transformer load shape in July (weekdays only)

The lessons learned stretch all the way from how to plan ZNE communities and how PV will get implemented, to customer perception of PV and the impact of storage, and finally the actual impacts on the grid and their mitigation. All the extensive modeling work provides the industry with projected data, but the acid test is building real buildings that are occupied and operated by members of the general population. Planning a ZNE community requires tight coordination between the builder, the energy designer, the solar provider, the energy modeler, and the local utility. Each decision impacts multiple stakeholders, such as the energy models impacting PV size, which then impacts roof fit. It is ideal all parties to start working closely on the front end when planning a ZNE community.

Neighborhood level solar planning is very important. Title 24 has a requirement for solar ready roofs (optional with connected thermostats), but it is not sufficiently large to accommodate enough PV for net zero energy homes. Developing the tools for builders, such as recommending roof plane changes in the early community design process could substantially accelerate solar adoption in the new home communities for large builders. Implementing new technologies requires a “hands on” approach by researchers and designers to oversee the construction process. Construction managers have their hands full with daily issues related to materials, contractors, and closings. Researchers and designers need to conduct planning sessions with the construction managers and be available on-site frequently, especially for the first few homes in new communities.

This project has led to a much higher level of awareness of distribution impacts due to the combination of high PV penetration, energy efficiency and electrification. The media coverage has raised the awareness in the R&D community, and many of the results are being fed back in to the Title 24 code development of the ZNE code in 2019.

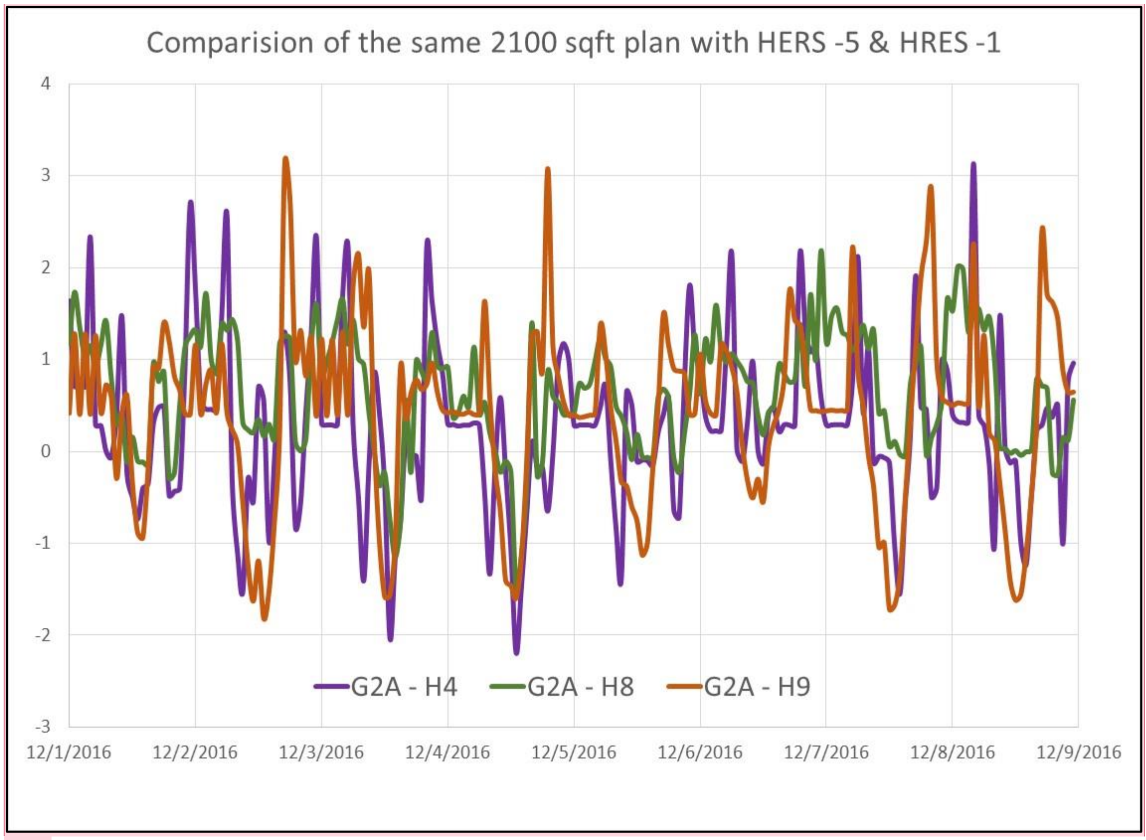
Key Takeaways

4. <u>Customer side energy storage is not cost-effective for grid balancing:</u> The total cost of the energy storage systems excluding the cost of installation was in the range of $20,000 per unit (borne as a cost share by EPRI's partners for this project). While there is some value to customers in terms of backup power, it is not sufficient to offset the cost at scale. This means most of the value for energy storage lies in grid scale storage – either at transformers, specific feeder locations or at substations. SCE's energy storage team indicated during the project that they are focused on larger energy storage systems for controllability (single point control) and cost effectiveness. If the edge of the grid is hardened through asset sizing, then moving energy storage to the utility side of the meter might be the most effective usage of energy storage. There might still be customers who adopt energy storage for other reasons, but it is difficult to obtain concentrations (e.g., requiring energy storage in ZNE homes would be cost prohibitive) of storage and control them coherently to achieve grid reliability.
5. <u>Community solar and storage should be considered for ZNE communities:</u> A key takeaway is that community solar and storage on the utility side of the meter could play a key part in attaining ZNE communities. While there are business model challenges (who pays for it, where is it located, land availability), from a technical perspective, it could address the major issues with both overgeneration, and electrification of end loads, and could also be lower cost. The storage could also be sized smaller to take load diversity issues into account. This should be highlighted as a large area for future research, both in terms of technology integration as well as business models.
6. <u>Adding distribution assets could be a cost-effective method to add reliability:</u> Distribution system planning time horizons cannot rely on load and storage controls. When control algorithms can be changed remotely through wireless connection, it is very easy to flip operation of controllable loads and storage from being beneficial to the grid to actually adding to peak loads or over-generation. There is not sufficient data about the long-term reliability of energy storage and load control (and in fact, there is data that the connectivity of customer WiFi-connected devices can drop off 10% year over year on average). Given this scenario, adding or upgrading distribution assets (for example, upgrading a 50 kVA to a 75 kVA transformer might only add a few hundreds of dollars), might be more cost-effective and provide greater long term reliability while the technology and market evolves.
7. <u>Net energy metering rules make electrification of heating loads cost-effective for homeowners:</u> A surprising learning was that ZNE can enable electrification of heating loads. With gas heating, these homes used an average of 255 Therms and 5000 kWh. However, the average PV production to attain ZNE is in the order of 6900 kWh. With only 5000 kWh to displace, nearly 30% of the production would be excess paid at just the cost of generation. To improve customer economics, with a current NEM of 2.0, it is preferable to keep solar PV annual production at 85-90% of total annual electric use. This can be achieved by switching gas furnace heating to heat pumps and tankless gas water heaters to heat pump water heaters. Surprisingly, compared to prevalent wisdom, electrification was net first cost neutral, as eliminating gas lines and flue gas stacks, along with additional NOx fees, made it less expensive to install electric heating systems.

8. Electrification of more end uses could require additional distribution grid assets: One of the very interesting results that emerged from the project was that electrification of end uses could substantially change distribution planning. Electrification was required due to current NEM rules, and it turned out that with electrification, energy storage and possible EVs in the future, the connected load for planning calculations was 30 kW, when utilities are planning for 6.5 kW. This requires very serious considerations, both in terms of evolving planning methods (the loads are not all coincident), as well as new technology developments for load control. This is a serious cost consideration that the state of California must consider (how much are we willing to invest in distribution assets), as the path to long-term decarbonization runs through end load electrification.

9. The definition of ZNE could have a significant impact on distribution planning: Another interesting insight was that the ZNE definition could drive the impact seen on distribution circuits. The analysis revealed that the 2013 and 2016 TDV factors result in a smaller PV system for ZNE homes compared to site or source energy ZNE. But the 2019 factors which account for the ISO duck curve would increase required PV size and negatively impact the grid. The most recent proposal for the 2019 code to move to Electric ZNE could actually be beneficial to the distribution system, but could detract from the longer-term goals of decarbonization and a cleaner energy system. Given this uncertainty, it might be a better option to leave "grid harmonization" out of the building code, working more closely with utilities so they can plan the future electric grid, given a set of rules for meeting Zero Net Energy.

10. Additional focus is needed on unregulated, behavioral loads for actual ZNE performance: The building code today and in the future is focused on regulated loads. These include HVAC, lighting, and water heating, with an allocation for appliance and plug loads. However, with deep efficiency and the march of electronics technologies, more than half the energy use is spent on appliances and plug loads. This significantly impacts the ability of homes to meet ZNE in operation. There are also other behavioral factors such as thermostat setpoint (the models assume 78°F cooling, 68°F heating) that can significantly impact energy use. For example, Figure 10-2 shows that three homes with the same floor plan and PV size have very different energy use (1 week usage of 54 kWh, 77 kWh and 124 kWh).



[GS1]

Figure 10-2
Energy use of three identical floor plans and PV size

11. <u>Impact of customer education on the cost of electricity network and ZNE:</u> The variation in energy use behavior has a significant impact on customer perceptions of ZNE. This project was also an experiment in customer perception of ZNE, which includes their perception of solar, storage and energy efficiency. Except for 2-3 homeowners, the majority were focused on electric bills and there is a perception that ZNE will result in zero bills. In fact, one customer was surprised that they were getting $100+ SCE bills when they had an electric vehicle, a second refrigerator and a freezer in the garage. As the state moves towards ubiquitous ZNE and as the NEM rules change, this really exposes the need to educate the larger public on the "network cost," i.e. the fact that grid connectivity will come with a cost. This education can also reflect research findings that 40-60% of the cost of electricity is related to the cost of the network [13].

12. <u>ZNE homes can be cost-effective and cash flow positive to homebuyers:</u> One of the achievements of the project has been to demonstrate that Zero Net Energy Homes can be cash flow positive to the homeowners. The additional cost of $17,000 (before incentives) spread over a 3.5%, 30-year mortgage equates to a $76 per month payment, which is offset by the savings, which are more than $100 per month. Up to a $22,000 in additional costs (with incentives) can be offset with less than $100 in monthly mortgage payments. This also emphasizes the importance of managing trade-offs in energy efficiency to manage the additional cost for attaining Zero Net Energy.

13. High performance envelopes and ducts in conditioned spaces are critical components of ZNE homes: High performance walls and getting ducts into conditioned space substantially reduces cooling and heating loads through better air sealing, duct loss reduction and reduction in thermal losses. Reducing HVAC sizing helps in cost reduction through elimination of a second HVAC system (in many cases), and with heat pumps reduces peak loads in summer evenings and winter mornings, and the energy efficiency helps to reduce the size of PV required for ZNE. This has multiple grid impacts in that reducing PV sizing reduces overgeneration during midday as well as the evening ramp. It also reduces winter peak loads by eliminating the need for auxiliary electric heat. Finally, it improves customer comfort by maintaining more even indoor temperature conditions.
14. Training field trades on new technologies is critical to attaining consistent performance in ZNE homes: One of the areas of concern is that most field trades are not prepared for new technology. This includes the electrical, mechanical and plumbing trades. Of the three, the biggest concern is the electrical side. Most new homes are wired by journeyman electricians without even the knowledge to understand electrical drawings. Energy storage installations are definitely beyond the capabilities of the current electrical contractors. Another area of where electricians are lacking in knowledge is installation of labelling loads; at times even the breakers installed were very inconsistent in the main load panels. This also raises concerns over making homes EV ready. Even the plumbers struggled a bit to install the heat pump water heater, but were able to do so once trained by the manufacturer. Moving forward, EPRI recommends electrician training be implemented for new technologies including energy storage installation, best practices in installing load centers and connected devices.

Future Research

Following this work, many utilities around the country are initiating similar projects to study load shapes, and how to mitigate load impacts as we move to a future scenario of high efficiency, solar homes. Projects have started with two utilities, Duke Energy, and Southern Company, to demonstrate Advanced Energy Communities in the Southeast.

In California, the project team is leveraging these learnings in a new EPIC-funded project to build community-scale ZNE. This project will scale the first ZNE neighborhood into the first few communities, implementing ZNE communities in Orange County, Fresno and the Bay Area with multiple builders. These initiatives will substantially help develop planning processes for ZNE communities. A focus of these efforts is to investigate the possibility of community solar through utilities and third parties, as well as large-scale measurement of customer behavior. All the lessons learned will be applied to these projects as California prepares for a future of high penetration distributed solar generation with ZNE communities.

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A
SUMMARY OF ENERGY MODELS AND PV SIZING

A summary of energy models and PV sizing can be found in the attached Excel Spreadsheets. Please see **ZNE Fontana Community_BeOpt Model Summaries.xlsx** which is attached to this report. The Excel file contains 21 tabs. Twenty tabs show modeled energy consumption for the 20 ZNE homes using the BeOpt simulations incorporating the technology packages used and detailed in Section 2. One tab constitutes PV estimations.

B
HOURLY DATA BY HOME AND TRANSFORMER FOR JULY AUGUST AND SEPTEMBER

The following embedded .xlsx files were used in the creation of this report.

- Peak energy consumption at the individual home level can be found in **Premise Level Energy Summary.xlsx**
- Transformer level energy consumption at the transformer level can be found **Transformer Level Energy Summary.xlsx**
- For minute-level energy consumption data at the end-use and at the transformer-level, please contact the authors of this report.

C
RESIDENTIAL ENERGY STORAGE MARKET SURVEY

Overview

EPRI conducted a broad survey of providers of battery energy storage components and systems. A subset of these providers were surveyed in more detail to provide a high-level overview of the types of products available as of the close of 2015. The 20 providers profiled below were a part of this more-detailed survey. EPRI gathered information about operating characteristics, components provided, key applications, and system availability. It should be noted that while the survey information provides comparisons of operating characteristics, it is not intended to be used as a product purchasing tool. Rather, the data reported for each provider provides a guideline as to what information needs to be sought when contacting a solution provider, and presents a general introduction to the range of performance characteristics to be expected with a battery energy storage system.

Of these profiled companies, some offer turnkey solutions (either on their own or in partnership with other companies), others bring partial solutions (for example, a PCS and battery system, but no EMS), and some focus on providing one of the three major components.

For comparative purposes, this section presents tables of key characteristics for those providers for which full system data were available in late 2015. For some partial-solution providers, it was possible to construct nominal systems using selected components to complete the system. EPRI normalized the system sizes to a nominal 3 kw/6 kWh scale. It is important to recognize that designs are in flux as solution providers combine products in new configurations and adjust designs in response to market demands in North America and globally. Also, note that system characteristics listed are as given by system providers at the time of the survey, not from any EPRI tests.

For each provider, to the extent data were available, key characteristics are provided:

Component data:

- provider of inverter (PCS)
- battery (BMS) provider
- software (EMS) provider

Capacity data:

- continuous power rating (kW): normal operating capacity
- maximum power rating (kW): upper limit to charge/discharge capacity
- energy storage capacity (kWh): total energy which can be stored

Operating data:

- Lifetime full cycles: anticipated number of full charge/discharge cycles over the battery lifetime without performance degradation
- Depth of discharge (DoD): fraction of battery capacity typically available for charge and discharge. Generally, a function of battery technology, under operating conditions DoD is also adjustable through software controls.
- Round-trip efficiency (RTE): the net overall battery system efficiency, for the DC-DC conversion cycle. (Figure C-1 does not encompass system efficiency, but is useful for comparing battery systems and estimating lifetime energy production.)

Market data:

- Availability: locations and expected time frame that system as described is available (reminder: these data reflect information collected in late 2015)
- Key applications: operating modes for which system can be configured, including self-consumption, grid-connected, backup, and more
- Duration: describes the rate of discharge, defined as energy capacity divided by hours of discharge at maximum kW; for example, a C/2 battery is fully discharged after two hours.

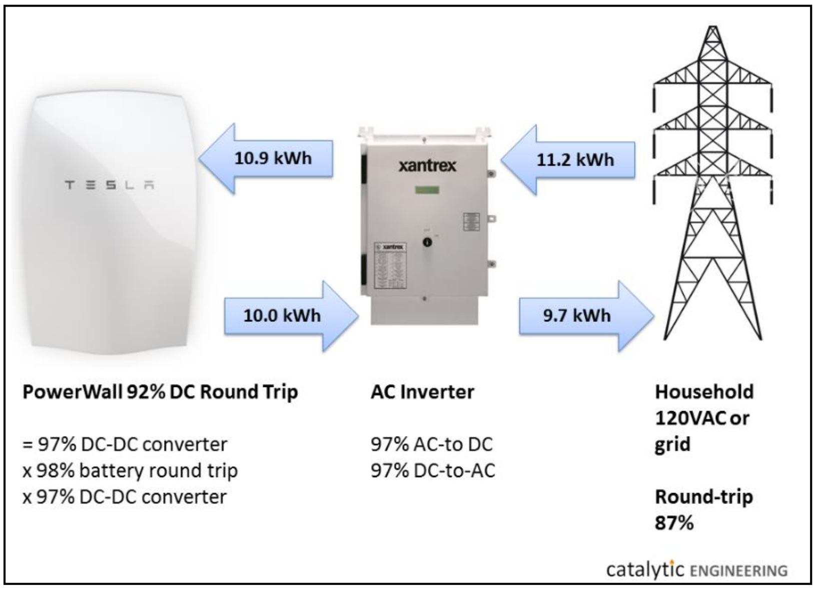

Figure C-1
Power conversion stages for DC battery in AC systems

ABB

Turnkey Solution Provider

ABB offers an integrated system focused on the market for storage systems designed for integration with PV systems, to support shifting PV energy to match the residential load (Figure C-2 and Table C-1). The battery module size is relatively small, storing up to 2 kWh in a lithium-ion battery coupled with a 4.6 kW single-phase inverter. The system is modular, allowing for combinations to provide up to 6 kWh. ABB expects a ten-year lifetime for the battery. In addition to Wi-Fi connectivity for ABB's energy management applications, the unit incorporates a port for Ethernet connection, providing local connectivity to monitor performance and manage operation. The unit also provides four direct ports to connect to energy management systems for loads such as HVAC systems. The system can provide AC output for use as a back-up resource.

Relative Strengths	Other Considerations
• Fully integrated • Data protocol meets global standard • Expandable • Native mobile app available	• High cost • Limited availability

Figure C-2
ABB Modular Unit

Table C-1
ABB key characteristics

Primary Provider	ABB
System Type	**Battery inverter**
System Coupling	**AC Battery**
inverter make/ model	ABB
battery/bms make/ model	Panasonic
data acquisition & control	ABB
power continuous (kW)	4.6
power (kW)	4.6
energy (kWh)	6.0
Lifetime full cycles	4500
Depth of discharge (DoD)	80%
Round-trip efficiency (RTE)	93%
availability	global, 2015
key applications	self-cons, backup, grid
duration (energy capacity/hours of discharge)	C/2

Adara Power

Turnkey Solution Provider

A small startup company based in Milpitas, California, Adara Power's energy storage system utilizes LFP (lithium-iron phosphate) storage and a custom-designed EMS (Figure C-3, Table C-2). Key company designers bring an electric vehicle (EV) industry perspective to battery system design.

Relative Strengths	Other Considerations
• Agile development • Reliable integrated platform • Experienced battery technology team	• Not designed for high volumes • Relatively costly (LFP storage) • Low bankability: relatively small, new company

Figure C-3
Adara Power installed system design

Table C-2
Adara Power key characteristics

Primary Provider	**Adara Power**
System Type	**Hybrid**
System Coupling	**DC Battery**
inverter make/ model	Schneider Conext
battery/bms make/ model	Samsung
data acquisition & control	Adara
power continuous (kW)	5.5
power (kW)	5.5
energy (kWh)	8.6
Lifetime full cycles	6000
Depth of discharge (DoD)	80%
Round-trip efficiency (RTE)	89%
availability	PG&E Territory
key applications	self-cons, backup, arbitrage,
duration (energy capacity/hours of discharge)	C/2

Delta

Turnkey Solution Provider

Delta Corporation, based in Taiwan, has its origins in power control systems, but announced a complete battery energy storage system in mid-2015. Delta has independent business units designing and marketing residential energy storage solutions in Poland, Taiwan, and Germany. To meet U.S. market requirements, the firm has retained a German design company, R&D Group.

An example of an anticipated US installed system is illustrated in Figure C-4.

Relative Strengths	Other Considerations
• 30 years of experience with PCS	• Product designed initially for non-US markets: Europe-Middle East-Africa (EMEA) and Asia-Pacific (APAC)

Figure C-4
Delta System Wall-Mounted Unit

E-Gear

Turnkey Solution Provider

One path to offering a turnkey solution is for a single-component provider to team with others to offer a full system. In this case, E-Gear is the EMS developer, while the PCS is an Eguana product, and the storage system comes from LG Chem. Figure C-5 and Table C-3 illustrate E-Gear's positioning in the component array. In addition to providing a full system, E-Gear's configuration allows for a hardware solution that can provide EMS functionality without smart meters. Both factors serve to improve the company's position in the market. In Hawaii, the company has also worked closely with HECO on interconnection studies.

Relative Strengths	Other Considerations
• Fully integrated turnkey system • For Hawaii installations • specific designs for the climate and latitude • approved supplier to HECO	• Potentially more expensive than Eguana system (additional hardware needed to provide PV inverter and utility meter diagnostics)

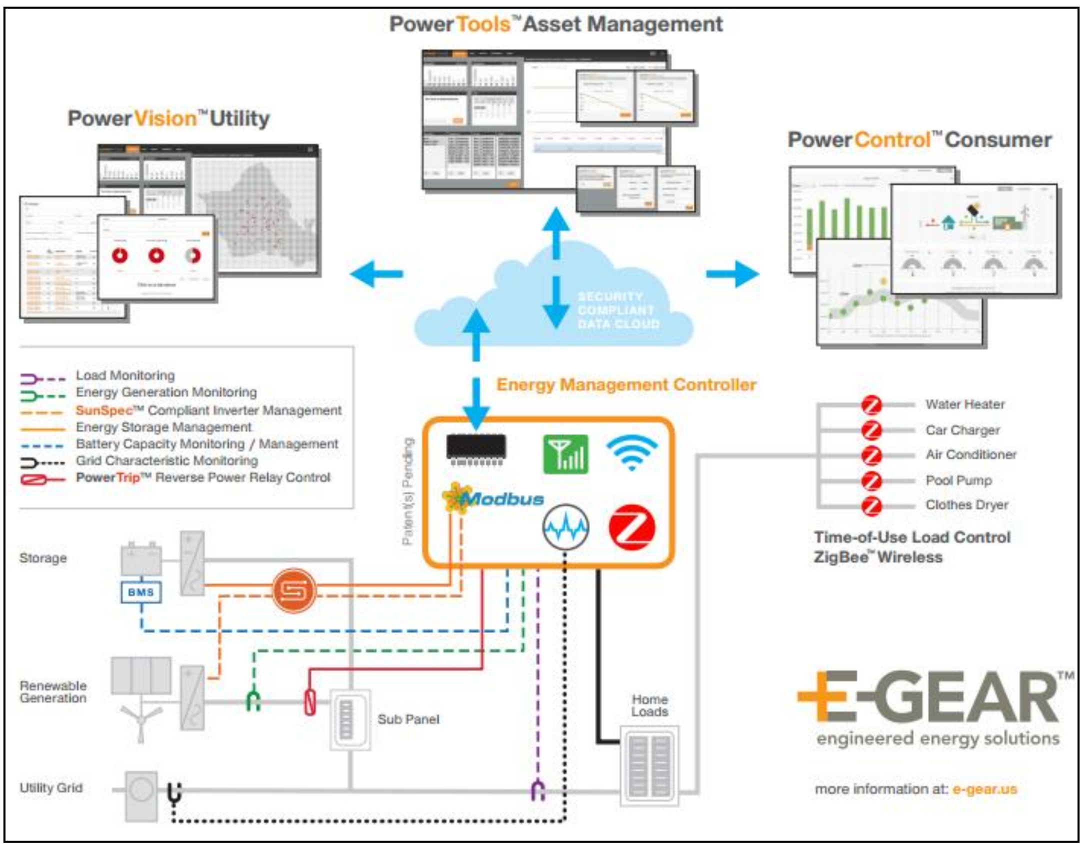

Figure C-5
E-Gear battery energy storage system centered on E-Gear management system.

Table C-3
E-Gear EMS system as employed with Eguana PCS system

Primary Provider	**Eguana**
System Type	**Battery inverter**
System Coupling	**AC Battery**
inverter make/ model	Eguana
battery/bms make/ model	LG (NMC)
data acquisition & control	E-Gear
power continuous (kW)	5.0
power (kW)	5.0
energy (kWh)	6.4
Lifetime full cycles	5250
Depth of discharge (DoD)	90%
Round-trip efficiency (RTE)	89%
availability	US, DE: today (AU/UK:Q4)
key applications	self-cons, backup, arbitrage, grid services
duration (energy capacity/hours of discharge)	C/2

Eguana Technologies

Turnkey Solution Provider

Eguana designs and manufactures power conversion and control systems for distributed energy storage. The company now offers a combined system with LG batteries and an E-Gear EMS to serve customers seeking to operate for self-consumption (zero grid export), for backup power, or for time of use (TOU) energy arbitrage. The control systems employ an open platform communication system and API integration for command and control implementations where utility signaling may come into play for reactive power, power factor control, frequency regulation, ramping, or other demand-side energy management services. Figure C-6 and Table C-4 illustrate Eguana's concept for delivering an AC-connected battery system.

Based in Canada, Eguana has manufacturing facilities in Calgary, Canada and Durach, Germany. The company has over 10 years of experience with solar PV, fuel cells, and battery technologies. In 2014, Eguana shipped more than 3,000 units in Europe. Eguana is now seeking to enter U.S. markets in California and Hawaii, as well as markets in the UK and Australia.

In the past, Eguana has focused on fleet operators, providing the PCS itself and integrating with LG battery systems. At present, the company's own product is agnostic with respect to available EMS, maintaining an open platform.

More recently, Eguana has supported SunEdison's Advanced Solutions efforts in the first dozen units deployed at California's first Zero Net Energy (ZNE) demonstration project. EPRI is the project manager, responsible for technology selection and due diligence. The ZNE project integrates storage, solar PV, smart heat pumps, smart appliances, and disaggregated load metering, all equipped to offer demand reduction services.

Relative Strengths	Other Considerations
• Wall mountable • Outdoor rated • Market experience • Open data platform • Partner firm offers low-cost storage technology • All components in one system • Also reliable in off-grid installations	• PCS uses a transformer, so component is relatively heavy (300 pounds)

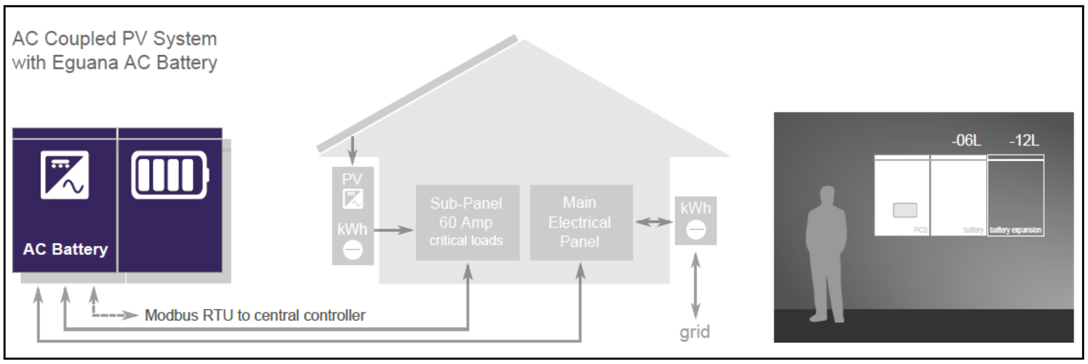

Figure C-6
Eguana system configuration concept.

Table C-4
Eguana key characteristics and costs

Primary Provider	Eguana
System Type	Battery inverter
System Coupling	AC Battery
inverter make/ model	Eguana
battery/bms make/ model	LG (NMC)
data acquisition & control	E-Gear
power continuous (kW)	5.0
power (kW)	5.0
energy (kWh)	6.4
Lifetime full cycles	5250
Depth of discharge (DoD)	90%
Round-trip efficiency (RTE)	89%
availability	US, DE: today (AU/UK:Q4)
key applications	self-cons, backup, arbitrage, grid services
duration (energy capacity/hours of discharge)	C/2

Enphase

Turnkey Solution Provider

Enphase has a strong history in providing micro-inverters for photovoltaic systems, and has been working on new developments for storage. The company has lab-demonstrated a 2017 AC Battery product. At present, the company's marketing focus is on Australia, but it has also begun a parallel effort to develop deployments in Hawaii and then in the UK and France. The initial deployments are planned as solar plus storage systems (using Enphase PV products), with the intent of offering a modular product capitalizing on the company's installation experience.

The module design is relatively small, offering 270 W/1.2 kWh per module, but the system economics may be favorable, given that the company can take advantage of economies of scale by using the same inverters used in their PV systems (Figure C-7 and Table C-5).

Relative Strengths	Other Considerations
• Flexible modular design • Reliable in both grid-connected and off-grid installations • Scalable • All components in one system	• Relatively small units sized at 250 W and 1.2 kWh (households in the U.S. would require 3-5 units • Do not yet offer a backup power feature (but planned for 2017)

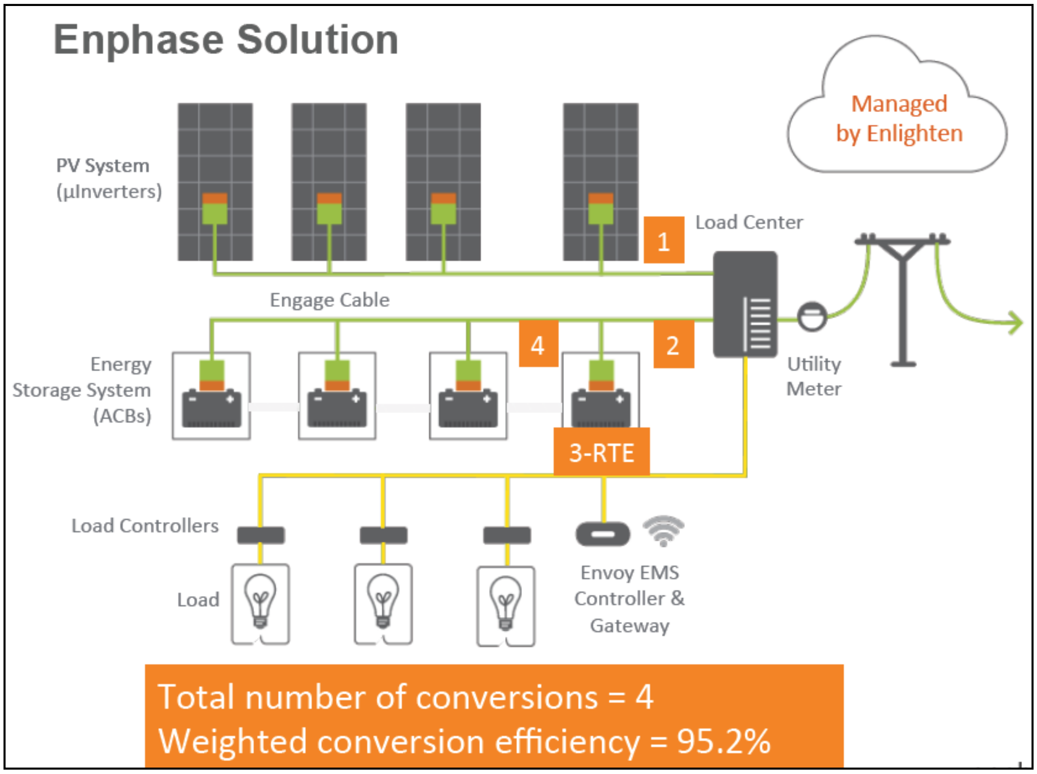

Figure C-7
Enphase integrated solar and battery system schematic

Table C-5
Enphase key characteristics

Primary Provider	Enphase
System Type	Battery inverter
System Coupling	AC Battery
inverter make/ model	Enphase
battery/bms make/ model	EliiY (LFP)
data acquisition & control	Envoy S
power continuous (kW)	1.2
power (kW)	1.2
energy (kWh)	6.0
Lifetime full cycles	5000
Depth of discharge (DoD)	90%
Round-trip efficiency (RTE)	95%
availability	AU (2Q16), US (4Q16)
key applications	self-cons, arbitrage
duration (energy capacity/hours of discharge)	C/4

Fronius

Turnkey or Partial Solution Provider (PCS and EMS)

Fronius markets two inverter units, the Primo (single phase) and the Symo Hybrid (three phase) (Figure C-8 and Table C-6). Both are designed to take input either from a solar array or from a system's battery bank, so that the residence is supplied by the most readily-available energy source, with the grid as backup. The available capacity range is 3.0 kW to 5 kW.

Fronius offers multiple configurations for integrating their Hybrid inverters into grid-connected solar PV systems:

- Both solar array and battery bank connected directly to the Hybrid unit
- Solar-only system (allowing homeowner to retrofit a battery system later)

Fronius has its own battery component, a reconfigured Sony battery using lithium-iron phosphate (LiFePO4) technology. Fronius specifications state that their Solar Battery supports up to 8000 cycles and provides very high charge and discharge rates. The battery is rated for indoor installation.

The company also supports a partial-provider approach, recommending linking their Fronius Hybrid system and EMS with a Tesla (TSLA) battery system. In either configuration, the battery component is modular, with size ranging from 4.5 kWh to 12.0 kWh. The energy management system includes online monitoring for the solar and battery operations.

Relative Strengths	Other Considerations
• With Sony battery system: highly-ranked battery, high cycle life, field-proven battery technology • With TSLA battery system: strong market appeal, costs strongly anticipated to fall	• For Sony battery system: not outdoor rated, large storage footprint, costly • For TSLA battery system: integration with Fronius Hybrid system is not yet proven • Fronius EMS is not highly rated

Figure C-8
Fronius Turnkey system using Sony battery under Fronius brand

Table C-6
Fronius key characteristics

Primary Provider	**Fronius**
System Type	**Hybrid**
System Coupling	**DC Battery**
inverter make/ model	Symo Hybrid 5.0-3-S
battery/bms make/ model	Sony (LFP)
data acquisition & control	Fronius Smart Meter & DAS
power continuous (kW)	5.0
power (kW)	5.0
energy (kWh)	6.8
Lifetime full cycles	6000
Depth of discharge (DoD)	90%
Round-trip efficiency (RTE)	89%
availability	AU (4Q15)
key applications	self-cons only
duration (energy capacity/hours of discharge)	C/2

Gexpro

Turnkey Solution Provider

Gexpro is a part of Rexel, a large international electrical distributor that operates in over eighty branches in the United States. This allows the company to combine productivity tools, maintain large local inventories, and offer dedicated product specialists to the US market. Some small, early-to-market integrators offering solar plus storage have reported they plan to utilize Gexpro as a distributor for their products.

At present, Gexpro offers two bundles which provide turnkey solutions (see Figure C-9). For residential markets, they use an Eguana PCS, LG Chem battery system, and an EMS by Geli. In commercial markets, the PCS is by Ideal Power instead of Eguana.

Relative Strengths	Other Considerations
• Turnkey solution • Fully-developed package • Experience distribution process	• High cost, due to distribution packaging margins

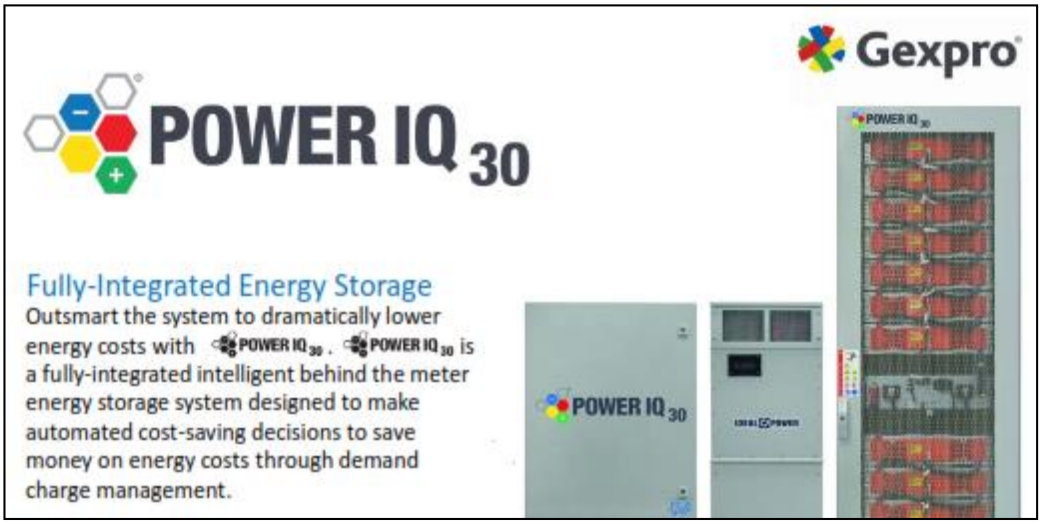

Figure C-9
Gexpro system components

JLM

Partial Solution Provider: Storage, EMS

JLM Energy, based in Northern California, was founded in 2007 and has shown significant growth since 2011, with 50 employees in California and Arizona. JLM provides battery systems and control systems for demand management (Figure C-10). The company has focused its efforts on developing aesthetic product designs for indoor installations, consistent with a longer-term company focus on niche products in renewable energy. However, the firm has not yet demonstrated a reliable, scalable system.

Relative Strengths	Other Considerations
• Aesthetic design • Relatively easy installation	• Indoor-rated only • Early-stage start-up manufacturing processes (requires close evaluation) • Unproven reliability • Relatively high-risk investment

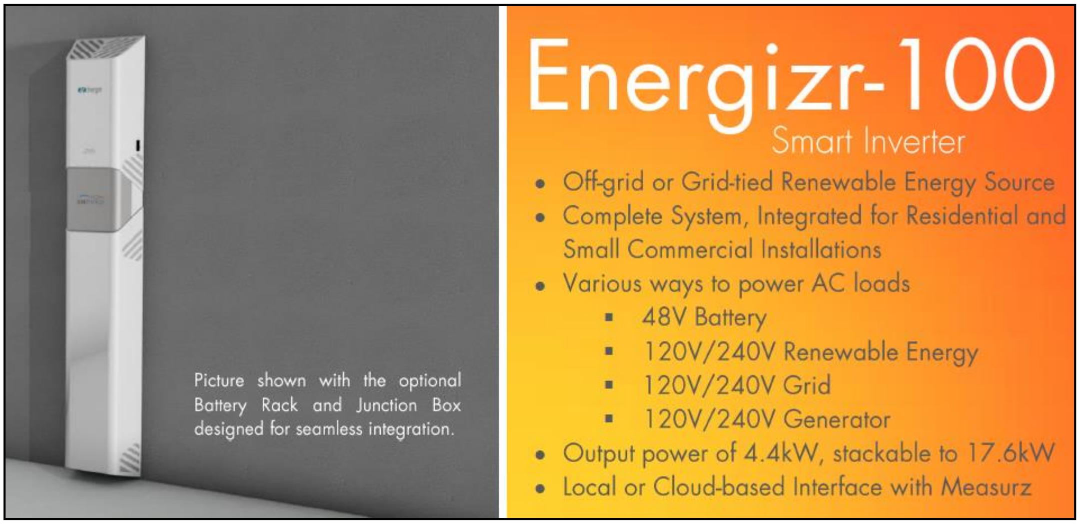

Figure C-10
JLM battery systems

LG Chem

Partial Solution Provider: PCS, Storage

LG Chem is currently a partial-solution provider, but intends to develop and market a turnkey solution in 2016. In the U.S. market, LG Chem has partnered with Eguana, Gexpro, and E-Gear to provide complete systems. At the same time, in Europe, Asia, and the Pacific, LG has been developing more-complete offerings, beginning with a battery system having its own EMS, leaving the system agnostic towards PCS vendors. The company is now designing its own all-in-one system; the battery/BMS portion is currently undergoing testing in Australia (Figure C-11). The next generation is anticipated to offer a flexible form factor. Table C-7 shows how LG batteries have been incorporated in a range of both AC-coupled and DC-coupled storage solutions.

Relative Strengths	Other Considerations
• Smallest footprint/highest package density on the market • Both DC and AC coupled varieties in development • strong integration between PCS and BMS	• Currently indoor rated only • EMS integration options yet to be defined (experience w/ integration challenges w/ beta product)

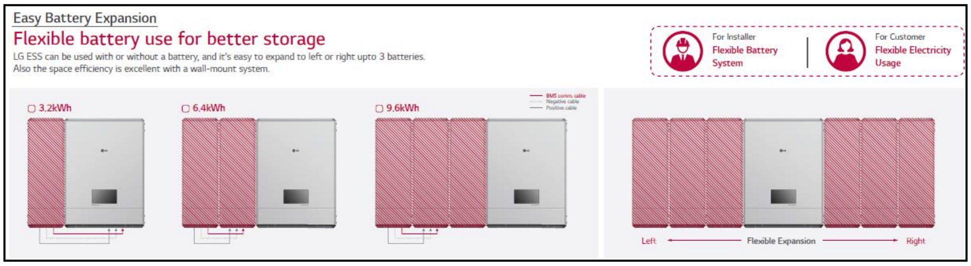

Figure C-11
LG battery system configurations

Table C-7
Key characteristics for a variety of systems employing LG batteries.

Primary Provider	**Eguana**	**SMA SI**	**Outback**	**SMA hybrid**	**SunGrow**
System Type	**Battery inverter**	**Battery inverter**	**Battery inverter**	**Hybrid**	**Hybrid**
System Coupling	**AC Battery**	**AC Battery**	**AC Battery**	**DC Battery**	**DC Battery**
inverter make/ model	Eguana	Sunny Island	Outback Radian A	SI 6.0H	SunGrow SH5K
battery/bms make/ model	LG (NMC)	LG (NMC)	LG (NMC)	LG (NMC)	LG (NMC)
data acquisition & control	E-Gear	SMA	Outback	SMA	not specified
power continuous (kW)	5.0	4.5	4.0	6.0	5.0
power (kW)	5.0	4.5	5.0	6.0	5.0
energy (kWh)	6.4	6.4	6.4	6.4	6.4
Lifetime full cycles	5250	5250	5250	6000	6000
Depth of discharge (DoD)	90%	90%	90%	90%	90%
Round-trip efficiency (RTE)	89%	89%	89%	89%	89%
availability	US, DE: today (AU/UK:Q4)	global, today	global, today	Australia only	AU (4Q15)
key applications	self-cons, backup, arbitrage, grid	self-cons, backup	self-cons, backup, arbitrage, grid	self-cons, backup	self-cons only
duration (energy capacity/hours of discharge)	C/2	C/2	C/2	C/2	C/2

Outback Power

Partial Solution Provider: PCS and EMS

Outback Power, based in Arlington, Washington, offers both off-grid and grid-connected inverters and control systems, together with integrated EMS components. The company's product focus and core competency remains in the PCS environment, but they have expanded recently into the integrated EMS space. Their products are agnostic to battery technology. The company reports testing both flow batteries and Lithium-ion batteries; however, their most-developed systems are tied to lead-acid batteries, and for such systems the company provides a substantial warranty (Figure C-12 and Table C-8).

Outback's product development team plans a new model for late-2016 release, aiming to lower Balance of System (BOS) costs, improve thermal cut-off (for lithium-ion configurations), and reduce installation times.

Relative Strengths	Other Considerations
• Legacy systems with demonstrated reliability under harsh microgrid conditions • Open protocol data communications for EMS • Agnostic to battery technology	• Cost-prohibitive • Challenging installation due to many components

Figure C-12
An Outback Power installation with lead-acid batteries.

Table C-8
Outback Power key characteristics

Primary Provider	**Outback**
System Type	**Battery inverter**
System Coupling	**AC Battery**
inverter make/ model	Outback Radian A
battery/bms make/ model	LG (NMC)
data acquisition & control	Outback
power continuous (kW)	4.0
power (kW)	5.0
energy (kWh)	6.4
Lifetime full cycles	5250
Depth of discharge (DoD)	90%
Round-trip efficiency (RTE)	89%
availability	global, today
key applications	self-cons, backup, arbitrage, grid services
duration (energy capacity/hours of discharge)	C/2

Panasonic

Partial Solution Provider: Battery, EMS

Panasonic's residential storage battery system uses Lithium-ion technology and is designed to be installed with existing residential photovoltaic (PV) systems (Figure C-13). The standalone storage battery allows for daytime excess PV power to maximize the self-consumption of PV-generated electricity. The unit also features a backup function to provide AC power during a blackout situation. For applications where peak load management and demand reduction (DR) are important, the company has developed a network adapter with a DR-EMS Platform. Table C-9 illustrates use of Panasonic batteries within SolarEdge and ABB storage systems.

Relative Strengths	Other Considerations
• Bankable • Experienced in Japanese and Australian markets • Aggressive pricing • All-in-one design for PV and Storage	• Design has a heavy, spacious form factor that is also inflexible • Inflexible on PV and storage sizing (2 kw peak/8 kWh) • Still waiting for a 60Hz product for the U.S. market

Figure C-13
Panasonic battery unit.

Table C-9
Key characteristics of systems employing Panasonic batteries.

Primary Provider	**SolarEdge: Global**	**SolarEdge: U.S.**	**ABB**
System Type	**Hybrid**	**Hybrid**	**Battery inverter**
System Coupling	**DC Battery**	**DC Battery**	**AC Battery**
inverter make/ model	SolarEdge	SolarEdge	ABB
battery/bms make/ model	TSLA/Panasonic (LMO)	TSLA/Panasonic (LMO)	Panasonic
data acquisition & control	SEDG	SEDG	ABB
power continuous (kW)	3.3	3.3	4.6
power (kW)	3.3	3.3	4.6
energy (kWh)	6.4	6.4	6.0
Lifetime full cycles	3650	3650	4500
Depth of discharge (DoD)	80%	80%	80%
Round-trip efficiency (RTE)	92%	92%	93%
availability	DE/AU/UK: 1Q16	US: 4Q15	global, 2015
key applications	self-cons, arbitrage	self-cons, arbitrage, backup	self-cons, backup, grid
duration (energy capacity/hours of discharge)	C/2	C/2	C/2

Samsung

Turnkey Solution Provider

Samsung was one of the first top-tier battery manufacturers to offer an all-in-one solution. The system is packaged in three modules to suit single-phase and three-phase applications (Figure C-14 and Table C-10).

Relative Strengths	Other Considerations
• Simplified package • Easy installation • Serviceable	• Specifically designed for new construction (i.e., not easily retrofitted to existing solar) • Proprietary data communication protocol (though a Modbus implementation is planned for 2016)

Figure C-14
Range of Samsung battery modules.

Table C-10
Samsung key characteristics and costs

Primary Provider	Samsung
System Type	Hybrid
System Coupling	DC Battery
inverter make/ model	Samsung
battery/bms make/ model	Samsung SDI
data acquisition & control	SEDG
power continuous (kW)	5.0
power (kW)	5.0
energy (kWh)	7.2
Lifetime full cycles	5000
Depth of discharge (DoD)	80%
Round-trip efficiency (RTE)	92%
availability	US: 4Q15
key applications	self-cons, arbitrage, backup
duration (energy capacity/hours of discharge)	C/2

SMA

Component Provider: PCS

SMA's Sunny Island units have been deployed since 2004, typically with deep-cycle lead-acid batteries. Currently, these backup and off-grid systems may also be coupled with Lithium-ion solutions. Similar to Outback Power's installations, SMA's widespread use gives the company a strong position as one with relatively long field experience. The yellow battery inverter shown in Figure C-15 has the largest European installation base for solar and storage. In early 2014, SMA entered the German market with a compact, all-in-one solution utilizing LG batteries (Table C-11). To compete effectively, the firm needed to reduce prices by 30%. This all-in-one solution is not yet available in the U.S.

Relative Strengths	Other Considerations
• Largest global installed base • Longest operating units • Well integrated with SMA solar inverters • Battery chemistry agnostic	• Proprietary protocol: standard adaptors are not adequately supported • Does not integrate well with non-SMA solar installations • Relatively high cost solution

Figure C-15
SMA's Sunny Island system.

Table C-11
SMA key characteristics

Primary Provider	**SMA SI**	**SMA hybrid**
System Type	**Battery inverter**	**Hybrid**
System Coupling	**AC Battery**	**DC Battery**
inverter make/ model	Sunny Island	SI 6.0H
battery/bms make/ model	LG (NMC)	LG (NMC)
data acquisition & control	SMA	SMA
power continuous (kW)	4.5	6.0
power (kW)	4.5	6.0
energy (kWh)	6.4	6.4
Lifetime full cycles	5250	6000
Depth of discharge (DoD)	90%	90%
Round-trip efficiency (RTE)	89%	89%
availability	global, today	Australia only
key applications	self-cons, backup	self-cons, backup
duration (energy capacity/hours of discharge)	C/2	C/2

SolarEdge/Tesla

Partial Solution Provider: Solar Edge PCS and EMS

Turnkey Solution Provider: Solar Edge PCS and EMS with Tesla Battery

In early 2015, Tesla set a goal to deliver a residential storage product with an installed cost of $3,000 (for self-consumption) or $3,500 (for backup applications). However, as of the close of the year, that target had not been yet reached. The package was intended for initial launch in Australia, after completion of vendor testing. The Tesla Powerwall design provides a relatively low power rating per module (2 kW/6.4 kWh), for self-consumption purposes (Figure C-16).

Tesla's CTO has projected that production volumes of 50,000 units would allow for premium pricing options. Similar systems designed for European markets (self-consumption only) have lower costs, by about 10%, than those designed for the US. The difference is due to the requirement for a load balancing transformer for split-phase environments in addition to labor costs to install a critical load panel.

This SolarEdge/Tesla product is a new offering. Although there had been reports that Tesla was developing an inverter to support the battery, SolarEdge was selected to provide the integrated PCS and EMS (Table C-12). Fronius is also being considered as a secondary option for Tesla batteries, most likely for deployments in Australia and European markets, although this would directly compete with Fronius' own turnkey solution, which employs Sony batteries. Tesla has developed an EMS for their commercial and grid-scale Powerpack product, which ultimately could lead to a turnkey residential Powerwall solution.

Tesla's battery warranty coverage declines significantly over time and does not cover the full 7 kWh storage capability. For the first two years or 740 cycles (whichever comes first), the warranty covers 85 percent of 6.4 kilowatt-hours (i.e., 5.4 kilowatt-hours) of capacity. For the next three years or 1,087 cycles, the warranty covers 4.6 kWh. For the next five years or 2368 cycles, it covers 3.8 kWh.

Relative Strengths	Other Considerations
• High marketing appeal (due to market tie-in with Tesla Electric Vehicles) • Top-tier cost roadmap • Integrates with SolarEdge	• Tied to SolarEdge for initial launch (dependent on integration and SEDG EMS) • Liquid-cooled (adds points of failure with liquid circulating pump) • North American deployment requires external devices to realize backup power (negative effects on to aesthetics and balance-of-system costs)

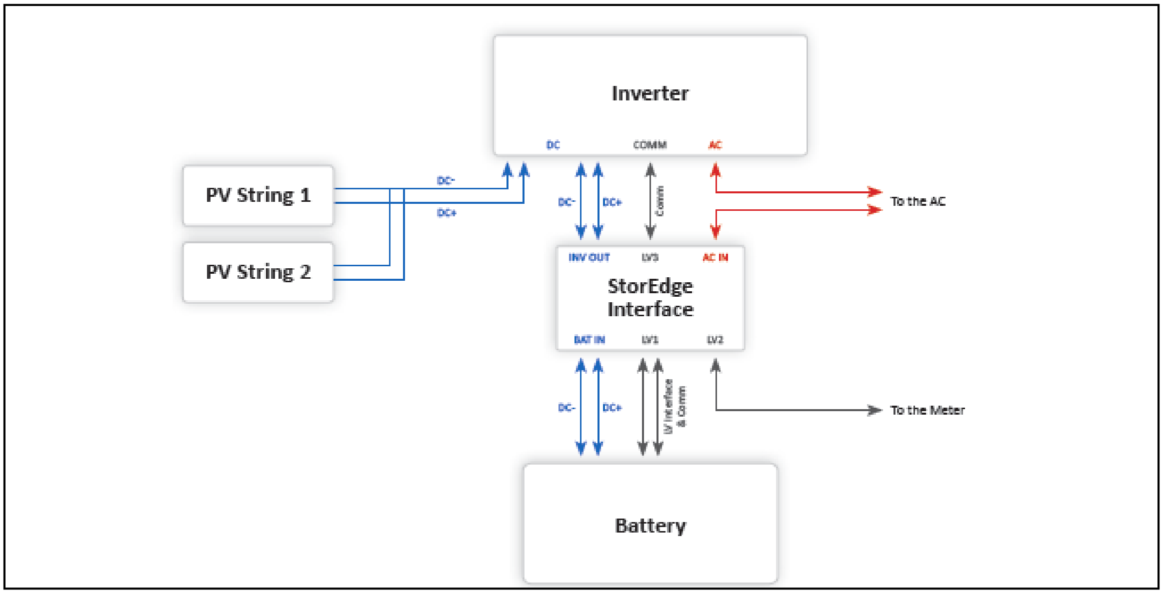

Figure C-16
SolarEdge/Tesla configuration plan

Table C-12
SolarEdge/Tesla key characteristics

Primary Provider	**SolarEdge: Global**	**SolarEdge: U.S.**
System Type	**Hybrid**	**Hybrid**
System Coupling	**DC Battery**	**DC Battery**
inverter make/ model	SolarEdge	SolarEdge
battery/bms make/ model	TSLA/Panasonic (LMO)	TSLA/Panasonic (LMO)
data acquisition & control	SEDG	SEDG
power continuous (kW)	3.3	3.3
power (kW)	3.3	3.3
energy (kWh)	6.4	6.4
Lifetime full cycles	3650	3650
Depth of discharge (DoD)	80%	80%
Round-trip efficiency (RTE)	92%	92%
availability	DE/AU/UK: 1Q16	US: 4Q15
key applications	self-cons, arbitrage	self-cons, arbitrage, backup
duration (energy capacity/hours of discharge)	C/2	C/2

Solarwatt

Component Provider: Battery

Solarwatt's MyReserve 500 battery and control unit was launched in 2015 to serve as a plug-and-play storage component to compatible off-the-shelf PV systems (Figure C-17). It is designed to tie in to a DC-coupled, bidirectional, hybrid string inverter. To date, the system has been marketed primarily in Europe, with German utility E.ON having adopted this battery system for a planned major deployment of storage.

Relative Strengths	Other Considerations
• History of design and manufacturing partnerships with BMW and Bosch (Based in Dresden, Germany) • Standards compliant • (DIN, UN, CE, KIT) • Accredited and tested • Modular and flexible design • String inverter agnostic	• Battery and BMS only • DC-coupled only at 93% efficiency • Protection rating: indoor only (IP31)

Figure C-17
Solarwatt battery module

Sonnen

Turnkey Solution Provider

Sonnen battery product's share in Germany's storage market is currently about 40 percent, with more than 8,300 lithium-ion based battery systems installed there. The company is now seeking to enter U.K., Italian, and U.S. markets. In the U.S., the primary target is the Los Angeles region, to take advantage of an early-adopter market willing to pay relatively high installed costs. This strategy poses some risks as these early markets reach market saturation. A recently-developed partnership with solar developer Sungevity may be a response to ameliorate such risks, as well as to actively translate their operations and processes to suit the U.S. customer base.

Selling points include a long cycle life and design to support independent power producers (IPPs), virtual power plant operation (VPP), and aggregation of distributed energy resources (DERs) (Figure C-18 and Table C-13). For the battery component, Sonnen claims a 10,000-cycle life. This is understood to be the result of operating the Sony Fortelion battery at ±10%, balancing near a 50% state of charge (SOC). The software system is known to support virtual power plant capabilities similar to those offered by LichtBlick, another German energy storage player.

Relative Strengths	Other Considerations
• Fully integrated and turnkey system	• High cost • Designed for German market (growing pains anticipated on entering U.S. market)

Figure C-18
Product sample: sonnenBatterie

Table C-13
Sonnen's sonnenBatterie system key characteristics

Primary Provider	**Sonnen**
System Type	**Battery inverter**
System Coupling	**AC Battery**
inverter make/ model	Outback
battery/bms make/ model	Sony
data acquisition & control	Sonnen
power continuous (kW)	5.0
power (kW)	5.0
energy (kWh)	6.0
Lifetime full cycles	6000
Depth of discharge (DoD)	80%
Round-trip efficiency (RTE)	89%
availability	Germany, today; US, 1Q16
key applications	self-cons, backup, arbitrage, grid services
duration (energy capacity/hours of discharge)	C/2

Sungrow

Component Provider: PCS (integrated with LG Chem batteries)

Initially rolling out under a partnership with Samsung, Sungrow has deployed hundreds of units to early market adopters in the Asia-Pacific region. Sungrow's own product is undergoing testing in Australia (as of October 2015), working toward meeting global standards for data communication protocols and integrating with LG Chem's outdoor-rated batteries. The company's energy storage solution is now being introduced to the North American market. Sungrow's strategy in the storage market is to target simplified, open-protocol, product lines with the most competitive costs (Figure C-19 and Table C-14).

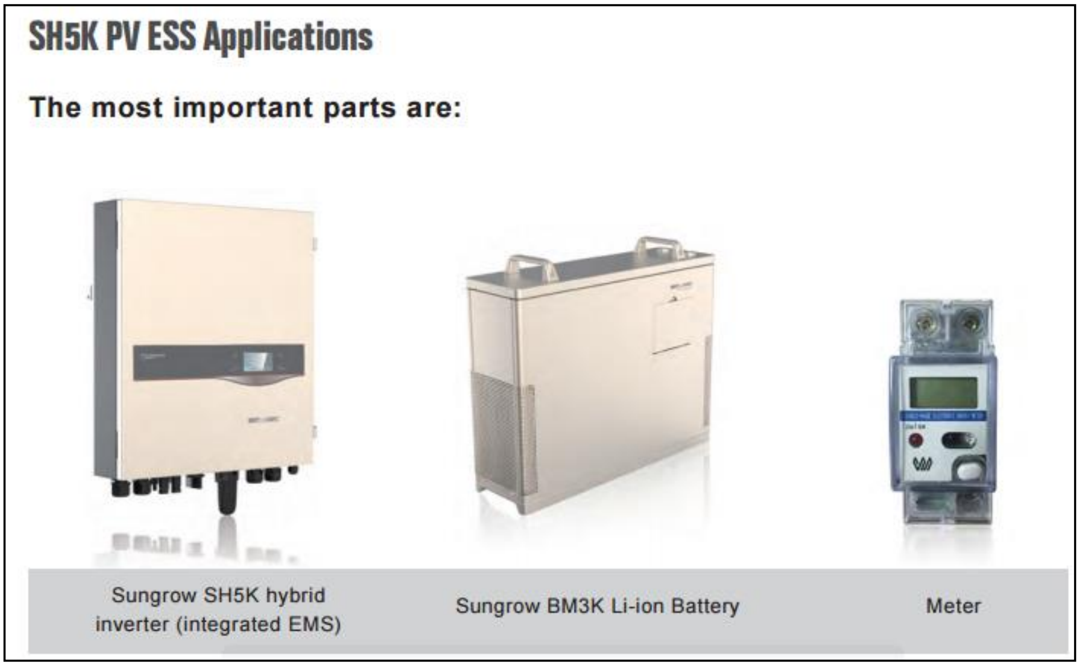

Figure C-19
Sungrow integrated system components

Relative Strengths	Other Considerations
• Most cost-competitive DC-coupled solution on the market • Agile development team • Technology agnostic	• Does not offer an integrated solution

Table C-14
Sungrow key characteristics and costs.

Primary Provider	SunGrow
System Type	Hybrid
System Coupling	DC Battery
inverter make/ model	SunGrow SH5K
battery/bms make/ model	LG (NMC)
data acquisition & control	not specified
power continuous (kW)	5.0
power (kW)	5.0
energy (kWh)	6.4
Lifetime full cycles	6000
Depth of discharge (DoD)	90%
Round-trip efficiency (RTE)	89%
availability	AU (4Q15)
key applications	self-cons only
duration (energy capacity/hours of discharge)	C/2

Sunverge

Turnkey Solution Provider

As of 2015, Sunverge had installed 400 operational systems globally. The product has performed well in demonstration projects with investor-owned utilities and municipal utilities in North America, including Southern California Edison (SCE) and the Sacramento Municipal Utility District (SMU) in California, as well as projects in Kentucky and Ontario. The company has recently entered a new market in Australia, winning bids with Ergon and now supplementing AGL's original plans to go with Panasonic.

Sunverge has positioned itself to be a software services provider, aggregating and orchestrating virtual power plant fleets. To that end, they have elected to package a relatively vintage-technology hardware stack with reliable off-the-shelf components (Figure C-20 and Table C-15). Recognizing that providing grid services is important, they are now developing an AC Battery version. The company has also targeted reducing the total cost of ownership and is aiming for an installed cost under $900/kWh, though current models are relatively high-cost.

Relative Strengths	Other Considerations
• Top-tier • Globally demonstrated and operational assets • Reliable off-shelf components	• Dependent on third-party suppliers for PCS • Legacy product • Bulky form factor • Difficult to install (fork lift required) • Cost prohibitive as of 2015

Front View (Open Door)
73" (186cm) x 34" (86cm) x 14" (36cm)

Figure C-20
Sunverge turnkey unit

Table C-15
Sunverge key characteristics and costs

Primary Provider	Sunverge
System Type	Hybrid
System Coupling	DC Battery
inverter make/ model	Schneider Conext
battery/bms make/ model	Kokum
data acquisition & control	Sunverge
power continuous (kW)	5.5
power (kW)	5.5
energy (kWh)	8.6
Lifetime full cycles	6000
Depth of discharge (DoD)	80%
Round-trip efficiency (RTE)	89%
availability	US, AU
key applications	self-cons, backup, arbitrage, grid
duration (energy capacity/hours of discharge)	C/2

Tabuchi

Turnkey Solution Provider

Tabuchi Electric, a well-established PCS provider, now offers its own complete-system solution (Figure C-21). A 5.5 kW bi-directional inverter is paired with a 10 kWh lithium-ion battery and BMS. The EMS is comprehensive, providing monitoring of home energy loads, battery operation, and solar production. The system can be operated for self-consumption, as backup power, or to take advantage of Time of Use or feed-in tariffs to minimize net costs of electricity. The EMS has a set of direct connections for managing and monitoring major loads, such as air conditioning.

The battery system is marketed as part of a solar-plus-battery all-in-one product. About 1,000 such systems have been installed in Japan, and the company is working to grow into the US and Canada. For example, to comply with California guidelines, Tabuchi provides a 10-year guarantee.

Relative Strengths	Other Considerations
• Well-established company • Over 10,000 PCS systems installed • Robust manufacturer	• Relatively basic EMS: no wireless data acquisition • Large footprint, bulky system difficult to install at scale

Figure C-21
Tabuchi Electric solar inverter and battery system

Framework for Technology Comparison

Normalized Comparisons of Lifetime Cost

Operating characteristics are important to understanding the value of battery storage for PV installations and distributed energy resource management. Local tariffs determine the ongoing economic benefits of operating a given battery system. However, initial costs are key to the potential for investment in storage. This section describes a methodology for comparing battery systems on a cost basis.

A complete battery storage system consists of four basic cost elements: PCS, EMS, battery/BMS, and installation. Each of these elements is subject to significant variation among vendors, depending on the type of technology, the depth of company experience in the product, manufacturing systems, and product distribution networks. In addition, within a given product line, costs vary depending on a specific customer's custom design choices and change as companies respond to price competition within given markets. Further, installation costs are driven not only by the physical characteristics of the equipment, but also by site-specific issues ranging from accessibility to local labor costs.

Developing costs for a comparative assessment will be driven by the specific characteristics of a given application. However, one can describe a four-step process for acquiring and using cost data:

1. Publicly-available media reports provide overview information, system comparisons, and general cost data, often in the context of discussing product markets.

2. Industry resources, such as EPRI's team of skilled engineers and subject-matter experts, can provide validation of publicly-available information and guidance on refining cost information.
3. Accessing product-specific and site-linked cost information requires moving on to making direct contact with those solution providers offering products with technical specifications well-suited to the given project.
4. Costs for storage have four key elements: the three system components plus the installation cost. Ongoing discussions with solution providers will include obtaining cost breakdown at least by component, as well as a separate call-out for installation expenses.

For example, EPRI experts developed the sample cases for this report by first gathering representative costs from publicly-available sources, then refining and validating those data through direct discussions with provider representatives. Using pricing model assumptions--in this case assuming preliminary production volumes of 100-500 units--for comparably sized systems, analysts developed comparative cost ranges. This research yielded the cost estimates used in the sample tables presented below, but it is important to note that costs vary significantly depending on both location and site-specific design factors, and that these costs are tied to market conditions and forecasts as of late 2015.

An accurate assessment requires system cost data for complete system solutions. When incorporating providers offering only single-component or partial solutions, the complementary components needed for a full system need to be incorporated in the assessment. To provide reasonable comparisons, the systems being assessed should be of reasonably comparable capacity. For the sample case here, the system size was normalized towards a storage capacity of approximately 6.5 kWh, with power ratings of approximately 5 kW.

Tables C-16 and C-17 summarize example cost-assessment results for a set of five AC-coupled solutions and a set of seven DC-coupled solutions, respectively. For this study, EPRI analysts used market readiness as a preliminary criterion for choosing which solutions to assess in more detail. As of the close of 2015, all but one of the AC-coupled systems were ready for at least one U.S. market, and the remaining one was anticipated to be ready for launch in mid-2016. Similarly, the DC-coupled systems are currently available on the global market, though some were not quite ready for the U.S. market as of the close of 2015.

In these tables, costs are shared in two forms:

- *Total Installed Cost ($/kWh)* is the cost of the system divided by its energy storage capacity (kWh). This view is the most basic form of a unit cost for a system for which the energy capability is the key factor.
- *Installed Cost per kWh delivered* is the total installed cost divided by an estimate of the energy delivered over the lifetime of the battery system: the total number of charge/discharge cycles anticipated multiplied by the round-trip efficiency, the depth of discharge, and the rated storage capacity (kWh). This view allows a comparison of the value of the energy produced via storage with the cost of delivering that energy by other means.

Each component of the system contributes to the total cost, with the shares varying substantially among suppliers. As a reminder, the information reported here is intended to provide a realistic guideline as to what information needs to be sought when contacting a solution provider, and to present a general introduction to the cost breakdown to be expected with a battery energy storage system. An important consideration that emerges from these results is that installation costs can be substantial, contributing between 9% and 20% to the total cost of these systems.

Table C-16
AC-coupled solutions: Comparison of costs for five complete battery storage solutions

	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E
Total Installed Unit Cost (USD/kWh)					
Low	**$825**	**$1,292**	**$1,561**	**$1,599**	**$2,017**
High	**$1,008**	**$1,580**	**$1,908**	**$1,954**	**$2,465**
Share of cost, by component					
Inverter (PCS)	36%	28%	30%	36%	22%
Battery/BMS (including cabinet)	44%	39%	39%	38%	52%
Software integration, EMS	11%	22%	18%	9%	11%
Installation	9%	11%	18%	18%	15%
Installed Cost per kWh Delivered * = Installed Cost / (Lifetime cycles x DoD x RTE) (USD/kWh)					
Low	**$0.19**	**$0.31**	**$0.37**	**$0.38**	**$0.47**
High	**$0.24**	**$0.38**	**$0.45**	**$0.46**	**$0.58**

** Note: the Installed Cost per kWh Delivered is an average cost for energy production over the battery system lifetime. It serves as a relative metric for comparing similar products but would not be the sole criterion applied in a value assessment.*

Table C-17
DC-coupled solutions: Comparison of costs for seven complete battery storage solutions.

Primary Provider	Vendor F	Vendor G	Vendor H	Vendor I	Vendor J	Vendor K	Vendor L
Total Installed Unit Cost (USD/kWh)							
Low	**$804**	**$844**	**$998**	**$1,088**	**$1,111**	**$1,622**	**$1,850**
High	**$983**	**$1,031**	**$1,220**	**$1,330**	**$1,358**	**$1,983**	**$2,261**
Share of cost, by component							
Inverter (PCS)	23%	20%	37%	25%	33%	17%	19%
Battery/BMS (including cabinet)	51%	50%	42%	46%	39%	64%	71%
Software integration, EMS	9%	5%	0%	14%	17%	6%	4%
Installation	17%	25%	21%	14%	11%	13%	7%
Installed Cost per kWh Delivered * = Installed Cost / (Lifetime cycles x DoD x RTE) (USD/kWh)							
Low	**$0.17**	**$0.31**	**$0.37**	**$0.25**	**$0.30**	**$0.38**	**$0.38**
High	**$0.20**	**$0.38**	**$0.45**	**$0.31**	**$0.37**	**$0.46**	**$0.47**

** Note: the Installed Cost per kWh Delivered is an average cost for energy production over the battery system lifetime. It serves as a relative metric for comparing similar products but would not be the sole criterion applied in a value assessment.*

As the tables show, costs for battery systems cover a wide span, depending on a variety of factors. To a certain extent, costs are driven by features offered. For instance, the least-cost AC system in Table C-16 does not include the capability to be used as a backup power system. EMS features vary substantially in features offered, from basic data monitoring to interactive wireless communication systems. The choice of battery technology affects costs: more-advanced chemistries may offer smaller footprints or higher efficiencies, but at a higher cost. In other cases, a system may be relatively expensive but especially aesthetically appealing to buyers. Providers already well established in markets for one or more components may be able to benefit from manufacturing-scale cost factors. Scale is also a factor in an individual system design; increasing the size of a residential unit from 6 kWh to 12 kWh can reduce the unit cost ($/kWh) by 30%. Installation costs are affected by the physical size of the system, its modularity, and the relative ease of installation for the electrical contractor. In sum, a complete assessment will address more than the total cost of the system.

Comparisons across Multiple Factors

When selecting a system provider, cost is an important factor, but it needs to be weighed against other decision factors. Table C-18 outlines the characteristics of a multi-factor assessment appropriate for battery storage, with general descriptions of the qualities sought under each metric. Installed cost is a key factor, with the best choice offering lowest costs, looking forward. Different systems offer a range of capabilities to integrate operating data with asset management tools. Vendors differ in the extent to which they can provide grid-interconnectivity. They also vary in their ability to support long-term operation (as a lease-based installation may require), in status as industry-approved suppliers, and in the set of features they offer. Residential installations are particularly facilitated by easy installation, ready serviceability, modular components, and designs that allow for both new construction and retrofit installation.

Table C-18
Assessment factors for comparing solution providers

Installed Cost	lowest forward cost curve
Data Integration	ability to integrate with centralized asset management system
Grid Services	demand reduction, fast reserve, local capacity requirements, etc.
Approved Supplier	based on industry-approved vendor list
Features	backup, self-consumption, TOU shifting, demand reduction
Installable	two-person
Serviceable	one-person
Flexible	capable of both new and retrofit installations
Modular	expandable sizing

Converting these factors into an objective metric-based assessment begins by assigning numerical values to the status of a given system with respect to each factor. In this demonstration, each factor may be scored on a scale of 1 to 5, with 1 being the least-desirable condition and 5 being the most-desirable. Table C-19 illustrates this process for three of the factors described above.

Table C-19
Example of setting assessment scores for individual factors.

Weight	Installed Cost (USD/kWh)	Data Integration	Grid Services
5	<1000	Full local data read/write	demonstrated grid support
4	1000-1300	partial local data read/write	partial grid support
3	1301-1500	full API	planned grid support
2	1501-1800	proprietary protocol, no API	potential for grid support
1	<1800	black box	no grid support planned

Applying a rubric developed in this way involves evaluating each candidate system according to each of the factor score definitions in turn, and identifying those candidates with the best overall offering, as indicated by the scores. For example, consider a system with costs in the lowest-price category but performing data integration under a proprietary protocol and offering only limited grid support. This system would earn 5 points for cost, 2 points for data integration, and 4 points for grid services, yielding a total (for this limited subset of metrics) of 11 points. A system at the opposite end of the range of costs but offering fully-operational grid support and complete data integration services would also score 11 points. Incorporating a more-complete set of factors allows the assessment to differentiate between these outcomes.

For a more complete example, Table C-20 presents a representative case. Here, three battery systems are compared based on all nine factors. For this example, an EPRI analyst developed five-point metrics to yield scores on the other seven metrics defined in Table D-16. For each system, these scores reflect costs, features, and general suitability as measured by each metric and as appropriate to a planned application.

Table C-20
Example of a completed assessment using metrics incorporating multiple factors

		Vendor X	**Vendor Y**	**Vendor Z**
Decision Metrics	Installed Cost	*1*	*3*	*5*
	Data Integration	*3*	*5*	*2*
	Grid Services	*5*	*5*	*1*
	Approved Supplier	*1*	*1*	*4*
	Product Availability	*3*	*4*	*2*
	Installable	*2*	*3*	*4*
	Serviceable	*3*	*3*	*3*
	Flexible (AC-coupled)	*5*	*5*	*3*
	Modular	*4*	*3*	*3*

In this example, all results apply to a particular sample site and draw on systems information available as of late 2015. SeeTable 7-3 for examples of metric definitions. The nine factor scores were assigned by an EPRI analyst using defined metrics to describe suitability for this sample case. Note: product names are not provided because this table is intended as an example of applying this methodology, not as purchasing advice.

Studying the array of scores highlights those areas in which one system may excel over others. Such knowledge is helpful because product offerings change over time, as vendors compete to improve their ability to meet these needs. As a result, assessments need to be able to adjust accordingly. In the sample case, Vendor X's system is expensive, but offers substantial grid interconnectivity, while Vendor Z's system has a limited set of grid services, but is inexpensive. Should grid interconnectivity be highly desirable for a given application, the higher cost may be justified.

The assessment scores could be added or averaged to yield a net score, but this may not capture the relative importance of the metrics themselves. If the comparative values of the different metrics are quantified, one can assign weighting factors to apply to the metric scores. For example, to assess a project for which data integration is a critical need and modularity is low priority, one might apply multipliers of 1.5 to the score on data integration, 1.0 on costs, and 0.7 on modularity. In that case, a system with limited modularity, but a sophisticated EMS would receive a relatively high weighted-average score.

Conclusions

As markets for battery energy storage evolve, investment in storage is expanding from early adopters who are relatively insensitive to cost, to purchasers who are seeking to minimize their overall energy costs. Battery storage is becoming an important element in supporting distributed energy resources, such as residential solar installations. At the same time, vendors of battery systems are enhancing their designs and forming cooperative alliances to offer complete, turnkey systems to appeal to a wider range of potential storage users in a global market.

Identifying the most suitable battery energy storage system for a given application requires assessment of the full spectrum of relevant factors:

- *Installed cost.* Vendors with relatively low installed costs tend to use efficient manufacturing and distribution systems.
- *Data integration.* The extent to which energy management systems for battery storage integrate with the customer's other energy management systems improves the customer's ability to maximize benefits from storage.
- *Grid services.* While many existing battery systems were installed as off-grid systems, newer installations are enhanced by grid-connected services.
- *Approval status.* Customer confidence is enhanced when vendors can demonstrate a strong industry reputation through inclusion on an approved vendor list.
- *Features.* To enhance the usefulness of energy storage, vendors offer system design and software features that enable customers to maximize their economic benefits through backup power ability, self-consumption, time-of-use tariffs, demand reduction, and more.
- *Installation and servicing.* Systems that allow simple installation and ongoing easy servicing keep installation and maintenance costs down while supporting a positive customer experience.
- *Flexibility.* Vendors that provide systems that can be installed in both new and retrofit construction offer customers the ability to time their installations for best results.

- *Modularity*. Modular design offers customers the ability to modify installations to suit applications, but without the expense of custom designs.

In the past, use of residential battery energy storage has been concentrated among those needing battery backup for off-grid operation. Currently, integrating residential solar and other distributed energy sources with the grid benefits from battery storage with energy management systems. At the customer side, the benefits accrue as a reduced net cost for electricity. For the utility, storage reduces the impact of injections of power from PV systems, allowing the grid to benefit from a net reduction in demand during peak hours. Utilities interested in supporting deployments of battery energy storage can use the assessment framework described in this report to assist residential customers or developers in selecting among products and features while balancing costs with other decision factors.

In addition to continuing to monitor and evaluate new technologies and solutions as they enter early stages of development, EPRI is demonstrating case studies in real-world contexts. Through the Energy Storage Research Center, a virtual collaborative laboratory designed to test and validate new technologies, members can look toward actual total installed costs, lessons learned from deployment, and objective approaches to combining economic benefits from multiple potential value streams attributable to energy storage.

D
LIST OF MEDIA PUBLICATIONS, ARTICLES AND TECHNICAL PAPERS TRANSFERRING RESULTS OF THIS PROJECT

The following is a list of media publications, articles, presentations and technical papers. The articles were targeted to various stakeholders that included the California IOUs, electric utilities across the United States, the homebuilder community, DER manufacturers and service providers, greenbuilders, the energy research community and the public. This Appendix is not intended to be an exhaustive list, rather a representation of the media outlets that were used as methods of technology transfer for this project. The references are listed in alphabetical order.

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