Grid Integration of Zero Net Energy Communities

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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 achieve Zero Net Energy in new buildings, first residential in 2020, Government buildings in 2025 and commercial by 2030. Zero Net Energy is achieved by substantially driving energy efficiency and offsetting remaining energy use (gas and electric) with PV. ZNE is a near-time (less than 3 years) practical implementation of high PV penetration as most new construction occurs in geographically concentrated areas and impact specific locations of utility distribution systems.

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 Zero Net Energy. EPRI along with Southern California Edison (SCE) worked with Meritage Homes, the 7th largest homebuilder in the US, to design, construct, occupy and monitor these homes.

The load profiles of ZNE homes is similar to the “duck curve” and shown (right) at the single home level. Energy efficiency substantially reduces energy use in morning times, and displaces afternoon peaks to 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 shape will be quite different between spring/fall, winter and summer. The initiative also electrified the heating loads eliminate carbon emissions from fossil fuels, required for reaching the 2050 goals. The peaks and valleys 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 (9 homes in a 50 kVA transformer or 11 homes in a 75 kVA transformer). But, with electrification, 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, and further, the laterals, load blocks and feeders had sufficient capacity with today’s planning methods.

To alleviate distribution impact, these homes were set up with controllable loads and with behind-the-meter energy storage. An aggregation platform was 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 morning, discharge 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 second that modelling tools still have a way to go to address the “needle” peaks that will be more common in our future buildings. The paper will discuss the experiences in developing the community, strategies for DER integration and possible benefits of demand response and energy storage in the future distribution grid.

Keywords

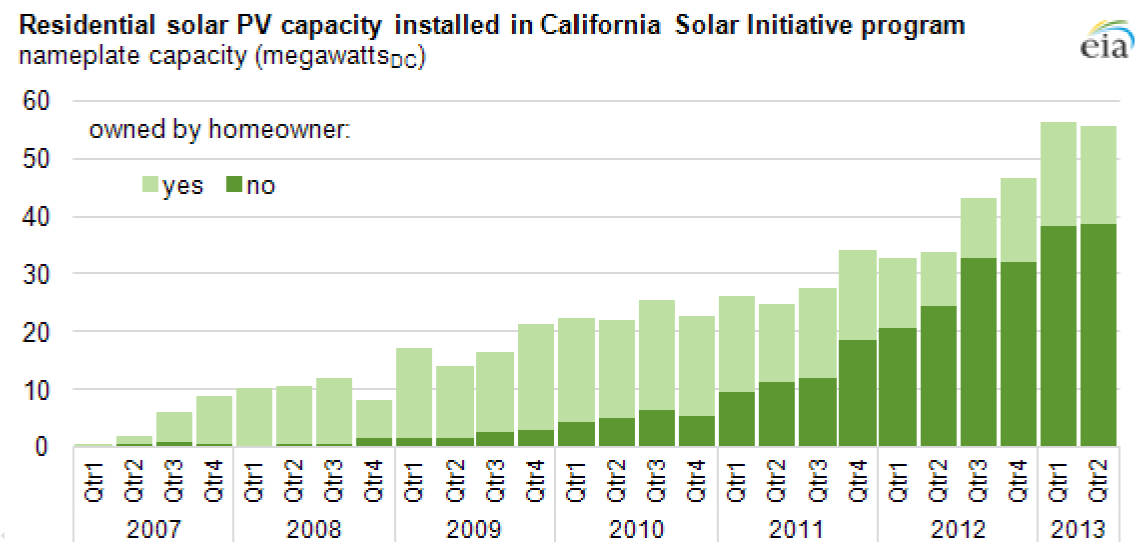
Retail Buildings
Lighting
ZNE
HVAC
Ventilation
Zero Net Energy
Small Business
On-bill financing

EXECUTIVE SUMMARY

As California moves towards its goal of reducing carbon intensity in the energy sector by 80% by 2050, a multi-pronged effort is essential to attaining these goals. The current initiative is aligned with three pathways of great relevance to meeting California's goals:

1. Achieving high penetration of distributed renewables
2. Goal of all new construction being Zero Net Energy by 2020
3. Electrification of end loads to accelerate decarbonization and grid balancing.

Customer side PV has been a great success story in California, reaching 4.4 GW of capacity in mid-2016. This is getting large enough to create an impact on the larger grid, and combined with nearly 8 GW of solar installation on the utility side, has permanently impacted the peak capacity requirements for the California ISO. The summer in 2015 was only a couple of degrees off the record summer of 2006. But the peak capacity requirement in California in 2015 was nearly 6% lower than 2015, and the net load was impacted by the renewables on California's grid.



Project Goals and Objectives

The growth of distributed renewables impacts not only the ISO bulk grid, but could also impact distribution circuits. The distribution grid is designed (for one way flow) with minimal intelligence at the edges (transformers, wires to homes and buildings) which makes it harder to measure the impact until failure occurs. These assets are designed to be 50 year assets and many are oversized to account for future load growth such as transformers and feeder lines. However, protection mechanisms have not been traditionally designed for two way flows and could be a point of failure. Further, in California, the distribution systems are designed for gas driven heating and appliances, and electrification of loads could stress distribution circuits through excessive loads. While California, even with the penetration levels of today has not run into distribution problems, high penetration of PV in places like Hawaii have already created significant problems at the feeder and transformer levels. This occurs when a large percentage of homes in a control volume install large PV arrays, with sizing on the same order of magnitude as the loads. The project focuses on a near-term high penetration future in California, when the goal to attain Zero Net Energy (ZNE) in residential communities could lead to every home on particular distribution systems having significant amounts of PV.

The project started with a set of four primary objectives:

- Demonstrate cost effective technology pathways for ZNE communities. Uses this to better understand load shapes and PV sizing in ZNE communities to create a roadmap for high PV penetration in new home communities.
- Model and measure how ZNE communities with high PV penetration and electrification can impact electrical distribution systems in an “as-is” scenario, addressing both distribution operation and planning.
- Evaluate using field data how emerging technologies with connected end loads, and customer side storage can be used to balance high PV penetration and load peaks.
- Develop end-to-end modeling approach that integrates building modeling and energy storage into distribution modeling and improves modeling with measured field data.

Project Plan and Construction

The key prot partners to EPRI in this initiative were BIRAenergy, Meritage Homes and Southern California Edison (SCE). The project progressed along the following high level work streams:

1. Design of Zero Net Energy Community: The uniqueness of the project was the actual construction and occupancy of a Zero Net Energy community. The first step was to design and build a Zero Net community. This required a series of efforts:
    a. ZNE community selection: This phase was a prolonged phase, as many constraints were applied to the site selection. Given the timeline of the project, the team had to find the right community that could have customer acceptance for ZNE upgrades, was not a high end community not representative of the larger population, had loads representative of California, and was early enough that we could isolate a distribution control volume. After 6 months and multiple site evaluations, the Sierra Crest community was selected in Fontana as it was early stage and we could isolate homes on the transformers. It was decided to build 20 homes (representative of a small community) instead of the entire community as the project timeline and budget could not accommodate an entire community. This community also represented homes in the average size range, from 1900 – 2900 sq.ft. (current US average is 2400 sqft).

    b. Planning and designing the community:

        The planning process overlaid three separate processes - end use energy efficiency planning, solar planning and electric grid planning.

        On the end use side, multiple energy efficiency pathways were evaluated, and a sophisticated optimization process was used. Because of the advanced construction techniques used by Meritage, only three significant measures were implemented – transitioning to all LED lighting, and switching to electrical heating with heat pumps, and electrically driven water heating using heat pump water heaters. It is important to conduct the energy efficiency analysis first, as it drives PV sizing, with a goal of attaining 0 TDV (Time Dependent Value of Energy).

TDV gives greater credit to PV than just straight kWh production value due to coincidence of production with peak bulk grid loads. The net result was that the required PV size for these homes ranged from 3.5 kW to 4.75 kW, probably smaller than expected. These are also some of the first homes to be built to California's definition of Zero Net Energy. Unlike retrofits, in new construction, roof space can be limited to meet builder constraints on aesthetics, roof planes, orientation and cost. Reducing PV size through energy efficiency (and TDV sizing), substantially assists in being able to better attain ZNE with different lot orientations and floor plans. In fact, some of the most involved work was in neighborhood planning, where hundreds of combinations of lot orientation, and floor plans and elevations had to be plotted to understand available combinations that also met the PV size requirements for ZNE, and PV arrays can face anywhere from 45 degrees (NorthEast) to 315 degrees (Northwest) to be fit on these homes. The solar PV is not on a lease, but owned as part of the home (Meritage standard).

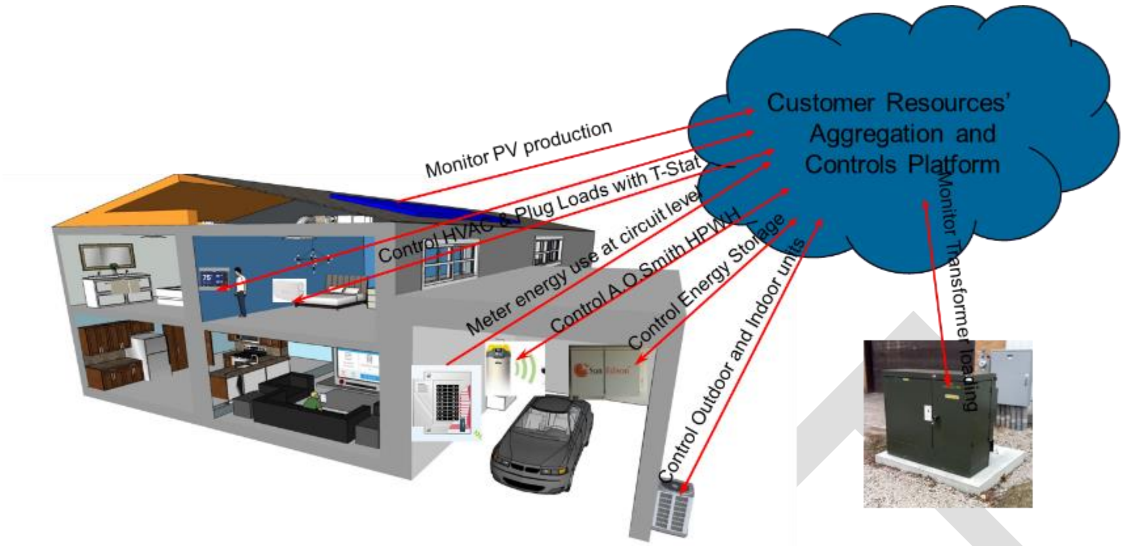
To measure the impact at a control volume that made sense from a grid perspective, two transformers were isolated for the ZNE community. The first, a 50 kVA transformer was designed for 9 homes in the 1900 – 2300 sq.ft. range. The second, a 75 kVA transformer was designed for 11 homes in the 2500 – 2900 sq.ft. range. The figures below show the planned sections that could help isolate impacts at the transformer level.

2. Construction, customer uptake and occupancy: The community was launched with a groundbreaking event on Earth Day 2015. The event was attended by two commissioners of the California Energy Commission, Commissioners McAllister and Hochschild, along with local government leaders, and SCE directors. Home sales began in April, and were slow for a couple of months. To rectify, new staff was trained on energy benefits and brought on board, and this resulted in a majority of the homes being sold in the period between June and August 2015. Meritage built the homes in 3 months, and there were occupied starting October 2015, and the last occupancy was in February 2016. During the construction phase, the team worked closely with Meritage construction management on all the changes, most of which was electrical including wiring for heat pump water heaters, low voltage networking of the connected devices, setting up circuit metering and the biggest challenge was integrating energy storage. Two homeowner orientation sessions were conducted, one in

October and another in February to get homeowners on-boarded with the technology and to better understanding operating their homes.

3. Developing grid balancing: Two hardware strategies were implemented for grid balancing of high penetration PV and loads, using connected devices and second using energy storage.
    a. Energy Storage implementation: The project was originally planned using community energy storage at the transformer to balance backflow and ramping at the circuit. It was changed to using customer side energy storage for a few key reasons – lack of space in a planned community, cost and time for adding hardware on the utility network, possible customer benefits and lack of approved products available. The customer side energy storage was applied to one transformer, with all nine homes being provided with a 6.5 kWh, 5 kW system. The storage unit was paid for, and will be owned and managed by NextEra Energy, with the inveters provided by E-Guana and the Energy Management System by E-Gear, who will continue to service the units. The energy storage implementation took nine months (longer than to build the homes), due to unfamiliarity of the city planning staff, recalcitrance of electrical contractor to install storage and due to issues with ownership of the interconnection process between the solar and storage providers. But, with E-Gear and EGuana working together, the systems are operational and have been tuned in their operating algorithms.

    b. Connected Devices: This project was a new effort in leveraging the emerging options with connected end loads to balance the grid impacts from PV. This project electrified end loads for the possibility of providing grid balancing, and implemented connected heat pump water heaters from A.O.Smith to go with the connected Nexia (Trane) thermostats already being installed in every home bey Meritage. In addition, the project also included three plug load controllers with every home. The connected devices were all tied in with the PV and storage through an integrated controls architecture designed and built by EPRI. In addition to the connected devices, each circuit in the home was individually metered and these readings were fed back into the controls schema to manage the end devices. All these devices were connected into the central architecture using API based integration.



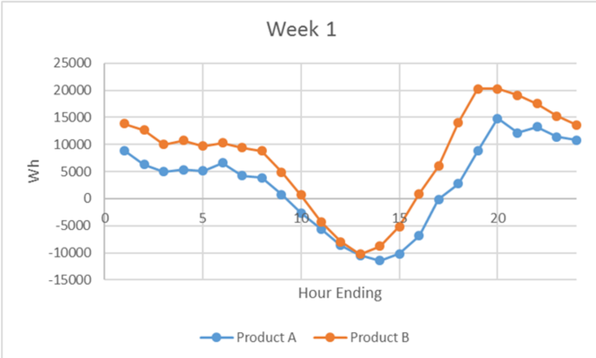
Measured Data and Comparison to Models

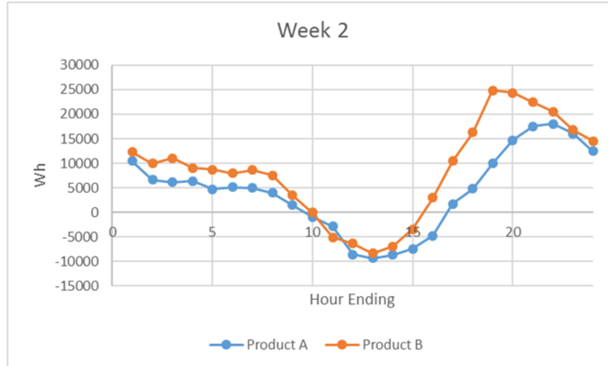
The design of the community was based on models of home performance. Each home was modeled using Beopt software to understand energy performance of these homes. These models provided the energy use of the homes, which were then used to develop PV sizing to attain zero TDV.

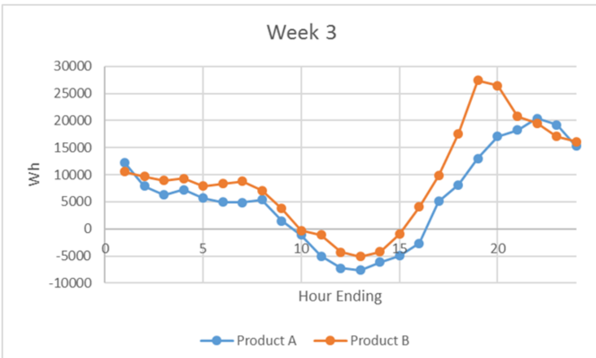
	Annual Energy Usage			PV Sizing	
Home	Modeled Annual Energy Used (kWh)	kWh Needed for ZNE (kWh)	kWh/sq. ft	Base Case PV	Integrated EE PV
6	6,923	6,099	2.59	6.1kW	4.5kW
7	7,485	6,518	2.57	6.4kW	4.5kW
8	6,882	6,199	2.57	5.5kW	4.0kW
9	7,485	6,518	2.63	6.4kW	4.5kW
10	6,882	6,445	2.36	5.7kW	4.0kW
11	6,923	6,208	2.44	5.3kW	4.0kW
12	7,518	7,213	2.58	5.5kW	4.0kW
13	6,926	5,956	2.44	5.5kW	4.0kW
14	7,512	7,213	3.24	5.5kW	4.0kW
15	6,902	5,961	3.16	5.5kW	4.0kW
16	6,773	5,768	3.5	5.5kW	4.0kW
121	6,331	5,801	2.73	5.5kW	4.0kW
122	6,550	5,800	3	4.6kW	3.5kW
123	6,143	5,021	3.17	5.0kW	3.8kW
124	6,521	5,759	2.99	5.3kW	4.0kW
125	6,559	5,560	3.01	4.7kW	3.5kW
126	6,521	5,568	2.99	5.0kW	3.8kW
127	6,035	5,798	3.12	5.5kW	4.0kW
128	6,451	5,800	2.96	5.0kW	3.8kW
129	6,451	5,800	2.96	5.0kW	3.8kW
AVG.	**6,789 kWh**	**6,050kWh**	**2.85**	**5.4kW**	**4.0kW**

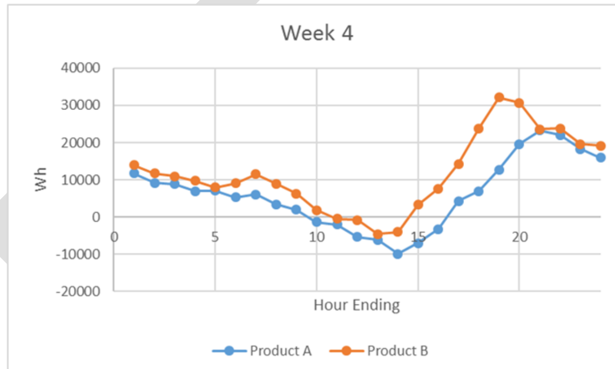
The BeOpt models were then used to develop the distribution grid models. The models were used in 5 minute increments to be able to capture the short term variability of PV generation and distribution impacts. These impacts showed that the peak loads shift from the 4 PM summer timeframe to 8 PM in the summer, and fall, and to 6 AM in the winter. In neither of these cases, PV is coincident with peaks and thus does not help with mitigation of peaks. The shifts occur due to the coincidence of the heat pump water heater and the heat pump operation.

The actual measured data proved out the models at the individual home level. Example data streams are shown for 4 weeks stretching between the spring and summer. The measured data emphasizes the non-coincidence of peaks between the PV production and load peaks. But, due to storage operation, the peaks did not hit the peak loading for the transformer and hence mitigates the concern to some extent.









Lessons Learnt and Data Analysis

This project has provided a whole myriad of lessons learned. All the extensive work on modeling gets us in the ballpark, but it is a completely different ballgame, once we build real buildings, and have real people representative of the general population operating these homes. The lessons learned stretch all the way for how to plan ZNE communities, how PV will get implemented, to customer perception of PV and further down on to the impact of storage, and finally the actual impacts on the grid and their mitigation.

Lessons Learned in the Planning Phase

1. Planning a ZNE community, requires tight coordination between the builder, the energy designer, the solar provider, the energy modeler, and the local utility. Even with the builder, the sequence process from the planner, to the purchasing agent, to the permits coordination and construction coordinator has to be become much more integrated. Each decision impacts multiple stakeholders, such as the energy models impacting PV size, which then impacts roof fit. It is better for all parties to start working closely on the front end when planning a ZNE community.
2. Utility grid planners are not yet familiar with the impacts of ZNE communities. California utilities are planning for widespread solar deployment on the distribution grid in the next 20 years, however ZNE raises the size of PV up a notch and could require additional changes to the planning process. It is likely that ZNE communities will require additional utility assets (e.g., more transformers per community, larger wire sizes).
3. Neighborhood level solar planning is very important. Title 24 has a requirement for solar ready roofs (optional with connected thermostats). Builders are choosing the optional thermostat, as they do not have the tools to guarantee universal fit of roof space with lot orientations. 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.

4. There is a need to develop and publish a planning process chart for ZNE communities, so builders are ready by 2020. In many cases, the planning has to start a year ahead, so that the right floor plans, and elevations are selected for the lots in the community, and the utility plans the distribution network correctly before the builder is ready to launch the community.
5. Energy storage planning is very nascent. Transformer level storage has challenges with siting and grid planning. The permitting process for customer sided energy storage is still exploratory. There has to be standard design process where the solar and storage are provided by different providers, one with backup power and one without. Permitting officials need to be educated on the electrical and safety impacts of customer sided storage.

Lessons Learned in Construction Phase

1. Advanced technologies require a “hands on” approach by researchers and designers to oversee the construction process. Construction managers have their hands full with daily issues with materials, contractors, and closings. Researchers and designers have to conduct planning sessions with the construction managers, and be available on-site frequently, especially for the first few homes in new communities.
2. The skill level of electrical contractors will need to be elevated to deal with emerging technologies, many of which incorporate wireless or wired connectivity. Training of electrical contractors in proper circuit layout, implementation of auxiliary power panels, and interconnections will need to be added, and journeyman contractors might not have the skills to implement these technologies.
3. Commissioning of systems has to be more rigorous. Current standards and enforcement will need to be updated to strengthen the commissioning process.
4. The solar and storage interconnection process could be improved. In many cases, homeowners take possession of their homes, and the interconnection of homes takes a month or two after, during which time they pay the full price of their utilities. Including storage could significantly extend this timing, if the design review and interconnection process are not standardized for customer side storage.

Lessons Learned in Grid Integration

1. Distribution grid planning practices emphasize the connected load on a network. For utility planners trying to assure 99.9999% reliability for a 50-year timeframe, controls based on optimization has not yet been proven reliable. This means that even energy storage counts as a load in distribution planning.
2. Current practices account for load diversity, and are based on summer peak loading in California. The load calculation is a function of home size, and climate zone, and ranged from a 5.5 kW to 6.5 kW average for the Sierra Crest subdivision. Edge-of-the-grid distribution systems extend from the transformer, through load blocks, laterals and to the feeder lines. Transformers are usually oversized, as well as feeders, and exposure needs to be above rating for a few hours to create problems.
3. The concern with PV is more about voltage rise in the last home on the network (it is the reverse calculation from traditional load calculations. SCE has already upgraded the wiring in their network from 350 gauge to 750 gauge for future PV penetration. Our analysis did not show a significant voltage rise along the homes on a transformer.

4. Electrification of heating loads combined with energy efficiency and future EV penetration can significantly affect distribution planning. Electrification can increase the peak load from the 6-10 kW range by another 9 kW, and if EV and storage are counted as loads that adds an additional 12 kW. While all these loads will not occur simultaneously in most situations, there is the rare chance that multiple homes might have coincident loads, especially in the evening.
5. The load shapes for ZNE communities is drastically different from the standard cooling peak driven load shapes. Energy efficiency substantially reduces peak energy use and operating hours, and "needle peaks" are more prevalent. Due to energy efficiency, there is a greater backflow to the grid from PV production in the mid-morning hours, and a steeper evening ramp when the cooling load kicks in just when the PV production tails off.
6. The peak load times shift to 7 – 8 PM in the summer, spring and fall, and to 6 AM in the winter (modeled, awaiting winter operation). These peaks are not coincident with PV production and hence PV does not substantially assist distribution capacity. Energy storage and load management techniques such as pre-cooling of homes in summer, and pre-heating the water heater to use it as thermal storage could assist in balancing the load shape.
7. Energy storage while quickly accelerating in the technology front, needs support in the implementation process, including electrical design, permitting, controls schema and interconnections. Energy storage providers are looking to stack customer and utility benefits, and they might not be in concordance to provide both.
8. Energy storage can either benefit or harm the distribution grid, based on the implemented controls schema. Current Time-of-Use rates are designed for system peaks in the Noon – 6 PM timeframe. If energy storage is operated for customer cost benefits, it will not absorb excess PV production in the 9 AM – Noon time, and will not address the ramping issues in the evening hours.
9. It is recommended that customer side energy storage be grid optimized so that it charges in the mid-morning hours and discharges in the 5 – 8 PM period. As the California grid load shape changes, time of use rates will need to shift to later periods in the evening (e.g., 5 – 9 PM) for energy storage to provide distribution grid benefits, while at the same time providing customer benefits.
10. Connected devices technologies have great potential to provide grid balancing. They can be installed as part of the home, and their load management potential can be available at no cost. The potential for load management between the heat pump and the heat pump water heater is about 3 kW. However, the data sharing and connect ability are still evolving and they need to be lined out with data standards to make them more viable for managing high penetration of distributed PV.

Next Steps and Future Initiatives

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.

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 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. All the lessons learned will live on in these communities as we prepare for California's future of high PV penetration with ZNE communities.

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

The State of California has set ambitious targets for greenhouse gas 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 by 2020. As defined by the 2013 California Integrated Energy Policy Report (IEPR), a ZNE home is defined by 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 be 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 have to be electrified. However, efficient electric heating and water heating systems today can distort the predicted premise-level load shapes that, when aggregated and deployed in community scale, could result in potential distribution systems issues.

This project demonstrated the impacts of a near-Zero Net Energy (ZNE) 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 PV installations. This project evaluated various ZNE approaches to derive photovoltaic (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 a/c).

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[1] CEC (California Energy Commission IEPR). 2013. *2013 Integrated Energy Policy Report*. Publication Number: CEC-100-2013-001-CMF. http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf

[2] http://www.cpuc.ca.gov/NR/rdonlyres/D4321448-208C-48F9-9F62-1BBB14A8D717/0/EEStrategicPlan.pdf; Section 1, p6

[3] CEC Business Meeting, July 12, 2013

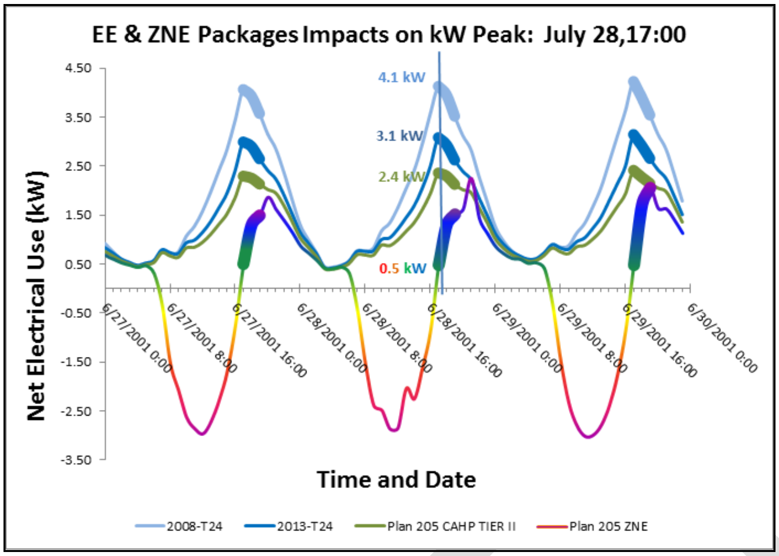

Figure 1-1
Projected ZNE impact on load shape

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 Energy Efficiency (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 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 impact on distribution systems and 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 the state of California using concurrent research being undertaken to categorize and model distribution feeders in the state of California. 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 CAISO with regards to future requirements for flexibility to address low midday loads and high evening ramp rates on the grid.

The primary goal for this project is 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 in particular, the distribution systems**. The homes built and evaluated in this project demonstrated substantial benefits to 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 incentives programs.

Data from the ISO, EPRI, and BIRAenergy[4] 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 be ultimately passed on to new-home buyer/occupants. This cost hurdle could potentially be avoidable, and ZNE homes that incorporate IDSM, HEMS, PV, and 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 reductions or elimination of mid-day over production, and 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 to the IOUs[5]. 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.[6]

The project goal is to ensure that the widespread development and Grid Integration of ZNE communities is beneficial to the distribution systems will be 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 wide-spread 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 requirement for energy storage in ZNE communities, considering both thermal and electrical storage; Demonstrate 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 end-to-end modeling approach for ZNE Communities that integrates building modeling and energy storage optimization, with distribution models.

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[4] Need references. For BIRA: Hammon, “Zero Peak Homes, A Sustainable Step,” ACEEE 2010; “FLP Improving ZNE’s”, ACEEE 2012

[5] Private Communication with IOU staff at 2012 ACEEE Summer Study on Buildings

[6] IBID (Hammon)

2
DESIGN PROCESS FOR ZERO NET ENERGY COMMUNITY

This section provides a record of the process taken by the project team to developing a relatively cost-effective, practical set of efficiency and renewable energy measures that, should result in ZNE homes, given the research assumptions used to represent typical occupants and their impacts on energy use. The work in this section supplements the primary objectives of the larger *Distribution Impact Zero Net Energy Communities* project as that this section will: (1) demonstrate technology pathways for builders and developers to design and construct ZNE communities that are cost effective and appealing to volume home-builders and to consumers, (2) provide roadmaps for large-scale integration of efficient homes with rooftop photovoltaic systems (PVs), 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 homes using the California definition based on time-dependent value of energy (TDV energy[7]; and ZNE_{TDV} or simply ZNE).

Neighborhood Selection

The neighborhood selection process was an extended, convoluted process as we were trying to meet multiple criteria with the selection of the neighborhood. A key requirement was that we needed the ZNE homes to be located on isolated distribution transformers and preferably be adjacent in order to isolate electrical and energy impacts for the evaluation. Electrically binding communities at the transformer level will help the project team assign treatment and control groups for current and future analysis. This meant that we needed a community that was early enough in the sales phase, so we could “assign” a set of contiguous lots for the ZNE neighborhood.

Initially, the project was designed to be a full ZNE community. However, a community of homes is not necessarily electrically bounded and also doing 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 be able to be fit in the 2-year timeframe that was given for this project. This pointed to a community that was in the early stages of construction with significant homes that were not yet sold or constructed.

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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

A third constraint was that getting to ZNE (and high PV penetration) required funding of a full size PV array in many homes (expected total size of 100 – 300 kW). The available funding mechanisms through the RD&D funds and match funds from project partner, Southern California Edison (SCE), could not support the procurement of this scale of PV. Meritage planned to offer PV as an option with an incentive to have prospective homeowners add the PV to their home purchase. But offering PV as an option would imply that we could potentially not achieve high penetration PV scenario as it would rely on homeowner market uptake that includes 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 we were hoping to obtain, a smaller subset of a community was chosen for project cost-effectiveness and overall project inclusion.

From the electrical perspective, we need to measure the impact of the ZNE neighborhoods. Most utilities do not have any measurement on the distribution system beyond the substation and feeder. So, the project team needed to find a control volume that was measurable. After talking to distribution system experts, we decided to focus 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.

Given these constraints, we had to find the right community. Meritage Homes is one of the largest builders in Southern California, with anywhere between 10 – 15 communities in development at one time. This substantially assisted us in our efforts, as we had a choice of communities. The original choice in the proposal was a community in Rancho Mission Viejo, which while in the right stage of construction was not in the Southern California Edison (SCE) territory. The second choice was a community in Montclair/Upland, which was about 60 homes and selected as the likelihood of selecting PV option was high, but when we reviewed the community electrical infrastructure drawings, we could not carve out the lots required for electrical isolation.

To make a final decision on the choice of community, a meeting, consisting of core project team members was held at the Meritage offices in Southern California on Feb 6, 2015. We reviewed the conditions for the community and all the communities that Meritage had on the drawing board. Overall community selection included factors that includes, but are not limited to:

- The community being selected would be early enough so that we can 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 homes 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, we would be able to build, sell, occupy and collect data within 1 year from project launch.
- The community was of interest to the homebuilder
- The community would not be a high end community that would, as best as possible, emulate single family, ZNE communities in California.

Based on these requirements, the Sierra Crest community in Fontana, CA was selected for the project. This community has 187 lots, and while sales started in Q3 2014, only 15 homes had been sold. The homes were divided into 3 collections (based on home size), and gave us the opportunity to select the appropriate electrical control volume. Meritage was also interested in promoting this community as it was a first time homebuyer community and it would be a great opportunity to evaluate how energy efficiency and solar were within reach of everyone and could potenmarketing tool.

There are two product-lines of home-models that Meritage identified for this ZNE project, for a total of 20 homes. These two product-lines constitute the entirety of the homes in the new master-planned community, Meritage's Sierra Crest development in Fontana. The 20 ZNE homes are clustered in a group, with 9 of the "Grand Canyon" product and 11 of the "Yosemite" neighborhood. Each product has 3 different models in the "ZNE Enclave" within the 187 lot community Sierra Crest. Together, these 20 represent California's first Zero Net Energy (ZNE) neighborhoods. These 20 homes are clustered so that the 11 Yosemite homes are all on one distribution transformer, and the 9, somewhat larger, Grand Canyon homes are all on another distribution transformer. There are no other homes on either of these two distribution transformers. 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. See Figure 2-1 below for overall Sierra Crest community map detailing location of the 20 ZNE homes.

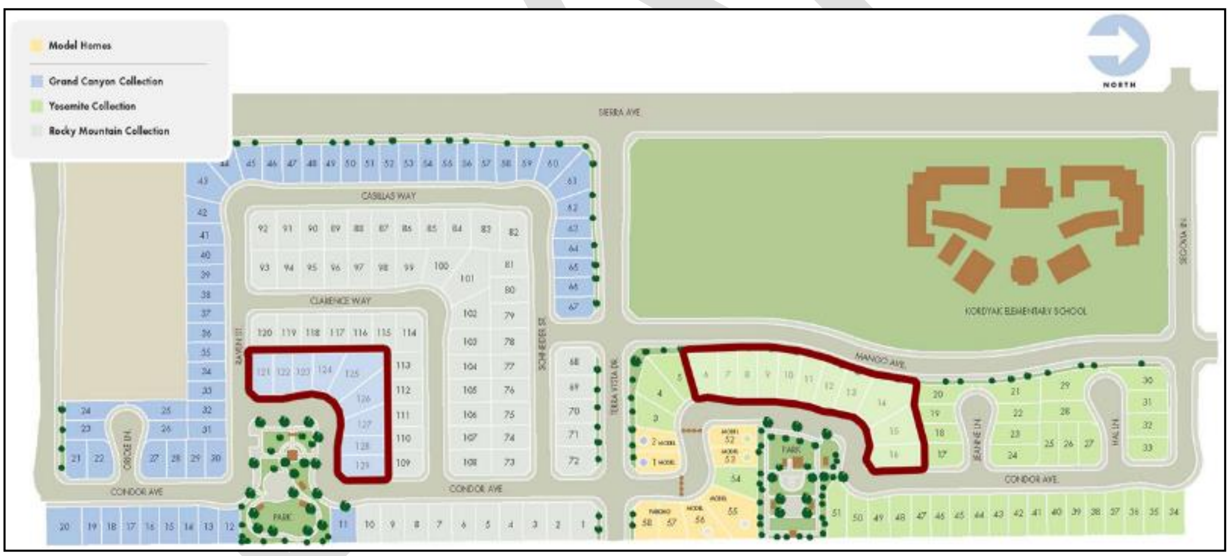

Figure 2-1
ZNE community locations as part of a larger 187 Meritage Home community

Figure 2-1 illustrates the community and the chosen control volume. Lots 121 – 129 were from the Yosemite Collection ("A" product) which consisted of homes in the 1900 – 2300 square foot range. Lots 6 – 16 were in the Grand Canyon collection ("B" product) with homes in the 2600 – 2900 square foot range. Lots 121 – 129 were serviced by a single 50 kVA transformer and Lots 6 – 16 were served by a single 75 kVA transformer. The transformers were sized by SCE based on distribution planning rules taking into account climate zone, and home size.

Distribution System Planning

It is important to note that distribution systems for this community were not designed to account for any considerations that a ZNE Community would entail. This includes, but is not limited to: (1) high penetration PV and resultant distribution infrastructure requirements and (2) any electrification of end-use loads that were required in order to meet other greater project goals. As previously stated any intervention with the 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 and was not scoped as part of this project. This results in a project that vets current high-penetration PV scenarios with the current distribution system planning practices.

Energy Efficiency Packages

The team developed Energy Efficiency (EE) feature packages for inclusion in the homes built by Meritage Homes in the ZNE Enclave at Sierra Crest in Fontana. We chose to use the energy-modeling tool BEopt[8] for this task. BEopt was chosen both for its relative ease of use and its accuracy. The team has demonstrated their ability to develop calibrated models of existing homes using BEopt, where the simulation results are within 5% of the actual, measured energy use. While later tasks in this project include collection and evaluation of actual energy use in the TDV Enclave homes, the accuracy of the simulations in this project will not be known because the monitoring period will be too short at the time this report was written[9]

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

[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

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

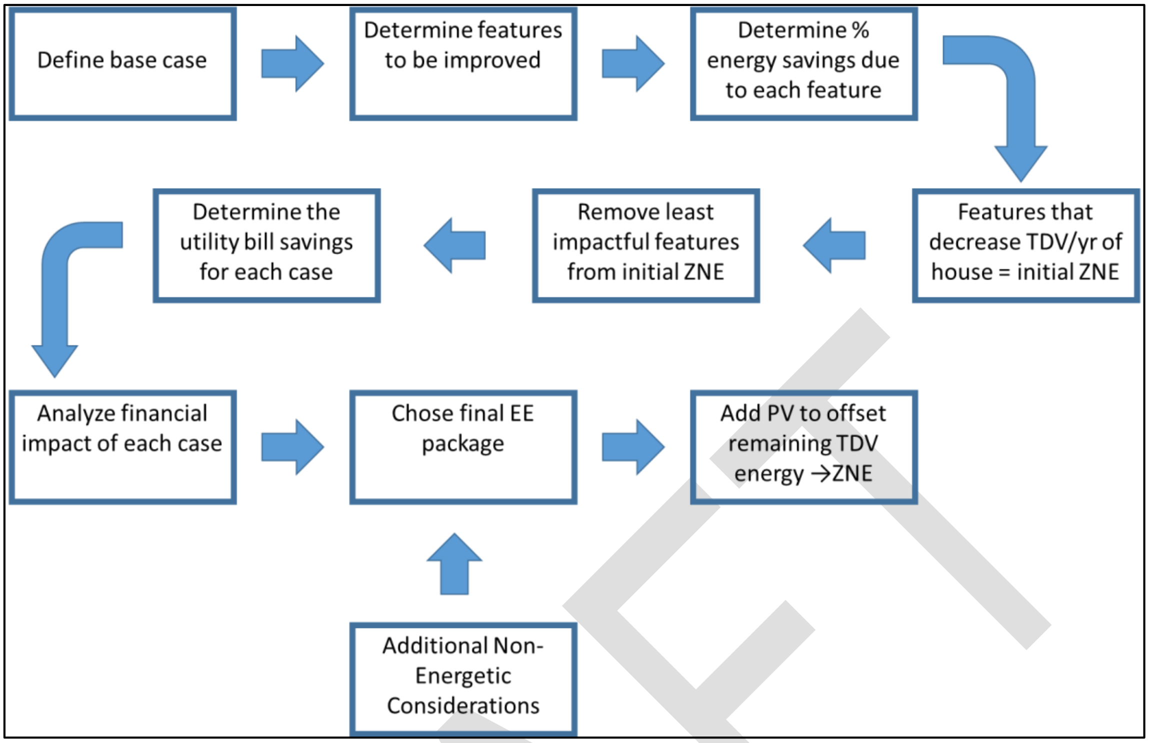

Figure 2-2
Flow diagram of generalized ZNE-features development process used to develop ZNE packages

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. 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 Sierra Crest Community. Upon review of the 20 homes sited on the 20 lots designated, there were no duplications of plan-type, elevation and orientation. Thus 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 efficiency measures, photovoltaic systems and energy storage systems. The photovoltaic systems were sized specifically to produce ZNE. Despite the fact that 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 2 efficiency packages, one for each product type (Yosemite and Grand Canyon). The final result was a single package for both product types.

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. The residential energy modeling/simulation software, BEopt v2.3.0.2 (described earlier) was used for all energy analyses, starting with a Meritage baseline for the 20 buildings. To do these baseline simulations, the team worked with Meritage to acquire a detail 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 aforementioned construction, efficiency-package, and other energy-related details were used to make BEopt models of each home. 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 NREL specific to new homes built on the west coast.

New EE feature packages were then developed independently for each model. 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. Reasons for eliminating features from the list were not recorded, but they included materials preferences, such as use of spray-foam in the walls and attic, national vendor contracts, fixing efficiency levels maximum efficiencies, 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.

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% AFUE furnace for a 10.5 HSPF, or greater, heat-pump) to determine the impact of each individual feature on the baseline. Results are shown below, in the Figure 2-3 below.

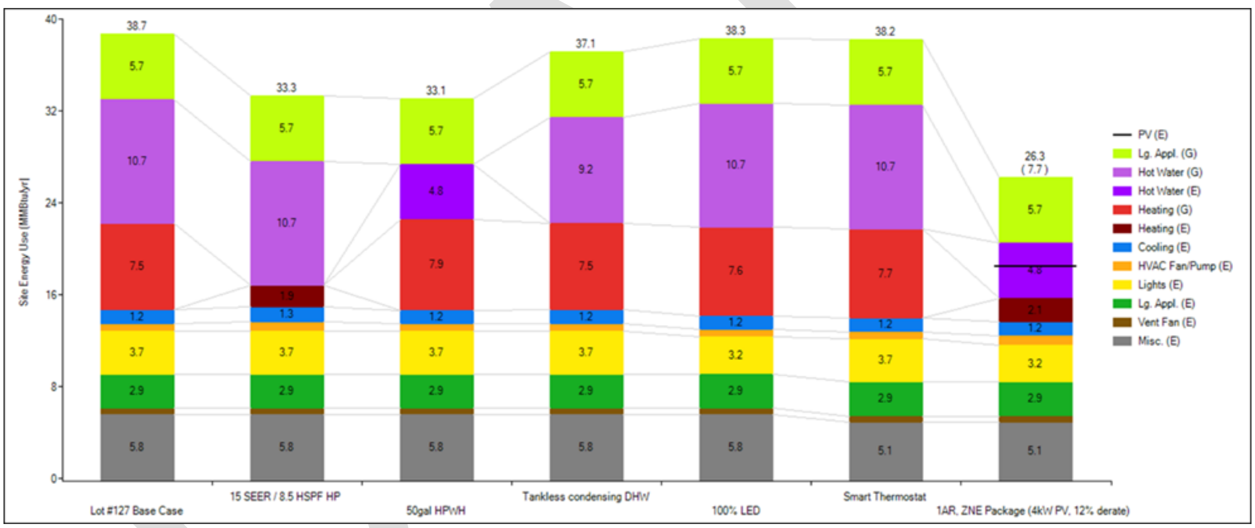

Figure 2-3
Sensitivity analyses results for the development of the ZNE package used in Lot #127 (Meritage Sierra Crest, Grand Canyon, Grandview) in shown

Each stacked bar shows the results of a sensitivity analysis of a different feature evaluated for performance in the initial ZNE case. 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% AFUE furnace for a 10.5 HSPF, or greater, heat-pump) to determine the impact of each individual feature on the baseline.

All comparisons are 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 on each other to visually show both 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 shows the contribution of PV, which is represented by the black bar across the bar.

Each feature is evaluated individually using a parametric analysis, as shown in below:

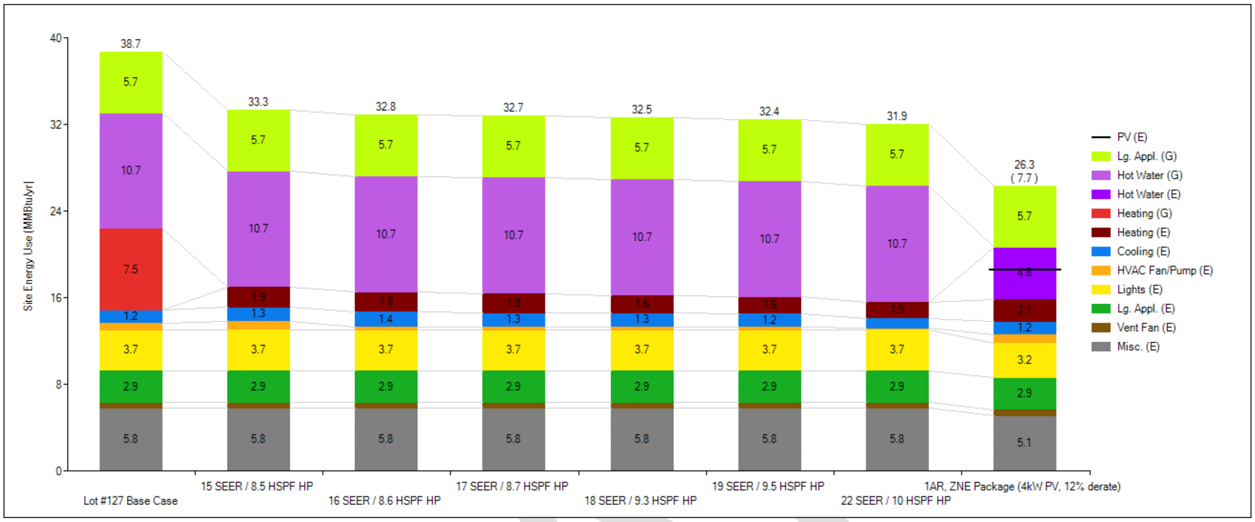

Figure 2-4
Parametric analysis results of replacements of different efficiency levels for a single measure-type, in this example evaluating the AC and FAU for replacement with a heat pump, in lot #127

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 are used to optimize cost and performance for each feature.

Table 2-1, below, shows the 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, including the results of the parametric analysis of the heat pumps performance range, as per the sensitivity analysis of the ZNE package.

Table 2-1
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 are other considerations that must be taken into account in developing the final ZNE packages, including interactions between different measures, product availability, installation/construction considerations, and consumer/home-buyer preferences. These "sensitivities" are analyzed in a method called a "sensitivity analysis." This sensitivity analysis was performed, on each of the 20 homes, as follows:

11. Working with Meritage we determine a model for their Standard, Unimproved Package and compare it to an identical model that just-meets-code for 2013-T24 and 2008-T24.
12. The simulation of the code packages allows us to produces a baseline performance of Meritage's unimproved case, including kWh and therms used per year, HERS, package cost differences, utility bill savings, and PV sizes needed to achieve ZNE.
13. A set of measures that would increase the efficiency of the unimproved model above the baseline performance is developed and vetted with Meritage. This is the ZNE package.
14. Each possible feature that can be upgraded is individually evaluated in a parametric analysis. A single feature replacement is 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 + single feature replacement) are simulated to determine the reduction in whole-house energy use due to the single feature replacement. The data from this single feature replacement is recorded in terms of annual energy use, change in annual energy used, and annual utility bill savings.
15. The incremental cost of each single feature replacement is determined using data from Meritage, BIRAenergy, and/or RS Means data from BEopt.
16. For each single feature replacement, the cost-effectiveness (a simple 30yr payoff metric) is determined using annual utility bill savings compared to the baseline, and the initial cost of the single feature replacement.

17. The ratio of cost of the single feature replacement over 30 years and the annual utility bill savings are recorded in the spreadsheet as simple ratio (see Figure 2-3). This metric is used to rank the features.
18. The highest ranking features from this sensitivity analysis are used to make the initial ZNE package.

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

The resulting initial ZNE package from the sensitivity analysis then undergoes another test, called a "perturbation analysis." This follows the same general scheme, where the ZNE package has each single feature replacement used "perturbed." This is where the value of each feature to the final ZNE package is 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 are shown below, in Figure 2-5:

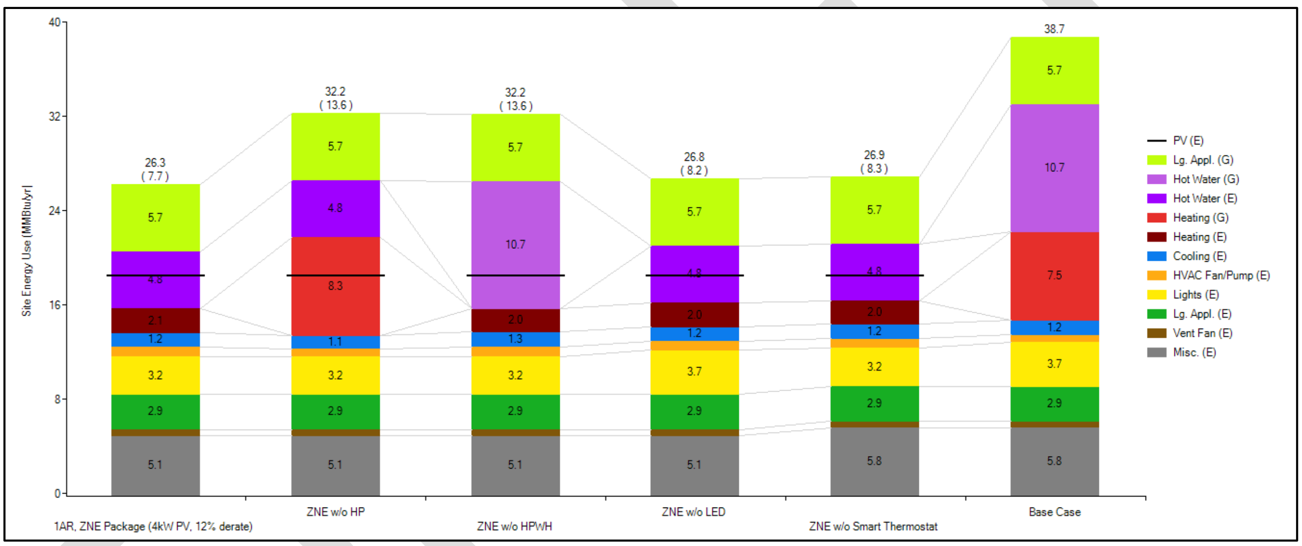

Figure 2-5
The results of the single feature replacement Perturbation analysis of the unimproved base case for Lot #127 (Meritage Sierra Crest, Grand Canyon, Grandview)

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

1. The initial ZNE package is simulated and annual energy use metrics recorded.
2. A single feature replacement is 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 is 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 are held at their ZNE performance level. Only measures that were improved for the initial ZNE package undergo 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) is 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 will improve the overall cost-effectiveness of the high-efficiency package.

4. Features in the initial ZNE package that can be reduced to baseline-level performance without a significant change in the annual energy use are removed from the ZNE package. A ZNE package results from the Perturbation analysis that is then vetted by Meritage, making whatever changes they deem necessary. This becomes the final ZNE package recommendation.

The results from the evaluation of the ZNE package, by sensitivity and perturbation analyses, includes 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 is typically equipment sizing. As the building envelope is improved, the required capacity or size of the heating, ventilation and cooling systems (HVAC) needed to maintain desired temperatures decreases. This decrease in system size reduces the cost of the heating/cooling system, and thereby of the package. The perturbation analysis will result in removal of features with large interactions that severely reduce their impacts, and includes savings due to updating systems sizing.

The final steps in developing the ZNE Package for each home are to size the PV array for each home, and to review the least cost-effective efficiency measures and compare total package costs, including PVs, for the package with and without the least cost-effective measures, where the PV size and cost would be increased to compensate for the efficiency measure being tested.

For these homes to be ZNE, in addition to being very energy-efficient, each requires a rooftop PV arrays sized to produce as much TDV energy as the very-efficiency house needs 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 (Home Energy Rating System) score for each home[10].

A minor difficulty with the HERS definition of ZNE is the granularity of PV systems. Rooftop PV systems consist of arrays of PV modules that have discrete outputs, meaning that the PV array size will increase in steps equal to the rated output of the PV panel used. The residential solar provider uses nominally 250Wdc PV panels. Thus, all array sizes are in 250W increments, that the homes in the ZNE community must either:

- All homes have PV systems that will produce a HERS score of zero or less or
- The communities are considered as a group, and the HERS score be as close to zero a possible, with the PV size rounded to the nearest 250W.

[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.

The second option was employed to minimize the likelihood of significant over production of electricity from each home of the ZNE community.

Using *EnergyPLUS* weather files for PV productivity, using roof tilt and azimuth from the building plans, each array size is determined manually. This array size, for the final ZNE package, is 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 have been developed for each home in the ZNE Enclave. These specifications provide the requirements for both energy-efficiency measures and rooftop PV systems. BEopt computer simulations of the Meritage ZNE homes show that the implementation of these ZNE measures should produce a reduction in the annual site energy use (MBtu/yr) in these homes of about 43% compared to if the homes were built to just meet the current energy code, and about 32% compared with similar homes in the Sierra Crest community that are built to the Meritage Energy Efficiency Standard Package – the set of energy efficiency measures in which the production homebuilder partner, Meritage Homes includes in its standard models.

Packages of integrated enhanced efficiency and properly-sized rooftop PV system were designed and developed 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 are a heat pump water heater, and 15 SEER efficient heat pump heating and cooling system. See Figure 2-6 below:

[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, are expected to be low, but not zero.

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

As part of this task, two baseline configurations were evaluated for each Meritage home: (1) with package features from the current 2013 Title 24, and (2) with the current Meritage Standard Energy-Efficiency Package. These two baselines provided HERS score of 90 and 70. The HERS score for the same home, but with the ZNE efficiency package, without solar was 69. Figure 2-7, below, shows a stacked bar graph, indicating 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.

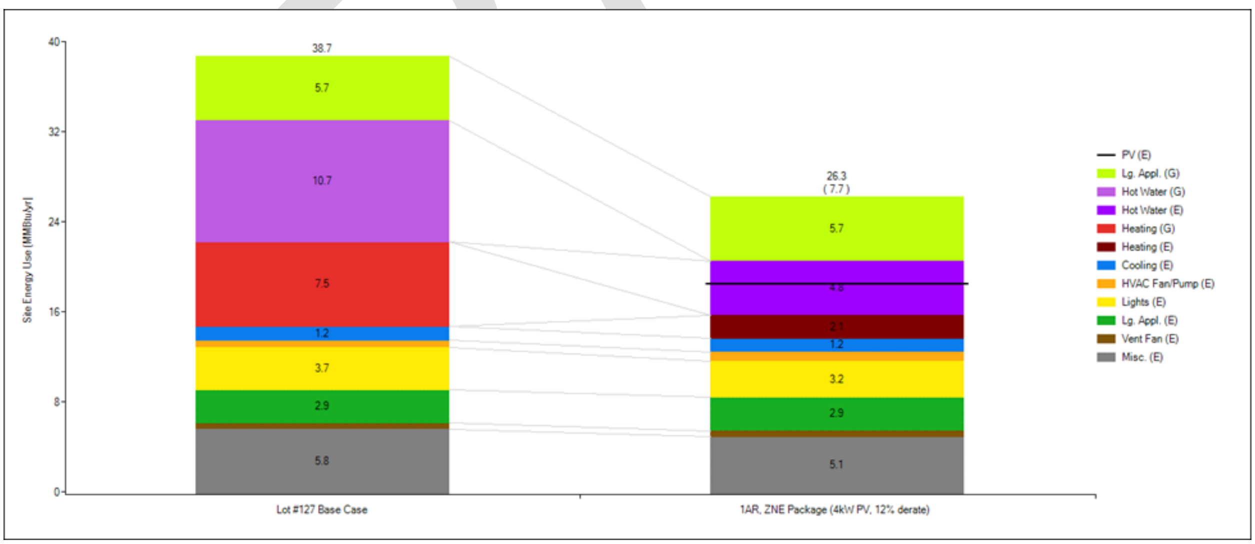

Figure 2-7
Stacked bar graphs of site energy (kWh and therms used per year) showing relative reduction of the base case (70 HERS) to the final ZNE cases (69 HERS with no PV) for Lot #127

These two stacked bars are for the same floor plan, one with energy-code minimum features, and the shorter with the ZNE efficiency measures. The difference between these two homes is magnified by the size of a PV array that is part of the ZNE package, and that would be need to be added to the code-home, to offset the energy uses with the different efficiency packages, and reach a zero HERS score. The code home would require 4.6kW – 6.4kW of PV, whereas the same homes with the much more demanding ZNE efficiency package required 3.5 – 4.5 kW PV to achieve a zero HERS. Shown below, in Table 2, are the range of PV sizes required to achieve ZNE for the models in this project, both with the base cases and the final ZNE packages.

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.

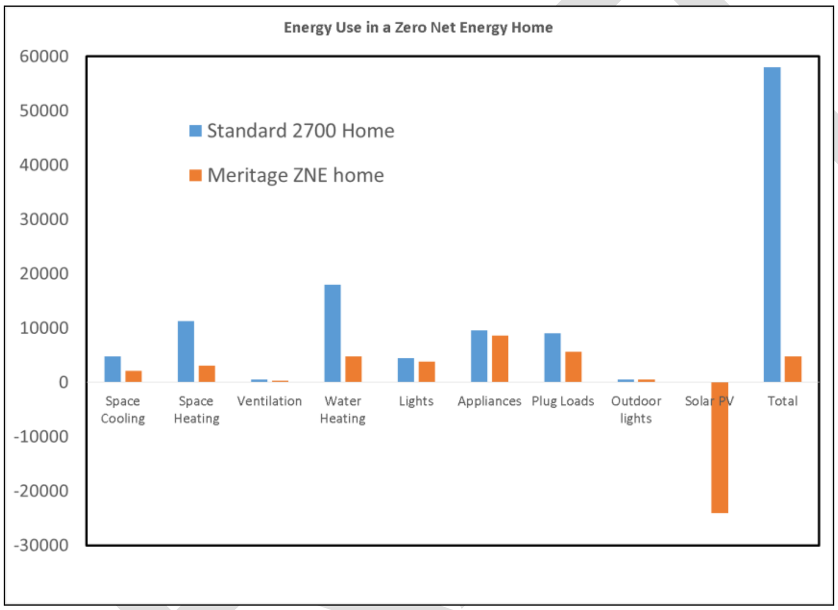

Figure 2-8
Average annual energy used and generated by 20 ZNE homes compared to Title 24 base case

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 measures. See Table 2-2.

Table 2-2
PV Size Delta between Base Case Homes and Homes with Integrated EE Measures

Community 1			**Community 2**		
Lot	Base Case PV	Integrated EE PV	Lot	Base Case PV	Integrated EE PV
6	6.1kW	4.5kW	121	5.5kW	4.0kW
7	6.4kW	4.5kW	122	4.6kW	3.5kW
8	5.5kW	4.0kW	123	5.0kW	3.8kW
9	6.4kW	4.5kW	124	5.3kW	4.0kW
10	5.7kW	4.0kW	125	4.7kW	3.5kW
11	5.3kW	4.0kW	126	5.0kW	3.8kW
12	5.5kW	4.0kW	127	5.5kW	4.0kW
13	5.5kW	4.0kW	128	5.0kW	3.8kW
14	5.5kW	4.0kW	129	5.0kW	3.8kW
15	5.5kW	4.0kW			
16	5.5kW	4.0kW			

Table 2 depicts an approximately 1.4kW 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.

ZNE$_{TDV}$, Net Metering, and Energy Bills

Net Metering in Home Energy Rating System Scores and in Actual Homes

All the ZNE homes are designed to be very energy efficient so that they should require relatively small amounts of electricity for space conditioning, water heating, and cooking. These homes will also have Home Energy Management Systems (HEMS) that will provide the occupants with the capability to better monitor and manage communicating appliances, in particular the thermostat and certain electrical circuits and outlets, all of which are integrated into a very energy-efficient home. The homes are also designed with integrated energy-efficiency and electricity generation systems so that the TDV-**electricity** generation, over twelve months is equal to the total TDV-**energy** use over the same period, using California Energy Commission (CEC) assumptions for energy-use simulations, including thermostat settings and thermal gains from occupants, hot water usage, the electricity used for lighting and by miscellaneous devices that are plugged into wall outlets. The design for the Meritage ZNE homes includes both electric and gas appliances, for reasons of both cost-effectiveness and homebuyer preferences. As detailed in Methods, the CEC method for calculating Home Energy Rating System (HERS) scores uses TDV-energy, and a ZNE home produces as much TDV-energy as it consumes, on an annual basis. The total TDV-energy from the ZNE homes includes the use of natural gas for water heating, cooking and clothes drying; thus, in the calculations for a zero-HERS score, or ZNE$_{TDV}$ home, TDV-energy from both electricity use and natural gas use is offset by TDV-energy from electricity generation. The ability to offset gas use with electricity generation would require net metering between both electricity and gas. This dual-fuel net metering capability does not exist in the market.

Net Metering in HERS Scores and Actual Energy Bills

The average HERS Score in the ZNE community is -3, which means that the annual amount of TDV energy used in the home is offset by slightly more TDV energy produced by the PV system. However, this does not imply zero energy costs for ZNE_{TDV} homes.

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. That is, 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 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 4 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 1. 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 ZNE Enclave 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 3.

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 week days 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 Home Energy Rating System (HERS) Index for each home was targeted to be 0 for each home. Due to practical limitations of PV sizing, HERS Index for the 20 homes ranged from +7 to -12 with an average of -3. Energy bills were also estimated for the 20 ZNE homes using the most common rate for SCE residential customers. Modeled HERS scores, annual energy consumption and utility bill analysis are shown in Table 3.

Table 2-3
Energy Consumption, HERS Index and Utility Bill Analysis for ZNE Community

	Annual Energy Used and Generated		HERS Index	Annual Utility Bills and Savings		
Lot	Modeled Annual Energy Used (kWh)	kWh Needed for ZNE (kWh)		Title 24 Base Case	ZNE	Utility Bill Savings
6	6,923	6,099	-7	$1,634	$223	$1,411
7	7,485	6,518	2	$1,786	$388	$1,398
8	6,882	6,199	-6	$1,618	$182	$1,436
9	7,485	6,518	2	$1,786	$388	$1,398
10	6,882	6,445	0	$1,612	$338	$1,274
11	6,923	6,208	-4	$1,598	$206	$1,392
12	7,518	7,213	2	$1,765	$199	$1,566
13	6,926	5,956	-3	$1,653	$248	$1,405
14	7,512	7,213	2	$1,786	$351	$1,435
15	6,902	5,961	-4	$1,639	$240	$1,399
16	6,773	5,768	-7	$1,615	$220	$1,394
121	6,331	5,801	-12	$1,498	$121	$1,377
122	6,550	5,800	5	$1,490	$404	$1,086
123	6,143	5,021	-2	$1,455	$267	$1,189
124	6,521	5,759	-5	$1,486	$257	$1,229
125	6,559	5,560	0	$1,512	$310	$1,202
126	6,521	5,568	-5	$1,492	$227	$1,265
127	6,035	5,798	-9	$1,439	$173	$1,265
128	6,451	5,800	-1	$1,477	$324	$1,153
129	6,451	5,800	-1	$1,477	$387	$1,090

Table 3 shows that the average annual electricity bill for the 20 ZNE homeowners are 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 understand the difference with standard construction. This economic analysis shows incremental cost of the EE and DER measures to be approximately $20,000 per home, with over 50% of the cost attributed to PV. Assuming a 30 year mortgage and the utility bill savings shown in Table 3, investing in these ZNE homes potential proves cash flow positive for the homeowner.

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 have been 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 publically available results being anonymous. Next steps will be to evaluate the monitored results and compared 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 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 our Team has the aforementioned 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, homebuilder process is to develop a set of "standard" plans for different home models, and create different elevations (as shown below) for each of the home models. This allows buyers the customer choice, 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 below 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 and Elevation C having a large contiguous roof area on the front. As traditionally, community planning would define lots before ZNE designs are considered, this means that there will 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 to 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 we move towards ZNE communities. This will also be an issue that the NSHP (New Solar Homes Partnership) 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, and that will also impact the community PV production profile.

Table 2-4 below shows the results of the solar planning for the 20 homes. As can be seen, some of the PV arrays are in non-optimal orientation, but that is what was required to meet the ZNE requirement.

Table 2-4
Results of the solar planning for the 20 homes

Lot	Plan	Plan #	Elevation	Garage, Front Orientation	Front Orientation	PV Roof Orientation	TDV zero PV size	PV sized for esthetics
6	El Capitan	2	C	Right	East	West	4.3	4.5
7	Tuolumne	3	B	Right	East	West	4.4	4.5
8	Bridalveil	1	A	Right	East	South	3.7	3.75
9	Tuolumne	3	C	Right	East	West	4.4	4.5
10	Bridalveil	1	B	Right	East	West	4.1	4.5
11	El Capitan	2	A	Right	East	South	3.7	3.75
12	Tuolumne	3	B	Right	East-Southeast	Southwest	4.1	4.5
13	El Capitan	2	C	Right	East-Southeast	Southwest	3.7	3.75
14	Tuolumne	3	A	Left	Southeast	Southwest	4.1	4.5
15	El Capitan	2	B	Right	Southeast	Southwest	3.7	3.75
16	El Capitan	2	A	Left	South	West	3.9	4.0

Table 2-4 (continued)
Results of the solar planning for the 20 homes

Lot	Plan	Plan #	Elevation	Garage, Front Orientation	Front Orientation	PV Roof Orientation	TDV zero PV size	PV sized for esthetics
121	Walhalla	3	A	Right	East	South	3.5	3.75
122	Mojave	2	B	Right	East	South	3.5	3.5
123	Grandview	1	C	Right	East	West	3.6	3.75
124	Mojave	2	A	Left	East	West	3.8	4.0
125	Mojave	2	B	Right	Southeast	Southwest	3.5	3.5
126	Mojave	2	C	Left	Southeast	Southwest	3.5	3.5
127	Grandview	1	A	Right	South	West	3.2	3.5
128	Mojave	2	A	Left	South	West	3.4	3.5
129	Mojave	2	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

3
CONSTRUCTION AND COMMISSIONING OF ZERO NET ENERGY HOMES

The previous section details the steps necessary and considerations taken when designing ZNE communities at scale. The main outcomes of the section was right-sized photovoltaic systems and a single EE technology that resulted, on 20 ZNE homes if taken on average (average HERS score of the 20 homes is -3). The next 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 to potential homebuyers.
- **Customer Uptake:** Results on sale of home from May, 2015 to the date in which last ZNE home was sold. Also discusses 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 efficient efficiency packages that comprise his/her home and the overall community in general.
- **Home Commissioning:** Steps required to commission and construct the ZNE communities. Includes any installation, testing, permitting, etc. required to operate all the efficient technology packaging and Distributed Energy Resources (DERs) that comprise these homes.

Construction Planning

In this community, Meritage Homes' process for a customer buying to closing a home starts with the Customer Purchase Agreement (conditional) and ends 99 days later with the closing. Meritage guarantees a 99-day build period, 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 deviate from standard practice for Meritage, we had to addresses a list of changes in a very rapid manner, where all energy efficiency and PV choices were made within the span of 3 weeks to meet the construction and community launch requirements. As one of the main themes was minimize the effect on current building process, 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 is listed below:

- **Lighting:** One of the first decisions was to switch to all LED lighting. This was easily accomplished and Meritage procurement was able to obtain the LED lights for an increase of a few hundred dollars. See Section 2 for additional details.

- **Space Conditioning** A key part of the project is electrification of heating loads. Current perception is that heat pumps might not be capable of maintaining comfort. This is mainly related to the occupant comfort (due to lower discharge air temperatures, air cooler than 100 F feels cold on the skin). However, Meritage had substantial experience with heat pumps in other parts of the country and was able to mitigate this concern as the longer run times provides better comfort. In addition, utility distribution representatives are 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 particular homeowner. The project team, along with the homebuilder, identified that in this climate region, resistive elements were not required on heat pump installation and 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. In this case, to meet several of the goals of this project, we had to change over to heat pump water heating. This required working with the builder to address their concerns about customer satisfaction and space limitations as garage layout was determined beforehand. Switching to heat pump water heaters, we worked very closely with the water heater manufacturer, A.O.Smith, on sizing. Recommended size for some homes were 50 gallon tanks, and, for the larger models, were 66 gallon units. In addition, as this project aims at unlocking additional grid services, the team determined that 80 gallon HPWHs were optimal to maximize thermal storage capability. However, as the main limiting factor in the original project plans were the available space in the garage, a 50-gallon heat pump water heater unit was chosen as this did not require substantial structural redesign, triggering additional work that includes additional permitting and resulting in not meeting overall project timelines.
- **Electrical Wiring:** The intent of the project was to be able to isolate appliances, plug loads and lighting. For new home construction it is standard practice that the remaining electrical end-uses are connected to 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 informed to group loads in the home by end-use type and not by location. Trade-ally buy-in was evaluated by limiting the amount of interaction with the electrical contractor to evaluate the degree of difficulty in installing these devices in a community scale by a production level builder and its trade allies. In addition, as water heating was now electrified, the electrical contractor added 240V to garage for heat pump water heater as the heat pump water heater 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 cooking ovens and clothes dryers were considered standard in this building, some homebuyers chose to include electric dryers and ranges in their particular home. In addition, 2 homes – homes 3 and 10 owned electric vehicles and could potentially charge his/her vehicle in the home.
- **Energy storage:** Energy storage was a big project in terms of installation process, responsibilities and permitting. As residential customer-sited storage is a fairly new technology, there was no prior experience from many of the project partners (permitting

organizations, installation contractors etc.) The result was the project team managed the storage process all the way from the electrical wiring design all the way to commissioning. First item was to set up a backup power panel to be able to serve the critical loads using energy storage. The design of the critical loads panel took a substantial amount of time, and more important required repermitting of the electrical drawings. Another challenge was the skill level and responsibility of the overall electrical installing. As previously mentioned, it is important to understand that an existing solar provider and electrical contractor was used in this project to simulate a scenario that can be occur during production level homebuilding and to better understand scaling considerations. In this case, each stakeholder thought it was the other’s responsibility to install the battery storage system. In the end, the electrical contractor was responsible for the installation (cost was $1,000 USD/home) with the BESS provider providing oversight.

These design efforts were of significant value to ensure that a holistic and 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 demand response events and to provide ancillary services. The objective was to design a network of smart, connected devices which would enable a combination of homeowner and utility visibility and control. Section 4 of this report focuses on specifics of this multi-faceted design architecture. A holistic connection schema illustrates local devices, wireless or hardwired connection, cloud supported and API connected topography. It is worth noting that several Ethernet hardwire runs had to be abandoned due to wiring issues, compromised conductors. As a backup, wireless connectivity was selected and generally has been maintaining a reliable connection. At a higher level, the design depended on a Verizon cellular uplink through a master modem connected to the device hub. In hindsight, a proper validation and long term testing of cellular strength would have greatly reduced hours of additional troubleshooting efforts related to dropped and weak signals. A standard dB test and communication with multiple providers is recommended as a first step prior to locking-in a final design and cellular provider agreement.

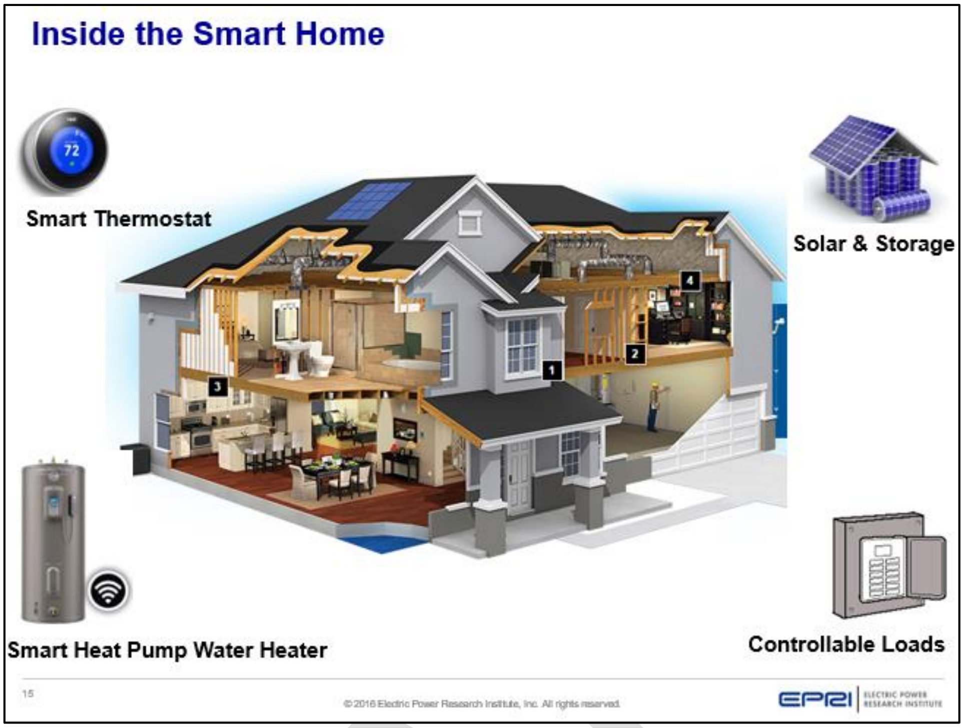

Figure 3-1
Inside the Smart Home

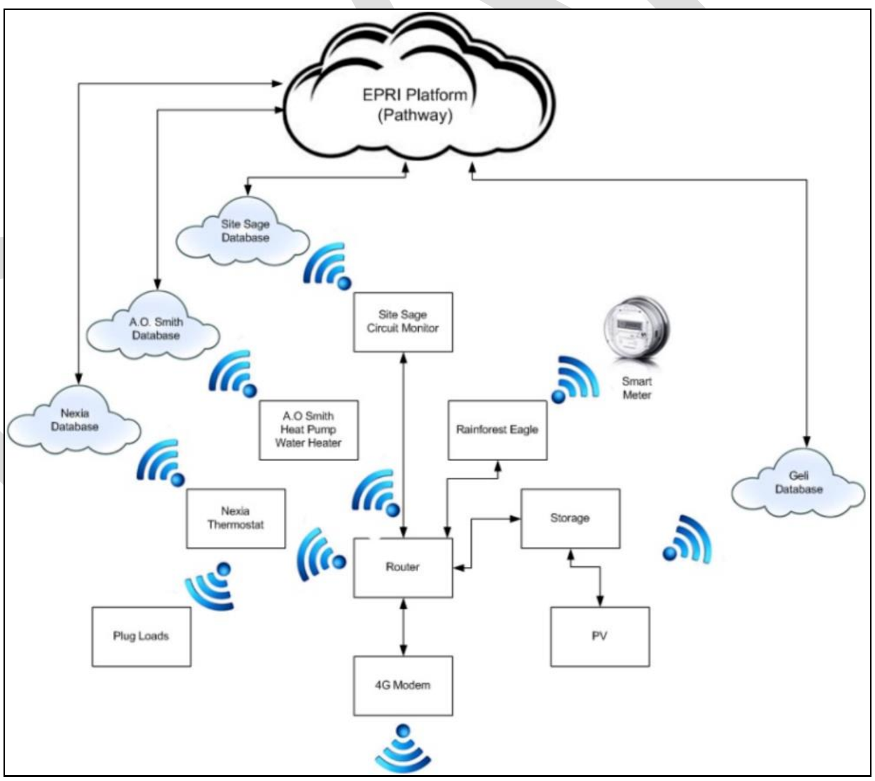

Figure 3-2
Smart, connected device architecture

A substantial effort was required to redesign the original battery energy storage system. After several months validating initial design, the primary energy management system provider was determined to be inadequate to support the flexible nature of the test plan. A backup 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 group could validate several value streams as it related to several project objectives. A notable physical design modification that was required a change-order mid-installation was that of 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 solved multiple problems: (1) interconnection fast-track w/ visual disconnect/reconnect feature (2) allows grid link to backup critical load panel in the event the BESS requires service or is fully discharged.

Considering the solar electric system was designed prior to selection of a BESS, a prominent product feature was determined to be too high risk to be implemented. Despite a provision in the BESS which allows the solar PV to be directly looped into the BESS (allowing solar to operate locally isolated 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 business conflict (separate solar O&M from battery O&M). This was agreed upon considering the relatively early market deployment of the storage provider and to isolate any issues in the event any modification needed to be made post installation and operation. Despite this decision, it should be emphasized that the solar and battery systems are technically connected (although only at the main AC bus) which allows the systems to work in harmony in grid-operation mode.

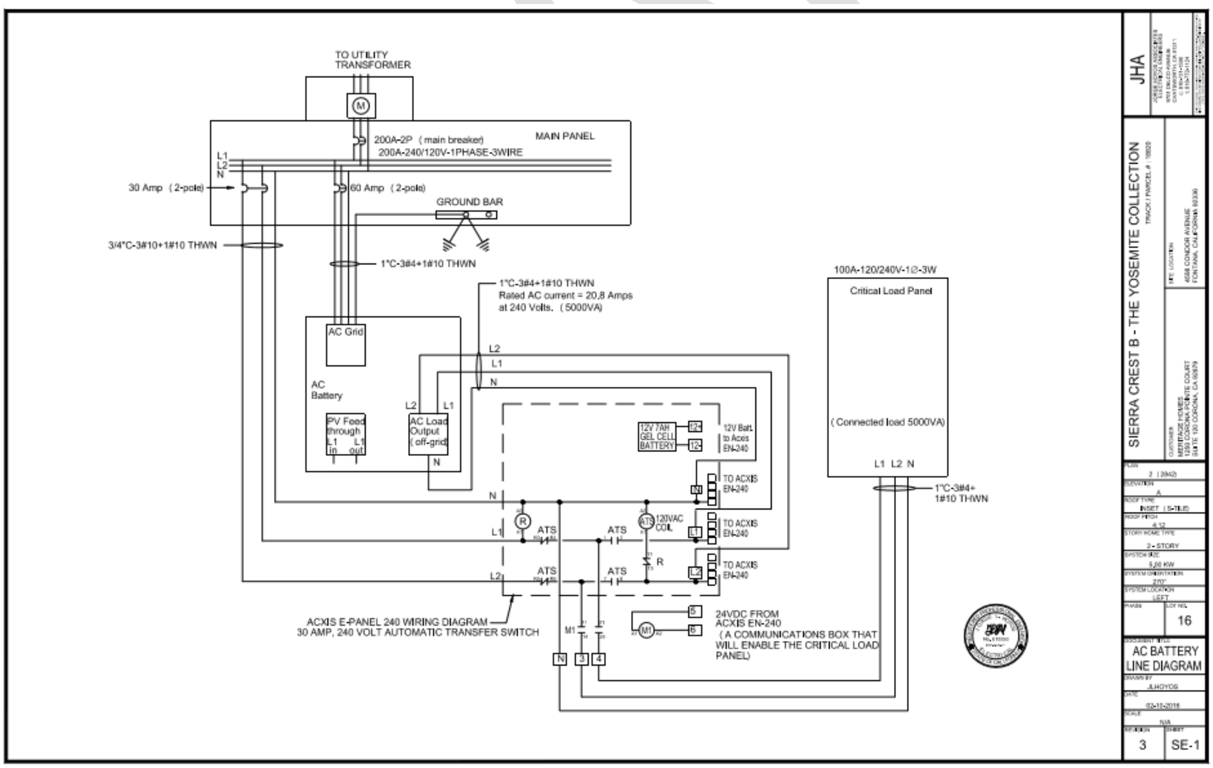

Figure 3-3
Battery Energy Storage System Architecture (as submitted to City of Fontana permitting and SCE Interconnection)

Sales Process and Customer Uptake

California Assembly Bill (AB) 32 raised the goal for the state to make every new home zero net energy (ZNE) by 2020. This means as one that generates at least 85% of its own energy needs over the course of a year.)

As a result, many utilities are evaluating ZNE homes as a way to meet the state's goal. ZNE homes rely on the grid to absorb excess solar generation during the day and to deliver power at night. The benefits they offer utilities include carbon reduction, as well as increased capacity benefits through the implementation of energy efficiency in combination with solar. In addition, with installation of smart, connected devices and higher levels of building thermal capacity, ZNE homes serve as demand response resources that compare favorably to standard homes.

While ZNE homes are designed to generate energy that is equal to the energy they consume with help from the grid (AB 32 requirements show that a ZNE home would generate at least 85% of its own energy needs over the course of a year), they have not been cost-effective to date.

Sales Process Kickoff

The project was kicked off in early March, with the first major milestone being the community's Ground Breaking event held on April 22nd, 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 2 commissioners from the California Energy Commission (CEC), Commissioners Hochschild and McAllister. Other dignitaries included the City of Fontana, representatives 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.

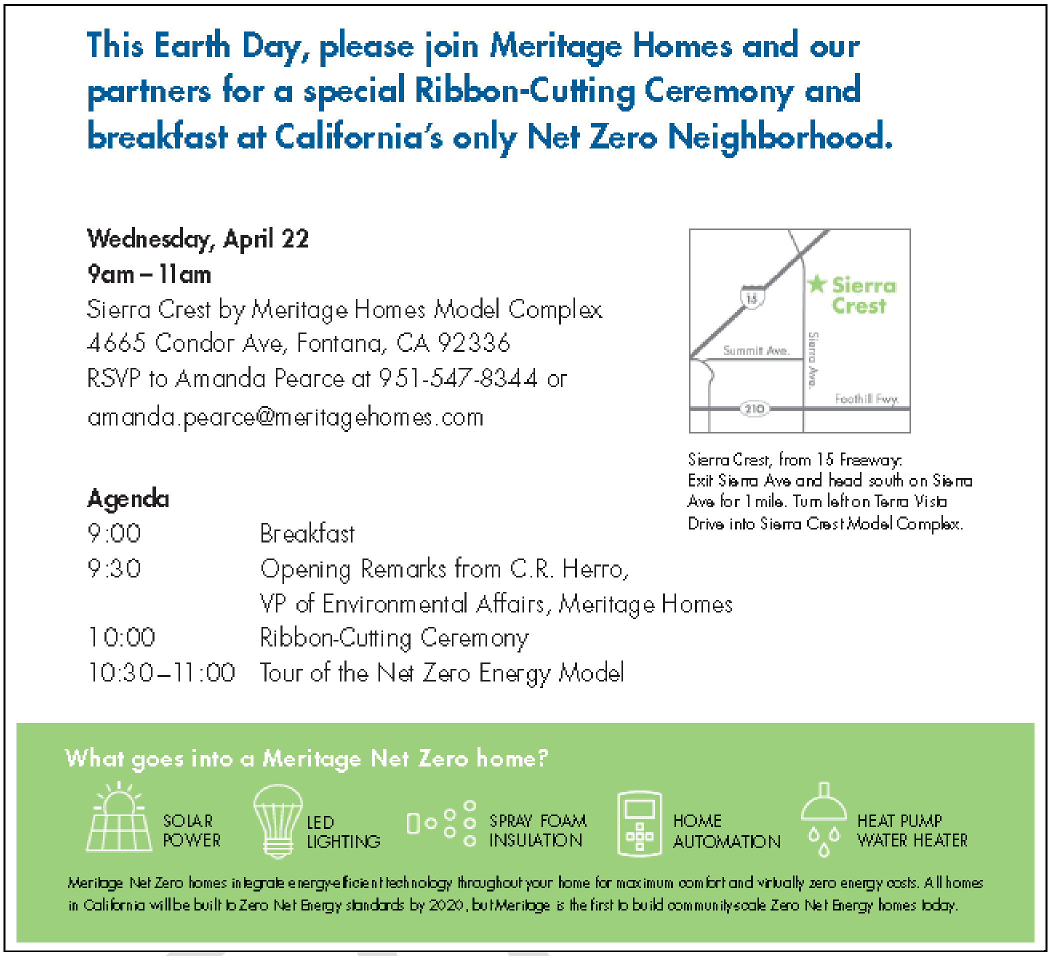

Figure 3-4
Flyer for ZNE neighborhood groundbreaking

Customer Marketing

Meritage Homes began selling the ZNE homes in June 2015. The homes were sold before they were built, and once the home was sold, the company would then break ground to build it. Home sales were off to fairly good start, as two homes were sold at the end of May. However, by the end of July, the team realized that sales at this point were not at the pace the team expected with no additional homes being sold for 2 months. With these results, the team discussed how to alter 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 make these ZNE homes stand out compared to other "green" homes that are being sold in neighboring communities.

Meritage and the rest of the team took several approaches to accelerate the uptake of the ZNE homes, since potential customers had a choice to buy a non-solar home vs. solar home, even in this particular 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 teamed used for increasing ZNE home uptake included:

- Evaluating and reporting on impact of various financial mechanisms for PV such as zero-down leases, lease buy-down, and builder purchase of PV.
- Assisting setting up model homes differently to highlight the benefits of ZNE as well as highlighting the goals of the project and the California Solar Initiative (CSI).
- Providing marketing collateral such as brochures, technical documentation and feature highlights that are tuned to 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: (1) open houses to promote uptake of ZNE homes, (2) advertising of ZNE homes to promote uptake and (3) workshops for customer education on ZNE construction and financing

Customer Education and Home Sales

By the end of July 2015, sales started to pick up, and the impact of the honed marketing messages resulted in the sale of ten 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 home 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 making this project a success. EPRI worked closely with SCE and Meritage to develop a schedule of community workshops designed to inform and educate on the process associated with the living experiment. The 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, the 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 institute 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 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, in order to ensure real-world load profiles were captured.

Prior to the customers occupying the home, Meritage and EPRI led a homeowner orientation workshop on 9/22, which included explanation of how the solar, storage and other home energy management technologies work together in the home. This helped explain how the solar and the storage work together and are controlled in unison using a device aggregation platform.

Figure 3-5
Excerpts from the Original Homeowner Orientation

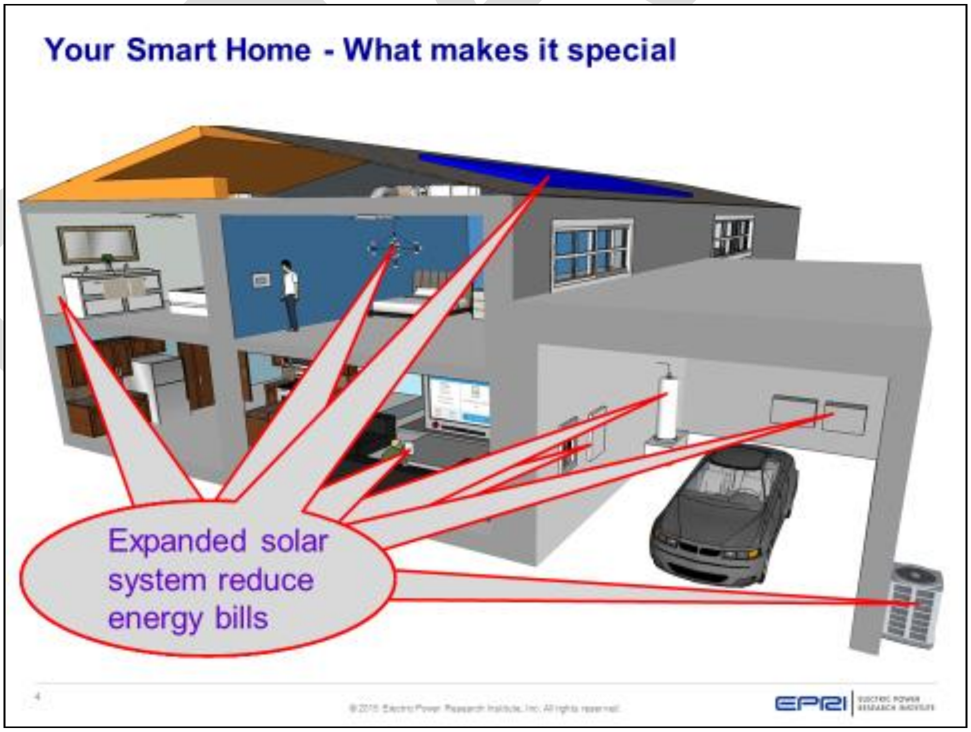

Figure 3-6
Explanation of how ZNE technologies could reduce energy bills

However, by the end of October only 16 of the 20 homes had sold. The team hypothesized that as the 16 sold homes had models homes that could be used as marketing tools by Meritage's sales staff, this was due to the fact that the remaining three homes did not have a model home for the potential homeowners to walk through. The lack of a model home slowed uptake of the homes with that particular floor plan. In December 2015, construction began on the remaining four homes. This way, customers were able to see the home they were going to live in. As a result, the number of houses sold reached 19 homes.

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 in Product A), as well as provide a forum to meet a new group of homeowners which would be moving-in to Product B (11 homes). The then CEO of SCE made an appearance, met with homeowners, and learned more about the ZNE community deployment, heightening the profile of the event. A presentation was provided to the group to capture 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 were able to attend. For those that did not, 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 represents 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. Now that the homeowners are able to fully realize the power of the apps, they are able to maximize their comfort and minimize the bill, and are enjoying their Zero Net Energy home. One homeowner even had a discussion with Ted Craver, Chairman and Chief Executive Officer of Edison International, the parent company of Southern California Edison (SCE), who then included her comments in the SCE shareholder quarterly review.

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 w/ 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 that "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 their lessons learned during the sales and marketing process. According to the marketing team, initial marketing efforts were centered around Earth Day, and worked on drawing parallels between environmental responsibility and the 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 was done on Earth Day, driving home the environmentally friendly aspect of the ZNE homes.

The focus on Earth Day helped drive 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, the 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 were 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 for 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 customers 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 can 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 homes technologies and explain this in a manner that a customer will understand. If the sales team did not feel comfortable with the technology, then they would not be able to explain it to the customer, and may even avoid selling those homes. 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. This with additional signage, helped the customers tie the physical aspects of the home with the technological benefits of ZNE. Combined with an aesthetically pleasing home, this helped customers purchase the ZNE home over the 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 in 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 particular 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 ones 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 the home. But for the majority of homebuyers, they need more education to understand the benefits of ZNE and how it can help enhance their day to day lives. For the majority of homeowners, it is important for them to fall in love with the house first, and then realized the potential benefits of owning a ZNE home.

Business Model, Agreements and Contracts

This project required a considerable effort to collect and execute on business agreements across 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 (Sunpower) installed and maintained the solar system, the battery service provider (EGear) designed and installed the battery energy system (BESS), and EPRI facilitated project plan and execution amongst these parties. One of the most challenging aspects to defining the business models around this project was that between the solar installer and the storage owner and operator. Although the solar installer was considered in 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). It was later discovered that another third party interested in owning and managing a storage asset specifically selected to meet this projects needs was settled upon. Six months after the storage group was selected, the 50 year old company filed for bankruptcy, leaving the need for a new owner and operator to take over. Fortunately, a fit was found in a national independent power producer, adding 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 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, direct utility smart metering (excluding heat pump communication). It was important to test against an identical reflection of product selection, design, and implementation in order 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 for example). 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 we 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 not able to be ascertained 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 were able to 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 could be 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 wifi module to remote control setpoints, the availability of the module was lacking 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 to big a process challenge and the group collectively decided to forgo the implementation on the remaining homes. The device worked well in connecting in a plug-n-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 by also abandoned as the product had not been designed to be used w/ the LED lighting technology deployed in the homes.

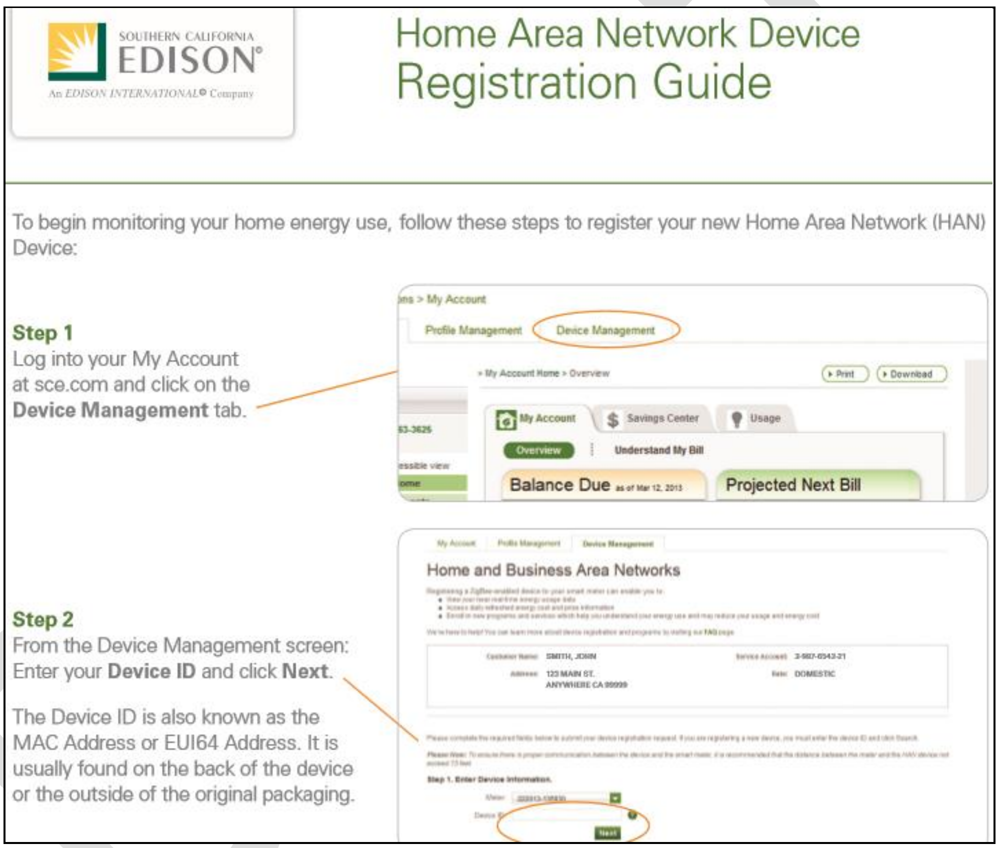

Figure 3-7
SCE Home Area Network Device Registration Guide

System Installation

In general, the installation of hardware was a straightforward process, considering that a large number of devices where required throughout the home, primarily located in the homeowners' garage. Commissioning efforts where focused on configuration of 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 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 challenges which 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 of twenty separate households.

Once initial testing and the preliminary installation took place on a model homeowner, 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. We initially settled with the builder's production electrician but came to the conclusion that a devoted data technician and electrician resource with a skillset to learn on the fly and install new products and technology was needed.

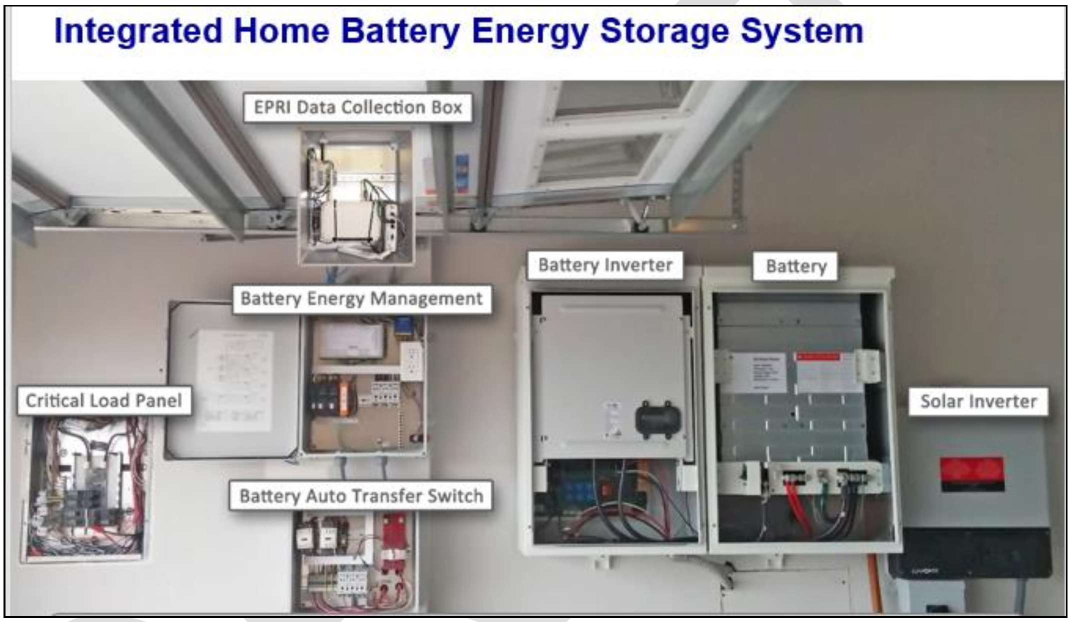

Figure 3-8
Integrated HEMS

System Commissioning

It was important to work with product and system vendors to pre-commission where possible, reducing time required in field. Selecting an Internet Service Provider for the initial commissioning effort was required to setup the smart meter, thermostat, solar and storage, and submetering systems. Most homeowners had yet to install a home area network to begin setup devices. It was determined that the EPRI cell modem signal is too weak to test for speadtest.net upload/download speeds. The smart thermostat setup proved to be one of the most significant impact to customer, as entrance into the customer home, after the HVAC system was running was required. 20% of homeowners had already preconfigured and setup their smart thermostat prior to EPRI instructions, required username and login credentials to be shared and data ported for EPRI research. The remaining homeowners required that EPRI support staff schedule a time to initialize the system, setup with customer/EPRI credentials, and ensure a reliable feed and handshake to EPRI backend data systems. Several homes required multiple visits to recommission due to data drop-outs and changes to access privileges/ requirements.

Solar/Storage Permitting

In parallel with the 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. 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 structured as the gatekeeper and relationship manager of multiple entities, and the dependency on this resource added excessive delays in deployment. A significant and potential improvement mitigating 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 project schedule and budget.


CITY OF FONTANA

Department of Building & Safety

JOB CARD

Fire Sprinklers:

PERMIT NUMBER

4792 CONDOR AV

DATE ISSUED: 03/22/2016

DESCRIPTION:

PERMIT FOR THE INSTALLATION OF A BATTERY PACK FOR THE SINGLE FAMILY DWELLING, LOT 127

SEE REVERSE SIDE FOR NOTES OR COMMENTS

Figure 3-9
Sample Permit for the Installation of a Battery Pack a Single Family Dwelling from the City of Fontana.

Interconnection

Generally speaking, electric utility interconnection approval is the next event in the sequence of construction events. It is best to start filing for a ‘generating facility interconnection application’ (SCE Form 14-957) months in advance to 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). In the case of this project, the builder had already agreed to partner with a solar integrator who sold the system to the builder under a cash agreement, which was then wrapped into the final cost of the home, and extended with a warranty to the homeowner. The standard practice has been for the solar electric integrator to file their agreements for multiple new homes with the utility. This project called for battery storage as a ‘change order’, so to speak, to design, install, and file for the storage system. Additionally, a third-party, independent entity was selected to own and manage the storage asset. This led to design implications which 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, added value to the homeowner and builder. The design was made to maintain system independence due to the separation of systems and their respective warranties. As an example, if the storage system connection was defective, that could impact the solar integrator’s operations and maintenance agreement and vice versa. Once an agreement was achieved between the solar and storage integrators on design, it was decided that the solar integrator would 'bolt-on' the storage system to the existing solar interconnection agreement. It turned out that this ad-hoc request was difficult to fit into existing solar integrator processes, and EPRI project management had to jump in to support directly with the SCE and make several exceptions to get interconnection agreements in the queue to meet the project schedule.

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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
++

Figure 3-10
Sample E-mail from SCE Giving the Homeowner Permission to Operate Self-Generation Facility Interconnected to SCE's Electric Grid

Operation

Once interconnection was received for all nine storage systems, data streams were enabled and analysis performed. Several homes posed data issues related to the cellular reception issue and one specific to challenges with the solar electric installation, which impacted the commissioning of storage and load profile of this home. Final analysis and impact on the shared 50kVA transformer was modified to account for this omission. Post operation, several site visits were required to adjust, reconfigure, and modify device settings, firmware, software, hardware, wiring, data communication, etc.

A snapshot of the virtual metering at the 50kVA transformer for the nine homes is depicted below. 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).

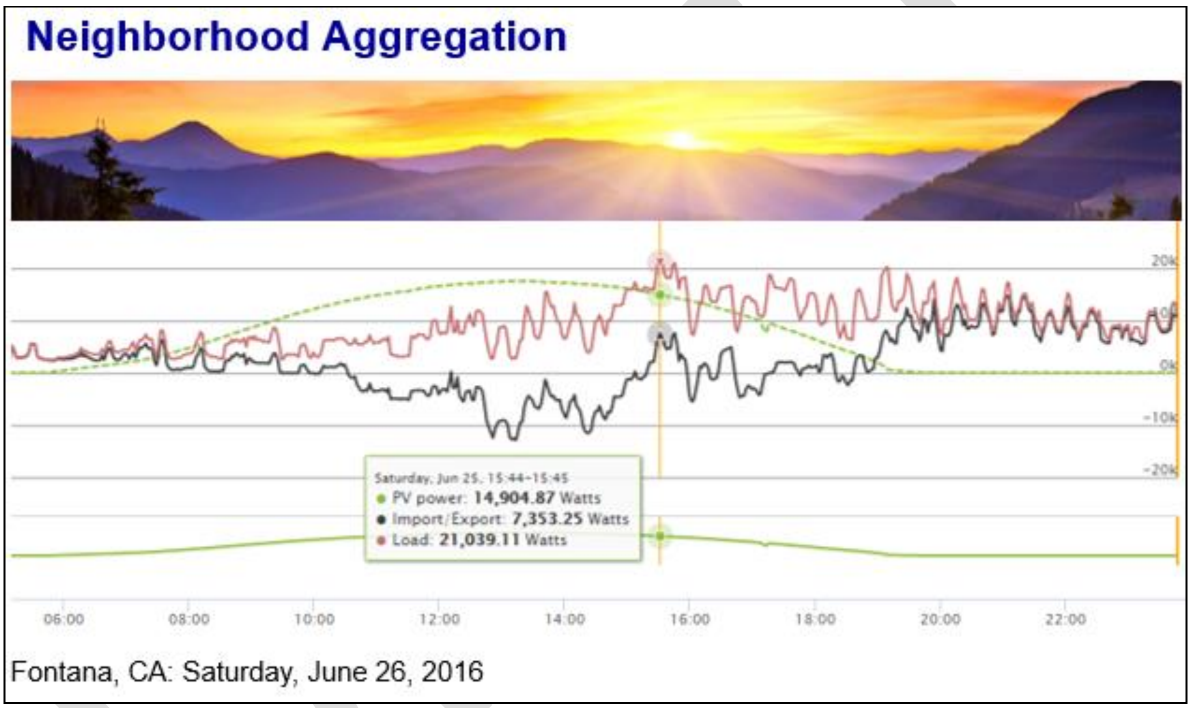


Figure 3-11
A snapshot of the virtual metering at the 50kVA transformer for the nine homes

Summary

ZNE homes are still a nascent technology, and new for 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 buyer 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.

In the end, after eight months working through the design to the operations phase, a great number of lessons were gained from this deployment of smart, connected homes in this community of twenty homes. The eleven homes which did not include storage generally required less effort and impact on the homeowners, with the exception of the data monitoring and cell modem challenges. Fieldwork and teams essentially broke in two groups, as one team developed expertise and relationships with Product A (the nine homes w/ storage) and Product B (eleven homes without). The two separate products proved to be of value to the experiment as Product B 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. The construction processes witnessed over the course of this project leave much to be gained as it relates to future improvements and efficiencies gained when deploying a demonstration project within a commercial deployment of state-of-the-art, new construction homes. 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 – Incorporate stakeholder approval at the beginning of the process
- Testing – Early system demonstrations enable maximized efficiencies in the field deployment
- Installation – Properly defined teams executing on coordinated critical path timelines necessary
- Commissioning – Use fully vetted products in a compatible environment and fully tested connectivity
- Permitting – As AHJ’s have more exposure to nascent technologies and education becomes more pervasive, process timelines will improve
- Interconnection – Similar to above; 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

4

CONTROLS AND DATA ACQUISITION ARCHITECTURE

Community scale data monitoring has been a challenge due to the cost. Traditional monitoring systems which consist of environmental and energy submetering packages can be relatively costly and intrusive to homeowners and operators. Traditionally, customer preference was generally determined through the use of surveys to homeowners and occupants. This too could potentially 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 customer preference is crucial as energy usage, especially usage of Miscellaneous Electrical Loads (MELs) varies in these ZNE communities. With increased two-way communication and low-cost sensors, an advent of communicating and connecting technologies are allowing customers becoming more “energy aware” and demanding 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, coupled with new methods to use connected loads such as water heaters (Hledik, Chang and Leuken 2016) and HVAC systems using smart thermostats (Davids 2015), can now provide additional load management capabilities to mitigate grid impacts of ZNE homes. The opportunity

This ZNE project applies a method for data acquisition, attempting to leverage data collected from connected devices. Today, common household devices such as thermostats and circuit panels have the potential to log data on customer preference, indoor and outdoor environmental information and system performance. For example, these data can be readily available to both customers and third parties. This project incorporates a platform consisting of a combination of local and cloud based data acquisition platform of multiple end-use devices, in particular, as part of this project. As connected DERs and end-use loads now are 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 (Callahan et al. 2014). 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. This project is deploying a monitoring and control strategy based on connected and smart home devices that use the data acquisition capability of each of the devices to collect and transmit the data. The attempt will be to organically collect will be more than end points monitored in each home collected by systems that include but are not limited to: (1) heat pump water heater data using 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.

There is a need to integrate all products that can serve as load management systems and load monitoring tools. As there are independent of competing standards and ecosystems, the project team attempted to complete the data monitoring task by using a “bottom-up” approach to understand customer preference and working with controls and data that product providers to acquire, collect and store data organically retrieved from each's system. By approaching data collection in this manner, the to develop (1) an inexpensive monitoring system which leverages device data and (2) a controls platform which 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 following high level approach to complete data acquisition and analysis.

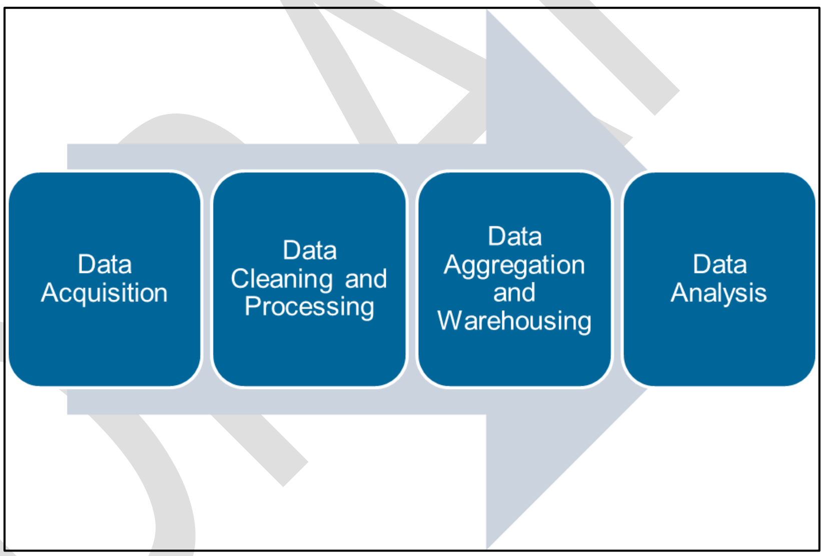


Figure 4-1
Approach Data Acquisition and Analysis

Each step of the process is summarized below:

- **Data Acquisition:** Steps necessary to install and collected data from the connected devices that will be used as 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 to be at later dates for data analysis.
- **Data Analysis:** Use to data necessary to provide insights as required by the project

Data acquisition consists of tasks that allows 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 his or her home.

Data Acquisition and Collection:

The project team aimed at developing a data collection and aggregation system which primarily leverages data from connected, communicating devices that were to be installed in the 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 third parties that 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 off of their ability to collect the desired data parameters, but product providers were chosen based on existing homebuilder national contracts. 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 is feasibly collected from each device provider and core requirements of this project.

The preliminary data acquisition plan listing the communicating devices installed and data parameters collected can be found in the table below:

Data Collection Software Architecture: Overview

For this project, it was important to minimize potential customer issues attributed to lost internet connectivity. Therefore, a parallel broadband network was installed in order to provide connectivity to the devices installed in each of the homes. A schematic of the system architecture is presented in the Figure 4-2 below.

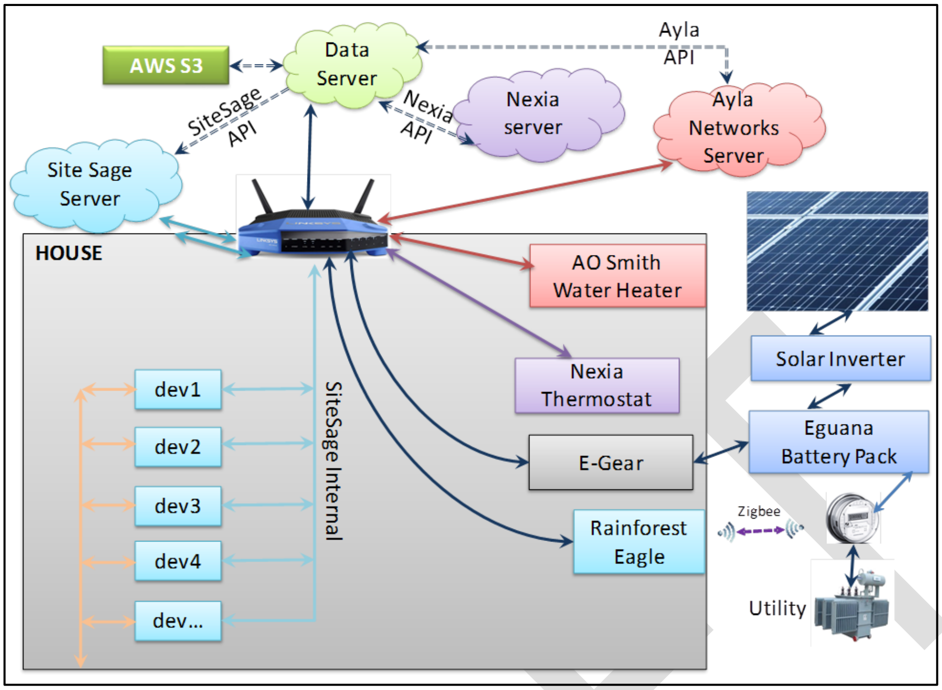


Figure 4-2
Schematic of Data Collection and Controls Architecture

The individual layers enabling the functions of the application in the cloud i.e. data server system is shown in Figure 4-3 below.

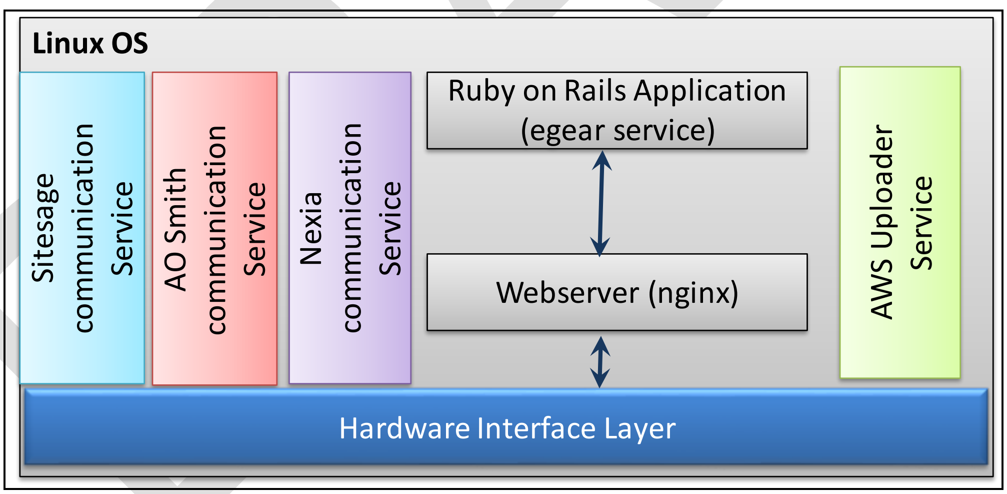


Figure 4-3
Layers of the Data Server Systems

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 setup to receive POST data from any devices or the system. In addition, this could provide additional info or credentials. All data that is received through the POST or any other method is stored on local file system. Data is sorted is based on individual identifier for each home. This system also provides a portal to set parameters for individual homes like setting up DR events.

An Amazon Web Service was used and was responsible for uploading collected files to Amazon Web Services Storage (S3). 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:

1. 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.
2. 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.
3. The service will identify those files that do not belong to the current month and year. Data in the files for the current month is still being updated and so they are not touched by this service.
4. The service will look at the folders where each connect device service provider stores their data.
5. Once the set of files have been identified, the service will perform the following tasks
    a. Zip the file up and upload to a private section of the AWS S3 directory
    b. Encrypt the zip file and upload to a public section of the AWS S3 directory.
    c. Delete the generated .zip and .enc files
    d. 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 that 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. Approach for each 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 Application Programming Interfaces (APIs), it is important to note that during data infrastructure implementation, delays occurred due to both technical capabilities and company philosophies. Data acquisition method for each product provider is detailed below:

Circuit Level Monitoring Provider

The Circuit Level Monitoring allowed access to its API for this project. The data API is through RESTful commands to circuit level monitoring provider’s current server. First time access to the system requires individual user login details, which is required to get a security key. To separate login access of the individual homeowner with the project team to minimize the disclosure of personal information, a 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 4-4 below:

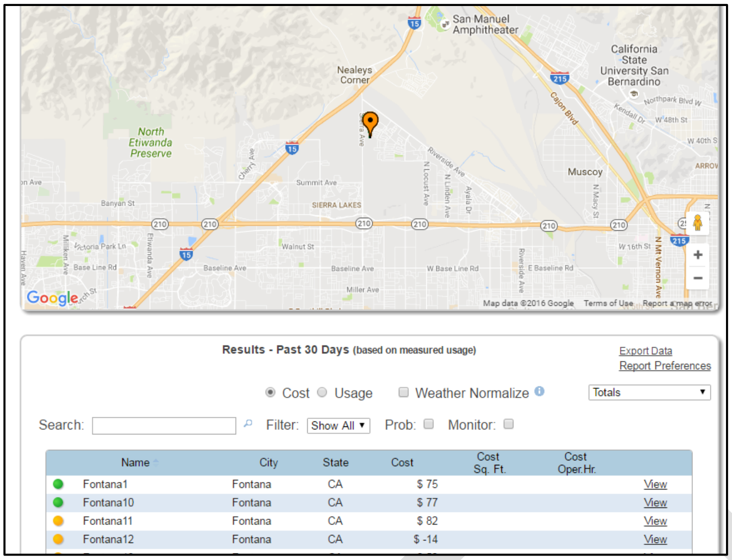


Figure 4-4
Screenshot of Aggregation Portal Provided by Circuit Level Monitoring Provider.

The service after authentication 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. 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 the steps for:

- 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 file corresponding to the identifier for the particular home.

In addition to the APIs, the circuit level monitoring provider allows data collection via a reporting function. See Figure 4-5 below:

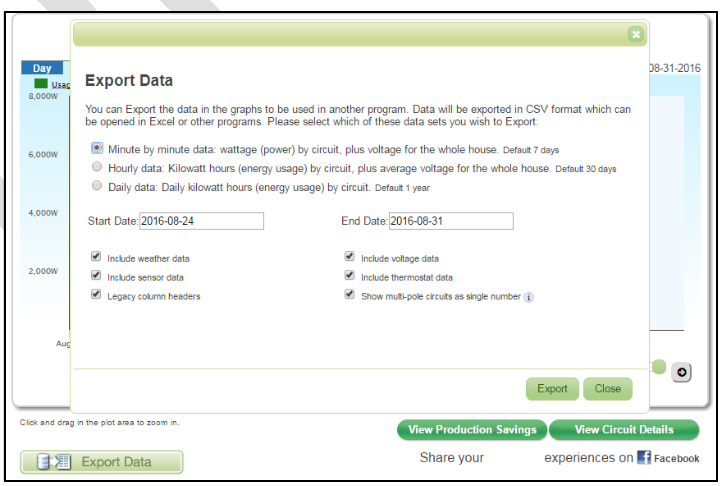


Figure 4-5
Reporting Functions Provided by the Project Portal.

As Figure 4-5 above shows, data can be provided on a home-by-home basis in minute, hour or daily resolutions. See Figure 4-6 below for 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-Micr	CH12-FAU	CH13-Kitcl	CH14-Dish	CH15-Gark	CH26-Frid	CH27-Kitcl	CH28-Gara	CH29-Gara	CH30-Livir	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 4-6
Data Report provided by Circuit-Level Monitoring Product Provider

As the figure shows, data is provided in fixed time intervals. Energy consumption is measured and then provided at both the premise and circuit breaker level. As loads such as the HVAC and the water heater are loads that are connected to an independent circuit breaker, energy usage can be attributed to that particular end use.

Smart Thermostat Manufacturer

For this project, the thermostat provider granted API to access to the data. It is important to note that certain data parameters collected as part of this project were only available due to agreement 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 requires individual user login details, which is required to get an authentication token and any successive attempts to get the data can be obtained using the authenticated token. The service after authentication repeats RESTful calls to the thermostats webserver every 1 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 the steps for:

- 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 file corresponding to the identifier for the particular home.

Water Heater Manufacturer

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

1. The system requires an “Application Id” and an “Application Secret” provided by cloud service for accessing data from its servers. This is required for each application that requests access to the Ayla servers.
   2. First time access to the system requires individual user login details and the ids, which is required to get an access token and a refresh token.
   3. 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.
      a. The access token can be refreshed even before 24 hours has expired.
      b. Successive attempts to get the data can be obtained using the access token.

The service after authentication 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.

Each line of data corresponds to the data received in each call to the water heater server. Please note that the 3rd 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. Through 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 AOSmith 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 4-7 below:

Figure 4-7
Communications Port Provided by Water Heater.

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

BEMS Service Provider

The BEMS Service provider was chosen for its experience in managing residential photovoltaic (PV) systems coupled with battery storage. Data is provided by the BEMS providers via a JSON posts “pushed” to the project team data server. PV, premise and storage information can be provided via web portal. See Figure 4-8 below:

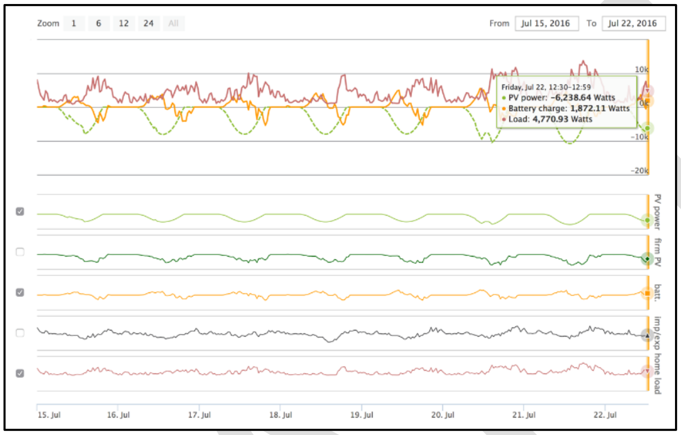


Figure 4-8
Solar, PV and Battery Information provided by the BEMS.

Hardware Requirements

Data collection and acquisition is enabled by a dedicated data acquisition system consisting of two main components: a conventional router and 3G cellular modem. See Figure 4-9 below for a high-level schematic of the 3G cell modem and router enabling data acquisition and local energy management.

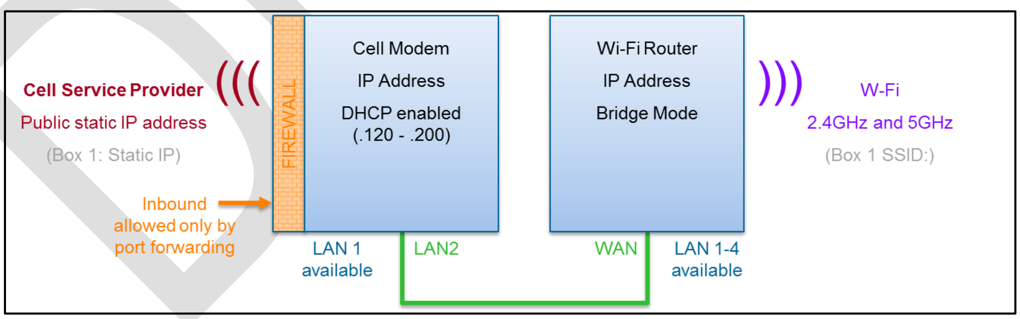


Figure 4-9
Cell Modem and Wi-Fi Router Configuration

The data box consists of a 3G modem equipped with 1GB/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 specific project's needs. The router can service 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"x10"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 4-10 below for the project team's data box installed in each of the 20 sites.

Figure 4-10
Data Box Installed in each of the 20 sites

Data Acquisition Progress and Lessons Learned

At the time of this report the hardware had been successfully installed in all 20 homes. See Figure below. As previously discussed, delays in data acquisition were caused by company data sharing policies by 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 provider via APIs of this specific water heater manufacturer. See below for data acquisition progress summary table and lessons learned by implementing a novel method for data acquisition.

Table 4-1
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 note information provided by electrical and plumbing contractors when installing and commissioning the overall data acquisition system. As previously mentioned, only hardware elements of 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 some homes did complete intentions of grouping end-uses to common breakers, several homes conventional groups 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 incentive is increased detail in the data monitoring and acquisition plan that is aligned with electrical circuit schedules. It will be important to understand cost premiums of this level of detail from both a commissioning and networking perspective. In addition, it was identified that certain loads as part of the circuit level monitoring were mislabeled. 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 in which to understand and treat data collected by the individual systems before completing analysis.

Resolving Installation Errors

The project team found end-use 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 fundamental understanding of the operating condition of each end-use. In addition, polarity issues were identified as well. To resolve the errors, the project team:

- Performed on-site reworks of the circuit-level monitoring system. With preliminary analysis, the team verified and adjusted CT location based on data received. Necessary changed made to the back-end infrastructure provided by the circuit-level monitoring system was also completed. The following summarizes when these reworks were completed:
  - Circuit-level monitoring was reworked for homes 1, and 3-9 on May 31st – June 2nd
  - Circuit level monitoring was reworked for homes 2, 11-15, and 17, 19 from June 20th – June 23rd
  - Circuit level monitoring was reworked for homes 10, 16 and 20 from July 7th – July 8th.
- Coordination with circuit level monitoring product providers. Polarity issues and other anomalies detected that could be potentially be addressed via software was coordinated with the product provider.

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, which might be relevant to but must be adapted based on the data collected and the use of that data.

For this project, the team used a its 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 such as 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 of time.

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

Data Aggregation and Warehousing

Although data warehousing was described in the data collection section, data aggregation as it provides additional insight that may be otherwise missed when data is analyzed in a disparate subset. In practice, the connected device manufactures and electric utilities have historically operated in "data silos," with limited visibility of other data sources not owned by that particular stakeholder. It can be assumed that value of data is exponentially increased when analyzed in aggregate. For example, circuit level monitoring data can quantify energy consumption to a particular end-use. For example, data analysis from 2 homes in the study show that similar sized homes consuming different levels of electricity attributed to space conditioning. Evaluation of the thermostat data identifies that this is attributed to differences in customer preference indicated by lower daily temperature set-points by one home compared to another. In this project, the team has a unique opportunity to not 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 completed, data warehousing was completed, but autonomous data aggregated was still in its development stages. No particular results can be provided at this time.

Example Data Analysis:

Implementing Controls Using Data Acquisition Architecture

Using the architecture previously discussed allows the team the opportunity to control multiple end-use loads in the home.

Energy Management using Controllable Loads

In recent years, there has been an increased interest in developing customer resource aggregation to provide grid services to the utility and/or provide customer services to the homeowner. Increased market penetration of DERs such as electrical residential energy storage systems, coupled with new methods to use connected loads such as water heaters (Hledik, Chang and Leuken 2016) and HVAC systems using smart thermostats (Davids 2015), can now provide additional load management capabilities to mitigate grid impacts of ZNE homes. Historically, load management only targeted peak demand reduction and therefore, resulted in single, disparate systems When energy storage was added, the load shapes were smooth over longer periods of time, but could be very peaky due to the combination of appliances and loads over shorter periods of time (Hammon and Taylor 2014).

Summary

5
ENERGY STORAGE IMPLEMENTATION AND LESSONS LEARNED

Residential Energy Storage

Background

Residential battery storage has been deployed globally for over thirty 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 photovoltaic (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 consist of three primary components: a power conversion system (PCS), a battery/battery management system (BMS), and an energy management system (EMS). 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. This chapter provides an overview of the products available as of late 2015, their relative strengths, and the ways in which vendors have teamed to provide complete storage 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 becomes important. 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.

Objective of this Chapter

The purpose of this chapter is to share 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) gathered 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 particular set of priorities, needs, and resource availability.

Approach

This chapter 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 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. 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 as a whole.
- "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 as a whole covers an array of related topics; this article describes a pilot project involving installation of battery storage systems in a small community of homes.
- (Upcoming) "Customer-Sited Technologies and Applications," *Strategic Intelligence Update: Energy Storage & Distributed Generation*, EPRI, Palo Alto, CA. November 2016. 3002007864. The newsletter as a whole 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 numbers 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.

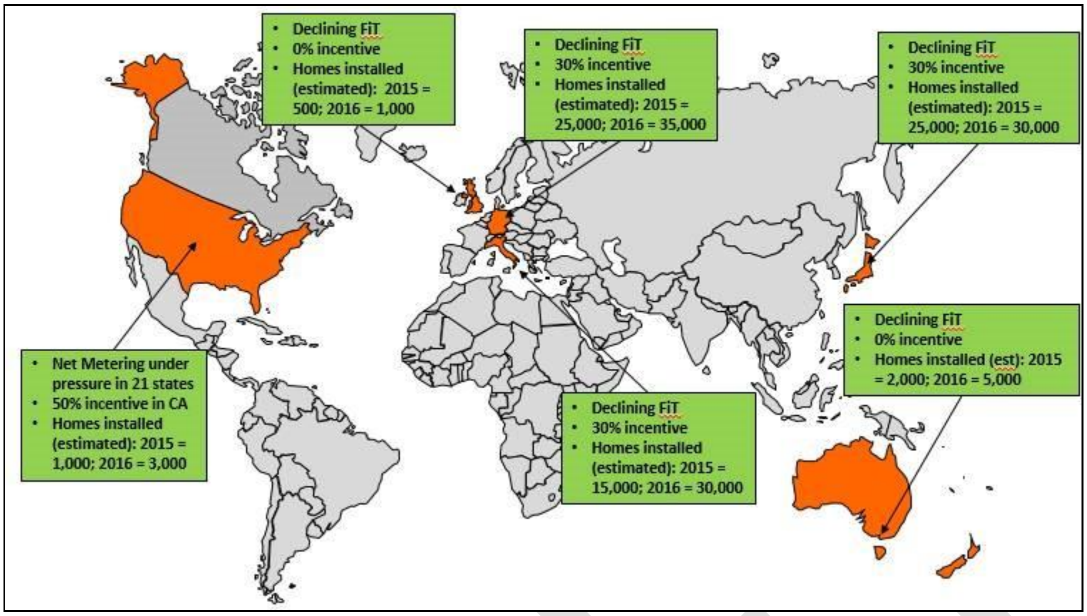


Figure 5-1
Global distribution of battery storage systems, including tariff structure (net metering vs feed-in-tariff), government incentives, and estimates of installed units.

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 of 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. With self-consumption systems managed to 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. As a result 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 such 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

An Energy Storage System (ESS) is composed of three major components: the power conversion system (PCS), the battery including its battery management system (BMS), and the energy management system (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 full 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:

- 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.
- 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 also decreases installation labor costs, because specialized solar technical skills are not needed.
- 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.
- 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.
- Efficiency: A key efficiency target is to reduce the number of energy conversion point, 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.
- 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.

- Cost-Effectiveness: Transparency as to the components of system costs, particularly installation costs, enables customers to weigh objectively 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 A is a compendium of available residential battery storage technologies

Community Energy Storage

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.

Background

The project--Demonstration of Grid Integration with "Locally Balanced" ZNE Communities in SCE territory, aims to demonstrate and evaluate the impacts of a near-Zero Net Energy (ZNE) home community on the local distribution systems, and evaluate the mitigation of the impacts using multiple strategies centered around building energy management systems and energy storage.

The primary goal for this project is 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 in particular, the distribution systems. The homes built and evaluated in this project should provide substantial benefits to 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 incentives programs.

For the purpose of this project, both storage on the utility distribution transformer level and storage on the residential customer level were of interest.

On the residential customer level, the storage systems will be installed at the residential homes (single family residential homes). Twenty 4kw energy storage systems (or similar size) were required, with the plan to install one storage system for each home. The 20 homes will be equipped with solar PV rooftop, heat pump water heater, and smart thermostat controls.

On the distribution transformer level, two 20kw (or similar size) systems would be required. One for each of the two distribution service transformers (20 kW / 40 kWh at 240V). The transformers are connected to the 20 single family homes with rooftop PV, heat pump water heater, and smart thermostat controls in each home.

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. The manager planned for 125K for storage procurement and installation, with the expectation that the vendor who participated in this project will get a chance to demonstrate the effectiveness of their storage systems in a high profile project, enhancing the publicity and credibility of their product.

The Search Process

The search for energy storage system started with a company 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 that meet the project requirements. As a way to communicate with the vendors, the team developed an "ask sheet" with basic project info and storage requirements and shared with potential vendors.

Due to the specific size requirement, tight timeline, and budget limitation, most of the vendors that we reached out to could not meet the requirements. The team eventually identified a vendor (referred to as "Vendor" 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 the Vendor to repurpose its existing units:

1. A few Vendor units were at SMUD and they were 30Kva/34kWh, pad mount units. These units were owned by NREL. Vendor suggested that NREL might be interested in selling or loaning one or more of the CES units to EPRI. For these units, EPRI would need to buy a few battery modules (2 to 4 modules) to replace some modules that were damaged in shipping.
    a. There might be a unit or two at SDG&E (30kVA/72kWH) that could potentially be in a transition from deployment to R&D resource and SDG&E may (or may not) be willing to look at a similar loan or sale arrangement.
2. There was one additional unit that may be available that does not have a battery pack in it but that could be available. In order to use that unit, EPRI would need to acquire a full battery pack.

The Vendor 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 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 rehab, test, and configuration update. Then the Vendor would send unit to California for deployment. An alternative plan would be for Vendor to come to NREL to do the rehab and configuration update and then have NREL test the unit to IEEE 1547 compliance. The Vendor 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. The Vendor estimated that Saft can support supplying these modules in a timely fashion at about $2k-3k 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 a commercial strip mall.

Safety Evaluation

Once it was determined that the Vendor could potentially meet the project requirement, the next step was to ensure the safety of the unit. The EPRI team put heavy emphasize on the safety of the unit because the units were planned to be in a residential neighborhood, and close to homes and backyards. EPRI 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. Manual for first responders in the event of fire and/or explosion;
6. Document of 15,000 hours of safe operation (or however much it is) with data on how the systems handled failures

The Vendor was only able to provide the following documentations on the unit:

1. A data sheet on the CE-3034
2. A (relatively old) brochure on the CE-3034 as installed in Sacramento
3. Installation manual for CE-3034
4. Installation manual for the DES-3072 -- which is similar but has twice the battery pack.

Potential Product Issues

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

The second issue was with 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 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 though NREL would be able to test for compliance, they cannot certify equipment for safety purposes.

The Vendor also had a couple 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 EPRI SMEs. The Vendor had some early issues with the inverter bias supply and some other support electronics, such as one IGBT device failure on a single bridge device on an early unit. All issues were repaired in the field and unit was returned to service. However, the EPRI team remained concerned about the potential impact in a neighborhood setting.

The fourth issue 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 have been provided that would guide the 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 as well as two disconnect means between the inverter and the AC mains). The unit design is per UL-1741 enclosure requirements (enclosure is NEMA 3R.)

The fifth issue was with the unit's fire suppression system. There is no fire suppression system installed in the battery compartment. SDG&E did install a fire suppression system in their DES-3072 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 CES-3034 unit.

The sixth issue was the lack of safety documentation provided by the vendor. Though the specific unit being considered for the CPUC project was deployed in Sacramento in a residential neighborhood, directly in the front yards of three different houses, there were other issues around the safety documentation of the energy storage system. The Vendor was also not able to provide 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 the Vendor's limited 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 EPRI team was not comfortable that the Vendor did not have any testing data to share either. The vendor was able to provide references from SMUD, as well as from Saft (the battery vendor) as a point of contact for Safety Reference.

The EPRI team asked the Vendor about how they planned to ensure safety by the units. The Vendor suggested that EPRI could either ask NREL/SMUD for a test report from the previous testing or EPRI could contract NREL to retest the unit after Vendor retrofit is complete. The Vendor also thought that there could be a modification to the system to place a segmenting contractor 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 100V is ever possible to access, as many as 5 controlled contactors would be required. However, locating and wiring such contactors will be very challenging in the CE-3034 battery enclosure.

Though the Vendor was willing to undertake more safety testing, analysis, and provide documentations, they needed to do it with coordination with NREL, because the unit was currently owned by NREL. The Vendor would also need external funding to undertake those safety testing, which was outside the budget of the CPUC ZNE project. EPRI 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.

Conclusion:

Due to the lack of safety testing and documentation, the team decided to not go with Vendor. As a result of the EPRI team's extensive due diligence, they were 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 establishes, more and 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, the Vendor 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 at this point in time.

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 time of use (TOU) tariffs, or as a battery backup system without PV. A version of the assessment framework described in Section 6 was used to identify a mix of components appropriate to this particular project.

The testbed system is composed of a 3.2 kW DC solar PV installation powered by microinverters, with a 5 kW PCS, and 6.4 kWh battery unit for which power throughput is constrained to 3 kW peak. The integrated EMS provides 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 5-1 illustrates relationships among the components of this system.

In the pilot project's location, home consumption was obtainable via Smart Meter, but that method is not available in all locales. The project team also tested an alternate method, polling a standard 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.

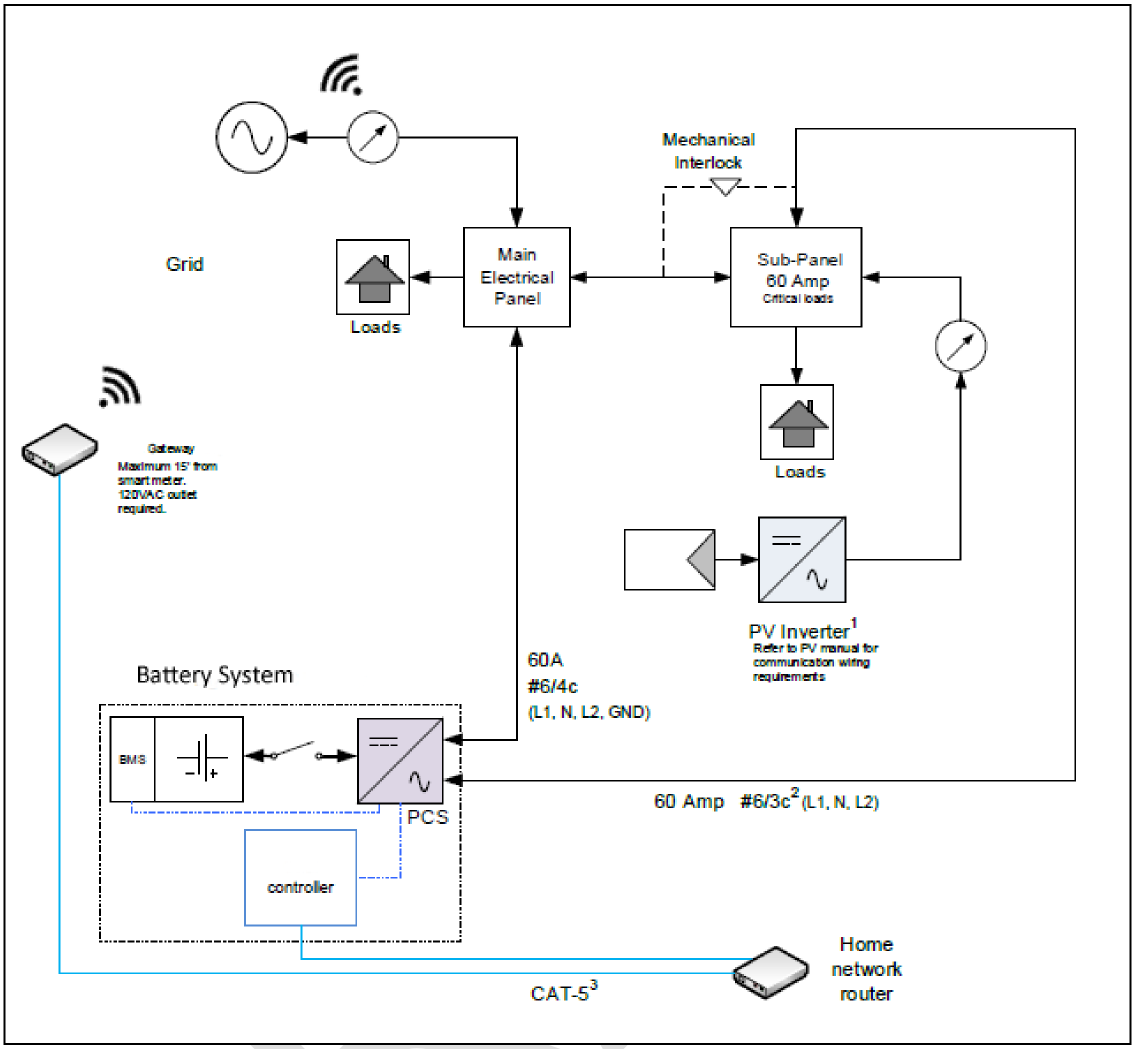


Figure 6-1
Schematic of Components of Pilot System Project

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 are 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.

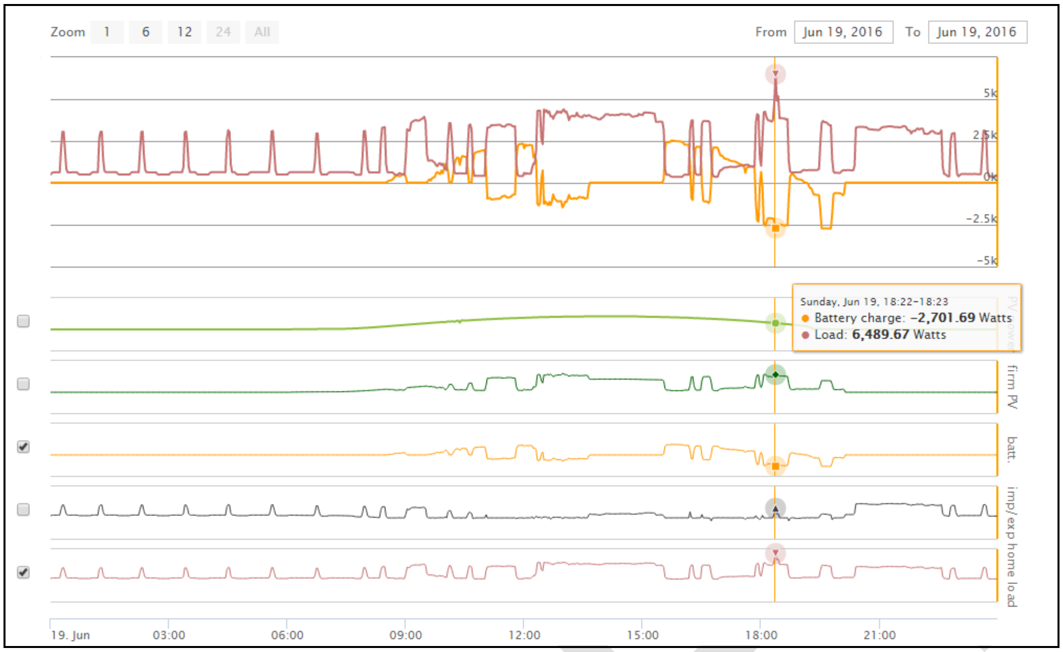


Figure 6-2
A single home's 24-hour operation with self-consumption.

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

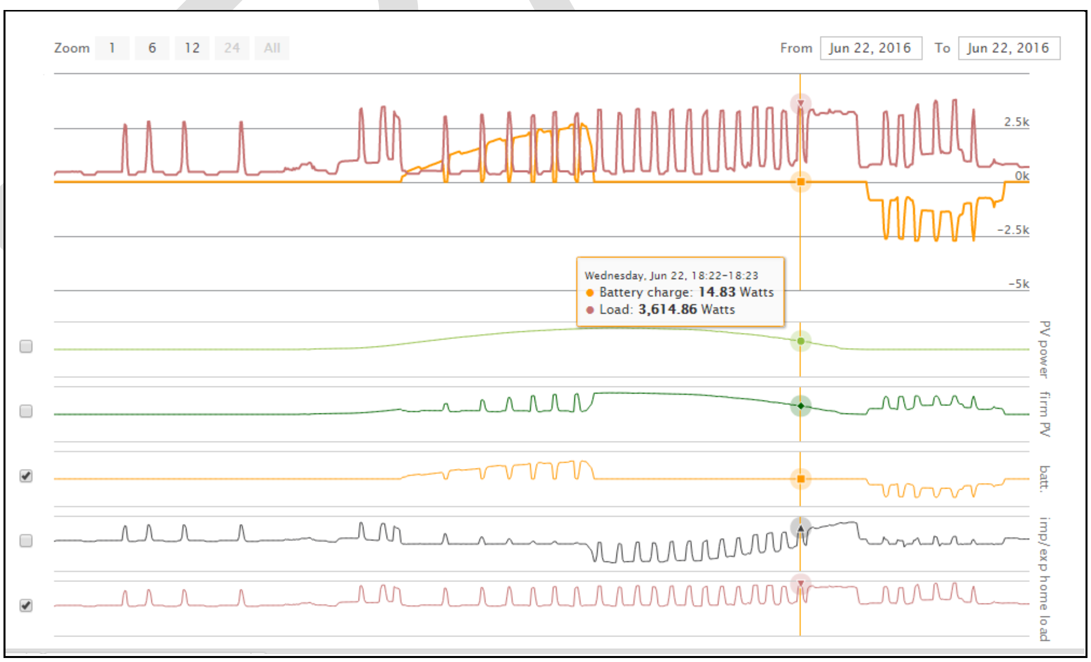


Figure 6-3
A single home's 24-hour operation in load-following self-consumption, scheduled according to take advantage of time of use tariffs

When these operations are aggregated over a group of homes equipped with such, 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 first priority over using the grid: grid power is only used when the home usage cannot be met by either PV or battery energy.

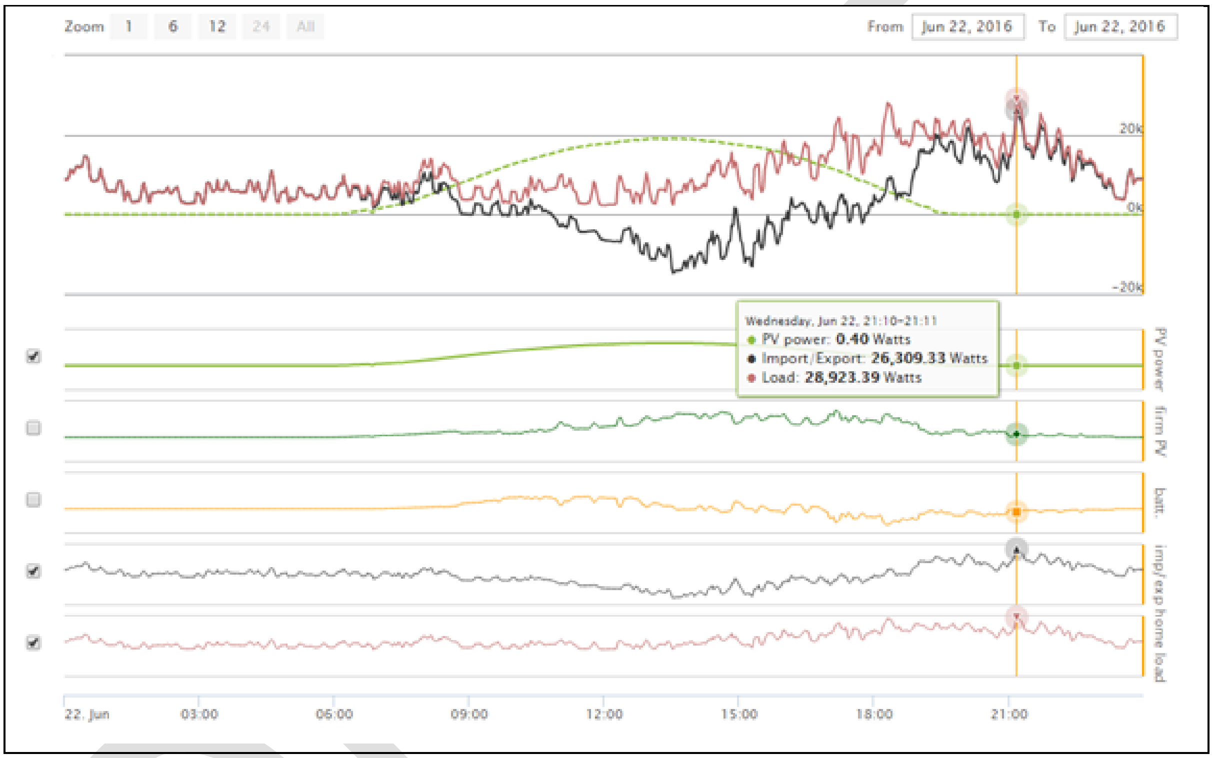


Figure 6-4
Aggregated operation of storage in a group of homes equipped with battery storage.

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 is 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 particular home's energy usage profile.

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 vast 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 SCADA systems or other sources.
2. Forecast load growth as granularly as possible (in most cases 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 mid-summer during noon, there can be a large portion of the customer-sited solar PV which 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 greatly varies between utilities. Some use historical data from past extremes and establish bounds to which 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 thereafter the initial installation. Typically, utility best practices are put into a table that has 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 due to the fact that 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 distribution planning process's fundamental assumption 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 is 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 the figure below for a single residence switching their gas loads to fully electric the shift does not only occur seasonally but also to a mid-morning peak, which is driven by morning water usage.

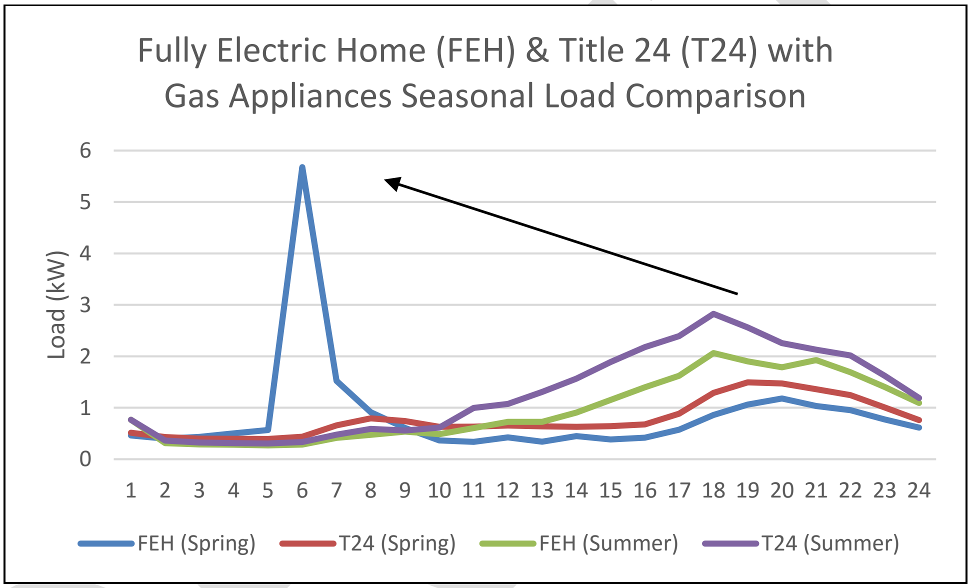


Figure 7-1
Fully Electric Home & Title 24 Seasonal Load Comparison

This change draws out the weaknesses in using the traditional planning process assumption of 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 cover 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 it is recommended that more extensive research is done for larger ZNE communities. The temperature driven load growth forecasting has worked historically, but since all residencies 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 will have to be studied further to develop safe and accurate models to be used for distribution planning.

Distribution Modeling & Analysis

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

To properly evaluate larger communities, we started with 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. We achieved ZNE using two methods. The first, using 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, using 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 we only had 20 home models in total, but required enough data to analyze up to the distribution circuit (feeder) we were required 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 we were modeling a year and not a short-term few day period in the near future we use average irradiance over the year instead of specifying specific cloudy days. The irradiance correlates to the performance of the system throughout the year so the summer season has longer daylight hours and higher irradiance than winter months. Lastly, for energy storage, it was modeled 3 different ways. The system size and efficiencies didn't' change, but the control strategy did vary.

ES Parameters:

- Capacity: 6.4 kWh
- AC 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 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 12pm at constant rate until 25% SOC; Charging begins at 6:30 pm at max 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 modeled homes made the assumption that hot water usage would be primarily in the morning, but the majority of usage ended up being in the evening. The figure below outlines the shift from morning to evening. The models also suffer from an overestimation of the hot water peak demand.

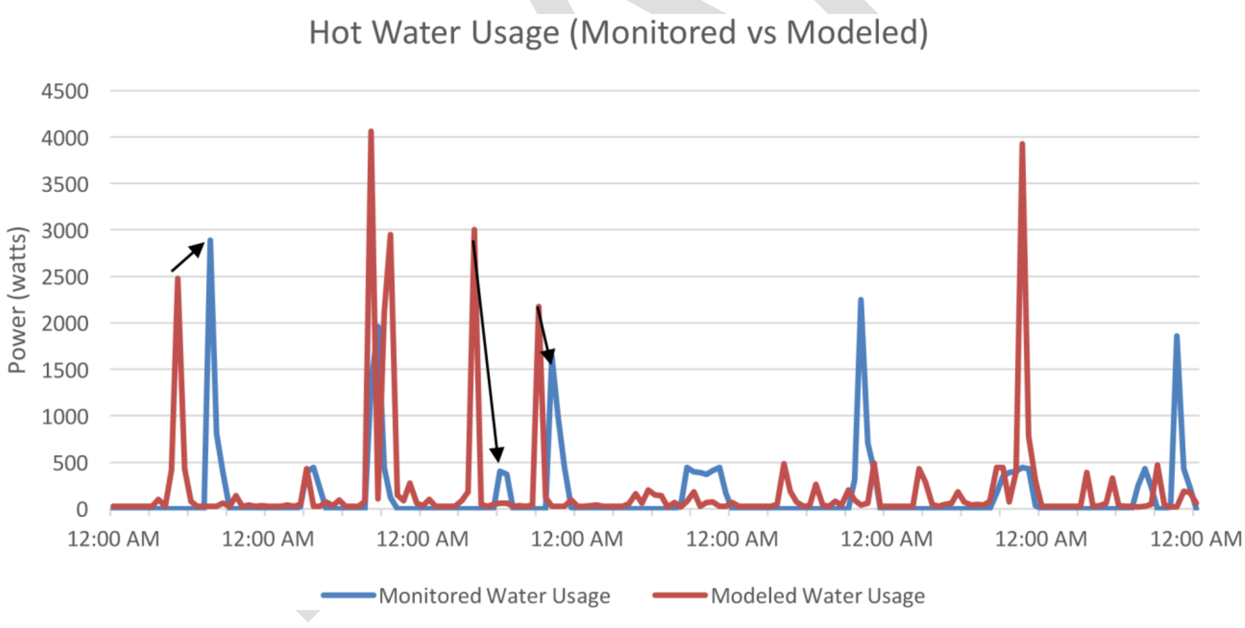


Figure 7-2
Monitored vs Modeled Hot Water Usage

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, it can be seen that 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. These are the distribution circuit (feeder), load block, lateral, and transformer. Each serving their own purpose the distribution planner typically uses 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. The table below 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.

The diagram below outlines the relationship between a distribution circuit and its components including: Load blocks, laterals, transformers, and secondary wires.

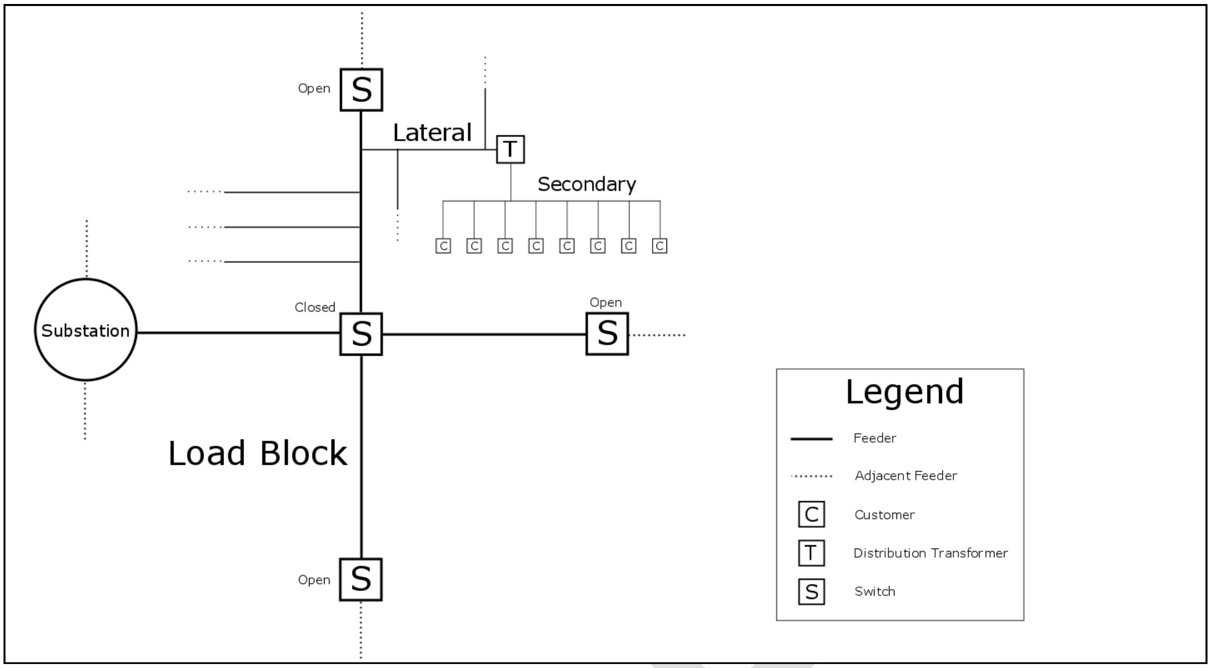
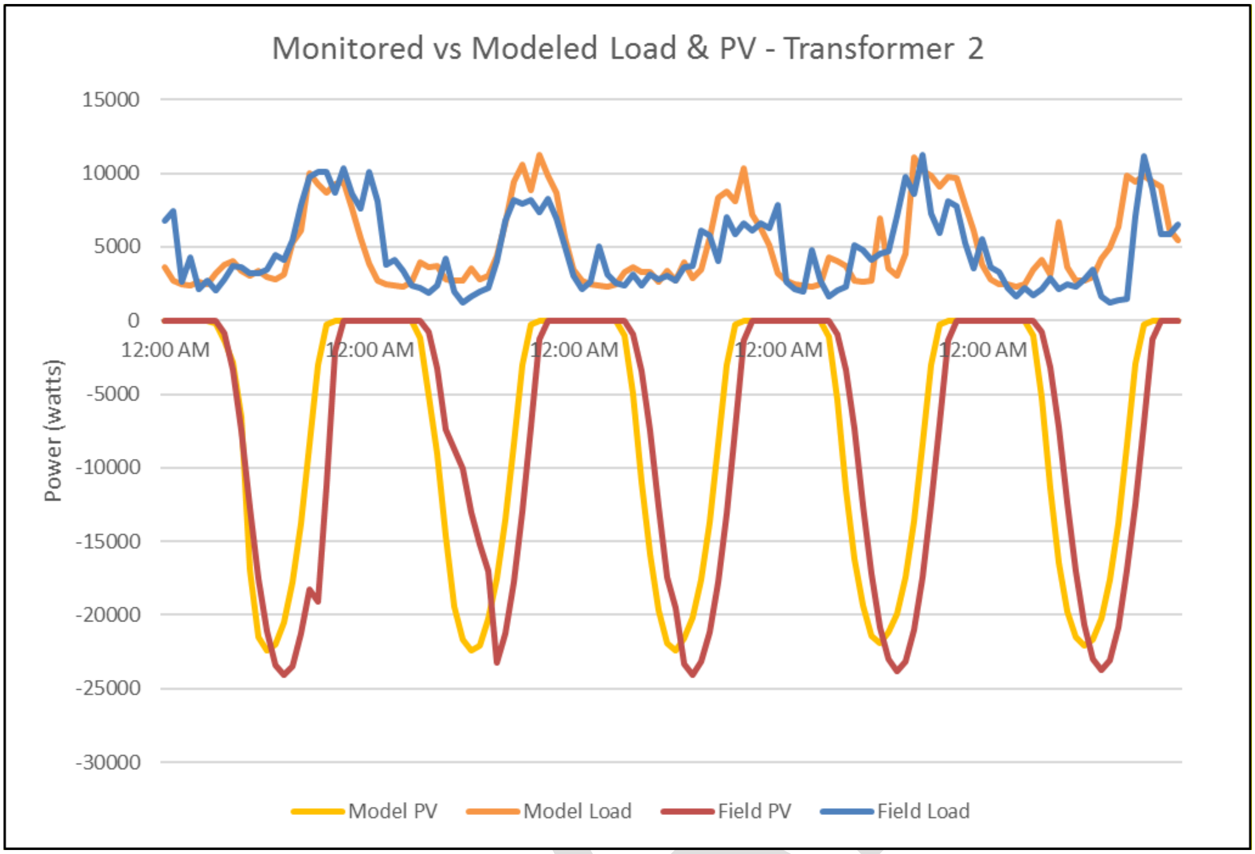


Figure 7-3
Distribution Circuit and Component Diagram

The analysis was done at the four planning levels and only had 20 house models were available to construct the larger circuit segments. This required us 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 the individuality of 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 we 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. With 20 individual models we were able to simulate Transformer 1 and Transformer 2.



*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.

Figure 7-4
Monitored vs Modeled Load & Solar PV for Transformer 2 (9 Homes)

The above chart compares performance from the modeled data and the monitored data recorded in the demonstration. 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 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 actually 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 is 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. The following charts 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 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 below is from extremely hot days at the Fontana site, whereas the modeled data doesn't account for extremes.

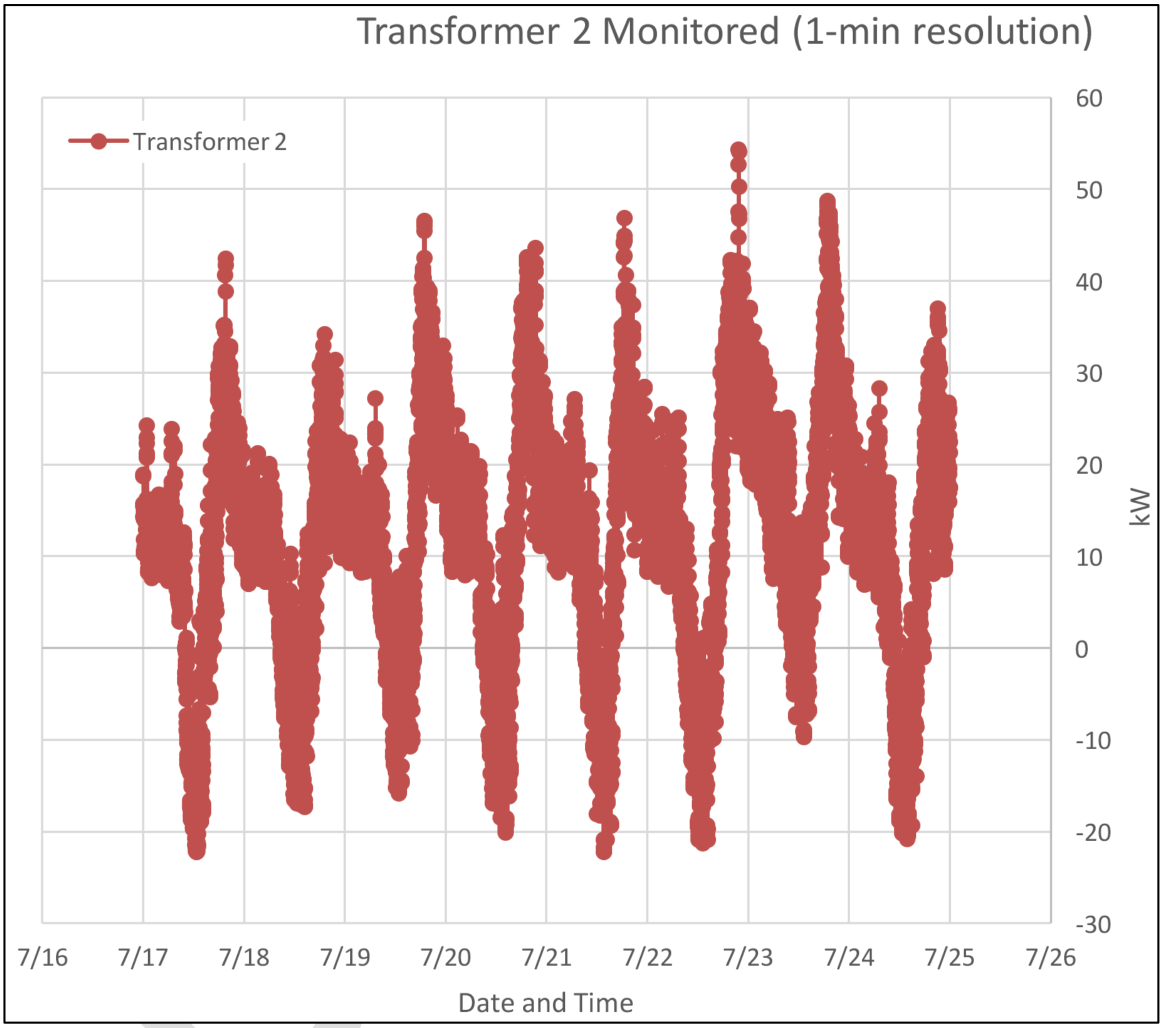


Figure 7-5
Transformer 2 Monitored Data (1-min resolution)

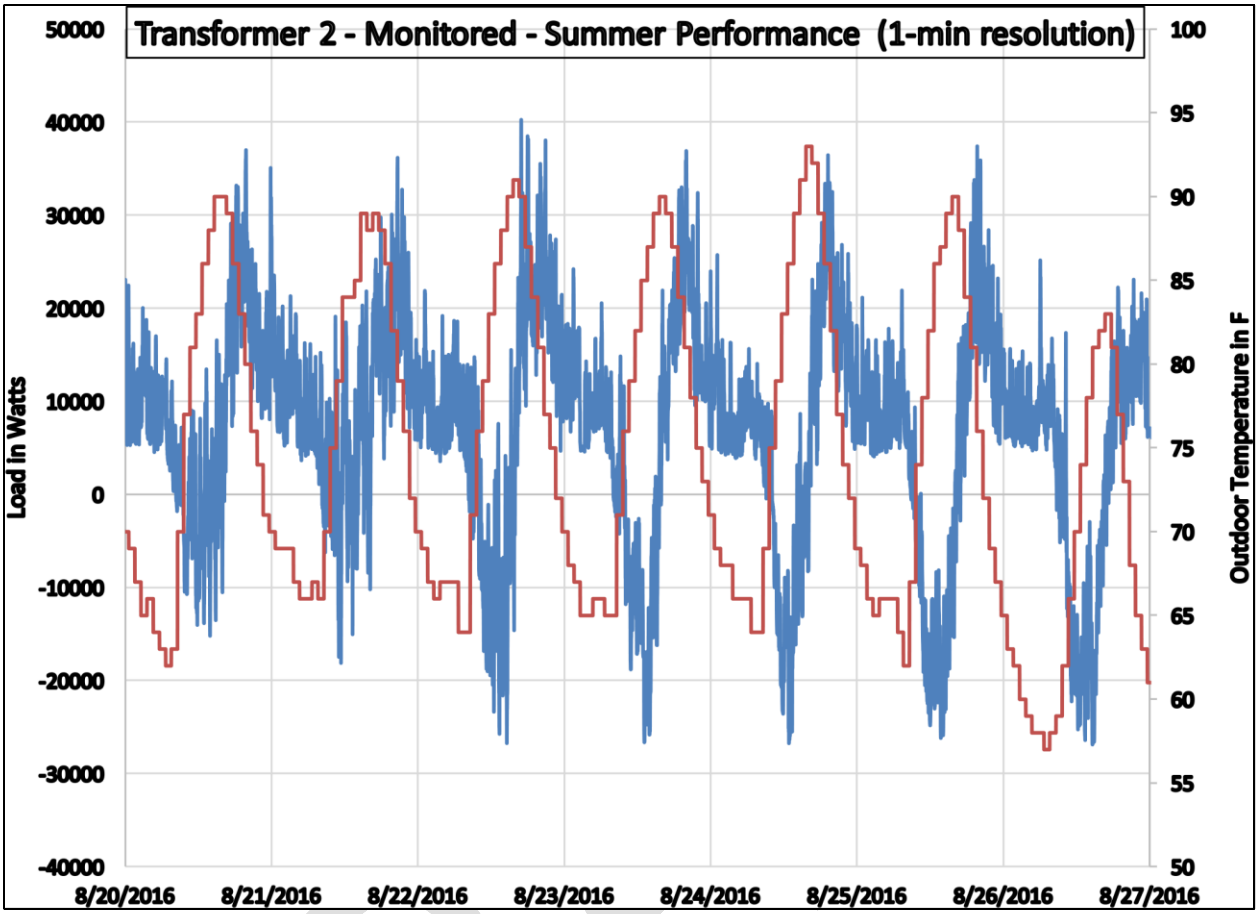


Figure 7-6
Transformer 2 Monitored Data for Summer Performance (1-min resolution)

To evaluate larger subsets of homes, we 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. There is a safe assumption to make when simulating larger groupings, and that is there is a decrease in diversity in electric load behaviors as the population goes up. As an alternative to BeOpt we duplicated the original 20 home models to scale up to larger sets by using a statistical sampling method until we reached a desired quantity. The method batched transformer 1 homes and transformer 2 homes 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. See table below:

Table 7-3
Transformer 1 Simulation Example Table

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

To ensure our analysis was not driven by a single instance we would run many simulations. As the simulations grew in scope from transformer to feeder there is less variance since the original sample consists of 20 models so it was safe to decrease the number of cases run as the scope increased. The following table 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, we then 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. Our random selection methodology with enough cases will identify a highly probable peak load. To ensure accuracy of the simulation we compared the peak case distribution to the evenly spread or Median Case, where each home was used once per transformer. The graph below compares the Median to the Peak case for Transformer 1 under the ZNE scenario:

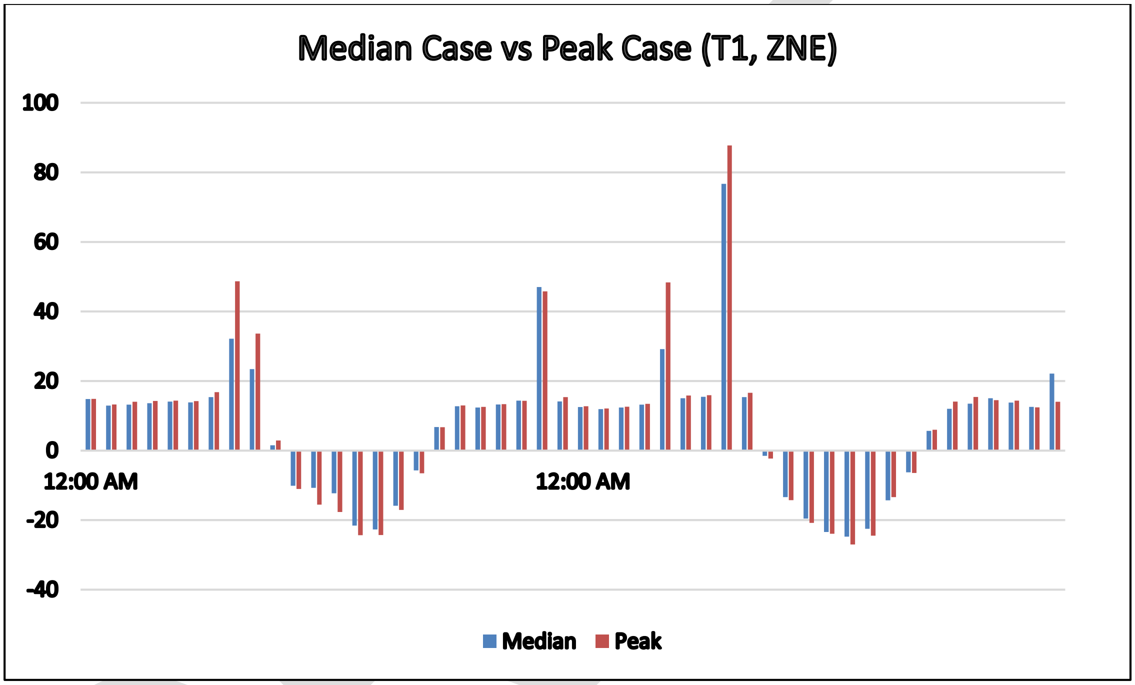


Figure 7-7
Median Case vs Peak Case For ZNE-EHA – Transformer 1

Results

Distribution Circuit Impacts of Zero-Net-Energy

The rate of transition from Title 24 homes with PV to ZNE-EHA homes is yet to be determined. If building code requirements mandate solar PV installations on all new homes the design standards will have to change for distribution infrastructure planning in high concentrated areas. At a high level there will need to be 3 major changes to the current planning process:

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

If communities switched to ZNE-EHA today the distribution grid would require significant upgrades in certain areas. When designing a feeder, the considerations include compensating for overloading including during contingencies and ensuring protection of the circuit in case of a fault. The feeder design limitation is 10 MVA, which includes extra buffer because it allows for added flexibility for grid operators in case of emergency roll overs. When converting to ZNE-EHA communities from today's standards the feeder's capacity, which has been designed for contingency scenarios has enough headway to allow for ZNE-EHA homes.. This however, does not include emergency capacity for contingencies, which will have to be examined further. There is no overcurrent for the feeder, but there is backflow and therefore proper protection systems should be put into place as well.

The following legend will be used for the next set of diagrams regarding peak loading:

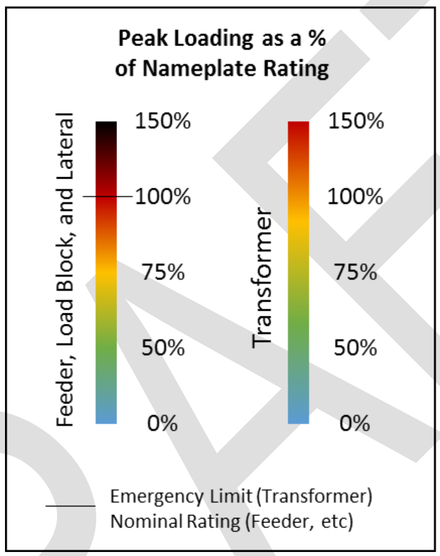


Figure 7-8
Legend for Figures 11-30

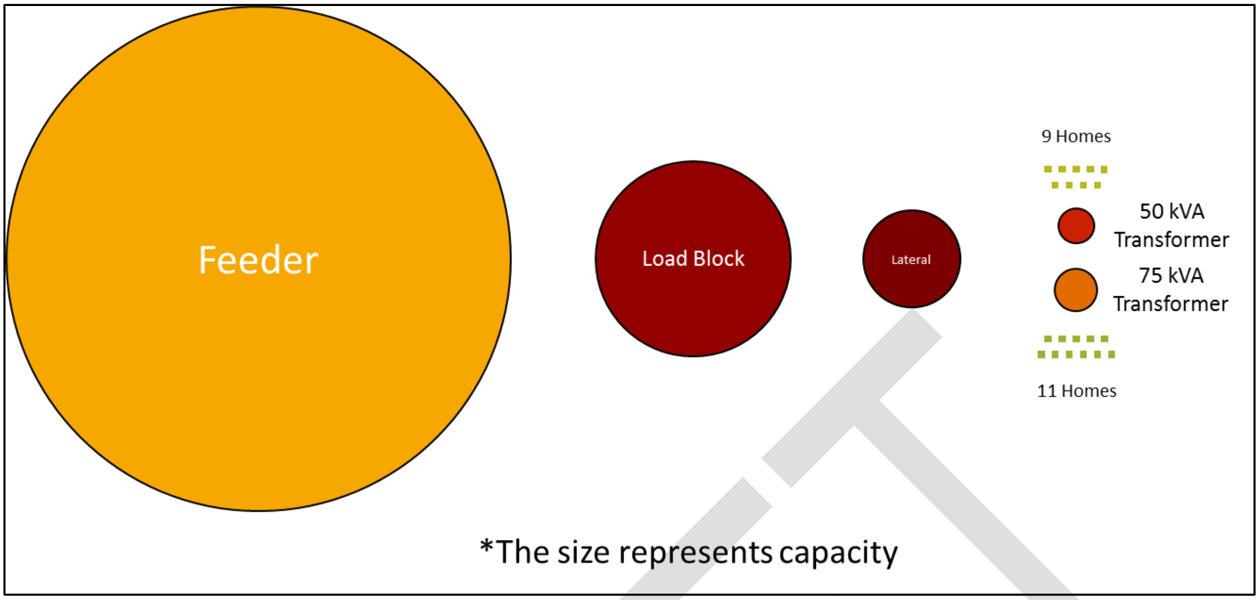


Figure 7-9
Peak Loading ZNE-EHA with No Energy Storage

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%

ZNE pushes the limits of all infrastructure because of the electrification of heating. However, this is highly dependent on current load models, which have a high coincident rate of hot water usage. 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 5-7pm. Customer peak usage also tends to be in the spring and winter as opposed to traditionally summer driven peaks in warm climate zones.

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 must also change for laterals as they are expected to be overloaded with the transition to ZNE by 16%.

Transformers are a vital component to electrical grid design. Allowing the safe transformation from a high voltage to lower, usable voltages. Transformers are built to be overloaded for medium durations, however they fare better when not. They 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 and that is, how should the system operate? Should it be called only during emergencies? Or used only in backup applications? We 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 it can be seen that for this demonstration, the systems are undersized. The following graph outlines a typical 24-hour period at the transformer level.

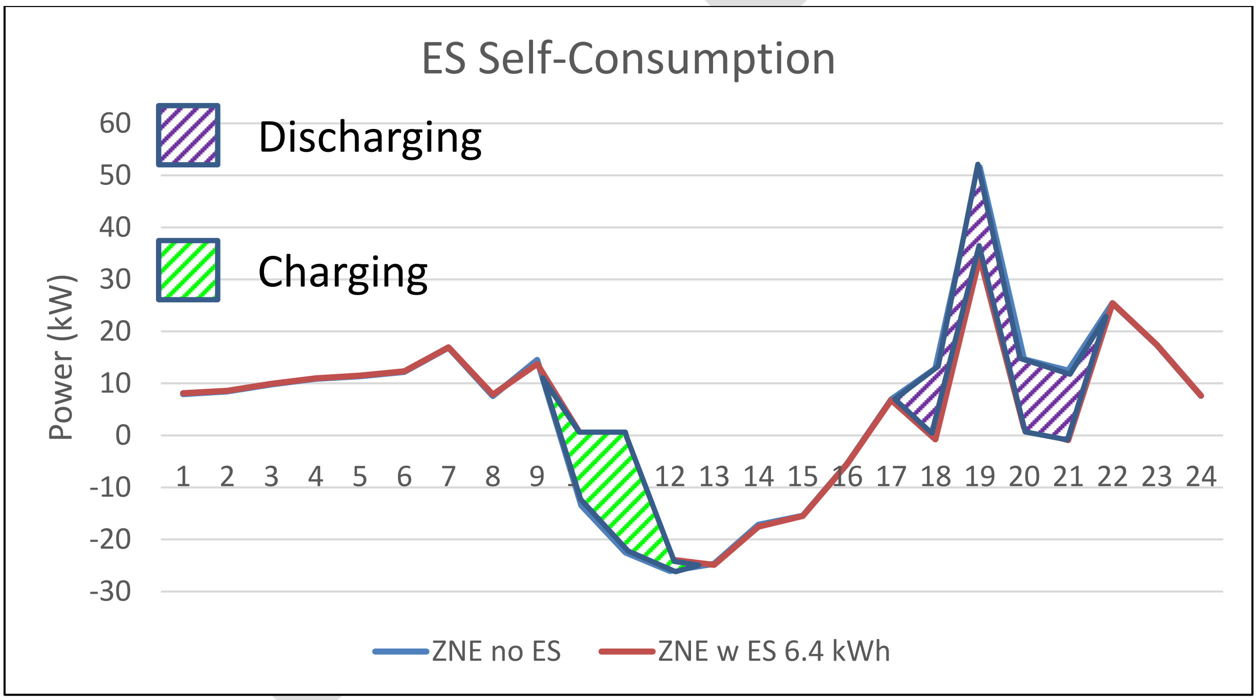


Figure 7-10
ES Self-Consumption Operation at Transformer

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 follows:

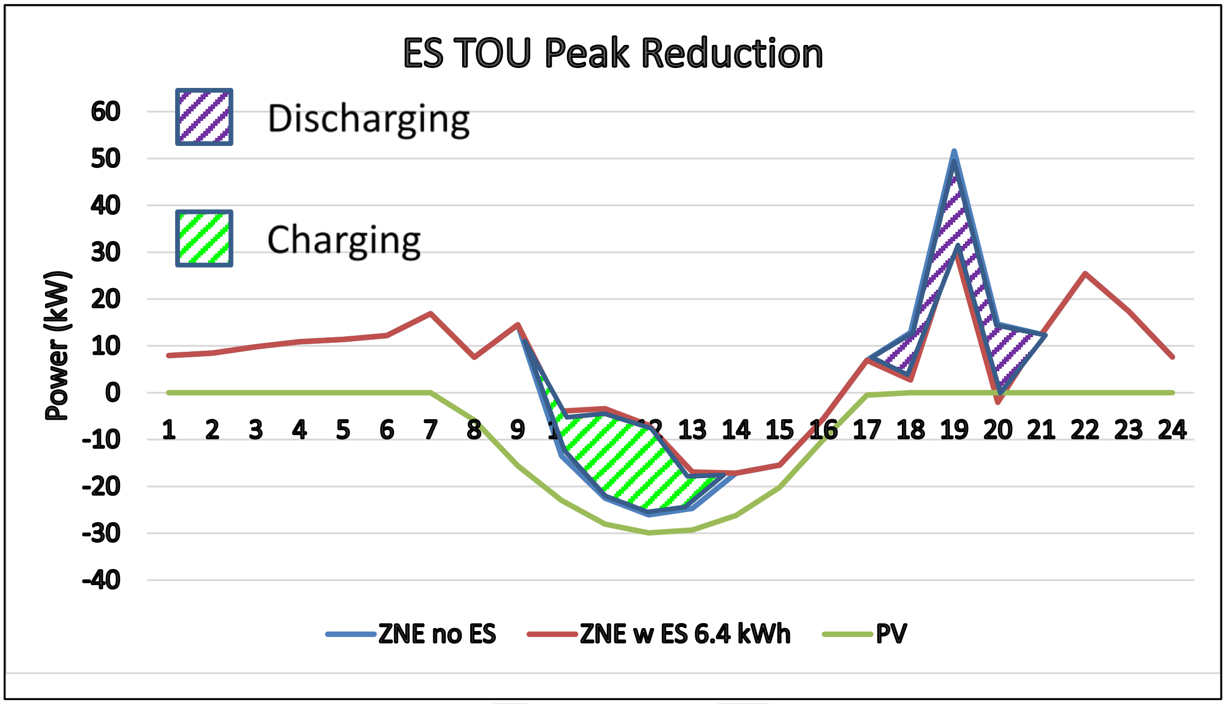


Figure 7-11
ES TOU Peak Reduction Operation at Transformer

Lastly, the final control scheme is likely to be the most popular today in California as it is the only one that provides bill savings to the customer. It is called TOU Tariff Optimization. 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.

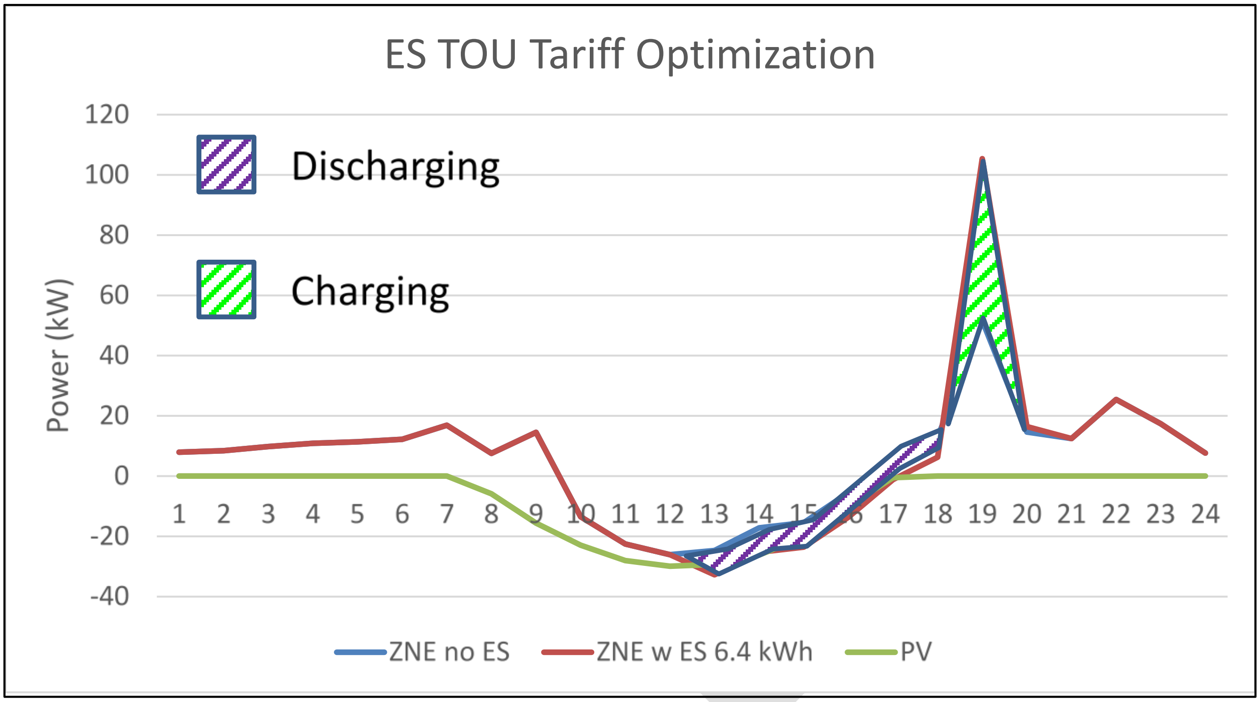


Figure 7-12
ES TOU Tariff Optimization Operation at Transformer

These three control schemes comprise the majority of customer-sited energy storage deployments today, but it is expected that more advanced systems that are dependent on pricing or grid power quality signals is 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 the charts below.

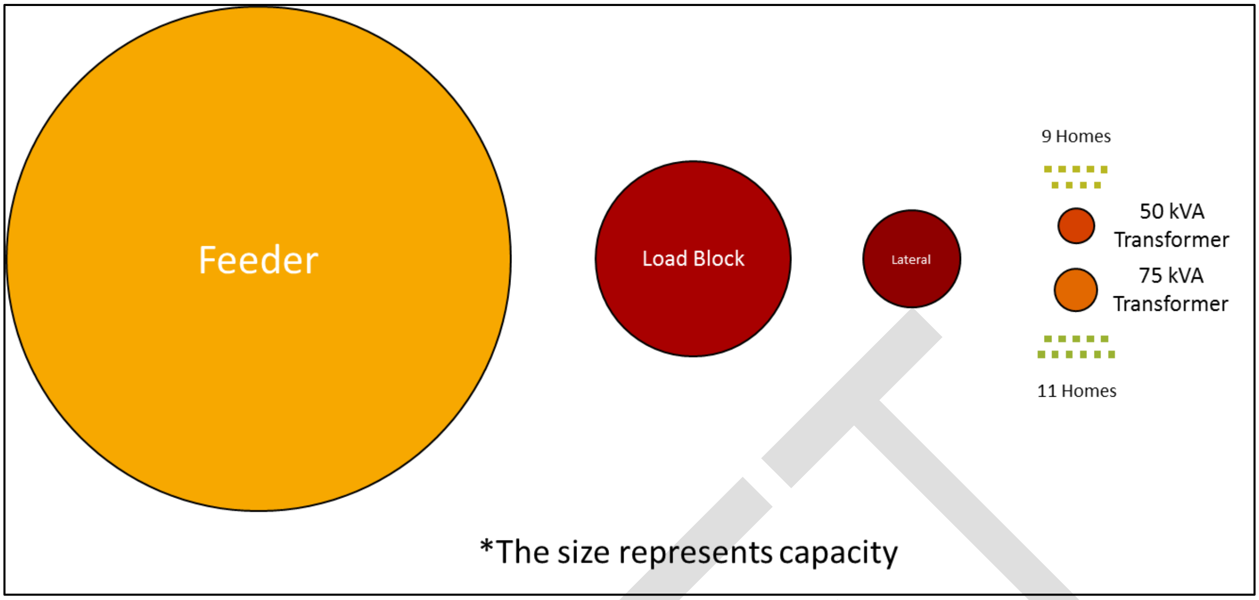


Figure 7-13
Peak Loading of ZNE-EHA with Energy Storage Self-Consumption

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%

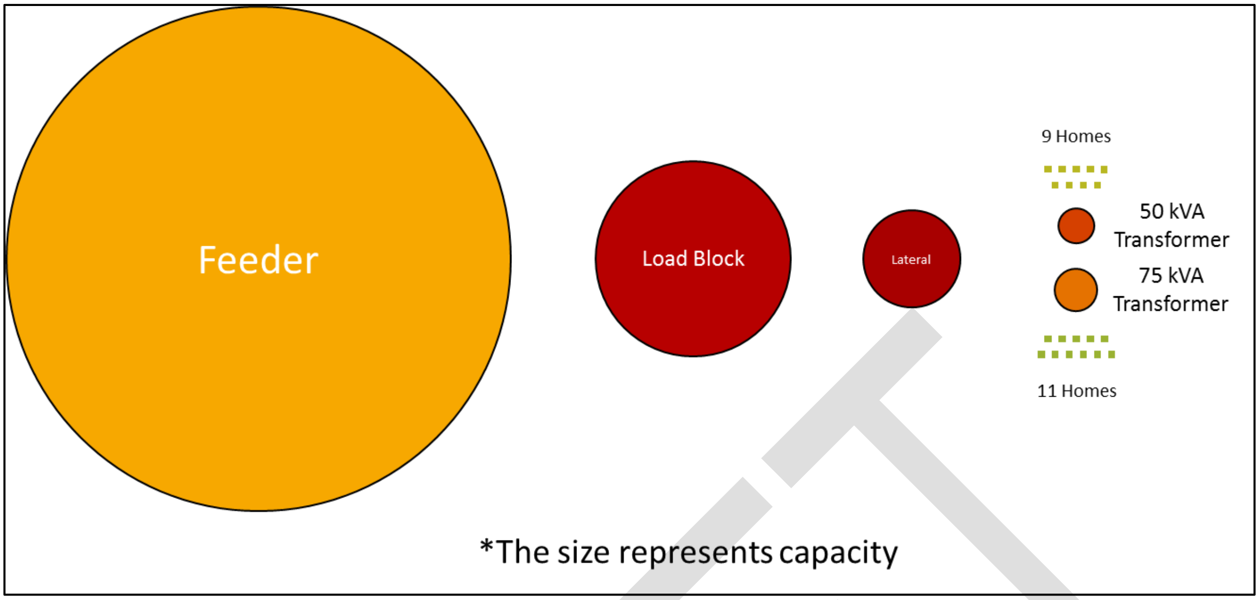


Figure 7-14
Peak Loading of ZNE-EHA with ES TOU Peak Reduction

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%

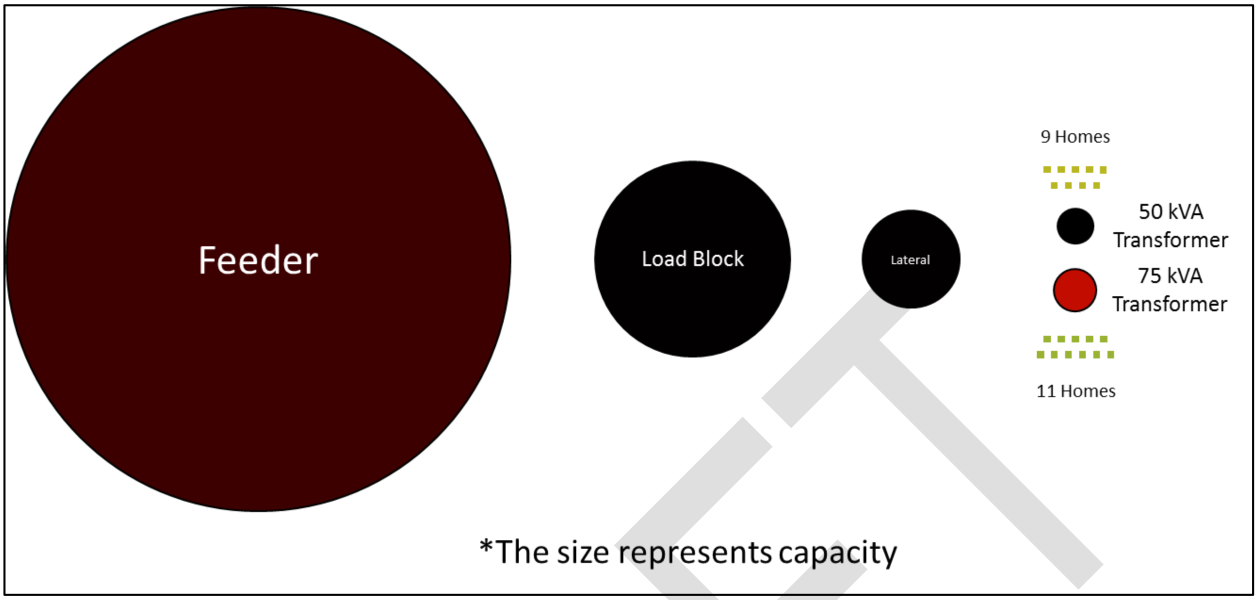


Figure 7-15
Peak Loading of ZNE-EHA with ES TOU Tariff Optimization

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 will only have to operate a few hours per year are beneficial at for the deployed quantity of PV. If ES gets deployed than customers can be encouraged to install larger PV systems, if it is desired. ES, even at small deployments, if coordinated under ES TOU peak reduction 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.

Alternate Zero-Net-Energy with Title 24 and Larger PV Systems

There is an alternative to ZNE-EHA systems that have 4 kW_{AC} PV systems, and that is T24 homes with 6 kW_{AC} systems installed to compensate for the losses in efficiency. These T24 homes would have gas heating and therefore would have more traditional ambient temperature driven load curves as opposed to behavioral.

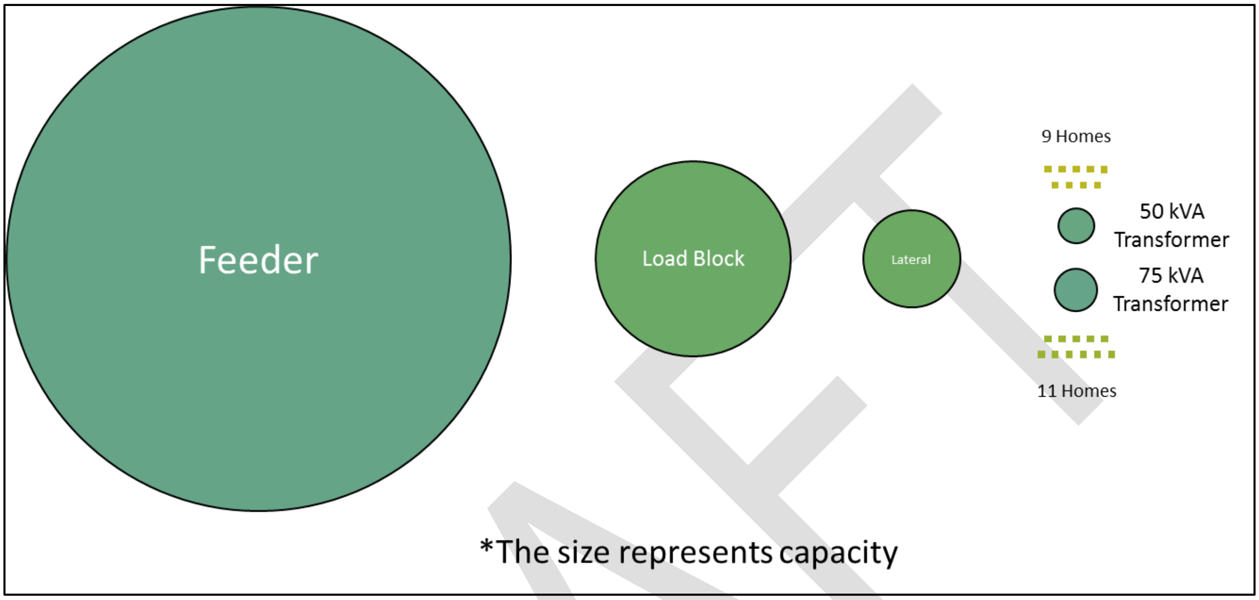


Figure 7-16
Peak Loading Title 24 with no Energy Storage

Table 7-9
Table of Peak Loading Title 24 with no Energy Storage

	T1	**T2**	**Lateral**	**Load Block**	**Feeder**
Peak kW	26.4	20.1	137.4	544	2706
Rating	75	50	375	1500	10000
% of Nameplate	35%	40%	37%	36%	27%

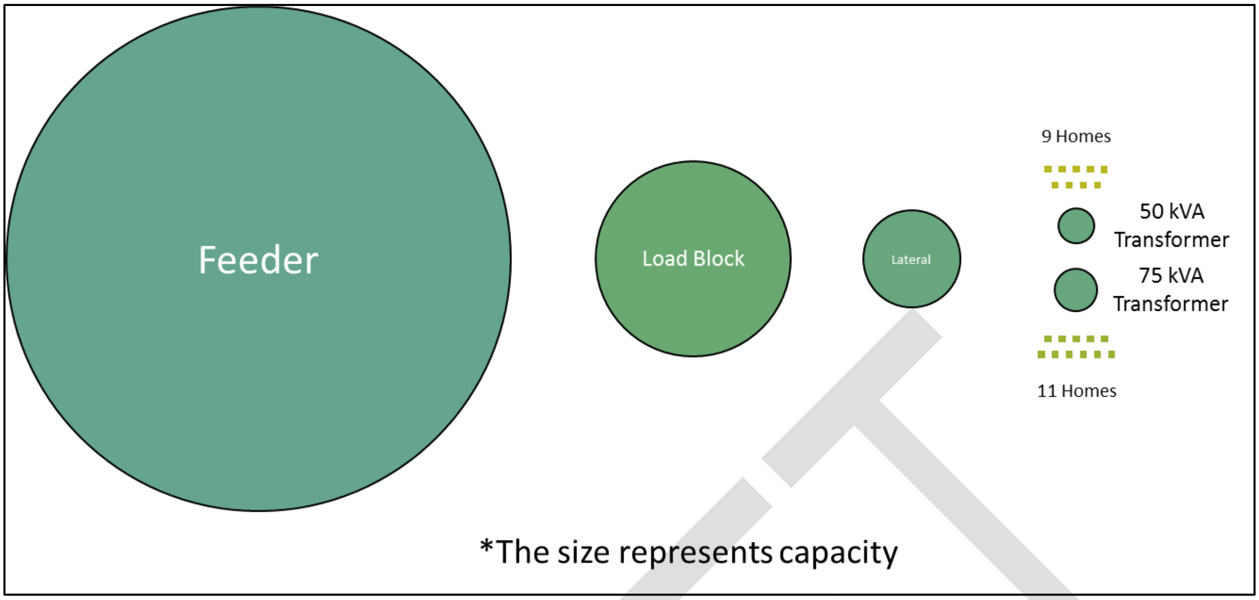


Figure 7-17
Peak Loading Title 24 with ES Self-Consumption

Table 7-10
Table of Peak Loading Title 24 with ES Self-Consumption

	T1	T2	Lateral	Load Block	Feeder
Peak kW	22.2	16.6	115	457	2279
Rating	75	50	375	1500	10000
% of Nameplate	30%	33%	31%	30%	23%

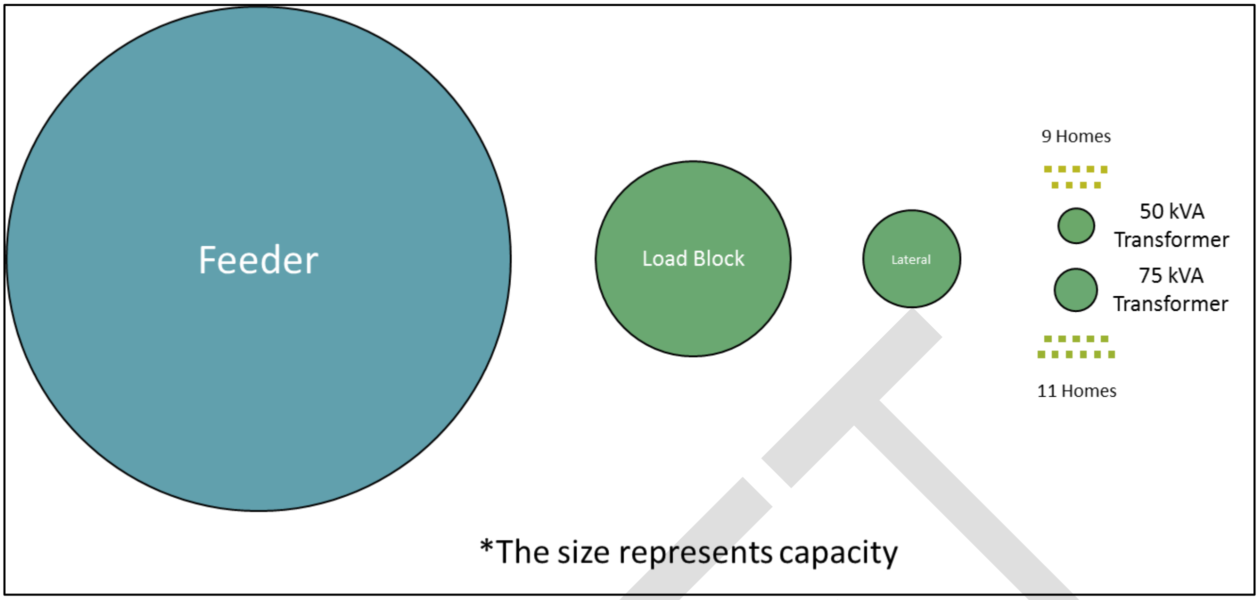


Figure 7-18
Peak Loading Title 24 with ES TOU Peak Reduction

Table 7-11
Table of Peak Loading Title 24 with ES TOU Peak Reduction

	T1	**T2**	**Lateral**	**Load Block**	**Feeder**
Peak kW	24.6	18	127.5	507	2145
Rating	75	50	375	1500	10000
% of Nameplate	33%	36%	34%	34%	21%

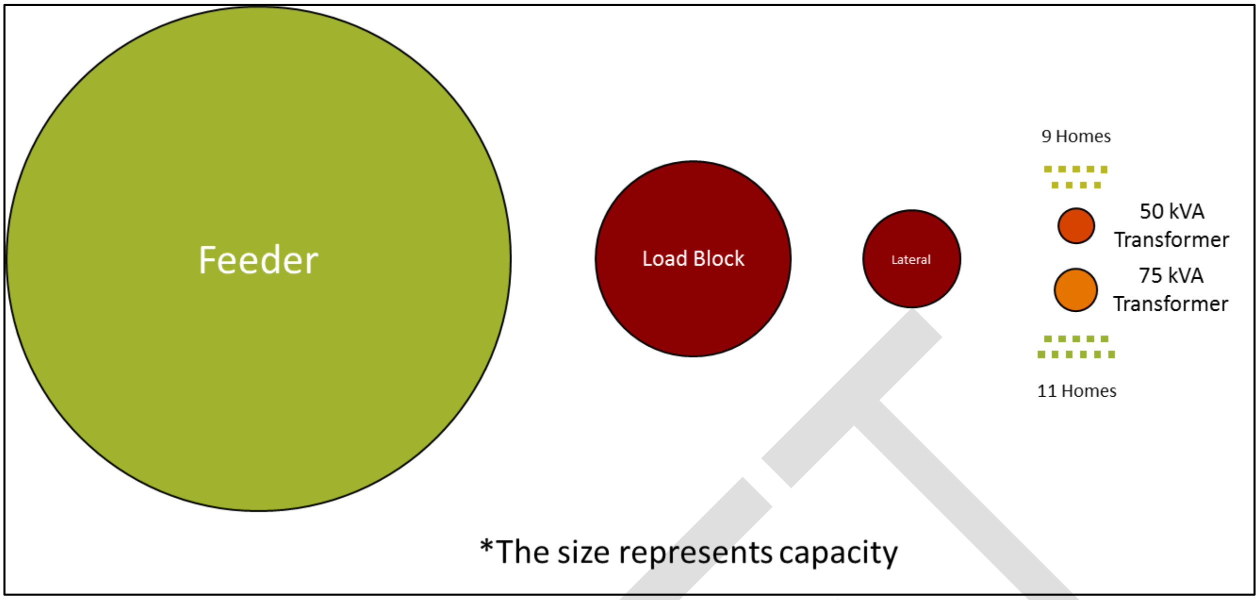


Figure 7-19
Peak Loading Title 24 with ES TOU Tariff Optimization

Table 7-12
Table of Peak Loading Title 24 with ES TOU Tariff Optimization

	T1	T2	Lateral	Load Block	Feeder
Peak kW	80.2	64.1	430.9	1718	6413
Rating	75	50	375	1500	10000
% of Nameplate	107%	128%	115%	115%	64%

The problem of ZNE-EHA is driven by peak loads, particularly heating loads. Electrification of heating loads causes peak load at all grid levels to rise when dealing with ZNE communities. ES can help here, but is not necessary as ZNE-T24 homes are vastly under nameplate ratings. There is PV backflow even at larger PV levels, but the backflow's difference between ZNE-EHA and ZNE-T24 are observed in large penetrations.

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. 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 at least for small deployments in preventing backflow.

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 630pm; during residential peak load.

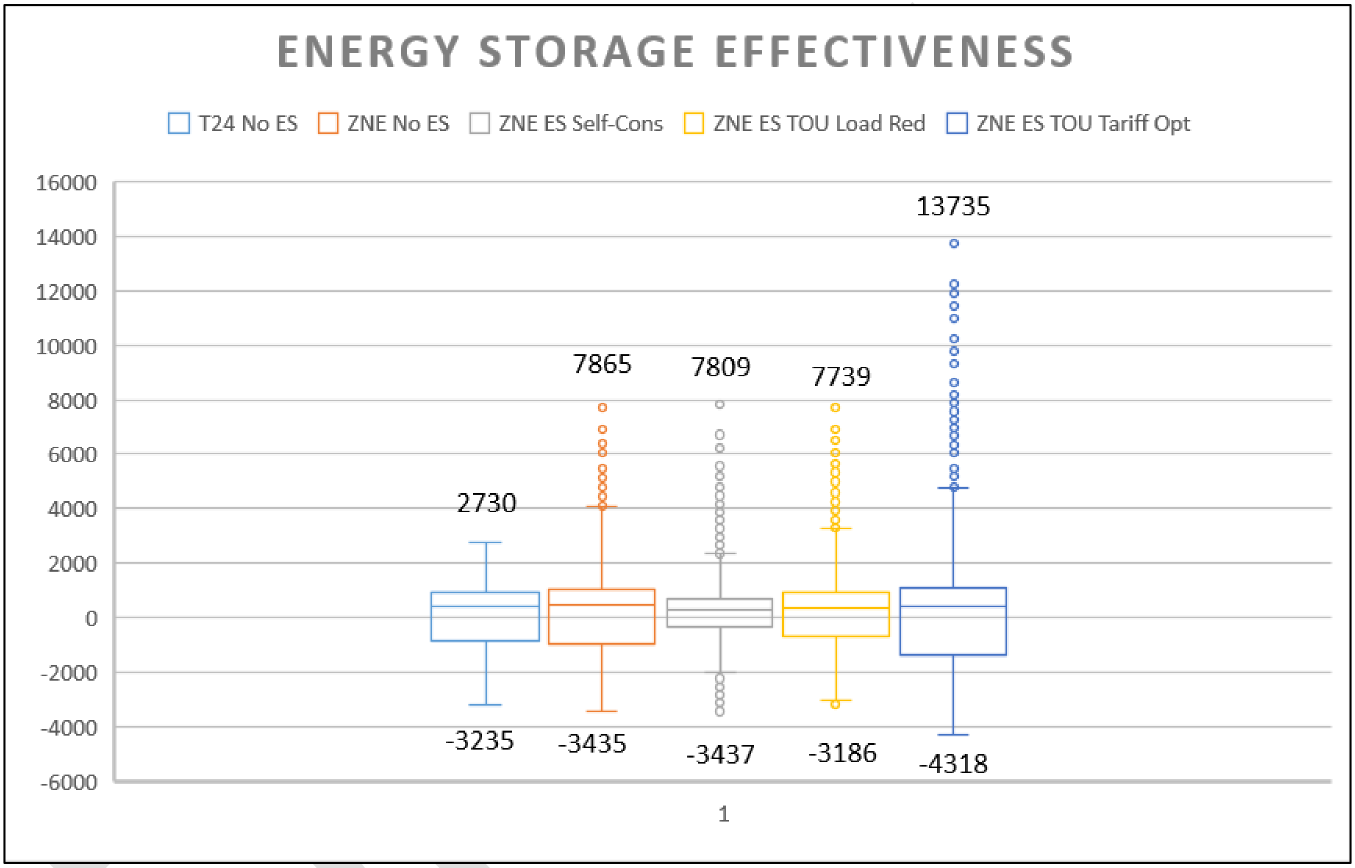


Figure 7-20
Effectiveness of Energy Storage

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 season of the year. It is suggested for the demonstration project to 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 served useful for understanding higher penetrations of ZNE, the models were lacking in accuracy. This can be improved by increasing resolution, improved modeling of hot water loads, and using actual weather data as opposed to averaged. 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 form 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 quicker to grid concerns. Including commercial customers is also necessary as most feeders are not homogenous with only residential or only commercial type 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 grid, and to evaluate whether and/or to what extent energy storage – Batteries – can mitigate problems that ZNE homes produce when connected to the grid. A similar guide was developed using CEC PIER funding of the DavisFREE project. That Guide targets the existing home market and provides information for how to set-up a successful ZNE-retrofit program for existing homes using volume market principals. This guide targets the new home market; specifically, the key steps required for design and construction of a ZNE community.

The process to develop the ZNE Package and construct the ZNE homes is divided into four stages; this report is organized around those stages, summarized here:

Stage I: Initial ZNE Package Design. Goal Setting and design of a package of energy efficiency features that will result in a zero HERS ("ZNE Package"). This process includes a review of builder's current standard practice for efficiency, a pre-design analysis, and an initial ZNE Energy Efficiency Package. This initial ZNE Package is designed based on experience with the builder's designs, the location and weather data, and knowledge of costs and typical preferences. The resulting initial ZNE package is not necessarily optimized for the builder.

Stage II: Final ZNE Package Development. An iterative analysis process to identify improvements upon the initial ZNE package going from an initial set of measures to a ZNE Package that is optimized for the builder. Optimization takes into account builder costs as well as their preferences for construction methods and components, manufacturers, vendors and installers to establish a final ZNE package. This stage also includes accurate sizing of the PV array based on available roof area and TDV generation (not kWh).

Stage III: Final Review, and ZNE Package Vetting. A final review with builder staff and their contractors of features that make up the final ZNE package to verify choices, construction and measure feasibility, and all incremental costs, that went into selection of final ZNE package. This review includes the specific package improvements, their cost, and the expected performance of the final ZNE Package. This performance analysis includes cost-effectiveness for the builder and buyer, which requires energy savings analyses and energy-bill analyses of actual package installed.

Stage IV: Construction, Inspections and Commissioning. Once the ZNE Package is vetted by the builder, any required local jurisdiction, and contractors, construction can commence. Prior to, or at time of plan submittal to the local jurisdiction, electric and gas utilities should be notified that this is a ZNE Community, that homes will be very efficient and have PV systems on their roofs, requiring interconnection agreements and possibly other agreements specific to ZNE homes. During construction, the builder should employ third-party HERS field contractors to perform inspections and/or performance testing of major ZNE and other energy-feature components of the homes.

Initial ZNE Design Issues

Stage I of the project involves setting goals specific to the ZNE design and desired performance and characteristics, including ZNE status for the community as a whole or by each individual home, a target average reduction in annual energy use of the ZNE home compared to standard practice, due to efficiency improvements, any improvements due to proper/improved operations and maintenance of the homes that require or depend upon occupant behavior, PV panel target sizes and desired locations, and any community-related factors, such as large trees, hills or neighboring homes/structures that could impact solar production.

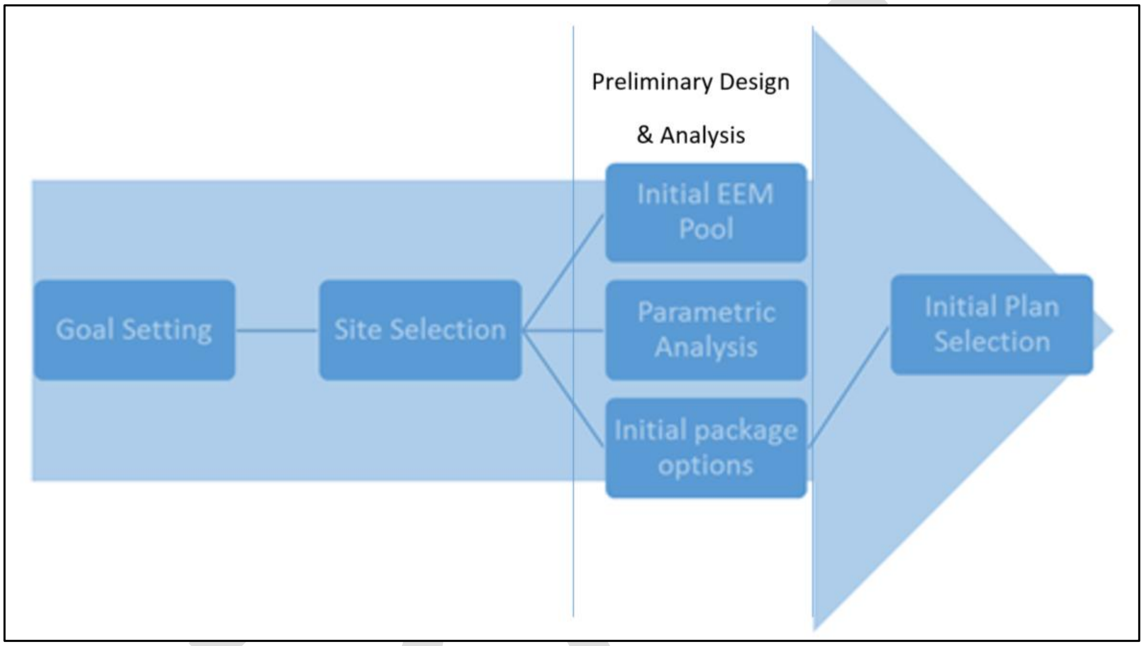


Figure 8-1
A step-by-step summary of methodology in the Initial ZNE Package Design, Stage I of the ZNE Pilot Project.

Goal Setting

Builders' goals for producing initial ZNE communities are likely multifaceted, but at this time, when there are only a very small number of ZNE communities, or even single pilot ZNE homes, the builder is likely to primarily want to establish what it takes to design and build a ZNE community, to be ahead both the market and of code implementation in 2020. This CSI-supported project facilitated that research, design, and development for a ZNE community, ultimately demonstrating a proof of approach to ZNE Package design in a production builder environment. In fact, the builder partner for this project was Meritage, one of the top five production home building company in the U.S.

Additional motivations for Meritage to partner on this project included the testing of market acceptance of ZNE construction by home buyers, realtors, and the construction trades. This included the compliance aspect of construction as well, bringing the inspectors together with educated tradespeople. All 20 homes in the ZNE community are instrumented via the electric panel to monitor all electricity use, by end-uses, which will allow direct comparison of actual energy use, by end-use categories, with the results of the simulations that were used to develop the ZNE Packages. The current project will also collect feedback from the occupants on performance of the homes for about 6 months; hopefully that part of this effort will allow the team to gauge market expectations and acceptance of ZNE homes and communities.

Site Selection

The specific community chosen by the team for this project was mainly made by the timing of land development in a location that would work for the project, in a location favorable to rooftop solar and to the team in general, and in a location favorable to rooftop PV, including solar access, isolation, marketability, and favorable planning and building departments.

Home orientation and roof design did become an issue in this prototype ZNE Community of 20 homes, because it was not possible to fit the required PV on the multi-sectioned roof. This problem was due to instruction by the builder to not specify PVs on front-facing roof segments. For this particular plan-lot pair, one side of the home, facing south, was multi-segmented and not amenable to installation of PVs; the other side, facing North, had a very large main roof section. It was possible to fix the solar location problem by switching the home specified for that lot with a mirror-image of the original plan. Sometimes a fix for this problem will not come as easy. In the future it will become necessary for builders to allow placing PVs on front-facing roofs, and possibly to have to re-design and re-engineer some roofs to provide sufficient roof area to accommodate the required PV array. This will particularly be a problem in larger two-story homes with hipped-roofs with many, smaller roof sections. In those cases, it may be required to average the homes in the community so that the "missing" PV on one home can be made-up by another. Alternatively, some additional PV panels might be installed on a community-center, or other building nearby that would be virtual net metered. There are both obvious complications that can and will arise in the development of ZNE communities. New policies for net-metering and other PV issues, as well as new or altered planning and development rules will be needed to move the entire market to ZNE.

Preliminary Design & Analysis

Typically, the information discussed in the previous Chapter includes the need for building simulations and developing initial ZNE Packages, as described in this Chapter. The detailed information developed using the processes discussed in this Chapter are refined using the processes detailed in Chapter 4 of this Guide.

At this point in the design process, there typically have been at least two meetings between the builder and the ZNE consulting team. At this point the team has set goals, chosen the location and community to develop as ZNE, and needs "concrete" ZNE Packages to cost and review with their construction staff. This Chapter describes the next step in the process: The development of preliminary but functional ZNE Packages for Builder Review.

There are three major steps for development of these preliminary ZNE Packages; they are illustrated in Figure 8-2, below.

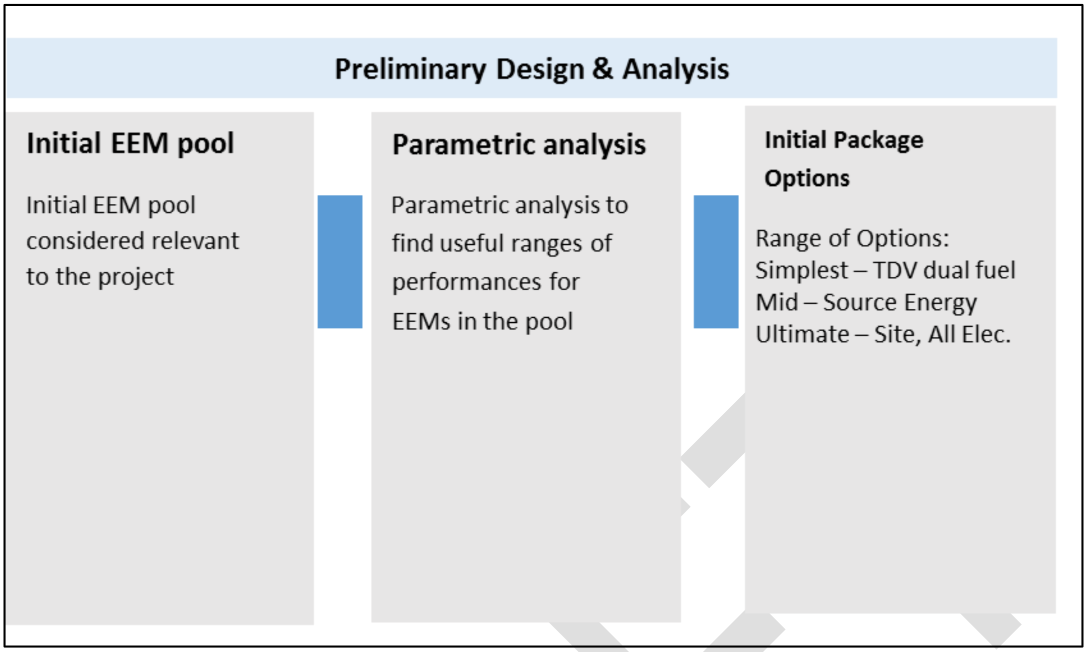


Figure 8-2
Preliminary design & analysis steps that precedes the client selecting the initial ZNE package.

Currently ZNE is calculated, determined or defined, using time-dependent valuation (TDV). California changed the metric for Title 24 energy-efficiency calculations to TDV from source energy as part of the 2008 Title 24 update. A main reason for the move to TDV was to focus energy-code compliance on features that should have their largest impacts on reducing summer afternoon cooling, reducing California's summer peak electricity demand. The largest TDV values are for summer hours during peak cooling periods. TDV values also favor PVs because they produce substantial energy during peak periods.

Simply stated, the definition of ZNE is 0 TDV energy using annual net-metering at retail rates, and can be represented by a HERS index of 0 for the house being analyzed. So, designing a house that has a HERS Index of 0 is the goal for it to be ZNE. TDV, and therefore the HERS Index for a home, is calculated using CEC-certified Title 24 compliance software program, e.g., CBECC-Res. This software calculates hourly site energy use in kilowatt•hours and therms for each hour of the year, and calculates the product of each hour's site energy value and the electric, gas, or propane hourly TDV factors associated by climate zone, hour, and energy type. The total of all hourly TDV x kWh plus all hourly TDV x Therms for a year (8,750 hours in a year; 8,760 TDV factors for each energy type, for each climate zone) must be zero for the home to be ZNE. This calculation, which is also the basis for HERS values can also be negative, meaning that the home generates more TDV-energy than it consumes, which would qualify it as meeting the ZNE requirements, but may not be a good choice for consumers because net metering rules in CA specify that over-generation is remitted at the energy wholesale rate, which is not economically attractive.

Initial ZNE Design from ZNE-Features Pool

In the ZNE-design process developed by The project team over many years of working with builders and the industry, the initial ZNE design process draws from a pool of energy efficiency features that, in combination, will typically result in a ZNE or near-ZNE Package that can be near lowest incremental cost, and/or optimized for ease of construction, and will generally be highly effective at improving comfort and quality. With minimal time and effort, a few different ZNE / near-ZNE packages can be developed using experience and/or data such as that collected by The project team over years of providing simulation results to builders. These ZNE-approximations provide the basis for needed conversations with the builder to help them understand the relative importance of different features to cost, energy savings, and other metrics that can be of importance to the builder. The comments resulting from discussions of near-ZNE example packages can be enlightening regarding the ultimate choices that the builder will make to achieve ZNE.

Parametric Analysis

Using building plans, a computer model of the home must be built for analysis/simulation using CBECC or some alternate, calibrated home energy modeling software. The project team has historically used BEopt[12] because The project team has calibrated it to within 5% of actual measured energy use, for both code-built and above-code homes, for single family and multifamily, both new and retrofit. BEopt is also the preferred energy modeling tool because it provides greater design flexibility than CBECC, making BEopt more useful for situations where there is interest in less common efficiency features that are desired in the design of ZNE Packages, at least for comparison for ZNE Packages that use common technologies, but high-efficiency versions.

The first models simulated should be the base-case for at least one or two different house-plans to be built in the planned ZNE community. Base-case simulations will employ efficiency features that are significantly less that required to be ZNE; they should use the features that are standard practice for the builder across the communities that they are currently or recently built. Theses base-case simulations provide the baseline for comparison of energy savings and any increased costs. These simulations should be performed using computer models of the builder's anticipated designs to be constructed in the ZNE community, as opposed to generic plans. The minimum base-case is the Standard Practice for the builder, that is, their current, typical efficiency features. This baseline is important so that both the consultant and builder know the base-case against which ZNE-features will be compared according to the effect each has on energy use, and their relative costs, impacts on marketing, product differentiation, and likely other parameters of interest or importance to each different builder.

While not entirely necessary, the project team recommends that, for builders whose Standard Practice is above code minimums, more than one base-case simulation be performed. The minimum is a single, representative model with Standard Practice features. It is generally useful and instructive to also simulate a code-minimum case, and preferably both of these reference cases, and for more than one model from the community designs. For those who have Standard Practice significantly above code minimums, the simulations of code-minimum cases can be helpful in demonstrating and/or evaluating those elements of their standard practice contribute to the amount their standard practice is above code, and can help guide the choices of further upgrades to help reach ZNE. The comparison of Standard Practice and code minimum cases can

[12] BEopt is a shell for easy use of Energy+ modeling software. See https://beopt.nrel.gov

also guide possible improvements to the Standard Practice, potentially with little or no additional costs.

In addition to the base-case simulations, the project team recommends performing sensitivity analyses to establish the range of available efficiency levels for the different features, as well as the relative impacts across features and feature types. One must understand, however, that 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 – there are often interactions between measures, diminishing the total impact. Also, interactions or not, there will always be diminishing returns – that is, with the addition of each measure, the amount of energy left to reduce with additional efficiency is reduced, so the savings will be reduced on an efficient home compared with a less efficient home. Nonetheless, the results of the sensitivity analyses and single-feature replacement analyses should be used to guide the choices of efficiency features that, together, will form preliminary ZNE Packages.

A few or several different ZNE packages can and should be built from the results of the sensitivity and single-feature replacement analyses, including the simplest ZNE Package that will produce HERS=0, several possible HERS=0 packages that may introduce the builder to alternative features, and, potentially, an all-electric ZNE package. Performing a combination of simulations provides an abundance of data regarding the possible feature improvements that can form the basis of a final ZNE Package. Evaluations are helpful to understanding some of the challenges of reaching ZNE, as well as helping to define the path desired by the builder.

After developing the base cases, this information is made even more clearly through parametric sensitivity analyses, where a single, key feature is improved to a few different levels, as shown in Figure 8-3.

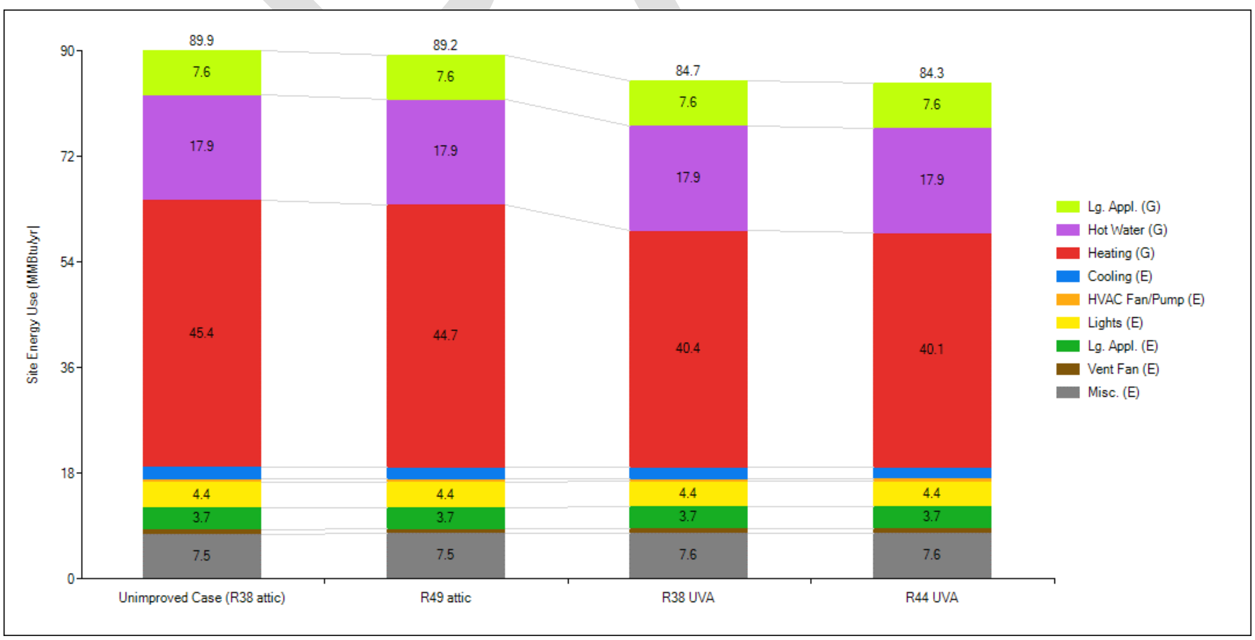


Figure 8-3
Example Parametric Analysis of different attic insulation levels

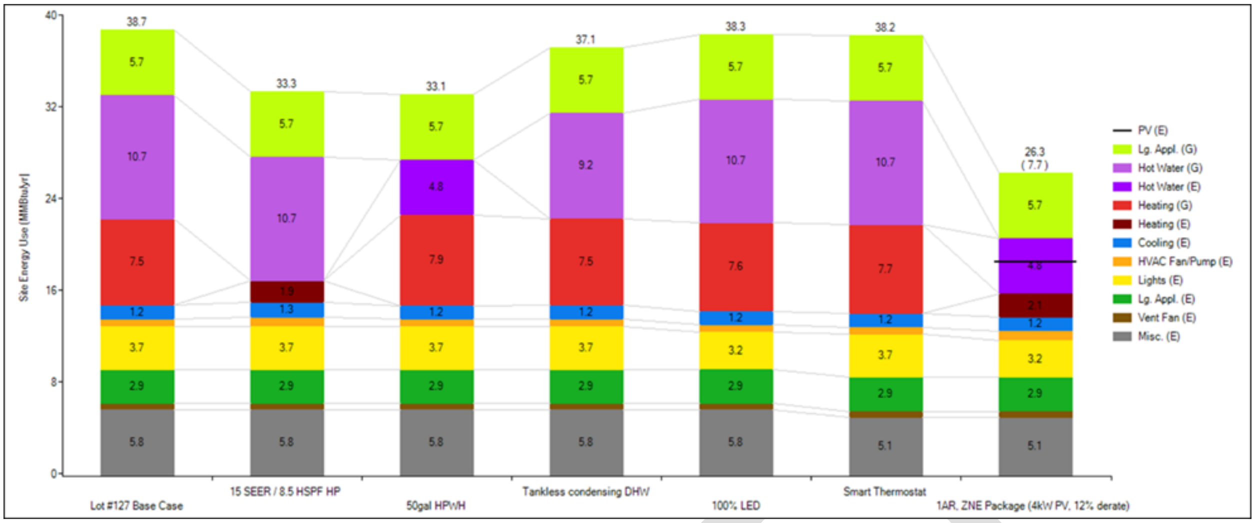


Figure 8-4
Example sensitivity analysis. The base case is at the far-left; in each column moving across to the right, a single efficiency feature is improved and the effects can be seen in both column height and the impact on individual end-uses

Initial package options

Two different groups of package were created: all-electric and mixed-fuel. Both groups of packages consisted of a "good," "better," "best," and "reach" package configurations. The initial package suggestions, for both the all-electric and the mixed-fuel.

Table 2. Initial ZNE packages, mixed fuel

Table 3. Initial all-electric ZNE packages

Initial Plan Selection

Initial package costs and cost effectiveness?

Historical development of package?

Selected "Better," mixed-fuel based on?

Stage II: Final ZNE Package Development

After the Initial ZNE Package was designed in Stage I, the Final ZNE Package was then developed by a 2-step refining process of the Initial ZNE package. The two main sub-sections of Stage II were as follows:

Step 1: Final ZNE Package Development. Course-tuning of the Initial ZNE package selection by iterative performance optimizations of the package and review of the ZNE packages by client to select a single ZNE package to implement.

Step 2: Final ZNE Package Implementation. Review of performance, costs, and feasibility for installation of features in selected ZNE package, including any further changes needed to make the selected package cost-effective and feasible for the client.

Figure 8-5 below illustrates the iterative ZNE design development in Stage 1 and Stage 2 followed by The project team for this project:

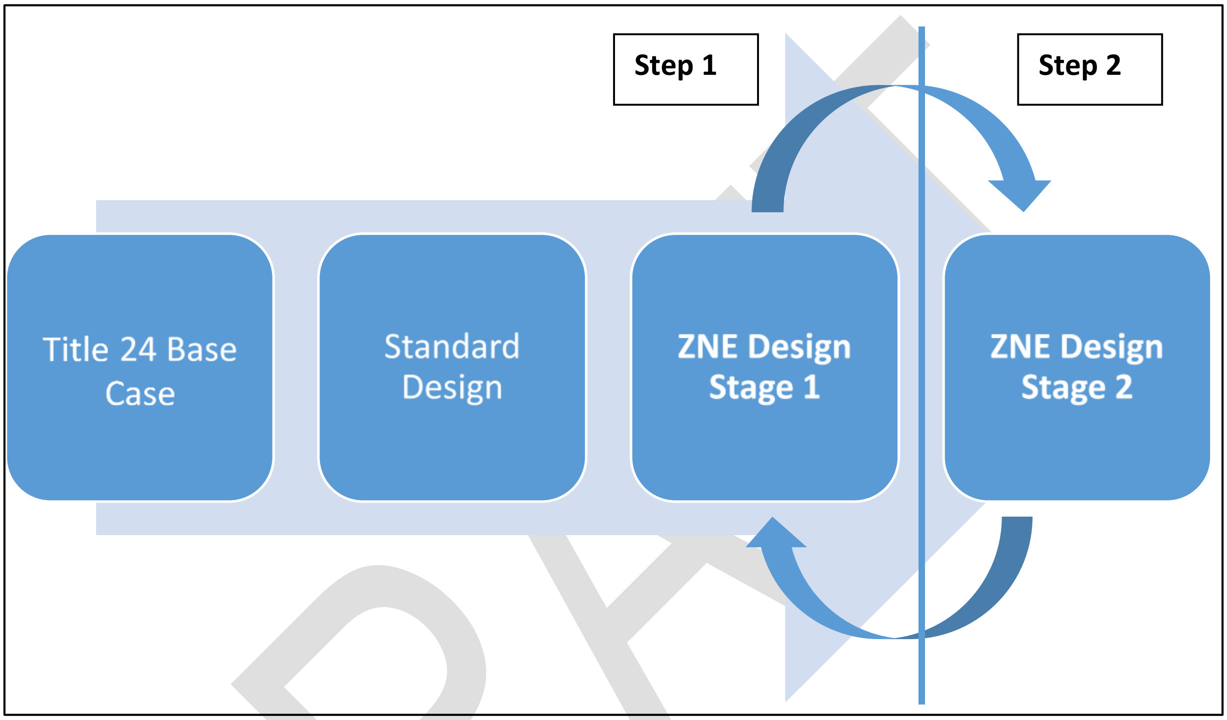


Figure 8-5
A summary of Stage II of the PG&E ZNE Pilot project, an iterative ZNE Design Development Process followed by The project team during the development of the ZNE package used by Pulte Homes for their PG&E ZNE pilot program home, in Brentwood, CA.

The following, Figure 8-6, summarizes The project team's method for developing and designing a ZNE package for Pulte, broken down into Stage 1 and Stage 2 (a 2-step process):

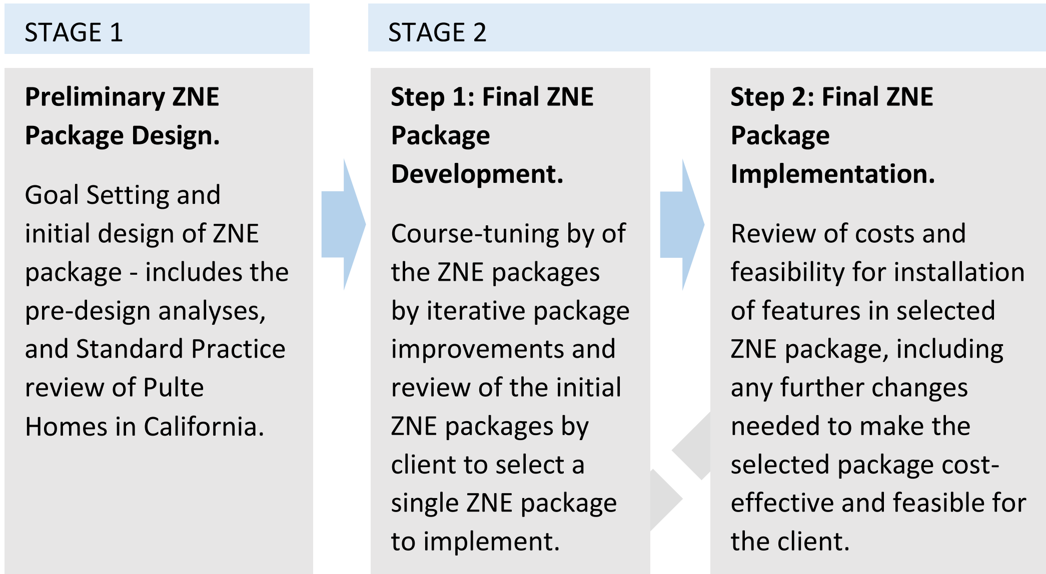


Figure 8-6
A summary of Stage 1 and Stage 2 of the ZNE Design steps used to develop the ZNE Package

Final ZNE Package Development

The second stage, Final ZNE Package Development, builds on Stage I where the initial ZNE package features were identified. Stage II consisted the actual acquiring costs for the features by the builder, and reevaluating the package to ensure that the installed features will perform and cost similarly to the recommended features from the Initial ZNE package. This stage was performed in the following manner:

1. Sensitivity Analysis of Initial Package selected by Client
2. Deliver Initial ZNE Model feature package to client
3. Client determines which features can be acquired for installation
4. Client determines the real incremental cost of installing each feature
5. Modeler substitutes the real cost data for the costs from the cost database in the financial analysis
6. Perturbation Analysis of ZNE package selected by client
7. Features that have a dramatic loss in cost-effectiveness are either dropped from the package and replaced with a more cost-effective option, or approved for final use by the client
8. The Final ZNE Package is the package that will be installed as per the client’s considerations
9. PV Size of the Final ZNE Package is then determined
10. Energy performance metrics are then estimated and reported using the Final ZNE Package

The Final ZNE Package development was built upon the previously discussed Initial ZNE Package, incorporating the feedback from the builder. The Final ZNE Package refers to a combination of individual EEMs that were vetted by the builder from a generic development procedure, that produced the Initial ZNE Package, and still achieved the programmatic goal of giving the house ZNE performance characteristics. The following subsections detail how the various features that were in the initial ZNE Package were accepted or rejected or modified to become part of the Final ZNE package.

Step 1: Final ZNE Package Development

BIRA's final ZNE development process is an iterative process where various Energy Efficiency Measures (EEM) have been included, or excluded, to further optimize an improved feature package pre-selected by the builder. These choices are based on a set of extensive performance analyses: sensitivity analyses and perturbation analyses. A number of individual simulations of two different types (sensitivity analyses and perturbation analyses) were conducted. They were used to identify the EE features in the Final ZNE package, and their impacts on site energy budgets of current Pulte design (sensitivity) and in the Final ZNE package (perturbation). These simulations were conducted and the data analyzed to determine the energy impact of each feature by adding each of the identified individual features to the current design Pulte Botanica plan (sensitivity) or removing it from the ZNE package (perturbation).

Sensitivity & Perturbation Analyses

The first process used by BIRA in the development of a ZNE package is called a sensitivity analysis. A sensitivity analysis is where various features are tested for their energy impacts individually. This allows the modeler to gage which features will have the most impact on a house. The cost-effectiveness of the impact was also estimated from the site energy savings and figures from a national cost database. EEMs that were most impactful, cost-effective, and/or desirable were then put together into an initial feature package. This initial upgrade package was then simulated and the impacts recorded.

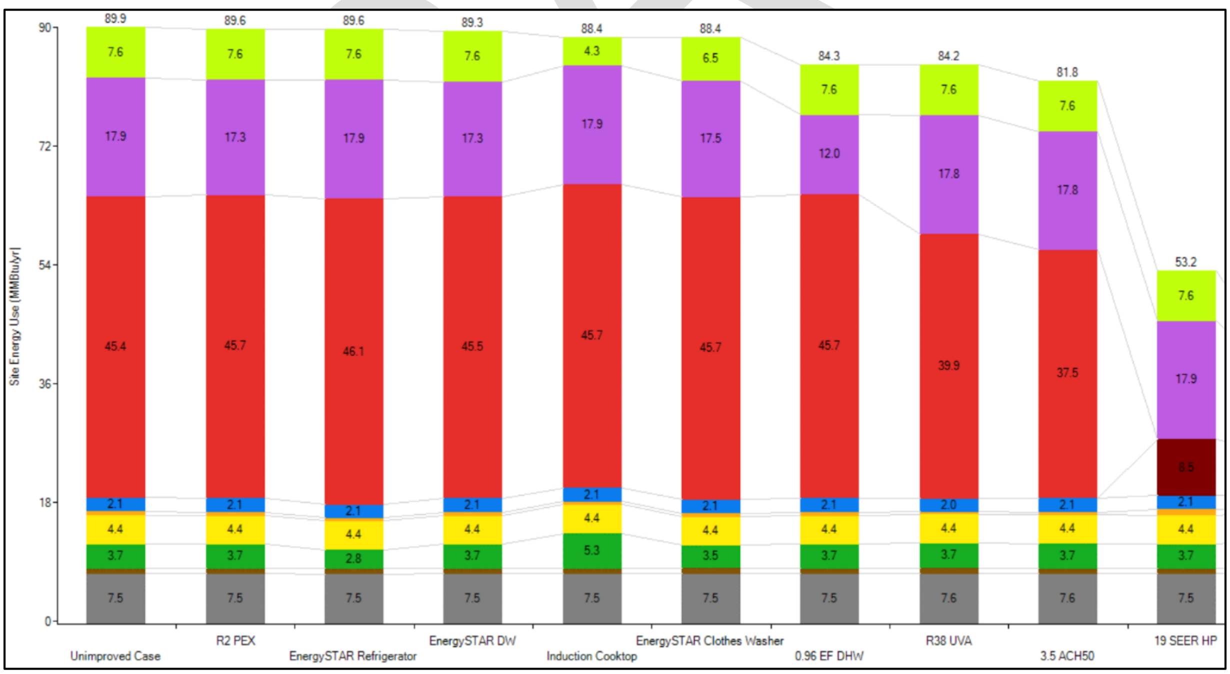


Figure 8-7
ZNE sensitivity analysis, excluding the final feature package

A second analysis BIRA developed for developing ZNE packages is called a perturbation analysis. With a perturbation analysis, each feature that was included in the initial upgrade package was then incrementally removed, one feature at a time, with the energetic loss to the initial upgrade package by the removal of each single feature recorded. From the perturbation analysis it was determined which EEMs did not contribute impactful, or in a cost-effective manner, to the final see any package. In that way, feature may have a higher cost effectiveness when added to the unimproved package then when removed from the initial upgrade package. This is because of diminishing returns.

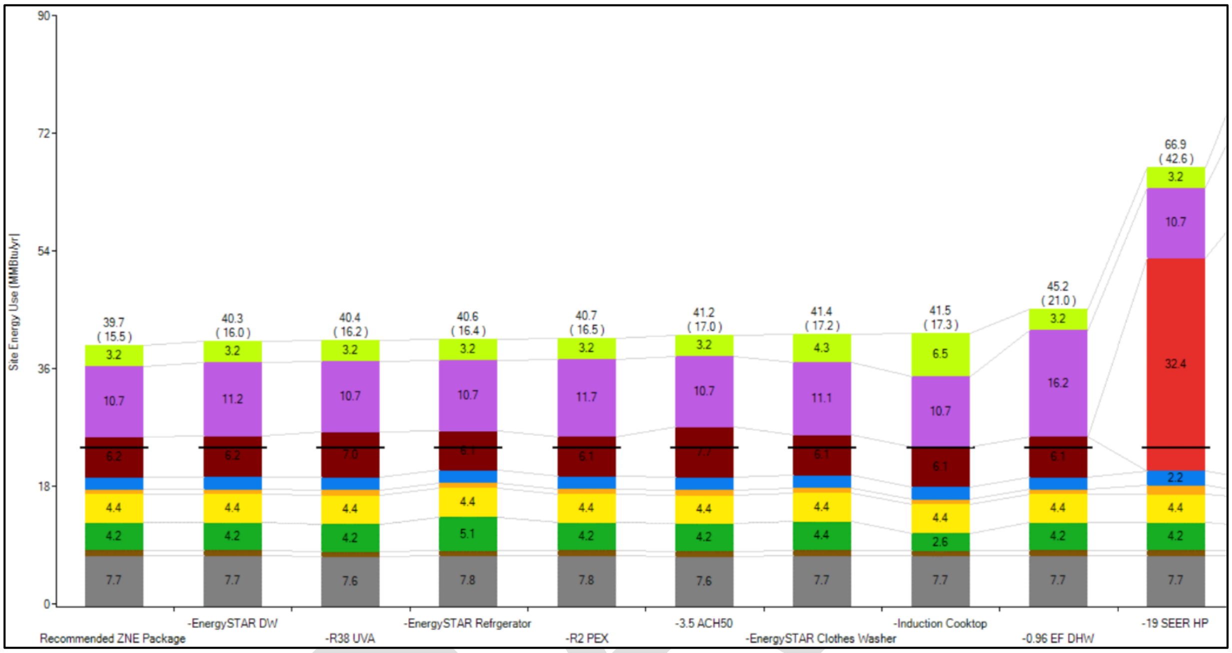


Figure 8-8
ZNE perturbation analysis, excluding the unimproved package features

The EEMs to be used the final ZNE package were then determined from the features used in the initial ZNE package that did not experience diminishing return.

Results of Final Package features and their impacts decided whether or not to incorporate them. Features that had 0% savings during a perturbation analysis were considered to be beyond the point of diminishing returns and were not included in the final package.

Table 8-1
Results of sensitivity and perturbation analyses

			Sensitivity	Purturbation
Category Name	**Base Case**	**Recommended ZNE Package**	**% Savings when added to Base Case**	**% Loss when removed from ZNE Package**
Unfinished Attic	Ceiling R-38 Cellulose, Vented	Roof R-38 Fiberglass Batt, Unvented	6.3%	-1.8%
Radiant Barrier	Double-Sided, Foil	None		
Air Leakage	4.9 SLA (9 ACH50)	3.5 ACH50	9.0%	-3.8%
Air Source Heat Pump	None	SEER 19, 9.2 HSPF	40.8%	-68.5%
Water Heater	gas, 0.62 EF, 50gal, garage	Gas Tankless, Condensing	6.2%	-13.9%
Distribution	Uninsulated, TrunkBranch, PEX	R-2, TrunkBranch, PEX	0.3%	-2.5%
Refrigerator	25 cu ft., EF = 15.7, side freezer	EnergySTAR, 21 cu ft., bottom freezer, 464 kWh/yr	0.3%	-2.3%
Cooking Range	Gas, Conventional	Electric, Induction	1.7%	-4.5%
Dishwasher	318 Annual kWh	EnergySTAR, 260 Annual kWh	0.7%	-1.5%
Clothes Washer	Standard	EnergySTAR, 145 kWh/yr	1.7%	-4.3%
EEM Package	None	all of the above	56%	-126%
PV System	None	4.62 kW	27%	61%
ZNE Package	None	all of the above	83%	N/A

The amount of PV required to make this package a ZNE package was then determined. This initial ZNE package was then delivered to the client with the total energetic impact, compared to the unimproved package. The builder settled on a ZNE package that included ducts and conditioned space, LED lighting, smart thermostats, and more (see Table 4, above).

Energy Efficiency Features Not Considered

The following well-known energy efficiency features were not considered for the initial ZNE package, based on client preferences, existing complications, and known performance issues:

1. Passive Solar Day-lighting: Skylights and Skytubes– Not considered further because of builder's concerns over maintenance and warranty challenges.
2. Direct and Indirect Evaporative Coolers – Not considered practical by the builder. The builder also raised concerns about local water, fouling and maintenance related issues.
3. House Orientation – is already fixed, the lot has been chosen. The chosen lot has available southwest facing roof area at the front of the roof area. The project team recommends planning for ZNE early in the design phase, so that the community and individual lots are planned for optimum solar PV orientation and maximizing passive solar gains, as well as the aesthetics of the solar panel orientation.

Table 8-2
no title

Energy Efficiency Measure ("Feature")	Included in Final Package?
Buried ducts	No
Passive Solar - Higher SHGC Windows	No
Passive Solar – Window Shading	No
Passive Solar - Sky-lights	No
Passive Solar - Thermal Mass	No
Direct and Indirect Evaporative Cooler	No
Home Energy Management System	No
Cool Roof	No
Solar water heating	No

Step 2: Final ZNE Package Implementation

Step 2: Final ZNE Package Implementation. Review of performance, costs, and feasibility for installation of features in selected ZNE package, including any further changes needed to make the selected package cost-effective and feasible for the client.

1. Step 2: Final ZNE Package Implementation
    a. Model updates and new PV size recommendations based on any unforeseen problems encountered during installation
        i. 4.961 ACh50 not 3.5ACh50
    b. Installation of final ZNE package features, actual products selected by client for final package.
        i. Induction cooktop

Final ZNE Combined Package Iterations

Following the iterative process where a number of features were combined to form various iterations resulting in the final ZNE Package, the final package can be said to consists of the all the below energy efficiency features, added to the base case design. This package results in cooling, heating and water heating savings of xx% over the Title 24 base case and xx% over the base case.

The individual measures' percentage savings do not add to a higher number because of the various interactions between each proposed energy efficiency measure and the law of diminishing returns.

The entire process included regular discussion with the builder on the practicality and cost benefit impact of the various features that were considered and simulated.

Solar PV System Design & Funding

BEopt utilizes a modified version of NREL's PV Watts,[13] an online tool that has become an industry standard for estimating the annual electricity generation for various size PV systems for different orientations. The ideal orientation varies based on the project end goal and the ZNE definition that is being targeted. While South orientation provides the maximum output for the PV system, a west facing system generates the maximum electricity output during the peak load period (for utilities) for the grid.

The PV system being considered is a crystalline silicon PV system, with a tilt equal to the roof pitch (4:12), and facing south (azimuth 180). Based on the energy calculations for the ZNE design, the final ZNE package (Table xx) coupled with a 4.62 kW solar PV system allows the house to qualify as a zero net energy (ZNE) house.

The following process was used to estimate the size of the PV size for the final PV size:

1. Determine the PV size
    - a. Multiply hourly data by TDV factors for appropriate code cycle
        - i. Supposed to use CBECC-Res
    - b. Determine annual TDVe + TDVg = TDV
        - i. "TDV used"
            - 1. Ex. 200 kTDV "used" per year
    - c. Determine TDV per kW PV
        - i. "TDV generated"
            - 1. Ex. 40 kTDV/KW "generated" per year
    - d. Determine PV size for 0 TDV (ZNE)
        - i. TDV used / TDV generated = minimum PV size in kW
            - 1. Ex. 200TDV / 40 TDV/kW = 5kW = 5000W
    - e. Estimate Actual PV Size
        - i. Round to the highest multiple of the PV panel size
            - 1. Ergo, 330W panels
                - a. 5000W / 330W = 15.15 panels => use 16 panels minimum
                    - i. 16 panels @ 330W/panel = 5.280 kW PV, not 5.000
        - ii. Determine TDV / panel
            - 1. 1000W = 40 TDV. 1 panel = 330W. 1000W/330W x 40TDV = 13.2 per panel

Conclusions and Next Steps

The ZNE design process has been an iterative process where the focus has been on developing a ZNE design solution that not only meets the end goal, but is also a viable option for a production builder. The project team therefore worked with the production builder at each step of the process ensuring that the final features and design selections were not only energy efficient but

[13] PVWATTS is a NREL online Solar PV output estimator. URL: http://rredc.nrel.gov/solar/calculators/PVWATTS/

also cost effective, practical and easily scalable from a production builder's perspective. The project team hopes to have the construction of the ZNE home with the proposed design solution, to be started next year – market and builder permitting.

9
OUTREACH AND TECHNOLOGY TRANSFER

Overview

This report is intended to compile all the technology transfer and outreach efforts conducted by the project team as part of this project. Technology transfer work has been ongoing in this project since the construction of the homes were in process. The technology transfer happens through multiple mediums to multiple parties:

- Public Tech Transfer through media articles and marketing collateral
- Tech transfer to R&D community through journal articles and publications
- Technology transfer to codes and standards through participation in the building standards development process
- Technology transfer to builder community through presentations at builder events such as EEBA
- Technology transfer to utilities to enable balancing of DERs and for planning of greater spread of ZNE and high PV penetration new communities.

Each of these technology transfer pathways is designed to influence the future deployment of ZNE communities in California. It is also important to incorporate necessary elements into grid planning to ensure reliable and safe provision of electricity to new home communities in California.

Material used for technology transfer is attached at the end of each section.

Public Tech Transfer

The first public notice of this ZNE community was its ground-breaking event on Earth Day, April 15, 2015. Guest speakers included CEC Commissioners McAllister and Hoschchild, Meritage Vice President C.R. Herro, Ram Narayanamurthy of EPRI, and Rob Hammon of BIRAenergy. The event was attended and covered by local print and TV media, and attended by local building and planning department leads. Following the speakers, the attendees were provided with tours of a model home retrofitted to be ZNE. This model home had a special room with interactive displays and actual efficiency measures just like those installed in the ZNE homes, such as a heat pump water heater. These ZNE displays saw continued use by visiting public, special visitors, such as the CEO of Southern California Edison, and most importantly, by the sales executives who sold these homes in near-record time, with nearly all 20 homes sold before the end of 2015.

Since the first public announcement, this project, the first ZNE Community in California, has received substantial attention from both technical and general media. The resulting media has substantially raised the visibility and increased the public awareness that ZNE homes are not limited to special, and expensive custom-designed and built homes, but that Zero Net Energy homes have entered the mainstream market, and could become available to all prospective homebuyers throughout California. This will happen due to public interest and demand, or by mandate in 2020; either way this project has played a key role in providing widespread exposure of builders, developers, local jurisdictions, utilities, and other stakeholders to ZNE homes.

Construction as well as the importance of customer acceptance and grid integration from Net Zero and Advanced Energy Communities. The following is a list of media articles that have been published about the project. The articles have been published from different angles – green building, customer uptake, energy storage, solar penetration and grid impacts. But, they form a substantial body of technology transfer that has really increased the visibility of high performance building, feasibility of zero net energy and how energy efficient solar communities can also be affordable and comfortable.

In addition to media articles, customer education is also accomplished through development of model homes and training of builder customer service staff. A model home was retrofitted to net zero to demonstrate that that serve as technology showcase as well as to establish that Net Zero Energy homes are everyday live-able homes. The models homes for Meritage serve as customer education centers on solar and energy efficiency technologies. The pictures below (insert pictures) illustrate the model homes and how customers were educated on energy efficiency by the displays.

Part of this technology transfer is accomplished by training sales staff at the community, who ARE the front line for customer education on energy efficiency and Zero Net Energy issues. They received individual training of all the key efficiency elements in the ZNE homes, including individualized refresher training, which was found to be important to the proper representation of the ZNE homes. their benefits also helped in charging up customer adoption where the uptake went from 2 homes in the first 2 months to moving 19 of 20 homes within 5 months.

In addition to informing the general public that ZNE homes are a reality and available to them, this project has generized a number of technical reports and papers directed at technical stakeholders. These include in-depth reports regarding the methods and tools used to perform the analyses required to develop the ZNE measures and design – the Task 2 detailed report for builders, designers, code officials, and other technically-oriented stakeholders.

While there is no task nor funds, it would likely be of great value to California rate payers to have a brief information "flyer" regarding some of the results of this project, in particular information regarding the costs, benefits, current and future availability of ZNETDV homes. Such fliers could be provided to the CEC, utilities, and other public entities that the general public rely upon for information regarding energy, energy savings, and energy efficiency for open and free distribution to parties requesting any related information from these entities.

This project has received substantial attention from both technical and general media and has substantially raised the profile of both Zero Net Energy construction as well as the importance of customer acceptance and grid integration from Net Zero and Advanced Energy Communities. The following is a list of media articles that have been published about the project. The articles have been published from different angles – green building, customer uptake, energy storage, solar penetration and grid impacts. But, they form a substantial body of technology transfer that has really increased the visibility of high performance building, feasibility of zero net energy and how energy efficient solar communities can also be affordable and comfortable.

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Another component of the technology transfer happens through the marketing staff at the community. They are the first point of contact between interested homeowners and the project itself. They are the front line for customer education on energy efficiency and Zero Net Energy issues. The training also helped in charging up customer adoption where the uptake went from 2 homes in the first 2 months to moving 19 of 20 homes within 5 months. Untrained marketing staff can feel that they do not understand the technology and worse, not comfortable with selling these homes. Trained marketing staff are essential to ensuring that they can sell the benefits of energy efficiency and solar generation to customers. Another strategy adopted by Meritage to help with market acceptance was to provide a free consulting from SunPower, the solar installer, who is better equipped to drive solar adoption.

A unique medium for technology transfer to the public is through "word of mouth" from informed homeowners. In the case of Sierra Crest, a couple of evangelist homeowners who have been happy with their homes, have been helping other homeowners in both the ZNE neighborhood and beyond with adapting to connected thermostats, and other conveniences provided as part of the standard home package. They have also been very vocal with their friends and family, which helps spread the word around.

Media Coverage of ZNE Community

This community has received extensive coverage in the media as a leading example of Zero Net Energy construction. This includes coverage in newspapers .

- **The Press Enterprise**
  - Fontana: Energy-Efficient Community a First for State
  - http://www.pe.com/articles/energy-778934-zero-homes.html

- **Edison International**
  - Helping California Meet Goals for Zero Net Energy Homes by 2020
  - http://www.edison.com/home/innovation/energy-management/zero-net-energy-homes-buildings.html
- **USGBC Inland Empire**
  - Fontana: Energy-Efficient Community a First for State
  - http://usgbcinlandempirechapter.wildapricot.org/widget/event-1977064
- **Edison International**
  - Green Homes Tour: Meritage Homes Net Zero Community, Fontana
  - http://newsroom.edison.com/stories/helping-california-make-zero-net-energy-buildings-a-reality
- **Green Homebuilder Magazine**
  - A Net Zero Neighborhood Sets a New Standard
  - http://www.greenhomebuildermag.com/article/net-zero-neighborhood-sets-new-standard
- **Yahoo Finance**
  - 20 Zero Net Energy Homes to be Built in California Community
  - http://finance.yahoo.com/news/20-zero-net-energy-homes-130542067.html
- **Electric Power Research Institute**
  - 20 Zero Net Energy Homes to be Built in California Community
  - http://www.epri.com/Press-Releases/Pages/20-Zero-Net-Energy-Homes-to-be-Built-in-California-Community.aspx
- **Orange County Register**
  - Meritage introduces California's first and only Net Zero Neighborhood
  - http://www.ocregister.com/newhomes/meritage-657529-neighborhood-zero.html
- **EcoWatch**
  - California's First Zero Net Energy Community Is a Model for Future Living
  - http://ecowatch.com/2015/04/27/zero-net-energy-sierra-crest/
- **Smart Grid News**
  - EPRI, SCE Developing First Residential ZNE Community in CA
  - http://www.smartgridnews.com/story/epri-sce-developing-first-residential-zne-community-ca/2015-04-23

- **Renewable Energy World**
  - California's First Zero Net Energy Community Opens on Earth Day to Support Bold State Goals
  - http://www.renewableenergyworld.com/articles/2015/04/californias-first-zero-net-energy-community-opens-on-earth-day-to-support-bold-state-goals.html
- **Clean Technica**
  - First Zero Net Energy Community In California Announced
  - http://cleantechnica.com/2015/04/28/first-zero-net-energy-community-california-announced/
- **Builder Online**
  - Meritage Opens California's First Zero Net Energy Community
  - http://www.builderonline.com/newsletter/meritage-opens-californias-first-zero-net-energy-community_c
- **ElectricityPolicy.com**
  - Gov. Brown Ramps Up GHG goals; EPRI, SCE, CPUC Support Zero Net Energy Units
  - http://electricitypolicy.com/News/gov-brown-ramps-up-ghg-goals-epri-sce-cpuc-back-zero-net-energy
- **Mother Earth News**
  - California's First Zero Net Energy Community Is a Model for Future Living
  - http://now.motherearthnews.com/story/featured/californias-first-zero-net-energy-commun/66646f4e2f6b4765634270562f726c4c5057477558513d3d
- **Fine Homebuilding**
  - California Project Tinkers With a Net-Zero Future
  - http://www.finehomebuilding.com/item/109729/california-project-tinkers-with-a-net-zero-future
- **Navigant Research**
  - Paving the Road to Zero Net Energy Buildings
  - https://www.navigantresearch.com/blog/paving-the-road-to-zero-net-energy-buildings

Tech Transfer to the Utility Industry

Key components of this project were directed at illuminating the building industry, including energy utilities, of the impacts that ZNE homes in volume could have on utilities. There is evidence that large numbers of homes with PVs can produce deleterious effects on distribution systems, as well as increasing CalISO difficulties in providing the optimal energy to the grid at certain times of each day. There is also very limited information regarding whether and how well battery storage could provide a buffer between Homes with PVs, specifically ZNE homes and the distribution system. The utilities, in particular SCE and PG&E, showed keen interest in this project because of the data it could provide, in particular, the effects of large numbers of homes with PVs on the electricity-distribution systems, and if and how PV impacts might be enhanced or mitigated by incorporation of battery storage of electricity ZNEs coupled with battery storage devices.

Southern California Edison (SCE) was a partner in this project, with interests including how to design and build ZNE homes, impacts of high market penetration of both PVs and ZNEs, and the potential for battery storage to solve some interconnection problems. It was clearly demonstrated that SCE's interest went all the way to the top of their organization when the CEO visited the project and the homes to learn more about the project and the ZNE homes.

The project team provided transfer of technical information to utilities through several channels, including direct contact, reports, meetings, and phone calls to provide them with project information they would likely find interesting and/or valuable from the projects.

Tech Transfer to Building Community

The building industry obtains technical information through a number of specific channels, the most important of which include their annual conference, 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 CEC has contracted a team to train the building industry regarding ZNE_{TDV}'s, PVs, and high-performance envelopes. It is critically important that the CEC provide a train-the-trainer element that includes information from this project, but that is well beyond its scope and budget. The information fed to the building industry via training programs needs to be sufficiently well understood by the trainers that they are capable of providing the right level of information for the particular audience. For instance, the information and knowledge needed by builder purchasing agents, builder superintendents, and engineer consultants about high-performance attics or PVs, for instance, can be very different. The trainers need to be sufficiently well versed in the technical information to expertly convey the right information at the correct level. The CEC would be well advised to closely monitor such training to ensure that it is properly conveyed to all the audiences who need to learn about it so that the homes are built, sold, maintained, and used properly, so that the buyers and their families (ratepayers) get the products they expect and that the codes require.

Tech Transfer to Codes and Standards Groups

The number-one "Big Bold Goal" set by the California Long Term Energy Efficiency Strategic Plan[14] for the 2020 update of the Energy Efficiency Standards ("Title 24") is for all new homes to be ZNE_{TDV}.[15] This goal is achievable, but it is very daunting, having "Zero… Energy" in the name, and being announced as a "Big Bold" Goal. In fact, it was a daunting task in 2008 when this Big Bold Goal was first set, but the industry and regulators have worked hard and together to develop two code changes since then (2013 and 2016) that have put the residential energy code on a trajectory to ZNE_{TDV} by 2020. The 2013 Title 24 update is about to sunset and be replaced

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[14] http://www.cpuc.ca.gov/General.aspx?id=4125

[15] Define ZNE_{TDV}, if have not already

by the 2016 update; simultaneously, work is underway to develop the 2019 update that will go into effect January 2020, and is currently planned to mandate ZNE_{TDV}.

The homes built under this project span the three code updates between 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, which they exceed by XX%; they also surpass the 2016 code efficiency requirements (effective January 1, 2017), and meet the 2020 code, as best we understand it in 2016, and they met the Big Bold Goal of ZNE_{TDV}. 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 demonstrate 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 a “concrete” example of what to expect to be required in 2020. If, after seeing the ZNE homes, one wants more information regarding the design and construction of ZNE homes, the Task 2 report provides substantial information, data and analyses showing how the team determined the optimal features for this builder, for this climate. The measures needed for ZNE will vary with home sizes, locations, orientations, and construction practices. Approaches and analyses to provide an optimized ZNE feature set are clearly defined and explained in the Task 2 report for this project.

CEC 2016 Code Addition for High-Performance Attics and Walls

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

The homes built for this ZNE community all incorporate HP-A’s, but not HP-W’s, as directed by the builder, Meritage. 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, Meritage, and other builders who construct HP-A’s 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. HP-A&W’s are new construction techniques for most CA builders. The HP-A costs, benefits, and construction basics and issues are all documented in the design and/or construction task reports for this project, which are readily available to industry, and the information contained has 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.

Add pictures of HP-A’s and SPF walls in Meritage Homes.

Tech Transfer to Buildings R&D Community

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REFERENCES AND BIBLIOGRAPHIES

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A
SUMMARY OF ENERGY MODELS AND PV SIZING

B
DISTRIBUTION SYSTEM SIZING PRACTICES

C
HOURLY DATA BY HOME AND TRANSFORMER FOR SPRING AND SUMMER

D

APPENDIX D RESIDENTIAL ENERGY STORAGE MARKET SURVEY

EPRI conducted a broad survey of providers of battery energy storage components and systems. A subset of these 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. (This figure 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.

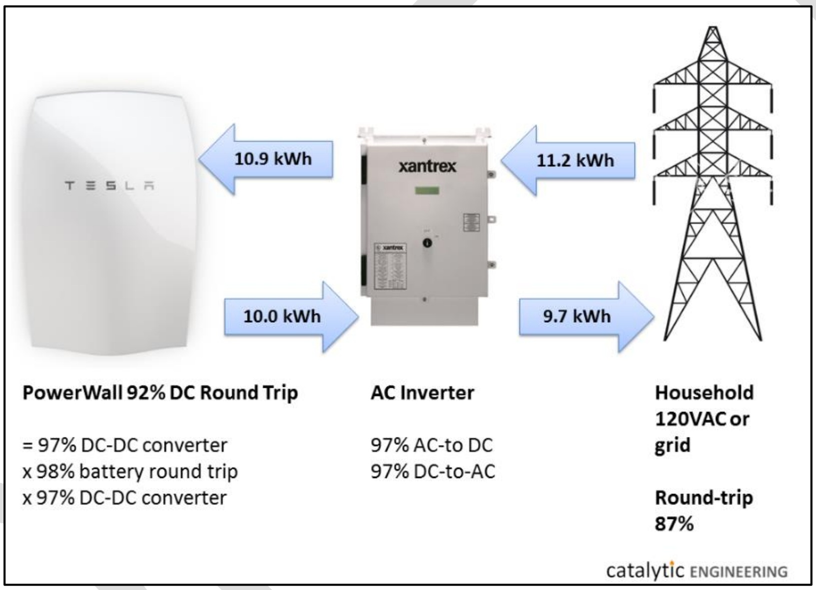

Figure D-1
Power conversion stages for DC battery in AC systems

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. 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 particular 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 D-2
ABB Modular Unit

Table D-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. 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 D-3
Adara Power installed system design

Table D-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 D-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 D-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 D-5 illustrates 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)

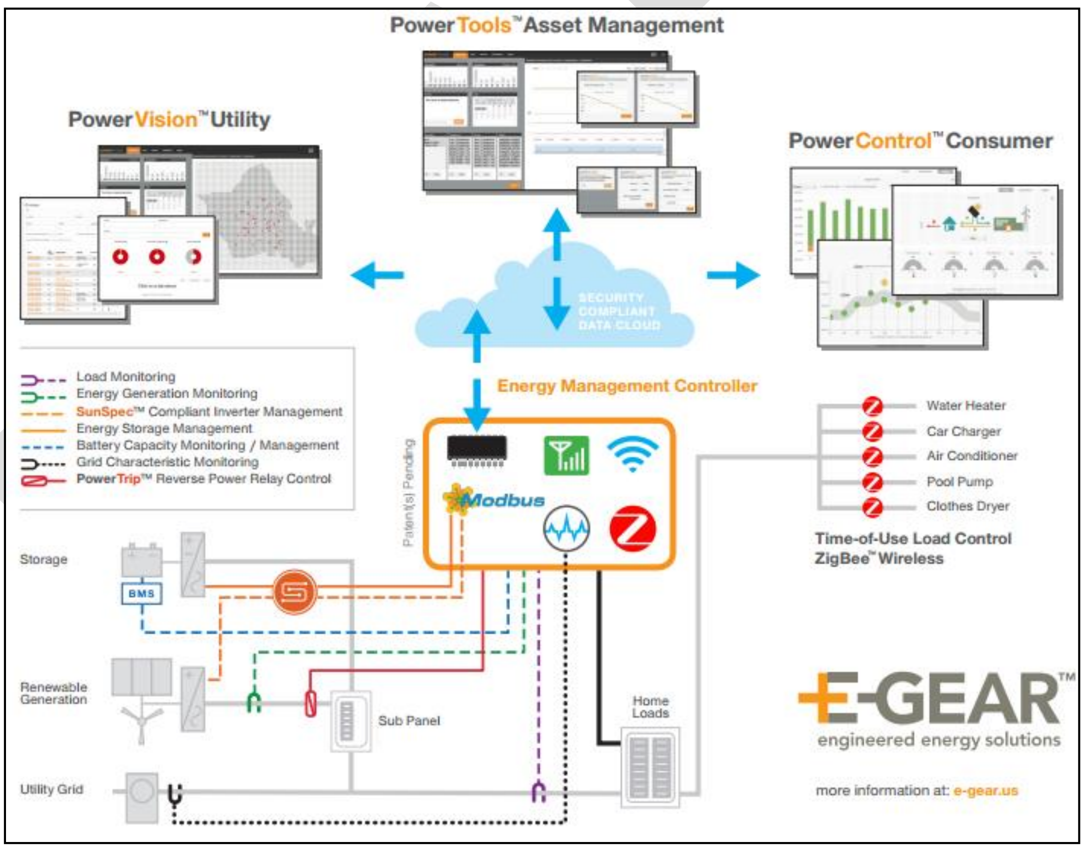

Figure D-5
E-Gear battery energy storage system centered on E-Gear management system.

Table D-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 D-6 illustrates 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)

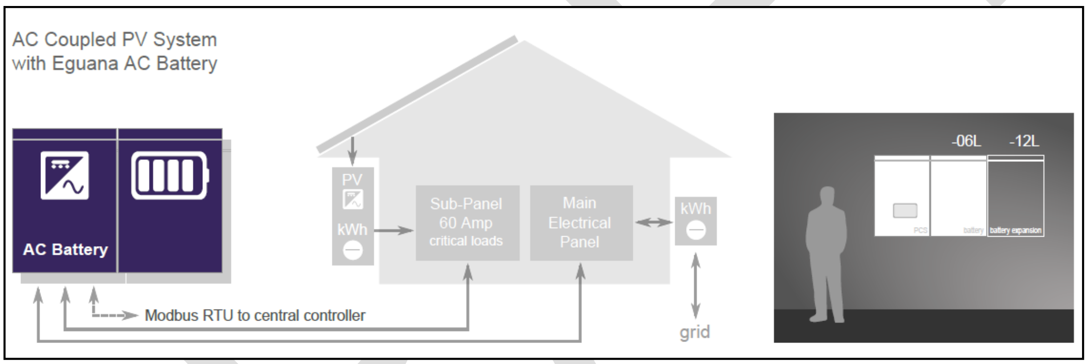

Figure D-6
Eguana system configuration concept.

Table D-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

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)

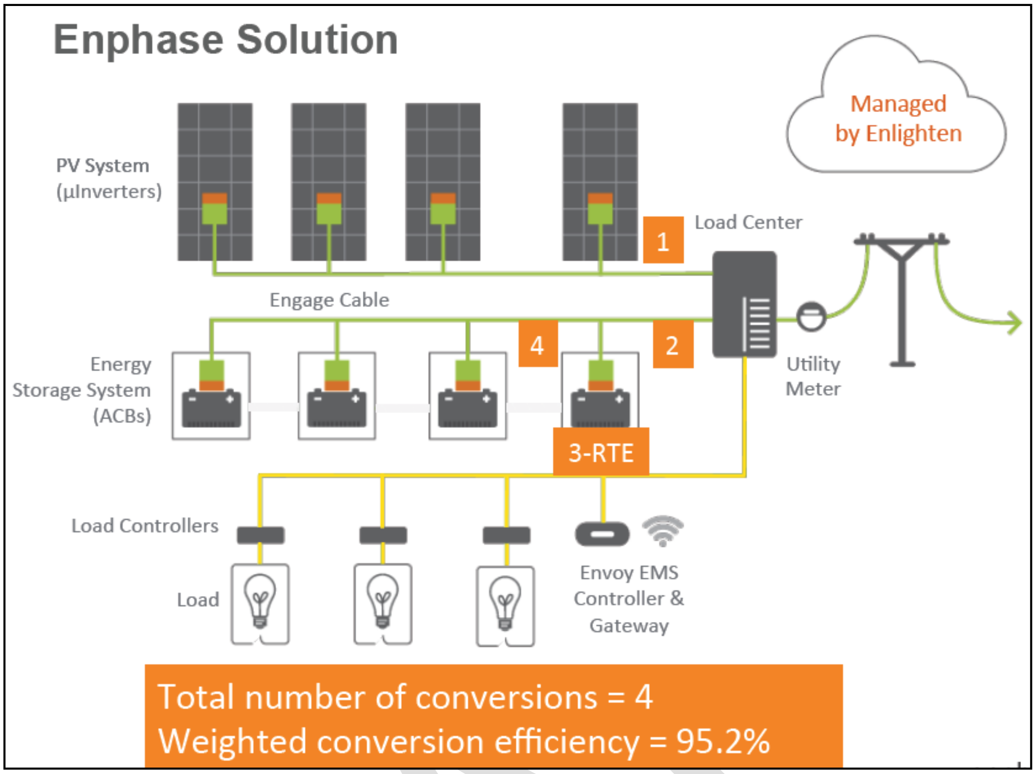

Figure D-7
Enphase integrated solar and battery system schematic

Table D-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). 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 also 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 D-8
Fronius Turnkey system using Sony battery under Fronius brand

Table D-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. 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

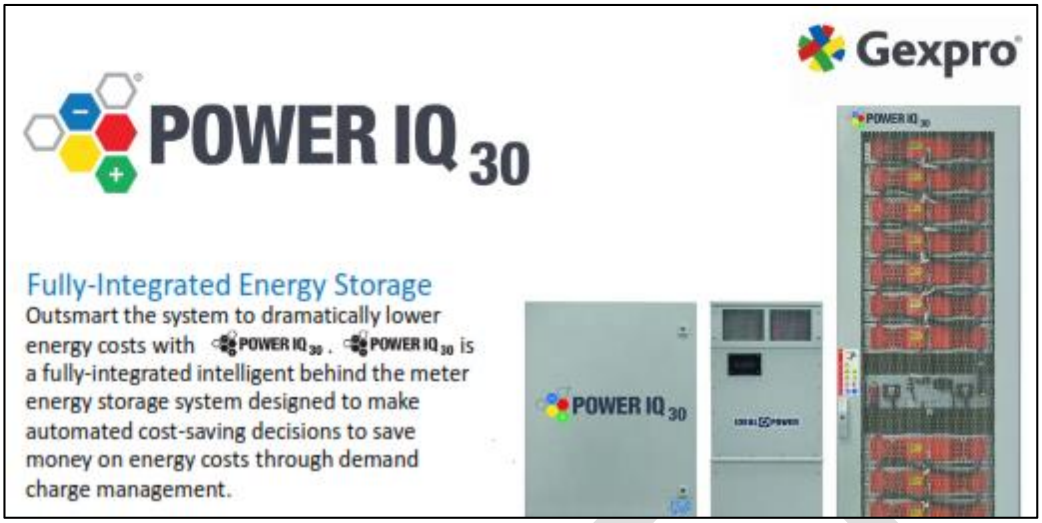

Figure D-9
Gexpro system components

JLM

Partial Solution provider: Storage, EMS

JLM Energy, based in Northern California, was founded in 2007, has shown significant growth since 2011, and now has 50 employees in California and Arizona. JLM provides battery systems and control systems for demand management. 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

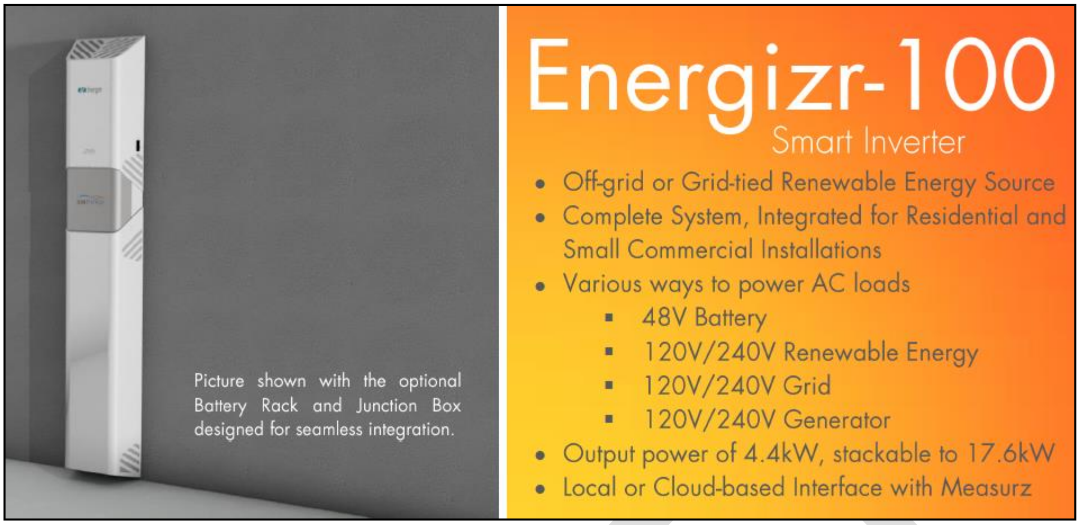

Figure D-10
JLM battery systems

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 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. The next generation is anticipated to offer a flexible form factor. Table 6-7 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)

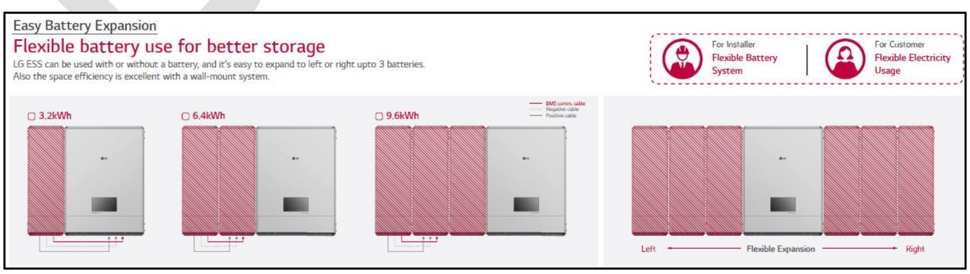

Figure D-11
LG battery system configurations

Table D-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.

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 D-12
An Outback Power installation with lead-acid batteries.

Table D-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. 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 6-9 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 D-13
Panasonic battery unit.

Table D-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.

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 D-14
Range of Samsung battery modules.

Table D-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 FigureD-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. 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 D-15
SMA's Sunny Island system.

Table D-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.

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. 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)

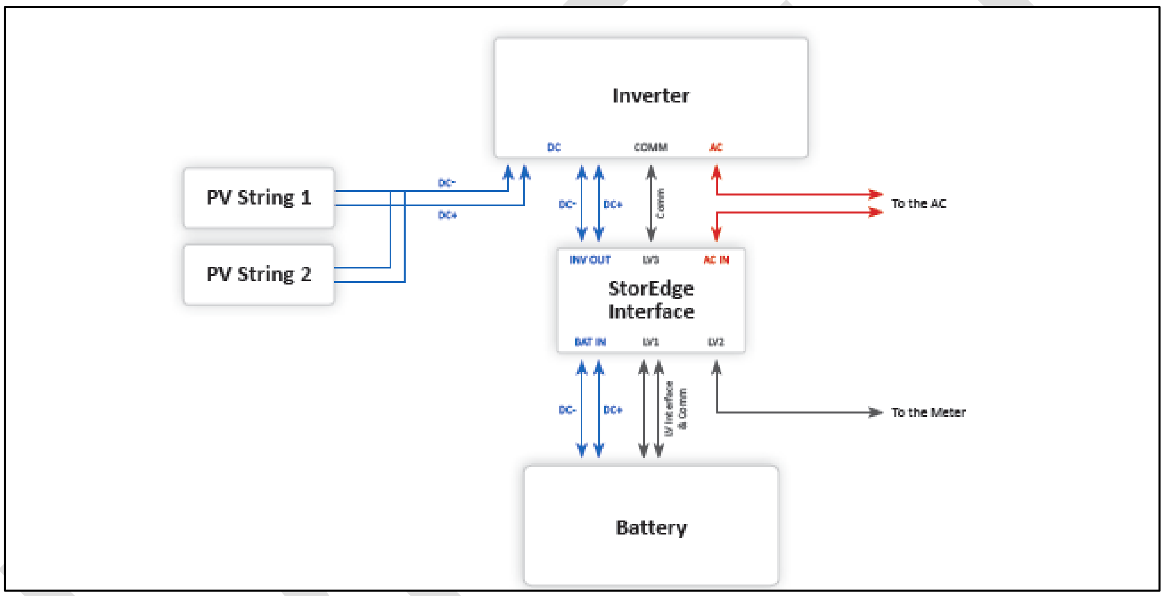

Figure D-16
SolarEdge/Tesla configuration plan

Table D-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. 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 D-17
Solarwatt battery module.

Sonnen

Turnkey Solution Provider

Sonnen's 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). 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 D-18
Product sample: sonnenBatterie

Table D-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 D-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 D-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. As a means to that end, they have elected to package a relatively vintage-technology hardware stack with reliable off-the-shelf components. 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

Figure D-20
Sunverge turnkey unit

Table D-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. 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 D-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 also 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 D-14 and D-15 summarize example cost-assessment results for a set of five AC-coupled solutions and a set of seven DC-coupled solutions, respectively. For this particular 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 D-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 D-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 D-14 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 esthetically 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 D-16 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 D-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 D-17 illustrates this process for three of the factors described above.

Table D-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 D-18 presents a representative case. Here, three battery systems are compared on the basis of 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 particular planned application.

Table D-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 particular 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.

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