Establishing Feasibility of Residential Zero Net Energy Community Development - Learnings from California's First ZNE Neighborhood

Bienvenido Clarin and Ram Narayanamurthy, Electric Power Research Institute
Rob Hammon and Ian Hammon-Hogan, BIRA Energy
William Vicent, Southern California Edison

ABSTRACT

The State of California, through the passing of Assembly Bill (AB) 32, has set the goal that by 2020, all new homes in California be constructed to Zero Net Energy (ZNE) standards as defined by the state. The Electric Power Research Institute (EPRI), BIRAenergy (BIRA), Meritage Homes and Southern California Edison (SCE) have partnered together to develop a community of 20 homes in Fontana, CA to this ZNE standard in order to:

- Evaluate the possibility of constructing cost-effective, ZNE communities that can be implemented at scale by homebuilders and affordable homes for the customer.
- Understand market drivers and barriers for homeowners to buy these ZNE communities.
- Identify trade ally drivers and barriers of groups that will sell and service ZNE.
- Model and monitor impacts of constructing ZNE communities on the electrical grid, in particular, the distribution system.
- Monitor real customer preferences of living in and operating ZNE homes.
- Develop a controls infrastructure for aggregating customer-sited resources to mitigate electrical distribution system impacts.

This paper reflects activities completed from February 2015 through March 2016 which focused on project planning, energy modeling and building construction of this Fontana ZNE community. The work at this point focused on the modeling and construction of 20 ZNE homes and the development of a data monitoring and controls infrastructure for these homes.

Introduction

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 (CEC 2013).

As the price of solar energy has fallen dramatically and a recent emergence of technologies have helped reach those ZNE goals, there have been an increase in homes that have been built to ZNE, near-ZNE and ZNE-ready specifications. By Q2 in 2014, it was estimated that there were approximately 1,110 ZNE-type homes in California, of which only 16 were ZNE (Fogel 2015). In 2015, the Team began planning, marketing and constructing 20 homes that meet

California ZNE standards. The Team chose Meritage Homes's Sierra Crest Community, a 187 home community development located in Fontana, CA. The City of Fontana is located in San Bernardino County, approximately 70 miles east of Los Angeles in California Climate Zone (CZ) 10. The Team chose to build the 20 homes in two community lots shown in Figure 1.

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

The 20 lots were chosen as the homes would then be isolated on 2 community transformers. Isolation to 2 dedicated transformers was done in order to better understand effects on the current electric distribution grid of community scale deployment of ZNE homes.

These ZNE homes in Fontana were also built in a manner to replicate construction and market considerations when deploying these communities at scale. These homes were sold as "normal" homes to first time homebuyers, with similar floor plans and elevations as other homes in the community. The technology packages were all available in the market. The project Team leveraged existing Meritage product providers and installation and service contractors in all cases except one, the residential energy storage system. To complete the project, the team plans on executing the following main tasks between January 2015 and June 2016:

- Design ZNE Energy Efficiency (EE) and Distributed Energy Resource (DER) packages to deploy in the community.
- Develop a monitoring and controls infrastructure that successfully aggregates customer-sited resources in order to mitigate electrical distribution system impacts.
- Model and monitor impacts of constructing ZNE communities on the electrical grid, in particular, the distribution system.

Designing ZNE EE and DER Packages

The first step of the project was to develop an integrated package of EE and DER measures that would result in zero net-energy rated homes, using the California TDV based definition. The process was to develop packages by using building simulation and modeling tools, while considering practical limitations when deploying these technology packages at scale.

The Team evaluated these EE and DER measures using NREL's Building Energy Optimization Tool (BEopt). Baseline information used to develop models for each plan was garnered from a combination of sources that includes building plans, technology feature specifications and CA Title 24 - California residential building efficiency standards (CEC 2013). Compared to the other 167 homes in the Sierra Crest community, no architectural changes were made to the 20 ZNE designed homes. As there were no duplications of plan type, elevation and orientation, all 20 homes were separately evaluated. However, one energy efficiency upgrade package was derived to emulate community scaling considerations.

To accurately model each of these 20 homes, building plans that include lighting and window schedules, as well as a complete description of standard energy efficiency upgrades that Meritage Homes completes as part of the other 167 homes built in the Sierra Crest community. Miscellaneous Electric Loads (MELs) were estimated based on both the Team's experience in calibrating existing home models (Hammon 2011) and NREL data (Wilson et al. 2014).

Energy efficiency feature packages were developed using building models which conduct a combination of a sensitivity analysis and parametric analysis of proposed measures. Before developing these packages, a list of prospected measures such as; lighting, Heating, Ventilation and Air Conditioning (HVAC), building envelope, water heating, appliances and plug loads that could be used in the final ZNE package was vetted by the Team for possible inclusion. In addition community scaling considerations were considered by eliminating features due to reasons that include but are not limited to: (1) material preference; (2) existing national product provider contracts; and (3) operation and installation issues attributed to a brand, device or equipment model. To perform sensitivity analysis, individual features such as high efficiency heat pumps, Heat Pump Water Heaters (HPWHs), tankless condensing water heaters, LED lighting, smart thermostats and advanced building insulation were evaluated for inclusion in the overall EE feature package. All features were compared to the 2013 CA Title 24. See Figure 2.

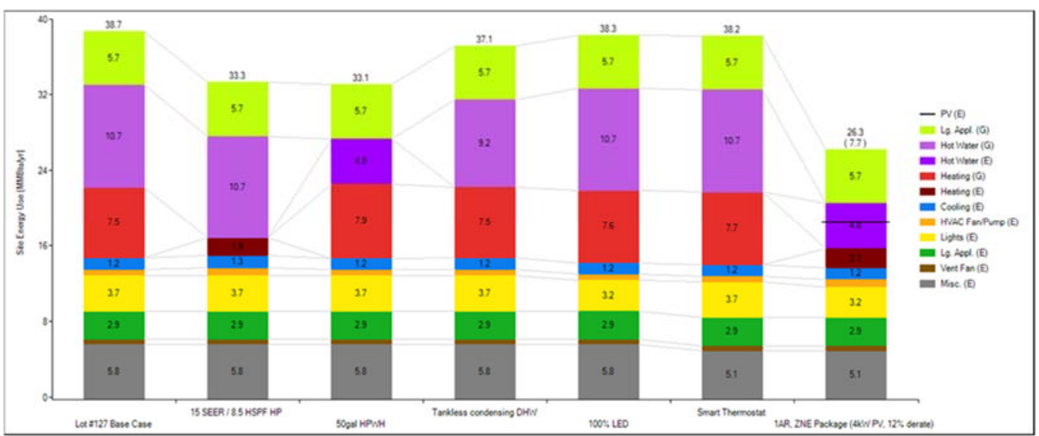

Figure 2: Example of sensitivy analysis to vet EE measures for inclusion in preliminary EE package. The figure depicts Lot #127, one of the 20 ZNE homes.

Parametric analysis was then completed to vet each EE measure. Each measure was tested by an optimization scheme where each home was modeled with 2013 CA Title 24 features. Individual features were then iteratively upgraded or swapped for efficient alternatives to determine impacts of each individual feature on the Base Case. Example results of parametric analysis are shown in Figure 3.

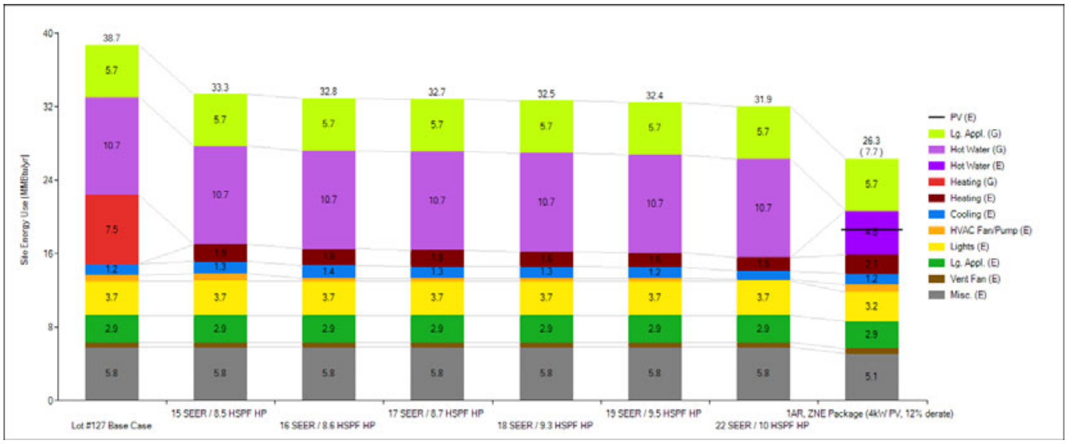

Figure 3: Example of parametric analysis of HVAC system for inclusion in preliminary EE package. The figure depicts Lot #127, one of the twenty ZNE homes.

Parametric analysis in Figure 3 shows different efficiency level replacements for CA Title 24 HVAC system with heat pumps of various SEER ratings. As Figure 3 shows, there are limited efficiency gains when improving HVAC systems for these homes after 15 SEER. Parametric analysis is then paired with cost analysis to finalize recommendations for each measure. Cost analysis used parameters such as capital cost of equipment and estimated annual utility bill. See Table 1.

Table 1: Cost Analysis of HVAC Systems for Lot #127, One of the Twenty ZNE Homes.

Proposed Measure	Capital Cost	Annual Utility Bill	Cost Over 30 Yr. Mortgage	Cost/ Benefit	Rank
14 SEER AC / 92.5% AFUE (Base Case)	$5,351	$866.60	$31,349	36.17	7
15 SEER / 8.5 HSPF HP	$3,544	$878.90	$29,911	34.03	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

Energy impact shown in parametric analysis and cost analysis provides a first order method of choosing measures to include in the overall ZNE package. The result of the sensitivity, parametric and cost analyses produces a preliminary ZNE package.

This preliminary ZNE package undergoes a perturbation analysis, where each feature is valued incrementally for inclusion to the final ZNE package. Pertubation analysis is completed in order to evaluate any effects of interactions between different measures. For example, an important interaction is HVAC equipment sizing. As building envelope is improved, the required capacity or size of the HVAC systems needed to maintain desired temperatures decreases, which in turn reduces the size of the HVAC system. See Figure 4. Results of the perturbation analysis is the final EE package to be included for each home.

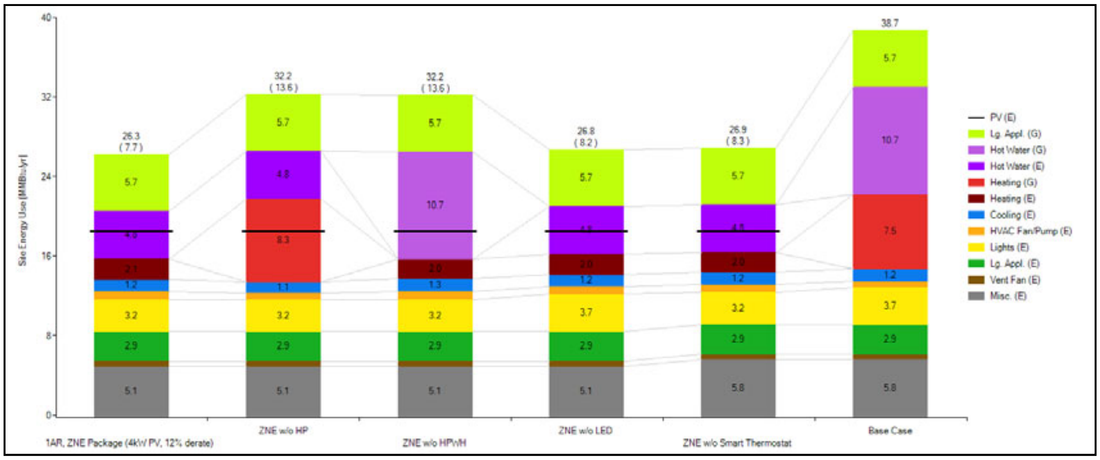

Figure 4: Example of pertubation analysis to validate EE measure for inclusion in overall EE package. The figure depicts Lot #127, one of of the twenty ZNE homes.

The final steps in developing the overall EE and DER packages are: (1) size the solar photovoltaic (PV) array for each home and (2) review overall EE and DER package costs for the community. To size the PV arrays, EnergyPLUS weather files for PV productivity were coupled with practical limitations of PV hardware available by Meritage's contracted solar provider. The array size for the final ZNE package is then corroborated with availble roof area on each building, being mindful of building aesthetics. Considerations were made to minimize overproduction of electricity generated at both the community and the home level.

Results

Simulations using tools such BEopt determined the following EE measures from sensitivity, parametric, financial and pertubation analysis. See Figure 5.

Figure 5: Final EE and DER measures used for ZNE community.

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 6.

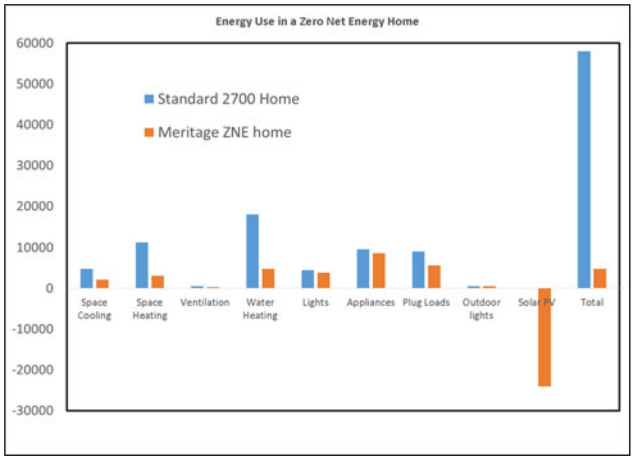

Figure 6: Average annual energy used and generated by 20 ZNE homes compared to Title 24 base case.

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.

Table 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.

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 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.

Developing a Data Monitoring and Resource Controls Infrastructure

Community scale data monitoring has been a challenge due to the cost and logistics of installing and commissioning traditional monitoring systems. Developing inexpensive monitoring tools of ZNE homes is crucial as energy usage, especially MEL usage, varies with customer preference. Customers are now becoming more “energy aware” and demanding connected energy resources that enable better management and comfort for these new ZNE communities. For example, three years of data from another California ZNE home (also in CZ 10) showed that this home attained ZNE, but that its load shape was extremely peaky without energy storage. 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). 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.

Developing customer-sited resource aggregation has drawn increased interest by electric utilities. The utilities hope to account for higher penetrations of DERs (Wesoff 2016). Product and service providers have interest in offering these services to the utility and its customers (Tweed 2014). Usually completed using “top-down” approaches by the utility or proprietary controls schema by service providers, these efforts of aggregating connected DERs and end-use loads have typically been customized in nature.

This ZNE project applies a method for monitoring and control, using data from connected devices. As technology evolves and communications, sensing and data acquisition have become more ubiquitous, common household devices such as thermostats and circuit panels have the potential to turn into power monitoring and data acquisition systems. This project will also incorporate a cloud based data acquisition platform that can also be used for monitoring and control of multiple end-use devices. 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). Figure 7 identifies how the various end-use systems are connected and data and controls are transferred. Each home is monitored at the end-use load level, plus additional 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. There will be more than 50 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.

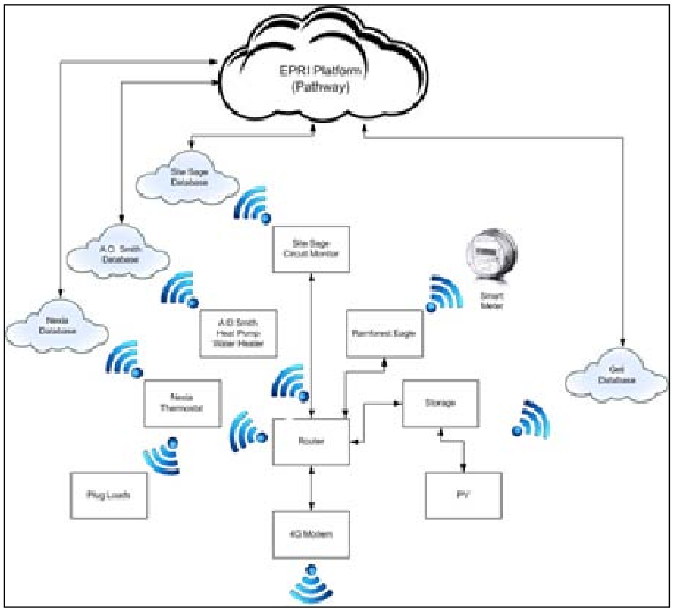

Figure 7: Data monitoring and control platform commissioned as part of ZNE community

In this era of higher customer engagement, energy management strategies will need to engage the customer and incorporate customer preferences. There is a need to integrate all products that can serve as load management tools, independent of competing standards and ecosystems, using an open source 3rd party approach that is accepted by majority product providers. By using "bottom-up" approach to understand customer preference and working with controls and data that product providers collect, the Team aims 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. Additional details of the control elements are detailed in a complimentary 2016 ACEEE Paper (Narayanamurthy et al. 2016).

Modeling Impacts of ZNE Communities on the Electrical Distribution System

The impact of scaling residential ZNE communities per California's 2020 goals has yet to be monitored and evaluated in detail as large ZNE communities have yet to permeate California's electrical grid. In these scenarios where large penetrations of DERs such as solar PV systems and energy storage are more and more achievable, it is important to address electrical distribution questions in order to support this fundamental shift in residential electricity usage. These questions are currently being investigated by policymakers and the electric utilities and include but are not limited to:

- At which concentration level do ZNE homes begin to impact current electrical distribution infrastructure?
- How DERs mitigate or exacerbate technical and financial impacts on the electrical grid?
- What end-use loads drive aggregate load curves at the transformer and the feeder levels?

As part of the project, the Team will model transformer and feeder impacts, aggregating variables representing combinations of energy efficiency packages, solar PV sizes and energy storage controls. Building models and plans designed in the previous section were also used to calibrate modeling. Overall outcomes of this effort and steps moving forward to provide monitoring data will be discussed in another 2016 ACEEE paper (Narayanamurthy et al. 2016).

Lessons Learned

The project Team has successfully designed a 20 home ZNE community per California Title 24 standards. Building models and financial analysis show feasibility to scale as designs are practical for the homebuilders and affordable for potential homebuyers. All materials needed to achieve ZNE are currently available on the market and no customized measures were designed for this community. It is assumed that costs of these incremental EE and DER measures will decrease as residential solar and storage cost continue to decrease and other EE measures reach quantities of scale. Overall, standardization of these measures to improve the building envelope implies a cost and/or consumer value proposition over current building practices when completed at quantities of scale. Through the construction of these homes, it was found that additional cost attributed to the EE measures stem less from material and equipment and more from labor cost in changing conventional trade practices.

Construction, marketing and eventual selling of these 20 homes has lead to various lessons learned that target following research questions that are part of this project: (1) understand market drivers and barriers for homeowners and (2) identify trade ally drivers and barriers of groups that will sell and service ZNE communities.

Another set of key learnings was found in the process of educating customers and selling homes. Selling homes still depends on location, pricing and floor plans. In particular, there was a lot of hesitation with regards to battery storage, and the ramifications with regards to safety, warranty, etc. Homeowners see the technology aspects as interesting, as long as they do not interfere with normal home operation and their enjoyment of their new home.

When every home is ZNE, builders will need to sell their homes as they always do – based on location, pricing and features. So, any ZNE community demonstration will need to incorporate these elements of the sales process to customers. In that regards, messaging on energy should be seamlessly integrated in the sales process, and not be the primary message.

Permitting of emerging technologies such as residential energy storage is relatively nascent in nature. The project has shown that depending on the combination of DER and end-use load product providers, collaboration can be difficult as there is no established business relationship and this becomes a barrier to storage installation. The project had to develop a new process with a third party Mechanical, Electrical and Plumbing (MEP) Coordinator to enable producing the drawings required for permitting. There is also a substantial amount of engagement and education of permitting officials required in both the chemical and safety features of batteries as well as the electrical connectivity.

Project Status and Next Steps

The project Team has successfully sold 19 homes, of which 14 homes are currently occupied by residential customers. Customer-sited energy storage systems have been successfully installed in the 9 homes. Data acquisition system commissioning and collection began late February 2016 and plans on being completed by early June 2016. The Team plans on collecting approximately 2 years of occupied home data using Advanced Metering Infrastructure (AMI), submetering and data collected from connected devices via Application Program

Interfaces (APIs) or standard reporting outputs. Data collection will be an important element to understand actual energy consumption of ZNE communities at scale with real homeowners and occupants. Community transformers will also be monitored to investigate impact on the electrical distribution system. The project will also plan on evaluating possible control strategies leveraging the customer-sited connected resources to address electrical distribution constraints caused by higher penetration of DERs such as residential photovoltaic systems.

As a result of attempting to align overall project schedule requirements with the Meritage construction schedule, there were limiting factors in the design and evaluation of developing scalable, California ZNE communities. The Team worked with a community that has already been developed where homes as part of that community were already being sold. As the project schedule could not wait for a new community to be designed from the ground up, space conditioning and water heating loads were electrified post-design of homes. This created commissioning challenges of some of the efficiency measures specified for the home during modeling. For example, pedestal design in the garage for water heating did not account for the HPWH. Electrical distribution systems were already set and could not be redesigned without substantial impact to the builder and the schedule. This created concerns as electrified space conditioning and water heating loads could potentially have adverse effects on this distribution system due to its electric resistive elements. Resistive elements appear to be the primary driver of peak load seen at the distribution transformer. Lot orientations were also set before project commencement meaning that PV sizing was a fixed process and the team had to be very judicious in selecting the right elevations. This also meant that the buyers did not have a choice in the homes that they were buying.

To address these limitations, the project Team is planning on developing additional California ZNE communities leveraging the lessons learned from this ZNE community development. This additional effort plans on developing three additional communities in Lake Forest, Woodland, and Clovis (California CZ8, CZ12 and CZ13 respectively).

Acknowledgements

The authors would also like to thank the California Public Utilities Commission for providing the guidance and funding to complete this project. The Team would also like to thank Smita Gupta and Ann Peterson (ret.) from iTron who served as project managers for this CPUC effort and guided the completion of the overall effort. Meritage Homes, especially CR Herro, Kevin Kimball, Todd Ward, Marcus Morales, Chris Courtney and Johanna Yee has been instrumental in this work and has provided various streams of support throughout the project. The team would also like to thank Ron Kliewer and Jerine Ahmed from Southern California Edison for their utility support. Finally, the authors would also like to thank Sunil Chhaya, Nicholas Tumilowicz, Rachna Handa and all other members of the EPRI project team.

References

Callahan, J., J. Anthony, T. Dillavou, L. Nock, and J. Peterson. 2014. “Faster, Cheaper, Better - Can Utilities Keep Up? New EM&V Approaches For Smart Connected Devices.” In *Proceeding of the ACEEE Summer Study on Energy Efficiency in Industry. Vol 5: 45-56.* Washington, DC: ACEEE.

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

CEC (California Energy Commission Title 24). 2013. *Building Energy Efficiency Standards for Residential and Non-Residential Buildings. http://www.energy.ca.gov/2012publications/CEC-400-2012-004/CEC-400-2012-004-CMF-REV2.pdf*

Davids, B. 2015. "Integrating Residential Energy Efficiency and Demand Response - How Smart Thermostats Change the Game." Presentation at the Rocky Mountain Institute Utility Exchange. http://utilityexchange.org/Resources/rmuee/2015/10b-Davids-Nest.pdf

Fogel, C. 2015. "California's Zero Net Energy Building Goals, How Local Governments Can Get Involved!" Presentation at the 2015 SEEC Conference.

Hammon, R. 2011. "Moving Hot-Dry Builders from Standard to Best Practices: Pulte Homes 30% Energy Efficient Design And Beyond!" US Department of Energy Building America Technology Update Meeting. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ns/eemtg082011_b6_hotdry_builders.pdf

Hammon, R. and N. Taylor. 2014. "ZNE Retrofit Home: M&E of EE, DR, Storage, HEMs and PV." Presentation commissioned by the California Public Utilities Commission CSI RD&D Solicitation 5. http://calsolarresearch.ca.gov/images/stories/documents/Sol5_funded_proj_docs/BIRA5/BIRAenergy5_Hammon.pdf

Hledik, R., J. Chang, R. Leuken. 2016. "The Hidden Battery: Opportunities in Electric Water Heating." Prepared for NRECA, NRDC and PLMA by The Brattle Group.

Narayanamurthy, R., S. Chhaya, N. Tumilowicz, R. Handa, and S. Shah. 2016 (forthcoming). "Grid Integration of Zero Net Energy Communities." In *Proceeding of the ACEEE Summer Study on Energy Efficiency in Industry*. Washington, DC: ACEEE.

Tweed, K.. "SunPower Invests $20M in Tendril to Link Solar with Home Energy Management." *Greentech Media*, December 15, 2014, http://www.greentechmedia.com/articles/read/sunpower-invests-20m-in-tendril-to-link-solar-with-home-energy-management

Wesoff, E.. "SolarCity's System for Self-Supply in Hawaii Includes PV, Storage, Water Heater and Nest Thermostat." *Greentech Media*, February 24, 2016, http://www.greentechmedia.com/articles/read/SolarCitys-System-For-Self-Supply-in-Hawaii-Includes-PV-Storage-Water-He

Wilson, E., C. Enebrecht Metzger, S. Horowitz, and R. Hendron. 2014. “2014 Building America House Simulation Protocols.” Prepared by the National Renewable Energy Laboratory, Golden, CO.