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Executive Summary

Encouraged by regulatory policies (Federal and State regulations along with local building code activities), together with energy efficiency programs directed by utility regulators and voluntary consumer initiatives, Zero Net Energy (ZNE) homes are attracting increasing market interest. This report summarizes the current state of this emerging market, typical design approaches drawn from ZNE case studies, and the competitiveness of mixed-fuel ZNE technology options compared to all-electric designs.

Overall, natural gas has a number of advantages as a fuel for ZNE homes. It enables lower-cost ZNE implementations by allowing smaller photovoltaic (PV) arrays to offset source energy use. It has high consumer preference for space heating, water heating, cooking, and clothes drying applications. Nevertheless, natural gas also has some challenges as a fuel for ZNE homes. Many ZNE home builders are opting for an all-electric approach, and technological advances are making electric heat pumps increasingly competitive with gas for space and water heating applications. Further innovation is required to develop optimal and competitive gas space and water heating solutions as well as continued improvements in cooking and drying performance for this new market segment.

Appendix A includes the following deliverables prepared for this project that are summarized in this report but may be of interest as stand-alone items:

- Original case study source material, grouped into All-Electric and Mixed-Fuel Designs
- A spreadsheet summary of key attributes of the ZNE case studies
- A two-page ZNE Snapshot brief summarizing ZNE market and case study information
- A two-page Builder Perspectives brief containing key comments from the ZNE builder interviews

1 Background

A Zero Net Energy (ZNE) home is an energy-efficient home where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy[1]. In practical terms, this is achieved by designing and building extremely energy-efficient homes, with sufficient area of photovoltaics (PV) applied to offset annual energy use. Encouraged by Federal and State regulations and code activities, together with regulated energy efficiency programs and voluntary initiatives, ZNE homes are attracting increasing market interest. Using the source energy definition, builders can use a variety of fuels to provide residential energy services. This report summarizes the current state of this emerging market, typical design approaches drawn from ZNE case studies, and the competitiveness of mixed-fuel ZNE implementations compared to all-electric designs.

1 Definition from DOE (U.S. Department of Energy), 2015, "A Common Definition for Zero Energy Buildings," Report No. DOE/EE-1247. http://energy.gov/eere/buildings/downloads/common-definition-zero-energy-buildings

2 National ZNE Snapshot

2.1 ZNE Market Status

A Zero Net Energy Coalition survey found there were 6177 housing units on the path to zero-net energy in 2015[2]. This figure included both zero-energy-ready units (highly efficient buildings without PV installed) and units with PV installed, for projects already built, under construction, and in design. Another 3000 units were planned but not yet in design at the time of the survey. Approximately 50% of these units are single-family homes. The geographical distribution of US units already built or in construction with known locations is shown in Figure 1, with nearly 70% in the Pacific states and 20% in the Northeast.

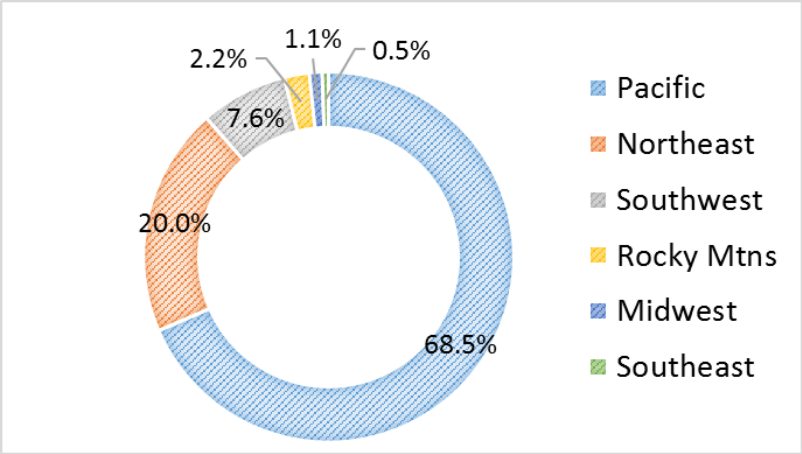

Figure 1: Distribution of ZNE Homes by Region

2.2 ZNE Case Studies

Figure 2: ZNE Case Study Home Locations

2 Source: Edminster, A., 2016, "Zero Energy Homes – Built Projects & Programs Chart the Road to Adoption," ACEEE 2016 Summer Study on Energy Efficiency in Buildings. http://aceee.org/files/proceedings/2016/data/papers/10_1128.pdf

GTI completed a review of 36 case studies of single-family homes across the U.S. built to achieve ZNE goals. One-third of these were in IECC Climate Zones 3C and 4C (Marine, Dry and Cold) and one-quarter were in IECC 5A and 6A (Humid, Cold) climate zones, as shown in Figure 2. About 20% of the case studies were in mixed humid climates (IECC 3A and 4A).

Nineteen of the 36 case studies featured all-electric designs, with the remainder using at least one additional fuel, usually natural gas. Common features by region are shown in Table 1. ZNE designs in the Pacific Northwest heavily favor all-electric designs – a sentiment confirmed by builder interviews. In contrast, the Northeast and the Great Lakes region of the Midwest with higher heating loads more often employed multi-fuel designs. The two all-electric designs in the Northeast were both had heat pumps, solar water heaters, and PV systems larger than 5 kW. A dozen of the surveyed homes had an electric charger in the garage for vehicle charging or were pre-wired for one. There was not a regional trend to the inclusion of this feature, but it may represent an increasingly common addition as the electric car market grows.

Of the 17 mixed fuel homes, 11 included tankless gas water heaters, which were the most common gas appliance. One home employed a condensing storage water heater in conjunction with a solar hot water heater. For space heating, only four homes had gas furnaces, and one of those was part of a dual-fuel heat pump system with an electric heat pump. Three homes featured boilers for space heating and water heating, with two of these working in conjunction with electric heat pumps.

Table 1: Typical ZNE Measures by Region

Region	Pacific	Northeast/Midwest	Southeast
Climate	Marine	Continental Cold	Mixed Humid
States	CA, OR, WA	CT, RI, NE, MN, IL, MA, NJ	GA, AL, FL, SC, VA
Walls	-Advanced wall systems common, including structurally insulated panels (SIPs)	-Advanced wood framing common, including double stud walls -Most with either spray foam cavity insulation or exterior rigid foam sheathing	-2x6 advanced wood framing common -Varied cavity insulation types -Some with exterior rigid foam sheathing
Roof/Attic	-Unvented; vaulted ceilings or unvented semi-conditioned attics with insulation at roof deck, SIPs	-Vented attic design with > R60 blown-in cellulose	-About half with traditional vented attics -About half with spray foam applied under roof deck
Water Heating	-> 50% with some type of electric heat pump -One-quarter with gas tankless units	-50% with heat pump water heaters -25% with other fuels (gas, propane, and solar)	-Eclectic mix of gas tankless, electric heat pump water heaters, solar, electric storage systems
Space Heating/ Cooling	->60% with electric ductless mini-split or air to water heat pump -50% with a heat recovery ventilator (HRV)	-> 60% with electric heat pumps -25% with gas furnace and electric AC	-50% with air source heat pumps -25% with electric ductless mini-split heat pumps
Renewable Energy	-75% with 6-10 kW PV systems	-Generally no system in place, most "solar ready"	-Mostly none

3 Builder Perspectives

3.1 GTI ZNE Builder Interviews

As we see from the ZNE case studies, builder design approaches vary considerably by region. GTI spoke to three ZNE builders operating in in four states to gain more insight into about their design considerations, customer preferences, and perspectives on the future of ZNE homes in their regions.

Clifton Homes and TC Legend Homes are father and son-owned companies operating in Washington state. They also offer their Positive NRG™ home plans for sale through an additional company, Zero-Energy Plans LLC, which has designed about 60 homes across nearly every U.S. climate zone. Both companies employ Structural Insulated Panel (SIP) envelope construction and take a strong stance that all home energy needs can be met with properly selected electric appliances and a photovoltaic (PV) system.

"The right way to heat a house (or to heat hot water) is with a heat pump. We have heat pump technology that works quite well down to -15F, and we can supply all the energy we need to an electric heat pump with energy from the sun. Because of this, with few exceptions our homes are 100% electric homes, and we are not interested in compromise. We have no shortage of customers who see this exactly the same way we do." – Ted L. Clifton, Clifton View Homes, Inc.

Mandalay Homes builds production homes currently based on a set of 17 master plans with a wide variety of customization options. Mandalay Homes has built hundreds of homes in Arizona, predominately in Prescott Valley and surrounding areas, as well as in Phoenix and Glendale. They typically build 120-130 homes annually. They also have a custom home division that is typically working on three to four homes at any given time. Mandalay markets all homes as achieving 50 HERS or less, as well as meeting ENERGY STAR, Indoor Air PLUS, EPA WaterSense, and DOE Zero Energy Ready program requirements. Currently nearly every Mandalay home uses electricity and natural gas, with most homes employing a gas-fired tankless water heater and gas cooktops. While Mandalay is a green builder, they noted that their buyers are more concerned with location and other building attributes than energy performance. Visible items, like the cooking range or dryer tend to attract more buyer attention more than furnaces and water heaters.

"From an Indoor Air PLUS standard perspective, we would be interested in using induction cooktops in the homes, but a lot of buyers are used to gas and want gas." – Geoff Ferrell, Mandalay Homes

Long term, Geoff Ferrell of Mandalay observes that codes are catching up to where they're currently building, and that the 2018 IECC will be a huge hurdle to builders that aren't already considering energy efficiency. As envelopes are mandated to be tighter, he believes builders will need to consider active ventilation systems, make-up air, and right-sizing HVAC equipment.

BPC Green Builders builds exclusively net-zero-energy homes in Fairfield County, Connecticut and Westchester County, New York. They partner with local HERS raters for independent confirmation of their homes performance, as well as connection to local utility ENERGY STAR home rebates and incentives. All their past homes have been ENERGY STAR certified and many LEED-certified, some as high as Platinum. Two of their homes are passive house certified, and one home won the 2015 DOE Zero Energy Challenge, a national

competition. BPC Green Builders buyer's main priorities are comfort, performance, and value. They are typically looking for no or low fossil fuel usage, but are often guided by builder recommendations.

Historically, all of the homes built by BPC Green Builders have been mixed fuel, but currently, about 30% are all-electric, depending on the client's needs and preferences. The principle driver for including gas is the availability of efficient low-operating-cost heating options, which mitigate for possible electricity cost increases. However, they note that gas systems come with increased complexity. The principle driver for all-electric designs are the low upfront cost and simple operation, particularly attractive where rooftop PV is deployed. Long term, Chris Trolle of BPC Green Builders believes that all-electric homes will become more attractive:

"I think as thermal envelopes become better due to improved building codes, [the] lowest cost option will rule, which I've shown on my Taft home […] is all electric. All electric heat pump heating/cooling and DHW with COPs between 2-4.0 and rooftop mounted PV selling power produced on-site back to the grid." – Chris Trolle, BPC Green Builders

3.2 Pulte Homes ZNE Demonstration

Large national production builders are not heavily engaged in ZNE home building yet, but **Pulte Group** has recently built a ZNE demonstration home in the San Francisco Bay Area in partnership with PG&E. According to Ryan Marshall, president of Pulte Group:

The Pulte ZNE prototype will help guide and create best practices for the Company in building more energy efficient new homes in California and, ultimately, across the nation… Our goal for this prototype is to help define the most efficient path to building zero net energy homes that effectively balance constructability, cost and quality.[3]

The planned features include a tighter building envelope, sealed attic with insulation at the roof deck, continuous exhaust ventilation with makeup air, a Seer 19 multi-speed heat pump, tankless water heater with demand recirculation, integrated PV, LED lighting, home energy management system, EnergyStar appliances, induction cooktop and gas drier.[4]

3 Source: Pulte Group press release, March 15, 2016
http://newsroom.pultegroup.com/presskit_display.cfm?presskit_id=10006
4 Source: Pulte Group website, accessed 3/20/2017
http://newsroom.pultegroup.com/news/pultezeronetenergy/pulte-zne-home-prototype-features.htm

4 Advantages of Mixed-Fuel ZNEs

4.1 Consumer Preference for Gas Appliances

The Energy Solutions Center Report, "New Homeowner Energy Preference Survey Closings March 2015 through February 2016," reveals that consumers prefer gas appliances to electric for residential space heating, water heating, cooking and clothes drying, as shown in Figure 3. Consumers that have gas like it, and those that don't have it wish they did, and this preference increased from 2011 to 2016. This implies that ZNE implementations incorporating gas appliances may be more readily accepted for many prospective buyers.

Despite the national preference for gas appliances, significant regional variations exist, and gas appliance market shares in 2016 were lower than 2011, in line with AGA market shares. As might be expected, the preference for gas space heating is strongest in heating-dominated climates, and weaker in cooling-dominated climates, as seen in Figures 4-7.

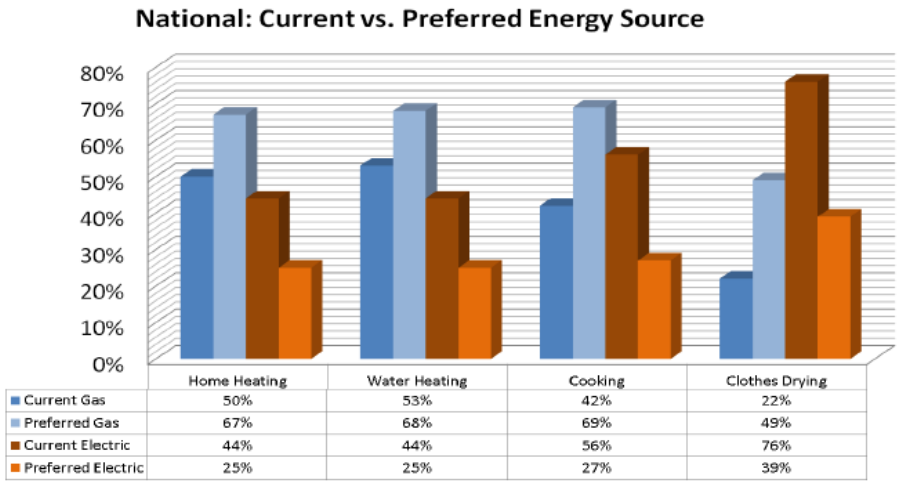

Figure 3: National Current vs. Preferred Energy Source

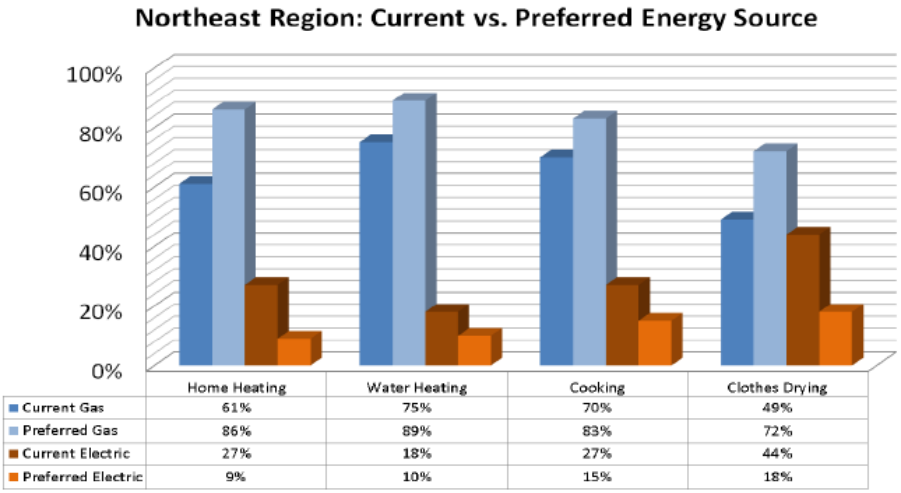

Figure 4: Northeast Region Current vs. Preferred Energy Source

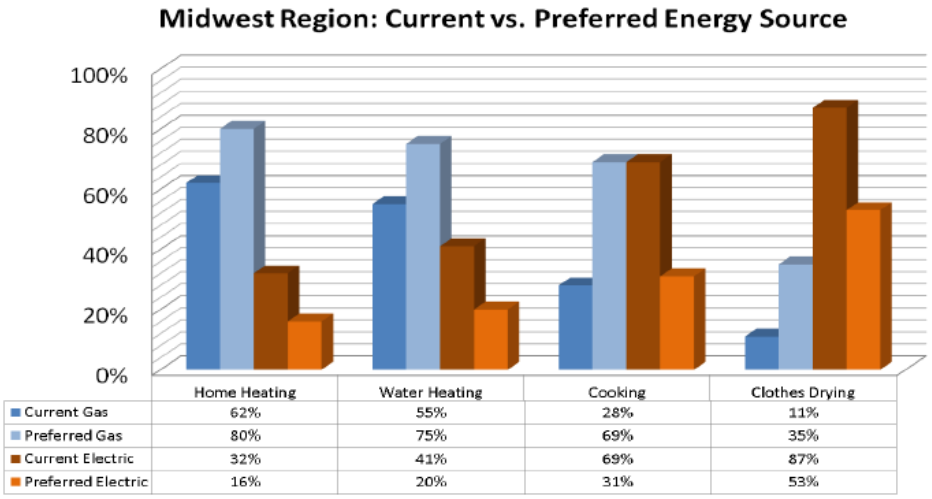

Figure 5: Midwest Region Current vs. Preferred Energy Source

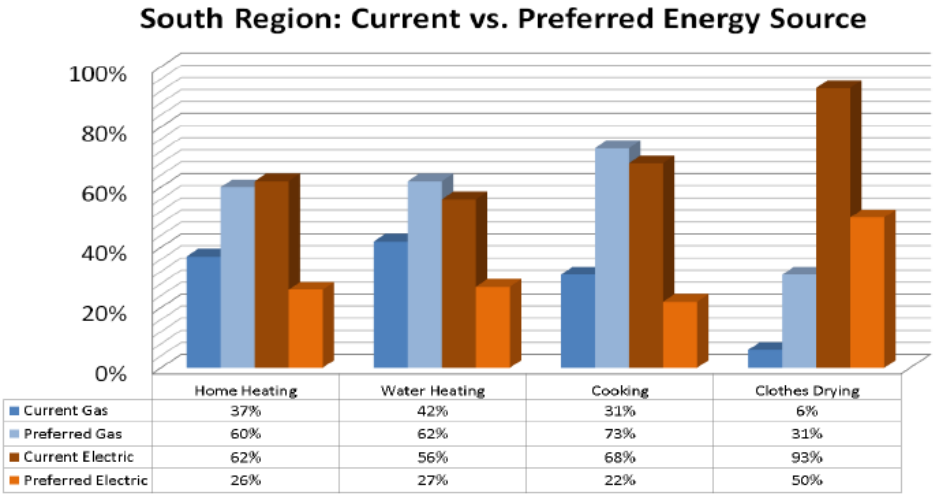

Figure 6: South Region vs. Preferred Energy Source

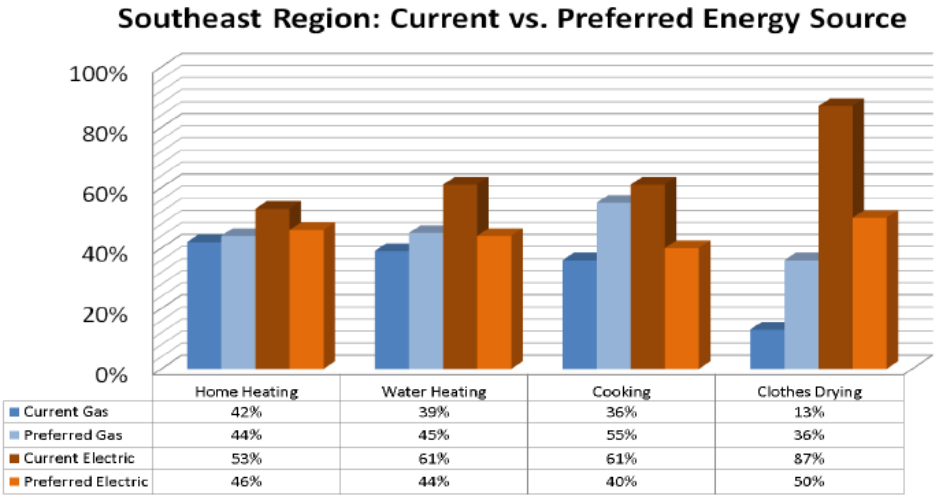

Figure 7: Southeast Region: Current vs Preferred Energy Source

4.2 Mixed-Fuel vs All-Electric PV Sizing to Achieve Zero Net Energy

A 2015 ASHRAE paper[5] found that mixed-fuel ZNE designs require smaller Photovoltaic (PV) arrays to achieve net-zero source energy use on an annualized basis. The study evaluated one- and two-story house designs in four California climate zones (mild, hot, very hot, and cold), comparing all-electric and mixed-fuel designs. As shown in Figure 8, using California's Time Dependent Valuation (TDV) metric, all-electric houses required PV systems that were 8% larger than the mixed fuel houses on average, and mixed-fuel home designs required smaller PV arrays in every case.

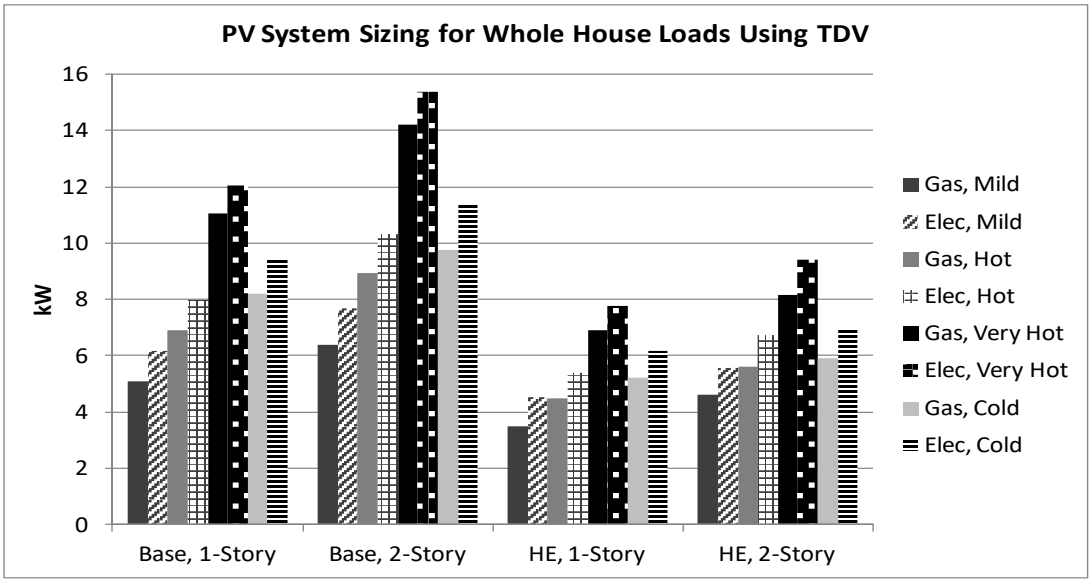

Figure 8: Required PV Size for Mixed-Fuel vs All-Electric California ZNE Homes

A 2015 Navigant technical analysis of the California market[6] evaluated mixed-fuel and electric-only ZNE homes against a baseline electric only home compliant with Title 24-2016. Key conclusions related to mixed-fuel ZNE homes were as follows:

- *Compared to baseline electric-only home, mixed-fuel ZNE homes require smaller PV systems, carry lower incremental cost, and offer higher TRC values than electric-only designs. On average, mixed-fuel ZNE incremental costs were 9%, or $2,200, less than all electric ZNE packages. Reducing PV size helps drive incremental costs down.*
- *These benefits support homeowner preferences for improved roof aesthetics, lower ownership costs, and incorporating gas cooking equipment, heating systems, and other end-uses (e.g., fireplaces).*

5 Source: Brand, L., Brook, M., and Leslie, N., 2015, "The Path to Achieving Zero Net Energy Homes – Energy Choices, Consumer Costs, and the Environment", ASHRAE Transactions, 121.
6 Source: Navigant Consulting, Inc., 2015, "Strategy and Impact Evaluation of Zero-Net-Energy Regulations on Gas-Fired Appliances," submitted by SoCal Gas as public comment to California Energy Commission Draft AB 1257 Natural Gas Report
http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-04/TN206350-2_20151014T112610_Appendix_B_B4_to_SoCal_Gas_Comments_to_AB_1257_Draft_Report.pdf

5 Conclusions and Recommendations

In summary, natural gas has a number of advantages as a fuel for Zero Net Energy homes. Overall, it enables lower-cost ZNE implementations which need smaller PV arrays to offset their source energy use. It has high consumer acceptance for space heating, water heating, cooking, and clothes drying applications. Overall, efficient tankless gas heaters were the most popular water-heating technology in the ZNE case study homes surveyed for this report, even in some cases where builders opted for electric heat pumps, induction cooktops, and condensing dryers.

However, natural gas also has some challenges as a fuel for Zero Net Energy homes. Efficient and affordable natural gas furnaces right-sized for very small loads are not commercially available, and unsurprisingly we don't see many ZNEs with furnaces represented in the case studies summarized for this report. Electric heat pumps and heat pump water heaters are competitive with gas from a source energy perspective, and many ZNE builders are opting for an all-electric approach. Gas heat pumps are an emerging technology, but need further development and market penetration to be a viable alternative. As such, these emerging technologies are excellent candidates for utility research and incentives support.

Appendix A Supplemental Information

ZNE Case Study source files have been provided as a separate deliverable in addition to this Final Report. Table X provides a summary listing of the case study homes.

Table 2: ZNE Case Study Listing

ID	Source	City	State	Builder
1	Southern California Gas	Lancaster	California	KB Home
2	U.S. Department of Energy	Vadnais Heights	Minnesota	Amaris Homes
3	U.S. Department of Energy	Derby	Connecticut	Brookside Development LLC
4	U.S. Department of Energy	New Fairfield	Connecticut	BPC Green Builders
5	U.S. Department of Energy	Watertown	Connecticut	BPC Green Builders
6	U.S. Department of Energy	Omaha	Nebraska	Charles Thomas Homes
7	U.S. Department of Energy	Danbury	Connecticut	BPC Green Builders
8	U.S. Department of Energy	Charlestown	Rhode Island	Caldwell and Johnson
9	U.S. Department of Energy	Houston	Texas	M Street Homes
10	U.S. Department of Energy	Prescott Valley	Arizona	Mandalay Homes
11	U.S. Department of Energy	San Jose	California	One Sky Homes
12	U.S. Department of Energy	Double Oak	Texas	Sterling Brook Custom Homes
13	U.S. Department of Energy	River Forest	Illinois	Evolutionary Home Builders
14	U.S. Department of Energy	North Plains	Oregon	Hammer and Hand
15	U.S. Department of Energy	Santa Fe	New Mexico	Palo Duro Homes
16	Massachusetts Department of Energy Resources	Townsend	Massachusetts	Transformations, Inc.
17	U.S. Department of Energy	Edgewater	Florida	Southeast Volusia Co. Habitat for Humanity
18	U.S. Department of Energy	Serenbe	Georgia	Imery Group
19	U.S. Department of Energy	Clinton	Washington	Clifton View Homes
20	U.S. Department of Energy	Bellingham	Washington	TC Legend Homes
21	U.S. Department of Energy	Coupeville	Washington	Clifton View Homes
22	U.S. Department of Energy	Greenbank	Washington	Clifton View Homes
23	U.S. Department of Energy	Port Hadlock	Washington	Clifton View Homes
24	U.S. Department of Energy	Coupeville	Washington	Clifton View Homes
25	U.S. Department of Energy	Seattle	Washington	Dwell Development LLC
26	U.S. Department of Energy	Seattle	Washington	Dwell Development LLC
27	U.S. Department of Energy	Bellingham	Washington	TC Legend Homes
28	U.S. Department of Energy	Seattle	Washington	TC Legend Homes

29	U.S. Department of Energy	Seattle	Washington	TC Legend Homes
30	U.S. Department of Energy	Phoenix	Arizona	Mandalay Homes
31	U.S. Department of Energy	Glendale	Arizona	Mandalay Homes
32	U.S. Department of Energy	Charlottesville	Virginia	Promethean Homes LLC
33	U.S. Department of Energy	Atlanta	Georgia	Heirloom Design Build
34	U.S. Department of Energy	Simpsonville	South Carolina	Addison Homes
35	U.S. Department of Energy	North Cape May	New Jersey	John Hubert Associates
36	U.S. Department of Energy	Russellville	Alabama	Southern Energy Homes, Inc.

A **ZNE Case Studies Summary** has also been provided as a companion deliverable. This is an Excel spreadsheet with several tabs. The "General Info" tab gives demographic information on the case study homes including the builder, location, and HERS (Home Energy Rating System) value. The "Case Study – Feature Breakdown" tab includes details on the energy-related features of each home such as the square footage, climate zone, envelope construction, HVAC systems, hot water systems, and other details from the case studies.

Two topic briefs prepared for this project which are summarized in this report but may be of interest as stand-alone items are included below:

- **ZNE Snapshot** summarizing ZNE market and case study information
- **Builder Perspectives** brief containing key comments from the ZNE builder interviews