ZNE Simulation Study – California Homes with Mixed Fuel vs. Electric Only Appliances

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ABSTRACT

California's Zero-Net-Energy (ZNE) building goals, action plans, and associated current and future standards will have a profound impact on the residential building industry over the next several decades. To assist technical discussion of ZNE building codes in California, Navigant conducted an extensive building simulation study to investigate the value of ZNE homes using natural gas appliances compared to homes using only electric appliances under the time-dependent-valuation (TDV) definition. The study analyzed the technical and economic impacts of available energy efficiency and renewable energy technologies for several home sizes, locations, and configurations in California. The analysis revealed that both mixed-fuel and electric-only home designs share many common characteristics to reaching ZNE goals with similar cost and performance relative to baseline electric-only homes. ZNE homes incorporating efficiency and solar PV technologies can greatly reduce annual utility costs, and require modest annual incremental payments when included in the home's mortgage. Nevertheless, mixed-fuel ZNE homes have several advantages over electric-only ZNE designs in most location/home size combinations, such as smaller PV system size and lower incremental cost. The results can help clarify any misconceptions about the role of natural gas under ZNE building codes and providing guidance for future research, development, demonstration, and policy-making activities.

Introduction

California has a long history of advanced energy efficiency initiatives, including: ambitious goal-setting, utility research and development (R&D), emerging technology testing and demonstration projects, energy efficiency rebate and incentive programs, continued advancements in building codes, air quality standards, and other regulatory policies. California's residential and commercial building standards ("Title 24"), typically lead the country in adoption of advanced features and practices designed to reduce energy consumption in buildings. To meet future greenhouse gas emissions targets, the California Public Utility Commission (CPUC) has set a goal for all residential and commercial new construction to qualify as zero-net-energy (ZNE) (CEC 2013).

Although different definitions exist (e.g., site energy, source energy, energy cost, CO_2 emissions), ZNE buildings in California must balance their net annual energy consumption with on-site renewable energy production on a time-dependent-valuation (TDV) basis. The TDV definition values energy consumption and efficiency savings differently depending on which hours of the year they occur, to better reflect the actual costs of energy to consumers, to the utility system, and to society (E3 2011). Because of the hourly weightings throughout the day, month, and season, the TDV definition encourages building designers to prioritize building performance during periods of high energy cost, i.e., peak summer hours for electricity, and winter hours for natural gas. The California ZNE definition is consistent with recent Zero Energy

Buildings (ZEB) definition as both consider source energy (Petersen et al. 2015), but the California TDV metric includes additional factors for the relative impacts to the local utilities and society.

Under these guidelines, all new residential construction in California must meet zero-net-energy targets by 2020. To meet these targets, ZNE homes will need to combine *energy efficient building technologies* and *on-site renewable generation systems* in ways that are economically attractive while also satisfying homeowner expectations for comfort, aesthetics, and other factors (CEC 2013).[1] When designing new ZNE homes, builders must address customer preferences and ZNE performance while also meeting the budget of the prospective homeowner, as the market is competitive and the incremental prices need to be affordable.

The choice of fuels for major appliances has a substantial impact on the home's operations and utility bills. Two major classifications for home fuel choice in Southern California are *electric-only* and *mixed-fuel*. Electric-only homes rely on electricity for all end-uses, while mixed-fuel homes use natural gas for cooking, laundry, space heating, water heating, and other secondary end-uses such as fireplaces, decorative lighting, pool and spa heating.[2] Because ZNE homes typically use solar photovoltaic (PV) systems to generate the necessary renewable energy to balance the consumption of other equipment in the home, homebuilders may hold misconceptions about ZNE building requirement. For example, they may believe that ZNE homes must only use electricity, or electric-only homes always offer lower incremental costs than homes with natural gas appliances.

Building Simulation Study Methodology

Mixed-fuel home designs require separate consideration to address stakeholder misconceptions, develop cost-effective gas-fired technologies, and evaluate the impacts of certain policy decisions, such as net metering regulations, TDV energy coefficients, and other topics. On behalf of SoCalGas, Navigant conducted a building simulation study and supporting analysis to assist in technical discussions of ZNE building codes in California. By investigating the value of mixed-fuel ZNE homes compared to electric-only ZNE homes, the study can provide guidance for future research, development, and demonstration (RD&D) activities in partnership with the CEC's Natural Gas R&D program and other research organizations. Our analysis answered the five key questions outlined in Figure 1.

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[1] ZNE status may be reached either through reduction in TDV energy consumption or on-site TDV energy production. Combination of these two elements provides the basis for the subsequent analysis.

[2] On a TDV basis, natural gas appliances account for roughly 33% of a home's TDV energy consumption. This value will vary based on home size, location, and whether there are any exogenous loads such as EV chargers, pool heaters, etc.

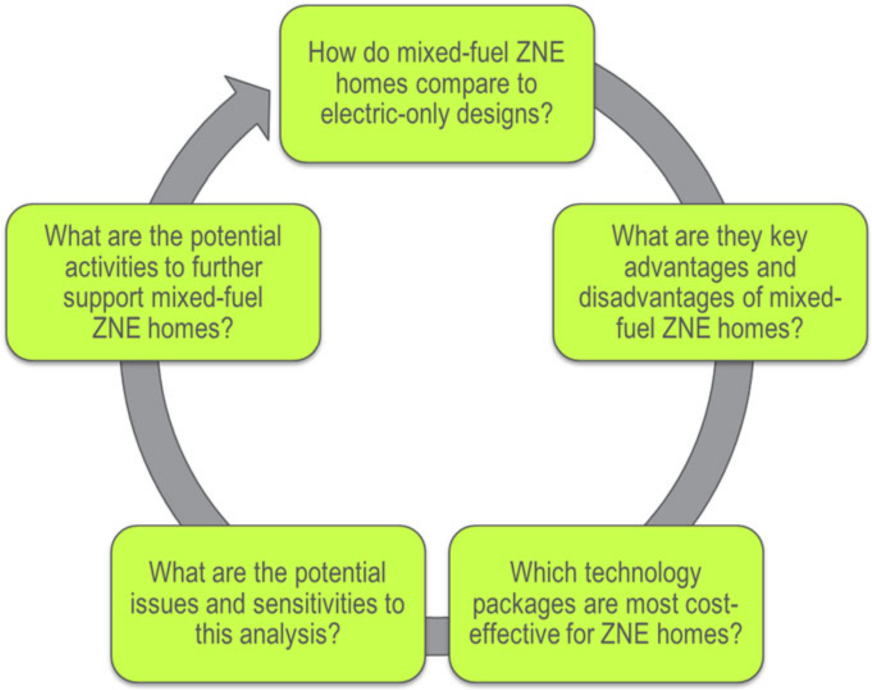

Figure 1. Key Questions for Mixed-Fuel ZNE Home Analysis in Phase I

The study investigated optimum approaches for mixed-fuel and electric-only homes to reach ZNE goals using building energy simulation software. We developed baseline home designs compliant with future Title 24 building codes[3] and conducted an extensive sensitivity study to identify the most cost-effective ZNE home features when optimized for TDV energy savings. [4] We used the simulation software BEopt[5] to optimize mixed-fuel and electric-only ZNE homes on a TDV basis for various inputs including building location, building size, building orientation, available technology options, and applicable building loads. We then analyzed the technical and economic results under different scenarios and perspectives and evaluated advanced technologies under current and future costs.

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[3] We simulated three baseline home designs (1,800 sq.ft., 2,500 sq.ft., 3,200 sq.ft.) for five major California climate zones in SoCalGas territory (Climate Zones [CZs] 6, 9, 10, 13, 15). We designed baseline homes to comply with proposed Title 24 building codes and federal appliance standards (CEC 2008, 2012a, 2012b, 2014) (CPUC 2014) (Wilson et al. 2014).

[4] For each home design and location, we conducted several optimization simulations for both mixed-fuel (i.e., electricity and natural gas appliances) and electric-only fuel configurations. We also analyzed the impacts of "exogenous" loads not included under Title 24 such as pool heating, pool pumps, and in-home vehicle refueling/charging systems. Our technology evaluation included both conventional efficiency measures such as improved insulation, advanced windows, tankless water heaters, etc. as well as advanced technologies such as: solar PV systems, solar thermal systems, mCHP systems, gas heat pumps, energy storage, and others.

[5] The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) developed BEopt with the purpose of analyzing ZNE home designs (Christensen et al. 2006, 2014). The tool performs an hourly simulation for each building end-use (e.g., lighting, water heating, etc.) and fuel type (e.g., electricity, natural gas, solar PV) using each combination of building features the user selects. The software evaluates the cost-benefit of conserved energy and the cost-benefit of on-site produced energy on a TDV basis during the selection process ($/TDV offset). For example, the software would optimize the selection of high-efficiency heating system relative to improved wall insulation, additional solar PV capacity, and other options. Out of the thousands of building feature combinations, BEopt quickly provides a package of technologies that provides the lowest life-cycle costs to achieve ZNE goals.

Key Findings and Results

California's ZNE building standards will have a profound impact on the residential building industry over the next several decades. Through this study, we determined that mixed-fuel and electric-only homes can each reach ZNE goals under a TDV definition using current energy efficiency and renewable energy technologies. Both mixed-fuel and electric-only home designs share a common characteristics to reaching ZNE goals with similar cost and performance relative to baseline electric-only homes. Regardless of fuel choice, each ZNE home implements certain building envelope, HVAC and water heating efficiency measures first, before adding moderately sized solar PV systems. These ZNE technologies greatly reduce annual utility costs, and require modest annual incremental payments when included in the home's mortgage. Nevertheless, mixed-fuel ZNE homes have several advantages over electric-only ZNE designs in most location/home size combinations, including: smaller PV system size, lower incremental cost, and higher Total Resource Cost (TRC) values (AEC 2011) (E3 2012). These results suggest stakeholders should conduct outreach efforts to the residential building community to clarify any current misconceptions and communicate the value and benefits of ZNE homes using natural gas appliances.

1. How do mixed-fuel ZNE homes compare to electric-only designs?

Based on our analysis, mixed-fuel ZNE homes present an attractive value proposition to residential builders, potential homebuyers, regulators, and other stakeholders. Our analysis revealed that mixed-fuel and electric-only ZNE homes share several key technical and economic characteristics, including:

- **TDV Energy Consumption:** Mixed-fuel ZNE homes almost always have 5-15% lower TDV energy consumption than electric-only designs. TDV values for electricity change significantly throughout the day and especially during the peak cooling season, whereas TDV values for natural gas have only moderate seasonal changes.
- **Selection of Advanced Technologies**: ZNE homes combine solar PV systems with energy efficient appliances to offset the home's annual TDV energy consumption. Solar PV systems provide the majority of TDV energy savings for both mixed-fuel and electric-only ZNE homes (91%) while efficiency measures for building envelope, HVAC, water heating, and pool heating provide the remainder.
- **Required Solar PV System Sizes and Roof Areas**: Under optimal siting conditions, solar PV sizes range from 3.5-4.3 kW for mixed-fuel and 3.8-5.0 for electric-only ZNE homes. The back roof of each home can accommodate the solar PV system as long as 50% of the roof space is available for optimal South-facing orientations, and 75% in worst-case North-facing orientations. Smaller solar PV system and roof area requirements allow for greater architectural design flexibility, especially for non-ideal situations where roof orientation and shading decreases the solar PV system's output.
- **Upfront Incremental Costs to Reach ZNE Goals**: Incremental costs for the solar PV system and energy efficient appliances range from $20,500-$24,600 for mixed-fuel and $21,800-$28,000 for electric-only ZNE homes.
- **Optimized Utility Costs**: Mixed-fuel homes have monthly utility costs of $25 or less, and annual savings of $875-$1,950. Electric-only homes have monthly utility costs of $20 or less and annual savings of $950-$2,000. Utility costs for ZNE homes does not go

to zero due to monthly connection charges, limits to surplus solar PV production, and imperfect correlation between hourly TDV values and utility rates.

- **Homeowner Mortgage Costs**: When financed (4.12%, 30 years), the annual incremental mortgage costs range from $1,200 to $1,425 for mixed-fuel and $1,250 to $1,900 for electric-only ZNE homes. Combined with annual utility savings, the annual net cost to homeowners who finance the ZNE technology costs will be relatively manageable.
- **GHG Emissions Savings:** ZNE homes support personal, statewide, and national environmental goals by reducing the associated GHG emissions of new homes by 55-75% for mixed-fuel and 78-87% for electric-only designs, relative to a baseline electric-only home.
- **Life-Cycle Benefit-Cost Analysis:** ZNE homes in all locations have life-cycle incremental costs for the solar PV system and energy efficient appliances that exceed life-cycle benefits, assuming no residual value. The net life-cycle costs outweigh benefits by $23,394-$27,824 for mixed-fuel and $25,760-$32,256 for electric-only ZNE homes. The majority of this cost is caused by periodic appliance replacement over the 30 year life-cycle analysis, such as the solar PV system replacement after 25 years.

These findings suggest that mixed-fuel homes can technically achieve ZNE goals at least as well as electric-only homes, and have more attractive economics in most characteristics. Results are generally consistent across home sizes relevant for single-family new construction, i.e., 1,800-3,200 sq.ft.

2. What are they key advantages and disadvantages of mixed-fuel ZNE homes compared to electric-only ZNE homes?

Our analysis also revealed areas where mixed-fuel homes have distinct advantages over electric-only ZNE homes when compared to a baseline electric-only home. As outlined in Figure 2, mixed-fuel homes have advantages in solar PV system size, incremental cost, simple payback, and TRC values compared to electric-only homes.

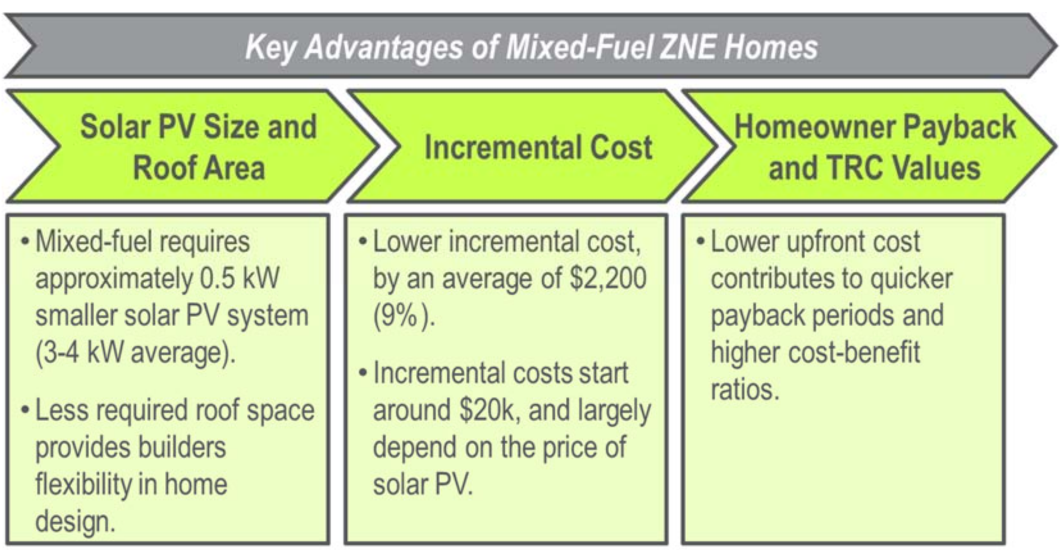

Figure 2. Key Advantages of Mixed-Fuel ZNE Homes Compared to Electric-Only Designs

Mixed-fuel homes typically offer an average 9% reduction ($2,200) in incremental cost compared to electric-only ZNE homes, based on the smaller required solar PV system size (reduction of 0.5 kW). On a utility programmatic perspective, mixed-fuel ZNE homes shows higher TRC values than electric-only ZNE homes when compared to baseline electric-only home for each location. On an incremental life-cycle cost basis, TRCs range from 0.42-0.46 for mixed-fuel and 0.33-0.38 for electric-only. When evaluated on an upfront incremental cost basis, TRCs range from 0.86-0.96 for mixed-fuel and 0.57-0.74 for electric-only ZNE homes.

These results suggest that stakeholders should promote the use of natural gas appliances for ZNE homes among builders and advocate their inclusion and consideration during regulatory and policy proceedings. Beyond technical and economic advantages, several past research studies suggest the market for new homes overwhelmingly prefers natural gas appliances, further increasing the attractiveness for mixed-fuel ZNE homes (SoCalGas 2015) (Pande et al. 2015). Highlighting the key advantages in promotional materials will help SoCalGas and other stakeholders communicate value and cost-effectiveness of mixed-fuel ZNE homes to the residential building community.

3. Which technology packages are most cost-effective for ZNE homes, both now and in the future?

Every ZNE home will use a combination of efficiency measures and on-site renewable energy to offset its energy consumption on a TDV basis. The selection of an optimized technology mix depends on each measure's cost-effectiveness ($/TDV offset) relative to other options. As outlined in Figure 3, our analysis revealed which technologies are cost-effective today relative to incrementally larger solar PV systems or other options, as well as which technologies might be cost effective with future performance/cost developments.

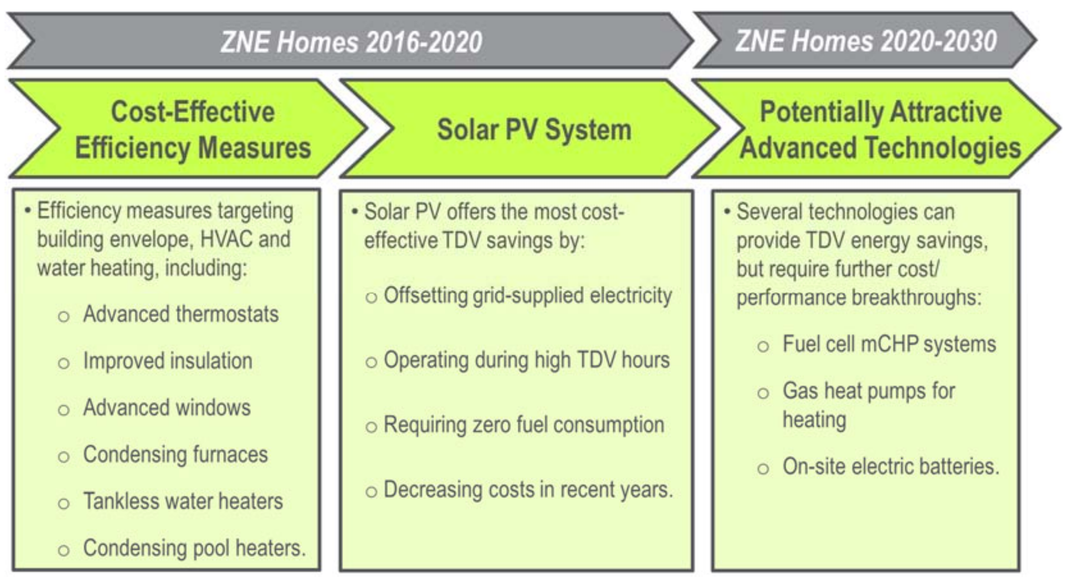

Figure 3. Progression of Cost-Effective Technologies for ZNE Homes

While stringent Title 24 (California Building Energy Standards), Title 20 (California Appliance Efficiency Standards), and federal appliance standards limit the cost effectiveness of savings that can be achieve by non-PV technologies like higher efficiency appliances and HVAC systems, several efficiency measures relating to HVAC loads and water heating can provide cost-effective TDV savings. Technologies such as improved insulation, and advanced windows reduce thermal loads, while advanced thermostats and condensing furnaces reduce the energy required to satisfy the home's heating and/or cooling loads. Tankless water heaters and condensing pool heaters showed cost-effective savings for mixed-fuel ZNE homes, while Title 24-compliant HPWHs and pool heaters created an already efficient baseline for most electric-only ZNE homes. Other efficiency measures can still provide cost savings, but are less cost effective on a $/TDV basis than solar PV systems for the life of the home.

As shown in Figure 4, the ZNE home of the future will incorporate a wide range of energy efficiency, production, storage, and management technologies. While our analysis revealed that several common efficiency measures and solar PV systems typically provide the most cost-effective pathway to achieve TDV energy savings, ZNE homes can also benefit from other advanced electrical and natural gas technologies. Technologies such as on-site micro-combined-heat-and-power (mCHP) that cover a portion of the home's electricity and thermal energy consumption can create net positive TDV benefits when the TDV value of their energy outputs exceeds their energy inputs. Electric battery systems and demand response technologies can also provide positive net TDV benefits by shifting electric consumption from higher TDV periods to lower TDV periods. Other technologies such as gas heat pumps reduce TDV consumption through higher efficiency. These advanced technologies can provide TDV benefits for ZNE homes today, but carry too high an incremental cost over other technologies currently. Projected cost reductions and performance advances over the next decade may significantly improve the economic attractiveness of these technologies. Small capacity fuel cell mCHP systems, gas-fired heat pumps, and customer-sited electric batteries could become complementary features to solar PV systems in ZNE homes. Nevertheless, experts project that solar PV costs will continue their steady declines, which will continue to present a challenge to the cost-effectiveness of these advanced technologies.

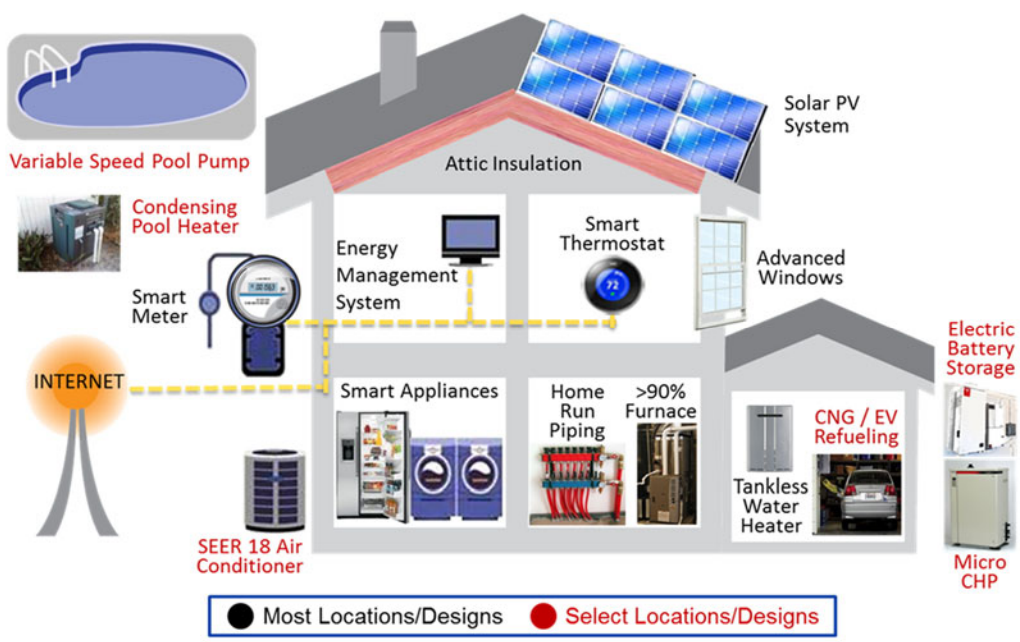

Figure 4. Building Technologies in Future Mixed-Fuel ZNE Homes

4. What are the potential issues and sensitivities to this analysis that stakeholders should monitor in the future?

The findings of this study suggest that mixed-fuel ZNE homes can offer a cost-effective pathway to energy code compliance and provide significant benefits to California homebuilders, homebuyers, and other stakeholders. These results are based on several key assumptions for ZNE building codes, utility rates, and technology costs, both today and over the next 15 years. If future circumstances or trends substantially differ from these assumptions, the economic attractiveness and key advantages of mixed-fuel ZNE homes could also change. We recommend stakeholders monitor the following issues, and consider the impacts of any substantial changes on builders, homeowners, and regulatory activities:

- **Electric and Gas Infrastructure within ZNE Homes and Communities**: The analysis in this report compares appliance costs and other efficiency measures, but does not take into account differences in infrastructure costs to deliver electricity or natural gas. Incorporating these costs into the analysis may change the advantages and/or disadvantages for mixed-fuel ZNE homes compared to electric-only designs.
- **Insufficient Roof Availability at ZNE Homes**: The analysis suggests that the solar PV systems to reach ZNE goals can fit within the 50-75% of the available space on back roofs. If homebuilders incorporate window gables or other features which constrain the available roof space, then additional efficiency measures or alternative solar PV strategies would be needed to achieve ZNE goals.
- **Relative Cost of Mixed-Fuel and Electric-Only Technologies**: The analysis compared mixed-fuel and electric-only ZNE homes featuring various appliances under current cost and performance estimates. The technical and economic attractiveness of mixed-fuel ZNE homes may change if further technology development, product availability, market acceptance, or other factors reduce the cost of certain gas or electric appliances. For example, how the future cost of an air-source heat pump and heat pump water heater for an electric-only home compares to the relative cost of a gas furnace and tankless water heater for a mixed-fuel home.
- **Inclusion of Exogenous Loads in Energy Budget**: Title 24-2016 does not cover pool heating, pool pumps, alternative vehicle energy consumption or ancillary loads currently but may include them in future versions. If the home's energy budget includes these loads, the ZNE home would need additional solar PV and the comparison between fuel types and the attractiveness of individual technologies may differ.
- **Adjustment in Miscellaneous Load Calculations for Energy Budget**: These findings suggest that miscellaneous electric loads or "plug loads" account for an increasingly significant portion of overall energy consumption. If Title 24 adjusts plug load assumptions, or building codes drive plug load reductions, the required solar PV size and comparison between fuel types and the attractiveness of individual technologies will change.
- **Relative Utility Rates, TDV Values, and Greenhouse Gas (GHG) Values for Different Fuels**: The comparison between mixed-fuel and electric-only ZNE homes, as well as the selection of optimized technologies relies on utility cost and TDV assumptions for electricity, natural gas, and solar PV. Similarly, if California were to adopt another ZNE definition, the comparison would change. If the relative cost-benefit for each fuel changes, the comparison within the fuel types and the attractiveness of certain technologies may change. In addition, the relative GHG reductions from ZNE

homes depends on the fuel-specific carbon emission factors and will change with future assumptions for renewable energy penetration and other policies.

- **Future Tariffs or Incentives for Advanced Technologies**: This report assumes advanced technologies operate under a net metering agreement with electric utilities (CPUC 2015) and does not assume any incentives, except where noted. Future tariffs for solar PV systems or other advanced technologies as well as any major incentives or payment strategies would change the economic attractiveness of certain technologies.

Building industry stakeholders should monitor these issues and evaluate whether changes in these areas could result in a changed position for mixed-fuel ZNE homes relative to electric-only homes from a technical or economic standpoint in the future. Homebuilders will likely wish to continue designing mixed-fuel ZNE homes because their customers are looking for natural gas features as long as the cost and complexity is reasonable relative to both existing housing stock and electric-only designs. Because of the overwhelming customer preference for natural gas appliances shown in past research studies, stakeholders should consider developing programs or conducting RD&D initiatives to mitigate these issues to continue to provide homebuyers cost-effective technology options for mixed-fuel ZNE homes.

Conclusion

ZNE building codes provide substantial benefits for the state of California, but require upfront planning to accommodate significant changes in current practice. Prospective homebuyers, residential builders, realtors, lenders, and others in the real estate community, utilities, regulators, and other stakeholders must adjust to new terminology and processes as well as shift their perceptions of utility-customer interaction. ZNE homes will consume significantly less energy than conventional homes and will incorporate on-site electricity production as well as other advanced technologies. This project's assessment of the value and benefits of ZNE homes using natural gas appliances can support outreach efforts to the various stakeholders in the residential building community, and outline RD&D needs for advanced building technologies that can provide cost-effective TDV energy savings for mixed-fuel ZNE homes both now and in the future.

5. What are the potential activities to further support mixed-fuel ZNE homes?

Based on the study results, we recommend SoCalGas and other stakeholders consider the activities outlined below to further support the adoption of mixed-fuel ZNE homes.

- **Technology RD&D Activities** support the RD&D of advanced building technologies that could potentially provide cost-effective TDV savings for mixed-fuel ZNE homes, and ensure the next generation of technologies can maintain the competitiveness of mixed-fuel ZNE homes in the future.
    - Support the development of the next generation of gas-fired appliances and technologies for California ZNE homes through RD&D activities.
    - Support the development of fuel cell mCHP systems for California ZNE homes through RD&D activities.
    - Support the development of gas heat pumps for California ZNE homes through RD&D activities.

    - Support the development of lower-cost and higher-efficiency NGV refueling stations.
- **Market, Policy, and Program Activities** promote the value and benefits of mixed-fuel ZNE homes to various stakeholders in the residential building community to resolve misunderstandings about future ZNE building codes, and ensure future building codes, incentive programs, and other initiatives recognize the potential of natural gas appliances to help achieve ZNE goals.
    - Develop an outreach strategy and materials to educate and support builders and the real estate community on mixed-fuel ZNE homes.
    - Conduct a willingness-to-pay study for mixed-fuel and electric-only ZNE Homes.
    - Conduct additional research analysis to ensure future building codes provide even consideration with respect to transportation- and pool-related end-use building loads.
    - Support the inclusion of advanced technologies in Title 24 compliance software.

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