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Due to the size of Appendix B-4, it is being submitted seperately.

# Appendix B

# Appendix B4

# Strategy and Impact Evaluation of Zero-Net-Energy Regulations on Gas-Fired Appliances

**Phase I Technology Report**

**Prepared for:**
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NAVIGANT

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# Executive Summary

***Introduction and Background***

Through industry-leading building codes, emissions standards, incentive programs, and other regulatory policies, California has a long history of advanced environmental and energy efficiency initiatives. California's Title 24 residential and commercial building codes ("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 Energy Commission (CEC) has set a goal for all residential and commercial new construction to qualify as zero-net-energy (ZNE). ZNE buildings balance their net annual energy consumption with on-site renewable energy production on a time-dependent-valuation (TDV) basis.[1]

Under these guidelines, all new residential construction 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[2]. When designing new ZNE homes, builders must address customer preferences and ZNE performance while also meeting the budget of the prospective homeowner.

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 or mixed-energy homes use natural gas for cooking, laundry, space heating, water heating, and other secondary end-uses such as fireplaces, decorative lighting. 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.

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. As the sole natural-gas only public utility in California, Southern California Gas Company (SCG) carries a large responsibility to evaluate the technical, economic, and market outlook of mixed-fuel ZNE homes and develop the necessary technologies to compete with electric-only home designs. SCG has a long history of conducting RD&D to

[1] 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. 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.

[2] 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 Navigant's subsequent analysis.

improve the safety, resiliency, and reliability of California's natural gas infrastructure and support policy initiatives through energy efficiency, air emissions, and environmental initiatives[3]. SCG's RD&D program relies on the support and collaboration with the CEC's Natural Gas R&D program to introduce advanced technologies that reduce customers' energy consumption, integrate renewable energy resources, and reduce air emissions. Collaboration between SCG and CEC on RD&D initiatives will be key to ensure mixed-fuel home designs can reach the technical goals of ZNE building codes, while also satisfying the economic and market demands and preferences from homeowners.

***Phase I Project Plan, Methodology, and Results***

On behalf of SCG, Navigant conducted an extensive building simulation study and supporting analysis to assist SCG in preparing for ZNE building codes in California by investigating the value of mixed-fuel ZNE homes compared to electric-only ZNE homes and providing guidance for future research, development, and demonstration (RD&D) activities for SCG in partnership with the CEC's Natural Gas R&D program and other research organizations.. This report summarizes the results and methodology for the technical and economic analysis for mixed-fuel ZNE homes when compared to baseline electric-only homes. The modeling study evaluated how several baseline mixed-fuel and electric-only homes[4] could cost-effectively reach ZNE goals through an optimized suite of advanced building technologies[5]. As part of the Phase I approach to this project, our analysis answered the five key questions outlined in Figure 1.

The remainder of this section summarizes the results to the five key questions outlined in Figure 1.

[3] SCG. 2015. "Research, Development, and Demonstration Program – 2014 Annual Report." Southern California Gas Company.

[4] 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 SCG 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. For each home design and location, we conducted four sets of 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.

[5] 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, solar thermal, mCHP, gas heat pumps, energy storage, and others.

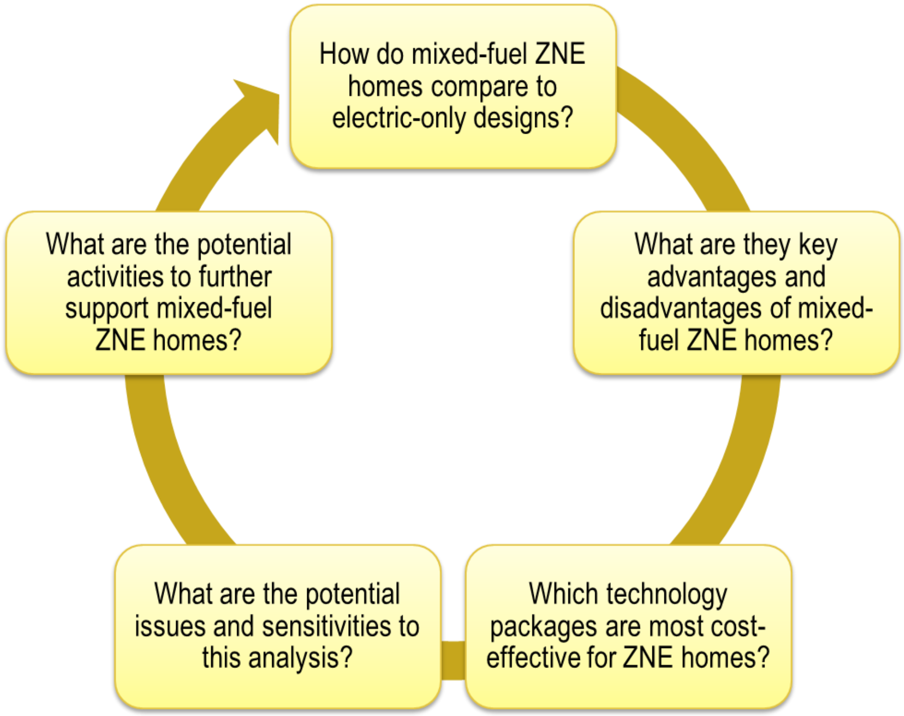


**Figure 1. Key Questions for Mixed-Fuel ZNE Home Analysis in Phase I**

***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 building simulation 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. As outlined in Figure 2, 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. These results suggest SCG and other stakeholders should conduct outreach efforts to various members of the residential building community to clarify any current misconceptions and communicate the value and benefits of ZNE homes using natural gas appliances.

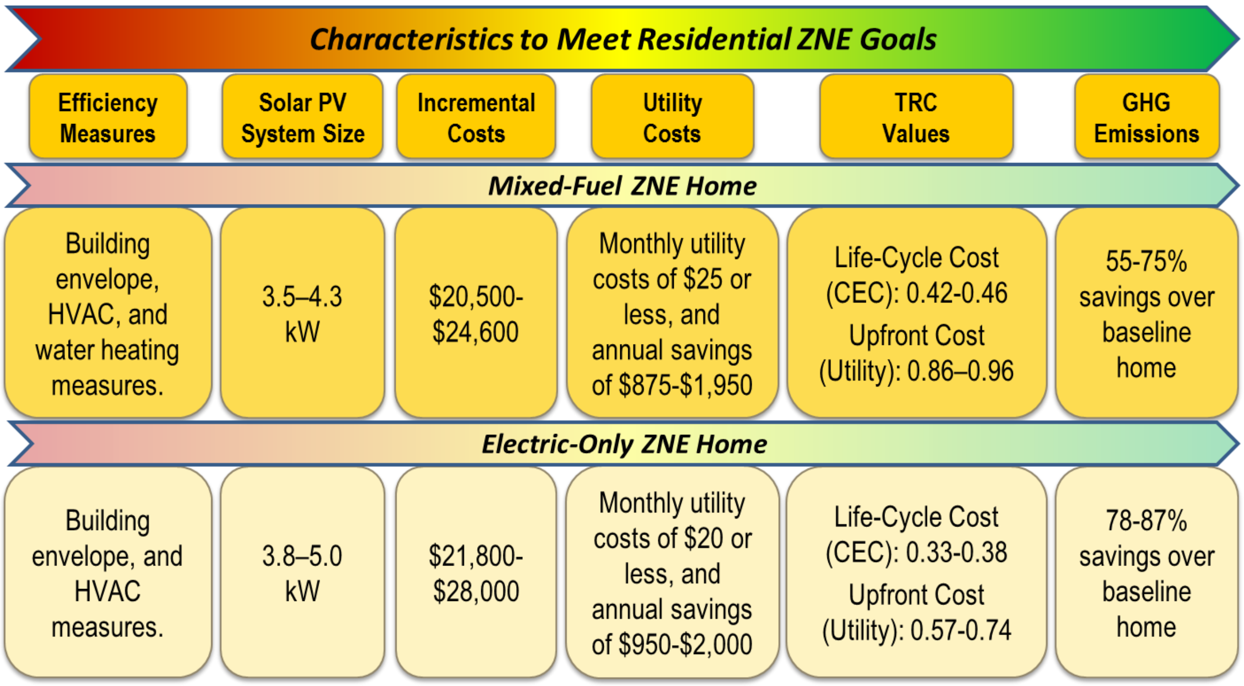


**Figure 2. Common Characteristics to Meet Residential ZNE Goals for Mixed-Fuel and Electric-Only Homes**

### *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.
- **Selection of Advanced Technologies**: 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**: 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.
- **Upfront Incremental Costs to Reach ZNE Goals**: Incremental costs 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.

- **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.
- **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 exceeding 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.

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 3, mixed-fuel homes have advantages in solar PV system size, incremental cost, simple payback, and TRC values compared to electric-only homes.

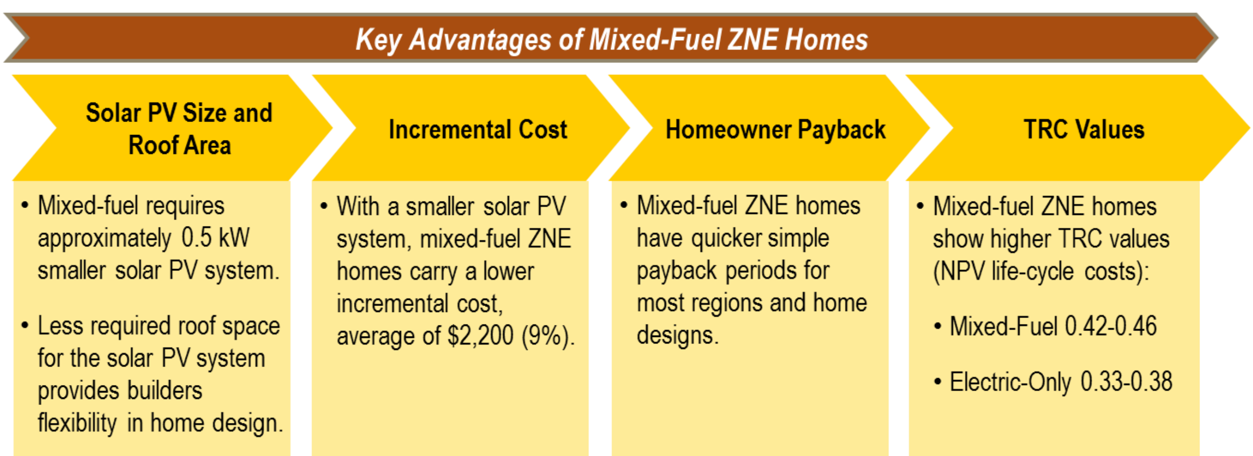


**Figure 3. Key Advantages of Mixed-Fuel ZNE Homes Compared to Electric-Only Designs**

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. Table 1 outlines where mixed-fuel ZNE homes provide advantages in solar PV size, incremental cost, and TRC values compared to electric-only homes.

**Table 1. Comparison of Mixed-Fuel and Electric-Only ZNE Homes by Home Size and Location**

| | | Location | | | | |
|---|---|---|---|---|---|---|
| | | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| Home A (1,800 sq.ft., single-story) | Solar PV Size | *MF* | *MF* | *MF* | *MF* | *MF* |
| | Incremental Cost | *MF* | *MF* | *MF* | *MF* | *MF* |
| | TRC Value | *MF* | *MF* | *MF* | *MF* | *MF* |
| Home B (2,500 sq.ft., two-story) | Solar PV Size | *MF* | *MF* | *MF* | *EO* | *MF* |
| | Incremental Cost | *MF* | *MF* | *MF* | *MF* | *MF* |
| | TRC Value | *MF* | *MF* | *MF* | *MF* | *MF* |
| Home C (3,200 sq.ft., two-story) | Solar PV Size | *MF* | *MF* | *MF* | *MF* | *MF* |
| | Incremental Cost | *MF* | *MF* | *MF* | *MF* | *MF* |
| | TRC Value | *MF* | *MF* | *MF* | *MF* | *MF* |

*MF* denotes where mixed-fuel ZNE homes *do offer* an advantage over electric-only ZNE designs.
*EO* denotes where mixed-fuel ZNE homes *do not offer* an advantage over electric-only ZNE designs.

These results suggest that SCG and other stakeholders should promote the use of natural gas appliances for ZNE homes among homebuilders 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[6,7]. Highlighting the key advantages in promotional materials will help SCG 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 the home's energy consumption on a TDV basis. The selection of an optimized technology mix depends on each measure's cost-effectiveness relative to other options. As outlined in Figure 4, our analysis revealed which technologies are cost-effective today relative to incrementally larger solar PV systems or

[6] SCG. 2015. "Visions 2014 Home Preference Study." Southern California Gas Company. Accessed March 2015. Available at: http://www.socalgas.com/for-your-business/builder-services/visions-home-survey.shtml
[7] Pande et al. 2015. "Residential ZNE Market Characterization." TRC Energy Services. CALMAC Study ID PGE0351.01. February 27, 2015.

other options, as well as which technologies might be cost effective with future performance/cost developments.

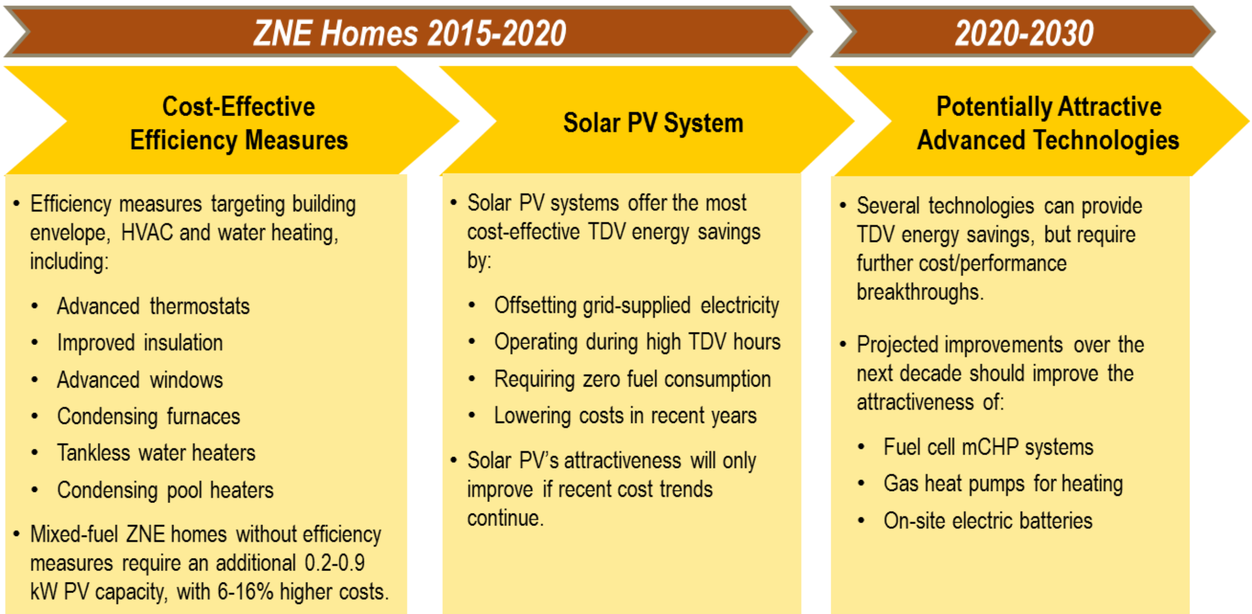


**Figure 4. Progression of Cost-Effective Technologies for ZNE Homes**

While stringent Title 24, Title 20, 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 5, 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) and electric battery systems create net positive TDV benefits when the TDV value of their thermal and electricity outputs exceeds their energy inputs. 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 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 also their recent declines, which will continue to present a challenge to the cost-effectiveness of these advanced technologies.

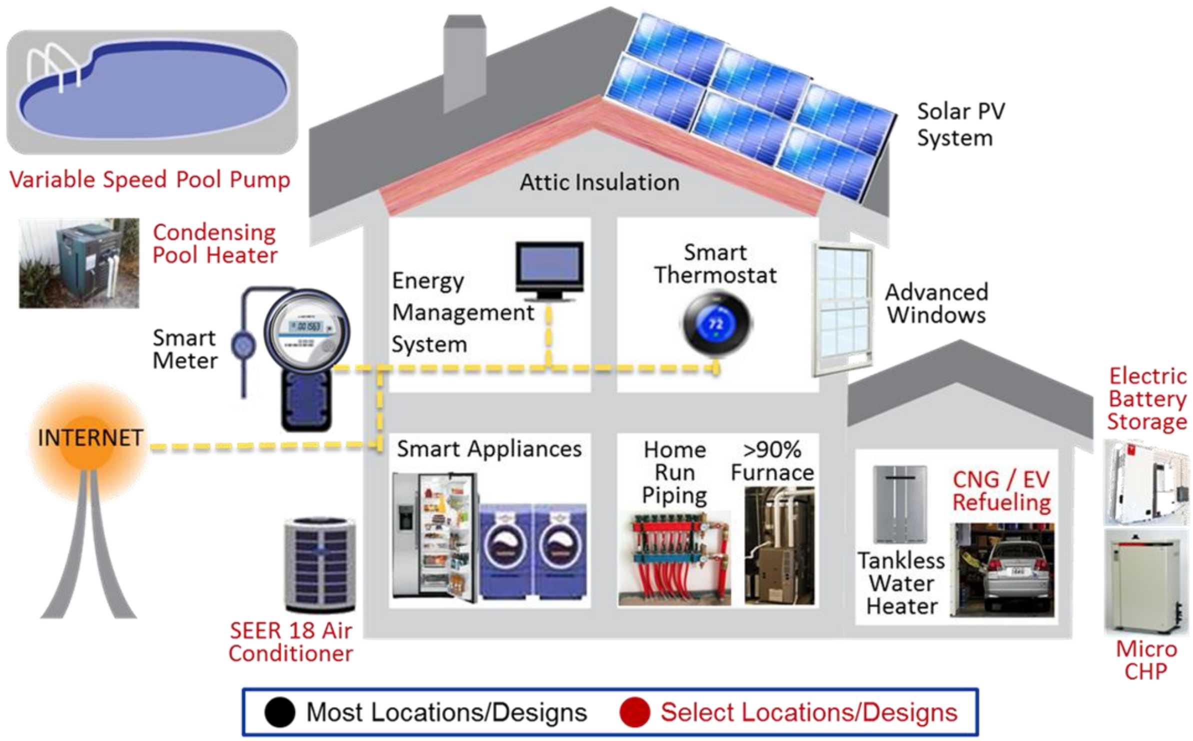


**Figure 5. Building Technologies in Future Mixed-Fuel ZNE Homes**

### 4. *What are the potential issues and sensitivities to this analysis that SCG and other 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 SCG and other 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 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 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. 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 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.

SCG, CEC, and other 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.

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

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.

Based on the Phase I results, we recommend SCG and other stakeholders consider the activities outlined in Table 2 to further support the adoption of mixed-fuel ZNE homes.

- **Technology RD&D Activities** support the research, development, and demonstration (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.
- **Policy 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.

**Table 2. Recommended Activities to Support and Promote Mixed-Fuel ZNE Homes**

| Activity Focus | Recommended Activities |
|---|---|
| **Technology** | • Support the development of the next generation of gas-fired appliances and technologies for California ZNE homes through RD&D activities.<br>• Support the development of fuel cell mCHP systems for California ZNE homes through RD&D activities.<br>• Support the development of gas heat pumps for California ZNE homes through RD&D activities.<br>• Support the development of lower-cost and higher-efficiency NGV refueling stations. |
| **Policy** | • Develop an outreach strategy and materials to educate and support builders and the real estate community on mixed-fuel ZNE homes.<br>• Conduct a willingness-to-pay study for mixed-fuel and electric-only ZNE Homes.<br>• Conduct additional research analysis to ensure future building codes provide even consideration with respect to transportation- and pool-related end-use building loads.<br>• Support the inclusion of advanced technologies in Title 24 compliance software. |

## List of Acronyms

*Acronyms:*

| | |
|---|---|
| ACM | Alternative Compliance Manual |
| AFUE | Annual Fuel Utilization Efficiency |
| APR | Annual Percentage Rate |
| CAC | Central Air Conditioner |
| CAHP | California Advanced Home Program |
| CEC | California Energy Commission |
| CO | Carbon Monoxide |
| COP | Coefficient of Performance |
| CSI | California Solar Initiative |
| CZ | Climate Zone |
| DC | Direct Current |
| DEER | Database of Energy Efficient Resources |
| DOE | Department of Energy |
| DR | Demand Response |
| EER | Energy Efficiency Ratio |
| EF | Energy Factor |
| EIA | U.S. Energy Information Administration |
| EV | Electric Vehicle |
| GGE | Gasoline Gallons Equivalent |
| GHG | Greenhouse Gas |
| HERS | Home Energy Rating System |
| HHV | Higher Heating Value |
| HP | Heat Pump |
| HPWH | Heat Pump Water Heater |
| HVAC | Heating, Ventilation, and Air Conditioning |
| LADWP | Los Angeles Department of Water and Power |
| LBNL | Lawrence Berkeley National Laboratory |
| mCHP | Micro-Combined-Heat-and-Power |
| NPV | Net Present Value |
| NGV | Natural Gas Vehicle |
| NOx | Nitrogen Oxide |
| NREL | National Renewable Energy Laboratory |
| PG&E | Pacific Gas & Electric Company |
| PV | Photovoltaic |
| R&D | Research & Development |
| RASS | Residential Appliance Saturation Survey |
| SCE | Southern California Edison Company |

| | |
|---|---|
| SCG | Southern California Gas Company |
| SEER | Seasonal Energy Efficiency Ratio |
| TDV | Time Dependent Valuation |
| TOU | Time of Use |
| TRC | Total Resource Cost |
| VOC | Volatile Organic Compounds |
| WF | Water Factor |
| ZNE | Zero Net Energy |

# 1. Introduction

## 1.1 Section Summary

Through Title 24 building codes, the California Energy Commission (CEC) has mandated that all new single-family homes built starting in 2020 must meet zero-net-energy (ZNE) standards through a combination of energy efficiency and on-site renewable energy technologies. California's proposed building codes evaluate a home's energy consumption and production on a time-dependent-valuation (TDV) basis, which accounts for hourly and seasonal differences among different fuel types.

ZNE homes must offset their annual energy consumption on a TDV basis with on-site renewable systems, such as a solar photovoltaic (PV) system. Regardless of whether a ZNE home uses natural gas (mixed-fuel or mixed-energy) or electric appliances (electric-only), building codes will drive all homes reach the same ZNE goal. Because the TDV value of energy changes with fuel type, time of day, and season, determining the comparative value of mixed-fuel and electric-only ZNE homes requires evaluation of many complex factors, including: building loads, equipment operating schedules, home orientation, solar PV system output, etc.

This project investigates the comparative value of mixed-fuel and electric-only ZNE homes through an extensive building simulation study and economic analysis. The results of this study will:

- Assist Southern California Gas Company (SCG) and other stakeholders develop programs and materials to support residential building partners in adapting to ZNE building codes
- Provide guidance for future research, development, and demonstration (RD&D) activities for SCG in partnership with the CEC's Natural Gas R&D program and other research organizations.

## 1.2 Background on ZNE Homes in California

### 1.2.1 Title 24 Building Codes and Zero-Net-Energy Homes

Through industry-leading building codes, emissions standards, incentive programs, and other regulatory policies, the state of California has a long history of advancing resource conservation and environmental initiatives. California's building energy codes, known as 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 (GHG) emissions targets, the California Energy Commission (CEC) has outlined a roadmap for all residential and commercial new construction to qualify as ZNE buildings. As shown in Figure 6, all new residential construction must meet ZNE targets by 2020, followed by all new commercial new construction by 2030.

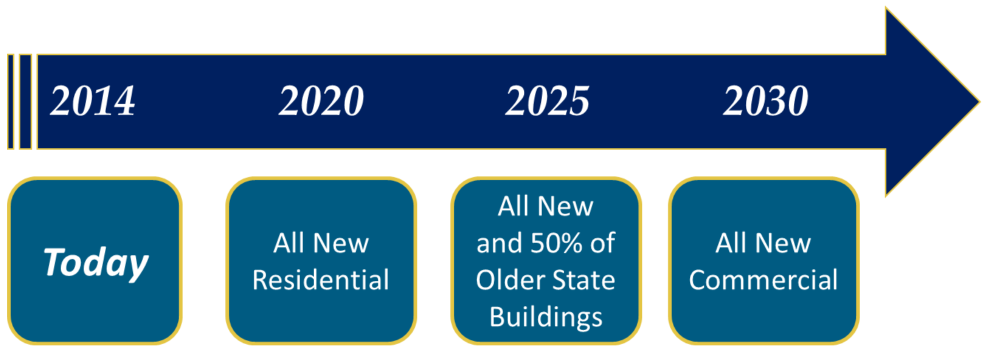


**Figure 6. History of Title 24 Impacts on Home Energy Consumption**

While many definitions for ZNE exist (e.g., source energy, site energy, utility cost), California's Energy Division has adopted the following definition for Title 24 building codes:

> "A Zero-Net-Energy Code Building is one where the net amount of energy produced by on-site renewable energy resources is equal to the value of the energy consumed annually by the building, at the level of a single "project" seeking development entitlements and building code permits, measured using the California Energy Commission's Time Dependent Valuation metric. A zero-net-energy code building meets an energy use intensity value designated in the Building Energy Efficiency Standards by building type and climate zone that reflect best practices for highly efficient buildings."[8]

Consequently, 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 functionality.

In the past, the high cost of achieving such energy savings and incorporating renewable energy systems, limited their widespread adoption. With the price of on-site solar PV systems decreasing and the adoption of energy-efficient practices and products increasing throughout the building industry, studies[9] have shown that homes using these technologies could provide attractive economics for homeowners. As shown in Figure 7, improved manufacturing methods, financial incentives, and new business models have exponentially increased the number of solar PV systems installations in recent years, while significantly reducing costs.

[8] California Energy Commission. 2013. "Integrated Energy Policy Report." Publication Number: CEC-100-2013-001-CMF. Available at: http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf
[9] ARUP. 2012. "The Technical Feasibility of Zero Net Energy Buildings in California." ARUP North America Ltd. CALMAC Study ID - PGE0326.01. December 31, 2012.

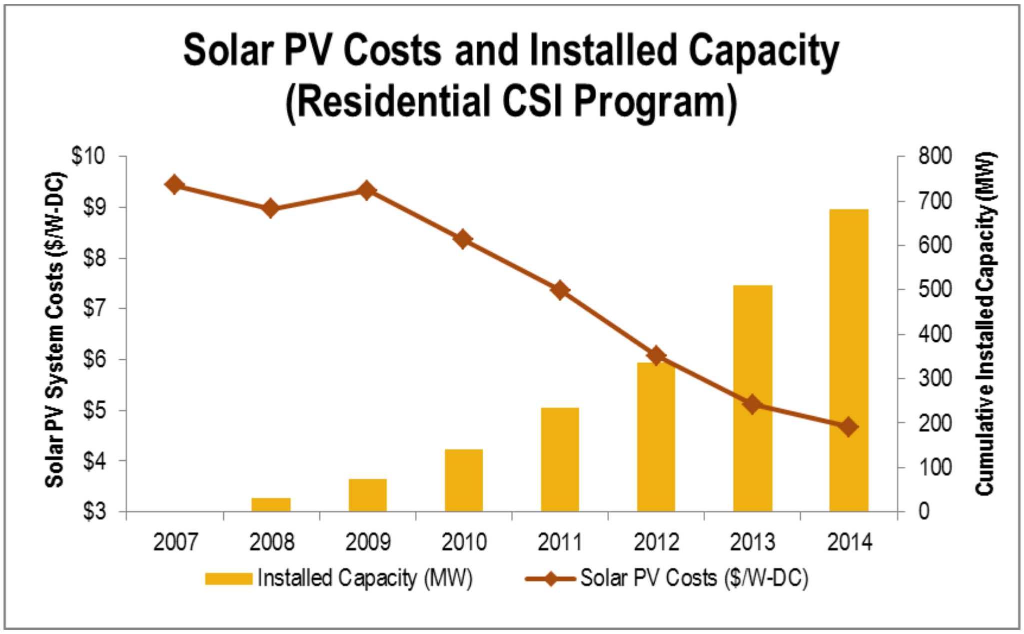


**Figure 7. Timeline of Solar PV Costs and Total Capacity in California**

Source: California Solar Initiative (CSI) data for residential CSI systems 2007-2014, accessed October 2014[10]

By specifying advanced building techniques and high-efficiency components, Title 24 building codes have steadily reduced space heating, cooling, water heating, and other end-use energy consumption, as shown in Figure 8. Because ZNE homes use renewable energy systems to offset energy consumption, reducing the overall consumption through building codes lower the size and cost of the required renewable energy system. Furthermore, as building codes mandate high efficiency measures, the cost for implementing high efficiency practices decreases as more homebuilders adopt advanced techniques or equipment. As shown in Figure 8, past Title 24 building codes have already reduced energy consumption for new homes substantially, and proposed measures for 2016 and 2019 code versions will reduce consumption even further. By the time 2016 and 2019 building codes take effect, most new homes could be considered "near-ZNE" compared to past Title 24 versions since they will include an already advanced set of efficiency measures and higher HERS scores, even before adding solar PV systems.

[10] California Solar Statistics. Date Range 2007-2014, Residential. Accessed October 2014. http://californiasolarstatistics.ca.gov/

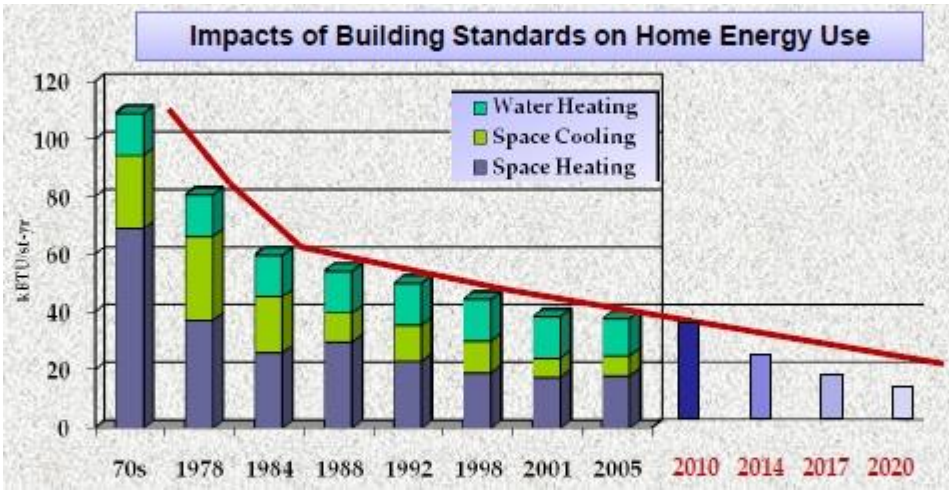


**Figure 8. History of Title 24 Impacts on Home Energy Consumption**

Source: November Title 24 Pre-Meeting[11]

### 1.2.2 Time-Dependent Valuation

The California definition for ZNE buildings complicates the balance of on-site energy consumption and production by incorporating an hourly time-dependent valuation (TDV) for each fuel type. The Energy Commission assigns a TDV value for every hour of the year to each fuel type (e.g., electricity, natural gas, propane, etc.) for each California climate zone (CZ). For each fuel type, a building's TDV energy consumption is calculated by multiplying the building's hourly energy usage by the hourly TDV coefficient for that fuel type. The following equations exemplify how a building's hourly and annual electricity consumption (kWh-site) would translate to TDV consumption (kWh-TDV):

$$Hourly\ TDV\ Consumption_{Elec.}(kBtu\text{-}TDV) = Hourly\ Site\ Consumption_{Elec.}(kWh)\ x\ Hourly\ TDV\ Coefficient_{Elec.}(\frac{kBtu\text{-}TDV}{kWh})$$

$$Annual\ TDV\ Consumption_{Elec.}(kBtu\text{-}TDV) = \sum^{8760} Hourly\ TDV\ Consumption_{Elec.}(kBtu\text{-}TDV)$$

The same relationship holds for other fuel types (e.g., natural gas, fuel oil) but with different TDV coefficients. Additionally, any on-site energy production can count as TDV energy production through the same coefficients.

TDV incorporates not only the amount of energy consumed or produced, but also the energy's value to California as a whole. For example, TDV valuations are higher during peak demand periods and lower during off-peak periods, in order to reflect the relative difference in cost for generating, transmitting, and distributing each unit of energy. This strategy not only incentivizes energy efficiency, but also peak demand savings. As shown in Figure 9 and Figure 10 for CZ 6, electricity TDV values increase substantially during summer peak hours, and natural gas TDV values increase during winter months. Additionally, natural gas will generally have lower TDV values than electricity.

[11] Shirakh, Mazi. 2013. "2016 Building Energy Efficiency Standards – Pre-Rulemaking Workshop." November 3, 2014. Available at: http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-11-03_workshop/presentations/Pre-Rulemaking_Workshop.pdf

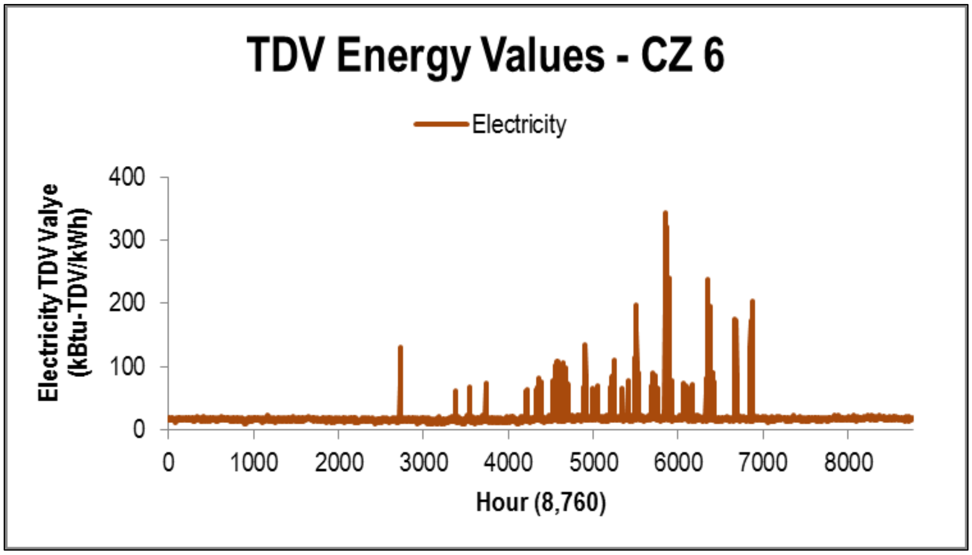


**Figure 9. Electricity TDV Values for CZ 6**
Source: E3 2013-2014 Calculator[12]

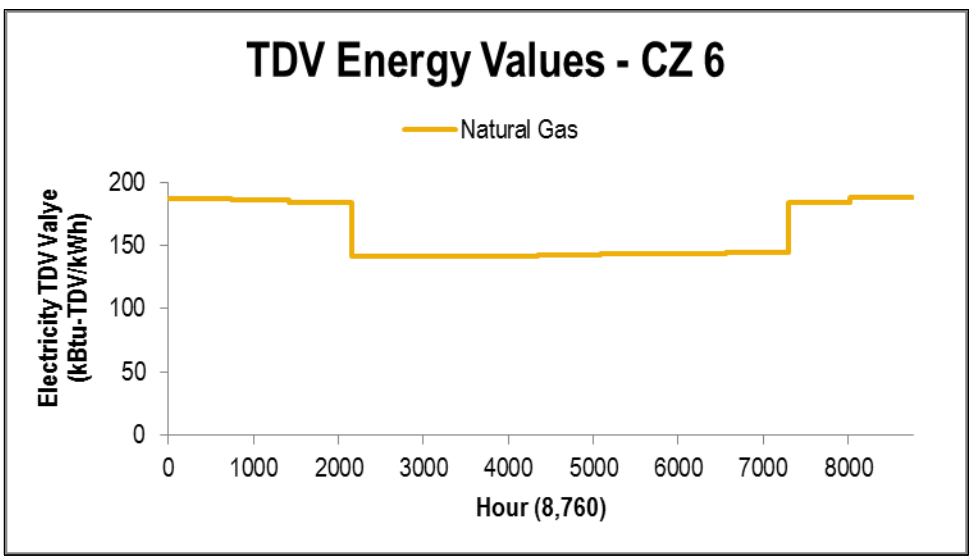


**Figure 10. Natural Gas TDV Values for CZ 6**
Source: E3 2013-2014 Calculator[12]

Figure 11 provides the electricity consumption, natural gas consumption, and solar PV production for a sample ZNE home. For ZNE homes, the annual renewable TDV energy production must meet or exceed the home's annual TDV energy consumption. Therefore, the homebuilder must size the solar PV system correctly to satisfy the expected electricity and natural gas loads. Because TDV energy consumption is

[12] E3. "Energy Efficiency Calculator-Draft 2013-2014 E3 Calculator Files." 2012. Available at: https://ethree.com/public_projects/cpuc4.php.

weighted the same as on-site TDV energy production, ZNE homes can incorporate efficiency measures to reduce the solar PV system size. For example, a more efficient space cooling system that reduces electricity consumption during peak demand hours could decrease the required on-site TDV energy production, allowing the home to use a smaller solar PV system.

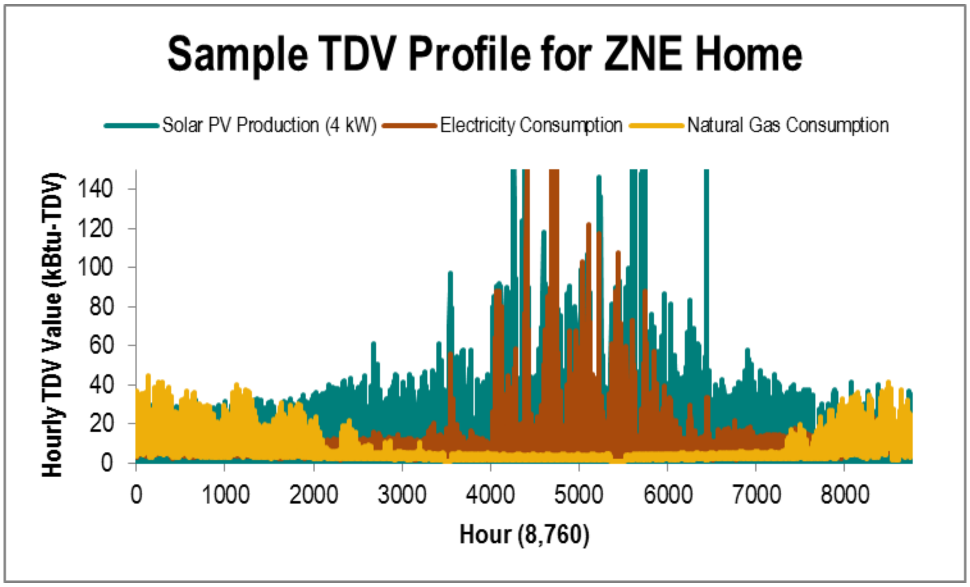


**Figure 11. Electricity, Natural Gas, and Solar PV TDV Profile for Sample Home**

All ZNE homes will include an on-site solar PV system or take partial credit for a shared solar PV system, e.g., community-based solar[13]. To reach ZNE status with the lowest incremental cost, the homebuilder must decide which efficiency measures to add before increasing the size of the solar PV system. While deciding which efficiency measures to use seems simple, efficiency gains in one area can have a cascading effect on other building features by lowering the baseline consumption, and subsequently affect the cost-effectiveness of high efficiency options. For example, the choice of windows, wall insulation, and roofing materials can decrease the required cooling load to such a degree that high efficiency air conditioning options may provide too long a payback. This issue is further compounded for ZNE homes when homebuilders must not only consider the cost of conserved energy, but also the cost of produced energy from solar PV or other advanced technologies.

### 1.2.3 Electric-Only vs. Mixed-Fuel Home Designs

Homebuilders have numerous options when designing a new home and 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,

[13] Community-based solar PV systems allow homes where solar PV is impractical to achieve ZNE goals by sharing the cost and benefits of a renewable energy system located in a common area. For example, a residential subdivision could offset the consumption of each home by placing a large solar PV system on the rooftop of a community center or other shared space. The 2013 Integrated Energy Policy Report[8] anticipates the ZNE Code Building definition will incorporate specific "development entitlements" to allow for community-based renewable energy generation systems.

water heating, and other secondary end-uses such as fireplaces and decorative lighting. Because ZNE homes typically use solar PV systems to generate the necessary on-site renewable energy, homebuilders may hold the following misconceptions:

*TDV Requires Electric-Only ZNE Homes*

- **Misconception:** Since the ZNE home's solar PV system generates electricity, ZNE homes can only use electricity for home appliances.
- **Response:** The TDV definition is fuel agnostic and equates the energy consumption for all fuels to a common MMBtu TDV metric. Therefore, any baseline home can reach ZNE status through efficiency measures and renewable energy production.

*Electric-Only ZNE Homes Carry Lower Costs*

- **Misconception:** Since ZNE homes using natural gas must generate enough TDV energy to cover both electricity and natural gas consumption, ZNE homes using natural gas are less cost-effective than electric-only designs.
- **Response:** This statement may be true under a different ZNE definition, but the comparative value of mixed-fuel and electric-only ZNE homes is complex under the TDV energy definition. Because the value of energy changes with fuel type, time of day, and season, determining the advantages and disadvantages of each fuel configuration requires careful analysis.

### *1.3 SCG and CEC Collaboration on RD&D Projects*

Because ZNE building codes will have such a large impact on residential new construction market, utilities, regulatory agencies, builder groups, and other stakeholders have worked together for years to understand the challenges that ZNE building codes will create for the building industry and homeowners and develop strategies to minimize the impacts. Mixed-fuel and electric-only home designs have many shared challenges (e.g., available roof space in different orientations) when adapting to ZNE building codes, but mixed-fuel homes also 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.

The success of ZNE building codes will depend on whether the ultimate customer, the prospective homebuyer, understands ZNE policies, recognizes the benefits of a ZNE home, and available ZNE homes meet their needs. As discussed further in Section 7, past research studies show prospective homebuyers overwhelmingly prefer natural gas appliances within their home for cooking, space heating, and other end-uses. Statewide ZNE activities should support the goals of developing and demonstrating ZNE home designs that meet market demands, using both mixed-fuel and electric-only fuel configurations. Where mixed-fuel homes are not cost-competitive either now or in the future, stakeholders should pursue activities to develop and demonstrate the necessary technologies or programs needed to bring the technical, economic, and market attractiveness of mixed-fuel homes to match those of electric-only ZNE home designs.

As the sole natural-gas only public utility in California, SCG carries a large responsibility to evaluate the technical, economic, and market outlook of mixed-fuel ZNE homes and develop the necessary technologies to compete with electric-only home designs. SCG has a long history of conducting RD&D to improve the safety, resiliency, and reliability of California's natural gas infrastructure and support policy initiatives through energy efficiency, air emissions, and environmental initiatives[14]. SCG's RD&D program relies on the support and collaboration with the CEC's Natural Gas R&D program to introduce advanced technologies that reduce customers' energy consumption, integrate renewable energy resources, and reduce air emissions. Past projects include: low NOx furnaces and water heaters, high efficiency cooking equipment, advanced combined heat and power systems, natural gas refueling stations, and many others[15]. Collaboration between SCG and CEC on RD&D initiatives will be key to ensure mixed-fuel home designs can reach the technical goals of ZNE building codes, while also satisfying the economic and market demands from homeowners.

### *1.4 Project Description*

SCG has retained Navigant to assist SCG prepare for ZNE building codes in California by evaluating the technical and economic prospects for single-family new construction using natural gas appliances based on a building simulation study and supporting analysis. As part of the Phase I approach to this project, our analysis answered the five key questions outlined in Figure 12. This report summarizes the results and methodology for the technical and economic analysis for mixed-fuel ZNE homes in Phase I.

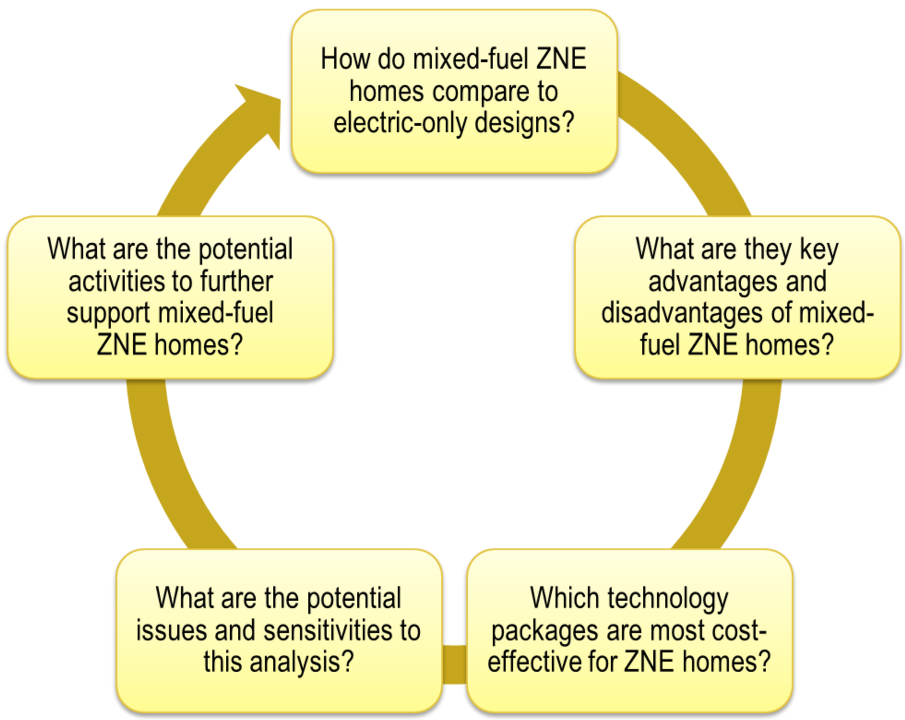


**Figure 12. Key Questions for Mixed-Fuel ZNE Home Analysis in Phase I**

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[14] SCG. 2015. "Research, Development, and Demonstration Program – 2014 Annual Report." Southern California Gas Company.

[15] California Energy Commission. 2014. "Natural Gas Research and Development – 2014 Annual Report." October 2014.

# 2. Evaluation Approach

## *2.1 Summary Overview*

Navigant used the building simulation software tool BEopt to evaluate mixed-fuel and electric-only ZNE homes using various building technologies under the TDV definition. The study includes the following steps:

- Researching of Key Modeling Inputs
- Configuring Baseline Models, Sensitivity Analysis, Calibration
- Executing Building Simulations and Follow Up Analyses
- Conducting Economic Analysis.

The building simulation study outputs provide the technical and economic data to understand how mixed-fuel ZNE homes compare to electric-only designs, suggest areas for strategic RD&D activities to improve the technical, economic, and market characteristics for mixed-fuel ZNE homes, and provide technical assistance for internal SCG planning and external discussions. Figure 13 describes key Phase I activities.

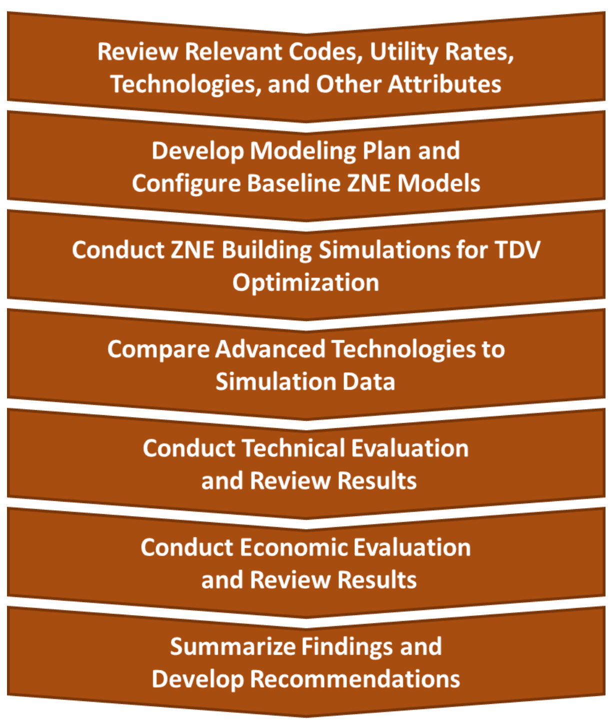


**Figure 13. Approach Overview**

### 2.1.1 Conduct Literature Review and Develop Modeling Plan

To ensure the study's results have wide applicability for SCG and other stakeholder activities, Navigant conducted a thorough analysis of relevant building codes, appliance standards, Title 24 CZs, software capabilities, and technology options. The findings were used to develop the final modeling plan.

#### *2.1.1.1 Baseline Building Characteristics*

*Floor Plan, Layout, and Orientation*

Navigant conducted the analysis for three baseline home designs in BEopt, each of which had a floor plan, including home size, number of bedrooms, and number of bathrooms. In order to ensure the designs were representative of typical homes, we consulted with relevant California building codes (Title 24-2013, Title 20-2014), Residential Alternative Calculation Method (ACM) manual, and the 2009 California Residential Appliance Saturation Survey (RASS) in creating the home designs. These sources enabled us to determine key characteristics such as parameters include square footage, floor plan, height, window area, foundation type, number of occupants, number of bathrooms, size of garage, etc. Table 3 summarizes the key features for each baseline home design, and Figure 14 provides a BEopt screenshot of each.

**Table 3. Baseline Home Designs and Features**

| Metric | Home A | Home B | Home C |
|---|---|---|---|
| **Conditioned Floor Area** | 1,800 sq.ft. | 2,500 sq.ft. | 3,200 sq.ft. |
| **% Single-Family New Construction (Floor Area Range)[16]** | 22% (1,501–2,000 sq.ft.) | 40% (2,001–3,000 sq.ft.) | 27% (>3,000 sq.ft.) |
| **Number of Floors** | 1 | 2 | 2 |
| **Number of Bedrooms** | 3 | 4 | 4 |
| **Number of Bathrooms** | 2 | 3 | 3 |
| **Ceiling Height** | 9 | 9 | 9 |
| **Window Area %** | | 20% total, 5% per side | |
| **Rough Dimensions** | 40 x 50 sq.ft. | 27 x 50 sq.ft. | 34 x 50 sq.ft. |
| **Garage Floor Area** | 418 sq.ft. | 440 sq.ft. | 440 sq.ft. |
| **Roof Pitch** | | 6 rise:12 run | |
| **Available Roof Dimensions (Back of House)** | 50 x 22.4 ft. | 50 x 15.1 ft. | 50 x 19.0 ft. |
| **Available Roof Area (Back of House)** | 1,118 sq.ft. | 755 sq.ft. | 950 sq.ft. |

[16] KEMA Inc. 2010. "2009 California Residential Appliance Saturation Study." October 2010. Filtered by: Building Type: Single Family, Townhouse, Duplex, Row House; Building Age: 2001-2008; SoCal Gas; Available at: http://www.energy.ca.gov/appliances/rass/

| Metric | Home A | Home B | Home C |
|---|---|---|---|
| **Foundation Type** | Concrete Slab | | |
| **Exterior Finish** | Medium Stucco | | |
| **Roof Material** | Medium Terra Cotta Tile | | |

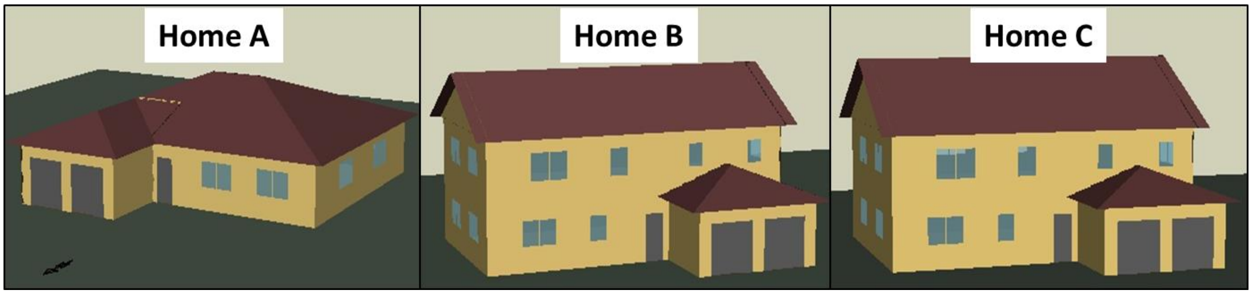


**Figure 14. BEopt Images of Each Baseline Home Design**

Home orientation can have a substantial effect on energy consumption and solar PV production. For example, roof orientation and tilt affects solar PV production and window orientation can alter the home's solar heat gain. Each simulation assumes solar PV and thermal systems tilt matches the roof pitch (i.e., 6:12) and the systems occupy a portion of the back roof of the home. With the solar system on the back roof, the solar azimuth is opposite the orientation for the front side of the house, e.g., North-facing home has a South-facing PV system. Because of this difference, Title 24 ACM requires builders to provide simulation results in North, South, East, and West directions. We also considered the impacts in each direction in BEopt, and conducted an initial set of simulations in each building orientation. During the preliminary simulations, we determined that home orientation had a substantial effect on solar PV system output and a negligible impact on home energy consumption for the sample home designs. Figure 15 illustrates the impact of building orientation on energy consumption and solar PV production.

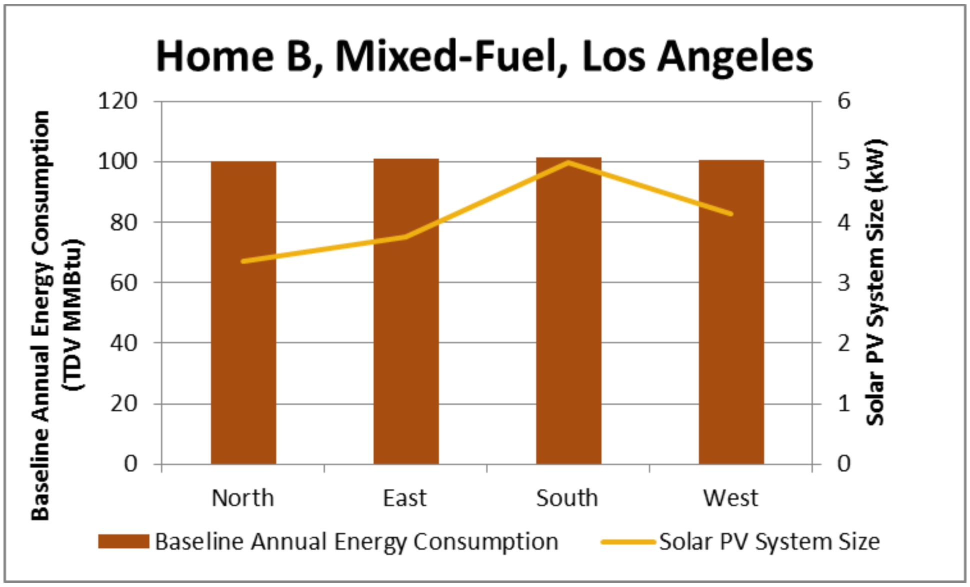


**Figure 15. Sample Baseline Annual Energy Consumption and Solar PV Production by Orientation**

For this analysis, North-facing homes with South-facing solar systems represent the best-case ZNE home configuration and South-facing homes with North-facing solar systems represent the worst-case ZNE home configuration. East- and West-facing homes represent moderate-case ZNE home configurations, with East results closer to North results, and West results closer to South results. Because the Scenario 1 simulations revealed how each home's energy consumption and PV system changed with orientation, Navigant could infer the impacts for the moderate East and West directions in the subsequent scenarios. By comparing the results for North and South orientations in Scenarios 2-4 to those in Scenario 1, Navigant extrapolated East and West results, reducing the number of simulations by 45%.

*Location and Utilities*

Because heating, ventilation, and air conditioning, (HVAC), water heating, solar PV, and other building characteristics vary with climate conditions, we simulated each of the baseline homes for five major California CZs in SCG territory. Table 4 provides details for each location. These five regions cover the full-range of conditions that builders experience in Southern California, including mild coastal conditions, moderate heating and cooling loads in the Inland Empire, high heating loads in the San Joaquin Valley, and high cooling loads in the high desert. Simulating for these regions also provides coverage for major electric utilities in SCG territory (Pacific Gas & Electric [PG&E], Southern California Edison [SCE], Los Angeles Department of Water and Power [LADWP]) and reveals any differences in TDV valuation for different Time-of-Use (TOU) electric rates. Note – Los Angeles climate zone (CZ 6) uses the LAX weather station, which is a more coastal climate than other parts of Los Angeles. Results for Pasadena or Riverside may better reflect specific portions of the Los Angeles area. Appendix A provides a summary of each utility rate structure simulated in this analysis.

**Table 4. Selected ZNE Home Locations and Utility Information**

| Location | Title 24 Climate Zone | TMY3 Weather Data | Natural Gas Utility & Rate | Electricity Utility & Rate |
|---|---|---|---|---|
| **Los Angeles** | 6 | CZ06RV2 | SCG (GR) | LADWP (R1B) |
| **Pasadena** | 9 | CZ09RV2 | | SCE (TOU-D-T) |
| **Riverside** | 10 | CZ10RV2 | | SCE (TOU-D-T) |
| **Bakersfield** | 13 | CZ13RV2 | | PG&E (TOU) |
| **Palm Springs** | 15 | CZ15RV2 | | SCE (TOU-D-T) |

Note – Los Angeles climate zone (CZ 6) uses the LAX weather station, which is a more coastal climate than other parts of Los Angeles. Results for Pasadena or Riverside may better reflect specific portions of the Los Angeles area.

Appendix A provides the assumed rate structures for each utility. Each rate includes monthly connection charges, consumption charges, and credits any monthly net electricity production at the retail cost of electricity on a net metering basis. Excess electricity production at the end of the 12 month period is compensated through a net surplus compensation rate that reflects the average wholesale market rate rather than the retail rate. SCE and PG&E provide a net surplus compensation rate between $0.04-$0.05 per kWh, whereas LADWP does not participate[17].

### *2.1.1.2 Building Simulation Software*

Navigant utilized the software program BEopt (Building Energy Optimization Tool)[18] to conduct the building simulation study. The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) developed BEopt with the purpose of analyzing ZNE home designs. 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. 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. Figure 16 provides a visual representation for BEopt's multi-step optimization process. Section 3.2 further details the optimization process.

[17] CPUC. 2015. "Net Energy Metering." California Public Utilities Commission. May 4, 2015. http://www.cpuc.ca.gov/PUC/energy/DistGen/netmetering.htm

[18] Christensen et al. 2006. "BEopt™ Software for Building Energy Optimization: Features and Capabilities." National Renewable Energy Laboratory. August 2006. https://beopt.nrel.gov/

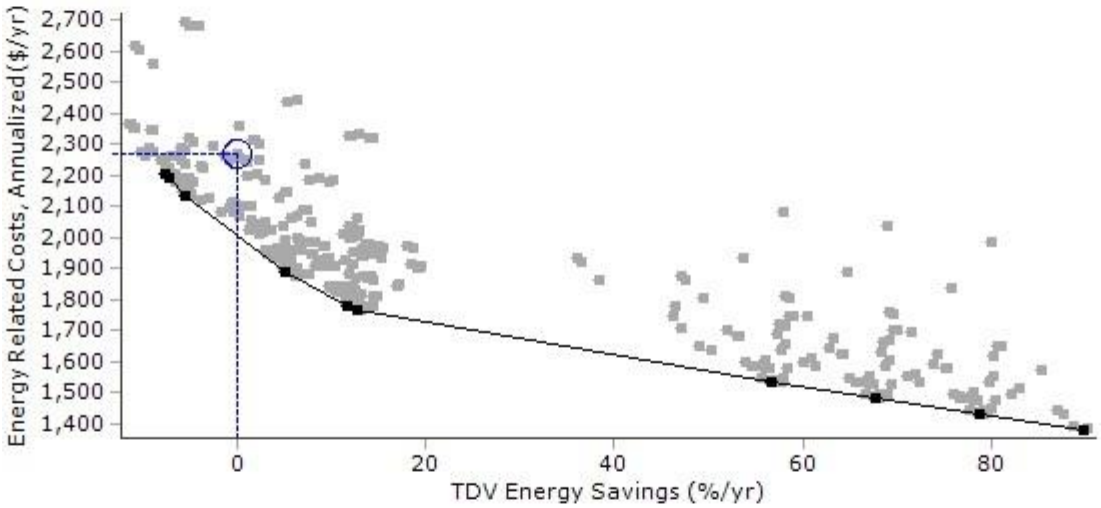


**Figure 16. Sample BEopt Optimization Output**

While BEopt is accepted by industry for ZNE home analysis, California home builders must use the CEC-approved compliance software CBECC-Res 2013 when submitting their ZNE home designs. Researchers have evaluated the differences between the BEopt and CBECC-Res programs with the intention of integrating the programs in the future, but there is no formal agreement yet[19]. We selected BEopt for this project due to its multi-variable optimization capabilities compared to CBECC-Res, which only analyzes a single configuration at a time. Nevertheless, we aligned BEopt's assumptions with CBECC-Res (as possible) either by scaling or through directly adjusting values. Appendix B outlines the key differences in operating assumptions between BEopt and CBECC-Res.

#### *2.1.1.3 Technology Library*

For each home design and location, we conducted four sets of optimization simulations for both mixed-fuel (i.e., electricity and natural gas appliances) and electric-only fuel configurations. Each set of simulations starts as a baseline, code-compliant home and then systematically add combinations of high efficiency technologies from a matrix of available appliances and features for that fuel configuration. Figure 17 provides a screenshot of BEopt's technology option and selection capabilities. The mixed-fuel homes select available gas-fired appliances (where applicable), whereas the electric-only configuration select higher efficiency electric appliances. Both mixed-fuel and electric-only homes consider the same non-appliance measures (e.g., insulation) or appliances that only use electricity (e.g., lighting, refrigerators). The output of these simulations provide the technology package that represents the lowest cost way to reach ZNE status for both mixed-fuel and electric-only ZNE homes of different sizes and locations. To ensure the simulations reflect both market conditions and future Title 24 requirements, Navigant updated the performance and cost for both baseline and high efficiency technologies where necessary. Appendix C contains the technology library for mixed-fuel and electric-only ZNE homes.

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[19] Christensen et al. 2014. "BEopt-CA (Ex): A Tool for Optimal Integration of EE, DR, and PV in Existing California Homes." National Renewable Energy Laboratory. April 2014. http://energy.gov/sites/prod/files/2014/06/f16/beopt_ex_california.pdf

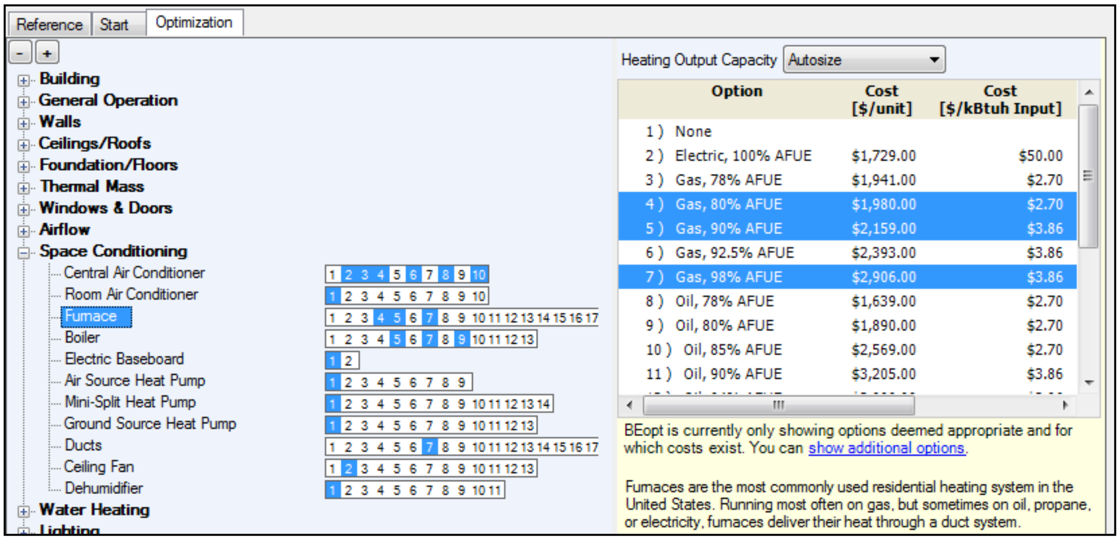


**Figure 17. Screenshot of BEopt's Technology Option and Selection Capabilities**

*Anticipated Updates to Title 24, Title 20, and Federal Appliance Standards*

Navigant reviewed current and proposed Title 24, Title 20, and other relevant codes and standards in California, as well as federal appliance standards to understand how these regulations may affect baseline home designs, features, and appliances. Table 5 provides a summary of the proposed changes to California building standards.

**Table 5. Anticipated Standards Updates that Affect ZNE Energy Consumption**

| Standard | Attribute | Proposed Standard |
|---|---|---|
| **Title 24** | High Performance Attic | High Performance Attic (R-13 below roof deck, R-38 ceiling insulation, R-8 insulation ducts with 5% leakage) |
| | Residential Lighting | All high-efficacy lighting |
| | High Performance Walls | U Factor of 0.05 (2x6 @ 16''OC R19+R6, or 2x4 @ 16"OC R15 + R8, and other combinations) |
| | Water Heating | • For gas water heaters, energy factor of 0.82 as basis for energy budget (essentially minimum tankless water heater for gas, or gas storage with solar water heating system (0.55 solar factor)).<br>• For electric, adding a heat pump water heater (HPWH, energy factor of 2.0) as an option to electric water heater with solar water heating system (0.5 solar fraction). |
| **Title 20** | Lavatory Faucets | 1.5 gpm (current is 2.2 gpm) |
| | Kitchen Faucets | 1.9 gpm (current is 2.2 gpm) |
| **Federal Appliance Standards** | Central Air Conditioners (CAC) and Heat Pumps (HPs) | 2011 amended standards provide SEER 13 AC, SEER 14 HP, for California, EERs 12.2 <4 tons, 11.7> 4 tons, off mode power consumption 30-33 W |
| | Clothes Dryers | 2011 amended standards establish in 2015, the following EF 3.73 (electric), 3.3 (gas) |
| | Clothes Washers | • Current Top Loading (1.26 MEF, 9.5 WF), 2015-2018 (1.29 MEF, 8.4 WF), 2018- (1.57 MEF, 6.5 WF)<br>• Front Loading Current (n/a), 2015-2018 (1.84 MEF, 4.7 WF), 2018- (1.84 MEF, 4.7) |
| | Dishwashers | Standards in effect post 2013 - 307 kWh/yr., 5 gal/cycle |
| | Furnace Fans | In effect 2019, W/CFM requirements |
| | Furnaces and Boilers | AFUE 80%, November 2015 with no requirement for 90%+ in California |
| | Pool Heaters | Gas-fired require efficiency of 82% |
| | Refrigerators and Freezers | Updated standards vary by size, but lower than ACM estimate |
| | Water Heaters | • For gas water heaters, EF of 0.675 for storage < 55 gal, 0.8012 EF > 55 gal, 0.82 EF for instantaneous<br>• For electric, 0.96 EF < 55gal, 2.057 EF > 55gal. |

After reviewing these proposed changes, Navigant assumed that each measure will likely pass through California codes and standards process over the time horizon of this study:

- Federal appliance standards already adopted for 2015-2018 will become California standards during the next Title 24 or Title 20 update cycle (e.g., clothes washers).
- Measures proposed for Title 24 or Title 20 standards will likely be adopted as they appear to meet cost-effectiveness criteria today, or will in the near future (e.g., high-efficacy lighting).
    - Note – In consultation with SCG, Navigant assigned a gas storage water heater as the baseline configuration for mixed-fuel homes. Although CEC staff has proposed gas tankless water heaters as the basis of design under the performance approach for Title 24-2016, using a storage water heater as the baseline allows for a greater variety of efficiency options.

We configured each mixed-fuel and electric-only model with these features to realistically simulate the baseline energy consumption that future ZNE homes will need to offset. Additionally, we reviewed any changes to the draft Title 24-2016 revisions that occurred after the start of the study. At the time of this writing, we have not recognized any major changes or omissions from this study.

*Title 24 and Exogenous Building Energy Loads*

Because the energy consumption for each home varies with the number and type of connected loads, Title 24 energy compliance calculations consider a subset of building loads, including: interior and exterior lighting, domestic water heating, space heating, space cooling, kitchen appliances, cleaning appliances, and miscellaneous loads. While this subset covers the majority of consumption for most homes, some homes have "exogenous" loads not included under Title 24 such as pool heating, pool pumps, and in-home vehicle fueling/charging systems. To accurately reflect the diversity of homes built in Southern California, we conducted simulations both with and without the exogenous loads for each home size, location, and fuel configuration.

- **Pool Heating and Pumps**
    - California Title 24-2013 Alternative Compliance Methodology (ACM) manual and 2008 California HERS Technical Manual provides the operating characteristics and schedules for gas and electric pool heaters and pool pumps.
- **Electric Vehicles and Home Charging**
    - Electric vehicle (EV) annual consumption estimated at 5,100 kWh/yr. assuming 34 kWh/100 miles and 15,000 miles/year[20].
    - Home charging station efficiency estimated at 86.5%[21] with standby power at < 5%[22] for a total EV consumption of 5,940 kWh/yr.
    - Charging schedule estimated using LADWP field data gathered by *The EV Project*.[23]

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[20] Estimate based on Nissan Leaf, Chevrolet Volt, and Tesla S from www.fueleconomy.gov. Accessed October 2014.
[21] Forward et al. 2013. "An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency." Efficiency Vermont. March 20, 2013.
[22] Estimate based on BlinkHQ. www.blinkhw.com . Accessed October 2014.

- **Natural Gas Vehicles and Home Refueling**
    - Natural gas vehicle (NGV) annual consumption estimated at 577 therms/year assuming 3.2 gasoline gallons equivalent (GGE)/100 miles, 10 therms per 8.32 GGE and 15,000 miles/year[24].
    - Home refueling station electrical consumption estimated at 912 kWh/year assuming 1.9 kWh/GGE for 480 GGE/year[25].
    - Home refueling schedule assumed to match that of EVs[23].

See Appendix D for full calculation for EV and NGV loads.

*Solar PV and Solar Thermal Systems*

Homes reach ZNE status through a combination of efficiency measures that lowers the home's energy consumption and renewable energy generation that offsets the remaining energy consumption. ZNE homes use rooftop solar PV to generate electricity, but some also use solar thermal systems to offset domestic hot water, space heating, and pool heating loads. To understand the potential benefits of using a solar thermal system in conjunction with solar PV, we conducted simulations both with and without rooftop solar thermal systems for each home size, location, and fuel configuration. As discussed in Section 4.2.4, solar PV and thermal output varies substantially with building orientation under the assumption that the solar system remains on the back roof.

#### *2.1.1.4 Technology Cost*

Because BEopt optimizes for lowest cost of conserved or produced energy, obtaining accurate technology cost is critical to our analysis. We used the following resources for measure cost estimates:

- Where applicable, we first used values from Database for Energy Efficient Resources (DEER) Measure Cost Database first[26].
- If the technology is not present in DEER, we consulted NREL's National Residential Efficiency Database[27].
- For solar PV costs, we used cost per capacity values ($/W) for 2013-2014 residential installations in California from California Solar Statistics[28].
- For advanced technologies, we referred to manufacturer literature, research studies, DOE research and development (R&D) roadmaps, and other resources.

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[23] Schey, Stephen. 2013. "Quarter 2, 2013 Quarterly Report." The EV Project. August 5, 2013. Available at: http://www.theevproject.com/cms-assets/documents/127233-901153.q2-2013-rpt.pdf

[24] Estimate based on Honda Civic NG from www.fueleconomy.gov. Accessed October 2014.

[25] Estimate based on Phill Refueling System. http://www.wisegasinc.com/wg-phill.htm. Accessed February 2015.

[26] Measure costs retrieved at http://www.deeresources.com/ from the following databases: *READI v.2.0.2 (DEER and Non-DEER Ex Ante data for the 2013-2014 Cycle – Under Development, Draft for Review)*, and *Revised DEER Measure Cost Summary (05_30_2008) Revised (06_02_2008).*

[27] National Residential Efficiency Database. Version 3.0.0 Accessed October 2014. Available at: http://www.nrel.gov/ap/retrofits/

[28] California Solar Statistics. Date Range 2013-2014, Residential. Represents >30,000 projects. Accessed October 2014. http://californiasolarstatistics.ca.gov/

### *2.1.1.5 Post-Simulation Technologies*

BEopt contains the majority of building features and technologies available to ZNE homes, but several technologies with limited market adoption to date required a separate, post-simulation analysis. We modelled technologies such as solar cooling, absorption chillers, micro-combined-heat-and-power systems (mCHP) by using available cost and performance data (e.g., $/ton, coefficient of performance (COP), kW/ton, etc.) against the hourly building loads simulated in BEopt. For these cases, we relied on our experience with emerging building technologies[29] and additional market research to develop simplified performance and cost models. For example, we matched the space cooling, space heating, and water heating demand (Btu) to the absorption heat pump performance characteristics to determine the impacts on electricity, natural gas, and ultimately TDV energy consumption relative to a baseline system. Table 6 summarizes the post-simulation technologies and key data sources.

Section 3.3 provides additional details on post-simulation analyses

**Table 6. Selected Post-Simulation Technologies**

| Technology | Manufacturers / Data Sources |
|---|---|
| **mCHP** | • **Engine-Based:** NextAire, M-CoGen, ECR FreeWatt, Viessmann, Vaillant, Bosch, Whisper Tech, Yanmar, Otag, Energetix, Baxi, Ecogen, BDR Therma, Ecopower<br>• **Fuel Cells:** BlueGen, Toshiba-Baxi, Panasonic-Viessmann, Plug Power, BDR Therma, Doosan, Hexis, GS Fuel Cell, Toyota/Kyocera, ENE-FARM program, Callux program, ene-field program |
| **Gas Heat Pumps** | • **Absorption:** Robur, Vicot, Veissman, Vaillant, SolarNext, ClimateWell, DOE BTO, ARPA-e, EU's Heat4U Project<br>• **Adsorption:** Viessmann, Vaillant, SorTech, InvenSor, SolarNext<br>• **Other:** ThermoLift (Vuilleumier) |
| **Energy Storage / Electric Batteries** | • **Manufacturers, Integrators, and Installers:** Solar City, Panasonic, SMA, E3/DC, Redfow, Sunverge Energy, ReneSolar, Stem, Coda, Green Charge Networks. |
| **Solar Thermal Heating and Cooling** | • **Manufacturers:** various manufacturers of solar thermal systems tied with absorption, adsorption heat pump manufacturers (see below)<br>• **Research:** DOE Building Integrated Solar Technologies Roadmap, EU's RHC program, others. |

### 2.1.2 Conduct ZNE Building Simulations

After reviewing the proposed modeling plan with SCG technical and program staff, Navigant configured the baseline ZNE options and set of efficiency measures, and performed the suite of ZNE building simulations. Table 7 provides the details for the simulation schedule.

[29] We have analyzed several of these emerging residential technologies in-detail for the U.S. Department of Energy, Buildings Technologies Office, including: Goetzler et al. 2014. "Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies." March 2014., and Goetzler et al., 2012. "Energy Savings Potential and RD&D Opportunities for Residential Building HVAC Systems." September 2012.

**Table 7. Selected Modeling Plan Criteria**

| Attribute | Number of Options | Modeling Options |
|---|---|---|
| **Floor Plan** | 3 | • Single-Story, 1,800 sq.ft.<br>• Two-Story, 2,500 sq.ft.<br>• Two-Story, 3,200 sq.ft. |
| **Location** | 5 | • Los Angeles – CZ 6<br>• Pasadena – CZ 9<br>• Riverside – CZ 10<br>• Bakersfield – CZ 13<br>• Palm Springs – CZ 15 |
| **Fuel Configuration** | 2 | • Mixed-fuel<br>• Electric-only |
| **Modeling Scenario** | 4 | • Scenario 1 – Title 24 and HERS loads with energy efficiency, mCHP, solar PV<br>• Scenario 2 – Title 24 and HERS loads with energy efficiency, mCHP, solar PV, solar thermal<br>• Scenario 3 – Title 24, HERS, and exogenous loads with energy efficiency, mCHP, solar PV, solar thermal<br>• Scenario 4 – Title 24 and HERS loads with energy efficiency, demand response (DR) capabilities, mCHP, solar PV, solar thermal |
| **Orientation*** | 2-4 | • Scenario 1 – North, East, South, West<br>• Scenario 2 – North, South<br>• Scenario 3 – North, South<br>• Scenario 4 – North, South |
| **300 Total Optimization Simulations** | | |

Note – As discussed in Section 4.2.4, building orientation has a substantial effect on solar PV system output and a negligible impact on home energy consumption for the sample home designs. Because the Scenario 1 simulations revealed how each home's energy consumption and PV system changed with orientation, Navigant could infer the impacts for the moderate East and West directions in the subsequent scenarios. By comparing the results for North and South orientations in Scenarios 2-4 to those in Scenario 1, Navigant extrapolated East and West results, reducing the number of simulations by 45%.

Section 3.2 contains further details on the building simulation methodology.

### 2.1.3 Technical Evaluation

At the conclusion of the building simulation modeling, we compiled the technical results for the optimized ZNE home designs including:

- Energy consumption by fuel type and end-use for baseline and optimized ZNE homes (TDV, kWh, Therm, Btu, etc.)

- Energy savings for optimized ZNE homes (TDV, kWh, Therm, Btu, etc.)
- Optimized technology selections for each building option, appliance, etc.
- Capacity of on-site solar PV system and other advanced technologies (kW, kBtu/hr., etc.)

Section 4 contains further details on the technical evaluation results.

### 2.1.4 Economic Evaluation

At the conclusion of the building simulation modeling, we analyzed the economics of each optimized ZNE home design. At a minimum, these selections include an optimized result for each home design, location, fuel configuration, and key design scenarios identified in the modeling plan. For each result, we used BEopt assumptions, market research, and Navigant experience to enumerate the life-cycle project costs and benefits of high-efficiency technologies over baseline features. With this information, we conducted three levels of economic analysis, as outlined in Table 8, each focused on a different audience and goal.

**Table 8. Attributes of Economic Analyses**

| Economic Perspective | Evaluation Criteria |
|---|---|
| **Customer** | • Total cost of ZNE features (e.g., upfront costs, installation cost, replacement cost)<br>• Incremental cost to ZNE<br>• Incremental mortgage payments<br>• Annual utility bills<br>• Homeowner payback<br>• Infrastructure needs (e.g., available roof size for solar resources)<br>• Annual GHG emissions<br>• Maintenance, safety, noise, reliability, and other considerations. |
| **Utility Program** | • Lifetime energy and cost savings<br>• Gross and net electricity and natural gas consumption<br>• Upfront and life-cycle incremental cost to ZNE<br>• Annual GHG emissions<br>• Total Resource Cost (TRC) test values in the E3 Calculator |
| **Regulatory** | • Lifetime incremental and utility costs<br>• Lifetime savings on TDV basis from efficiency and on-site renewable measures. |

For each case, we compared the results of the three economic analyses for mixed-fuel and electric-only configurations and identify where mixed-fuel homes have comparable, greater, or reduced attractiveness relative to electric-only configurations. For these instances, we conducted further analysis of technical and economic results to determine the underlying causes and trends for economic outcomes. Where mixed-fuel results are less attractive, we quantified the disadvantage compared to electric-only ZNE homes, investigated potential alternatives, and recommended strategies to address this issue for builders, homeowners, utility technical and program staff, and regulators. Conversely, where mixed-fuel homes greater or equal attractiveness, we highlighted the key advantages and potential strategies to communicate these benefits to stakeholders. Table 9 outlines several of the major financial assumptions used in the economic analysis.

**Table 9. Financial Assumptions**

| Metric | Value | Source |
|---|---|---|
| **Mortgage Interest Rate** | 4.12% | Freddie Mac National Average (October 2014)[30] |
| **Mortgage Period** | 30 years | HERS 2008 |
| **Inflation Rate** | 2.40% | BA Simulation Protocols[31] |
| **Discount Rate** | 3% | BA Simulation Protocols, HERS 2008 |
| **Federal Tax Rate** | 28% | BA Simulation Protocols |
| **State Tax Rate** | 9.30% | BA Simulation Protocols |

Section 5 contains further details on the economic evaluation results.

### 2.1.5 Summarize Findings and Recommend Activities

To understand how optimized ZNE homes might change in future years, we evaluated the impacts of advanced technologies under several cost and performance projections and incorporated these impacts into our results for mixed-fuel and electric-only ZNE homes. In addition, we compared these technical and economic results against available information from past research studies on builder and customer perspectives on natural gas appliances, ZNE homes, and other topics. We then summarized these findings and developed a set of potential activities for SCG and other stakeholders to support the adoption of mixed-fuel ZNE homes among homebuilders, utility staff, and regulators.

Section 7 reviews available past research on customer and builder perspectives, Section 8 contains a summary of results, while Section 9 describes the recommended activities.

[30] Freddie Mac. 2014. "Mortgage Rates Survey." Accessed October 2014. Available at: http://www.freddiemac.com/pmms/

[31] Wilson et al. 2014. "2014 Building America House Simulation Protocols." March 2014. http://energy.gov/sites/prod/files/2014/03/f13/house_simulation_protocols_2014.pdf

# 3. Evaluation Methodology

## 3.1 Section Summary

This section summarizes the methodology employed to develop and analyze the results from the building modeling study. As outlined in Figure 18, we configured and ran the BEopt building simulation models for each ZNE home scenario, evaluated additional technologies not included in the software, analyzed technical results, and performed additional analyses to determine the economic impacts for ZNE homes.

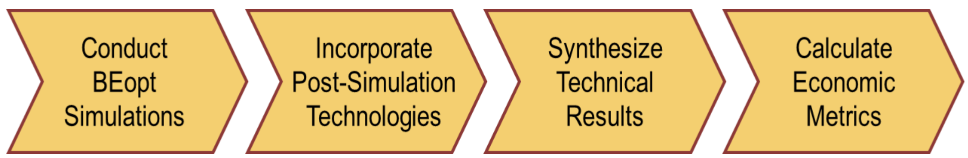


**Figure 18. Methodology Overview**

The BEopt software selected an optimal mix of efficiency and renewable energy technologies for each ZNE home based on the lowest life-cycle cost to reach ZNE status on a TDV basis. The optimization process involved several stages, where each combination of efficiency options is simulated before selecting the mix with the lowest $/TDV-offset. Once identifying the most cost-effective option in each step, the technology becomes part of the new energy baseline, and the process begins again until reaching the ZNE goal.

For emerging technologies not featured in BEopt (e.g., mCHP), we modeled the technology's performance against the hourly simulated consumption values and then evaluated its cost-effectiveness relative to other technologies. Technologies that show a net TDV benefit could technically offer value to ZNE homes, but need to provide TDV energy savings at a lower incremental cost than competing technologies, (e.g., mCHP vs. solar PV systems).

While BEopt provides most of the economic measures of interest, we conducted additional economic analyses for homeowner mortgage payments, TRC estimates, and life-cycle benefit-cost analysis. Because federal and state programs offer a variety of incentives for advanced ZNE technologies, we also calculated homeowner economic metrics and TRC values assuming a 30% and 10% federal tax credit for solar PV systems.

## 3.2 Overview of Optimization Process

As part of the technical evaluation for mixed-fuel ZNE homes, Navigant conducted a building energy modeling study using the simulation software BEopt (Building Energy Optimization Tool).[32]. Navigant specified building parameters (e.g., location, orientation, utility rates, building features, etc.), customized cost and performance information for each ZNE home. Using these inputs, the software then developed optimized packages of technologies for mixed-fuel and electric-only under the TDV ZNE definition. The

[32] Christensen et al. 2006. "BEopt™ Software for Building Energy Optimization: Features and Capabilities." National Renewable Energy Laboratory. August 2006. https://beopt.nrel.gov/

results generated by the building simulations provide the technical and economic data to develop promotional packages for buildings, suggest areas for strategic RD&D activities in the roadmap, and provide technical assistance for internal SCG planning and external discussions.

Table 10 provides a summary of the key inputs and outputs of the optimization process.

**Table 10. Key Inputs and Key Outputs of Optimization Process**

| Key Inputs | Key Outputs |
|---|---|
| • Suite of available technology cost and performance<br>• Location data (e.g., utility rates, weather data)<br>• Home design and orientation | • Optimized suite of technologies<br>• Energy consumption (e.g., TDV, kWh, Btu)<br>• Incremental cost<br>• Utility cost |

BEopt's optimization process evaluates the advanced technology against alternatives on a $/TDV basis to determine whether the advanced technology may offer a more cost-effective pathway for the ZNE home. Because the home can reach ZNE status either through reduction in TDV energy consumption or on-site TDV energy production, advanced technologies must not only compete with more conventional efficiency options, but also incrementally larger solar PV system. For example, to be selected as the lowest-cost option for the ZNE home, an absorption heat pump must have a lower $/TDV-conserved value than the $/TDV-conserved value for high efficiency furnace options as well as the $/TDV-produced value for incremental solar PV addition.

Figure 19 and Figure 20 provide a visual representation for this optimization process using two illustrative examples. Note – these examples do not use real energy and cost results, but are a simplified illustration showing how the optimization process compares and selects different energy efficiency and production technologies.

### 3.2.1 Illustrative Example 1 – Single-Step Optimization Process

Illustrative example 1 evaluates the choice between several higher efficiency furnace options and an incrementally larger solar PV system in the following process:

- Each dot in Figure 19 represents the TDV energy consumption and life-cycle costs for a single configuration using the same home design and features, but with different heating system options (e.g., 90% AFUE furnace, 98% AFUE furnace, absorption heat pump), or the baseline heating system with an incrementally larger solar PV system.

- Each configuration provides TDV energy savings, but their value to the ZNE home differs based on their life-cycle cost, including purchase, installation, operating, and replacement costs. Ultimately, the simulation software would chose the option that provides the best value on a $/TDV basis over the 30 year evaluation period.

- The 98% AFUE furnace (i.e. Red Dot) is not a viable option because the upfront incremental cost exceeds the operational savings relative to the standard furnace.

- The 90% AFUE furnace and absorption heat pump (i.e., Blue Dots) are viable options for achieving ZNE because their operational savings exceed their incremental costs over the standard furnace. In this situation, the absorption heat pump not only provides larger TDV energy savings than the 90% AFUE furnace, but also has a lower $/TDV-conserved value, as shown by the slope of their respective lines. If additional solar PV were not an option, the absorption heat pump would provide the most cost-effective path to ZNE goal of these limited options.

- In this case, the incrementally larger solar PV system (i.e., Green Dot) provides the lowest cost to reach ZNE goal on a $/TDV basis as shown by the slope of their respective lines. The PV system's steeper slope suggests that the combination of a standard furnace with a slightly larger PV system is more cost effective than installing an advanced heating system in this situation.

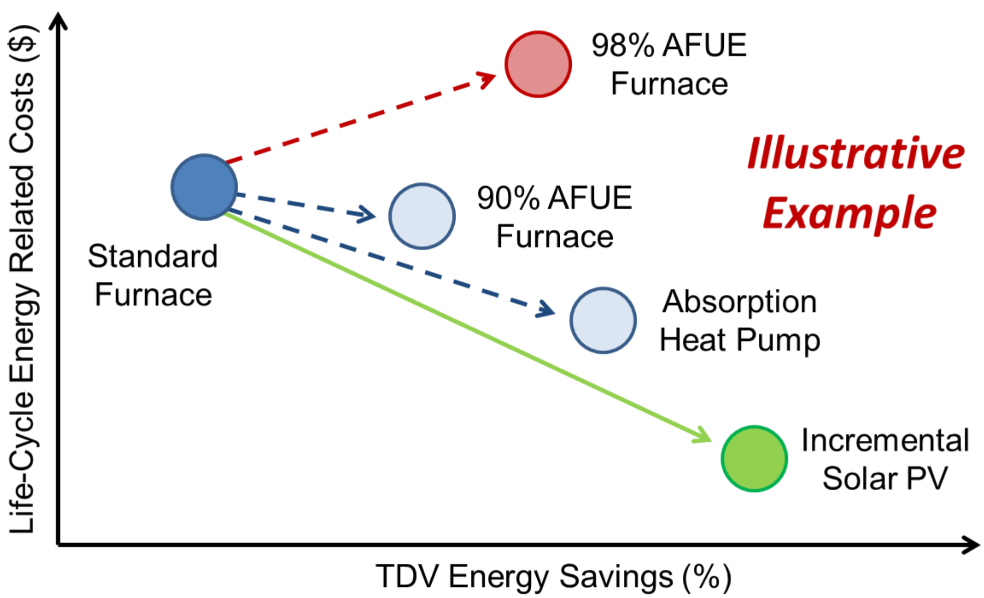


**Figure 19. Illustrative Example 1 - Evaluation of Advanced Space Heating Technologies Relative to Solar PV System**

### 3.2.2 Illustrative Example 2 – Multiple-Step Optimization Process

Illustrative example 2 introduces an additional efficiency measure, a tankless water heater, into the optimization process in Example 1. Example 2 evaluates the choice between several higher efficiency furnace options, a tankless water heater option, and an incrementally larger solar PV system in the following process:

- Similar to Example 1, the advanced furnace options are not cost-effective compared to the incrementally larger solar PV system, but the tankless water heater does show more cost-effective savings. Although the tankless water has lower savings percentage, its $/TDV-conserved value is lower than the $/TDV-produced for an incrementally larger solar PV system for the same savings percentage.

- Because the ZNE home must offset 100% of its TDV consumption and solar PV output is scalable by increasing the size of the system, the optimization algorithm selects efficiency measures that show cost-effective savings compared to solar PV first, and then select a smaller solar PV system size.

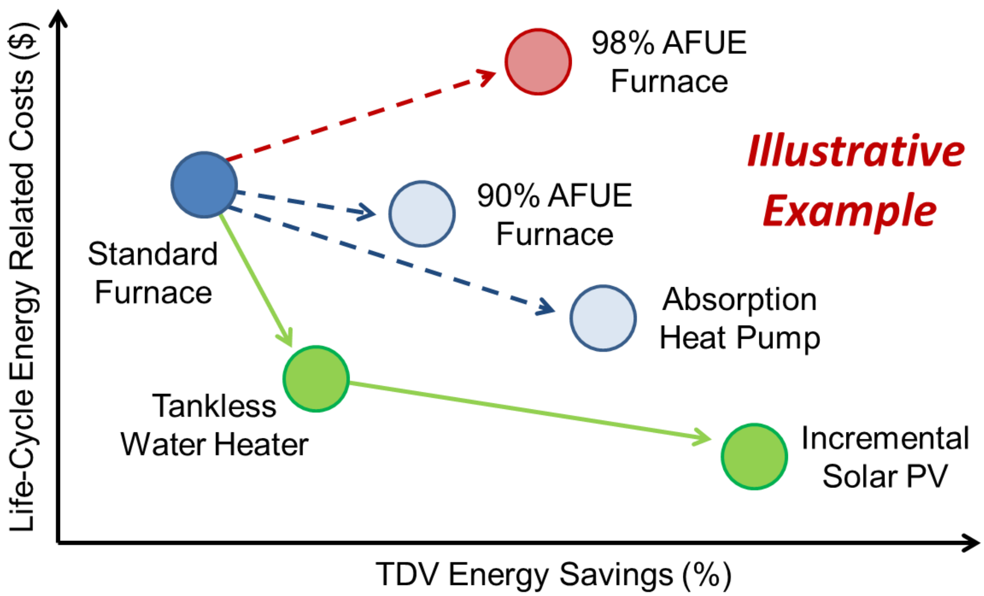


**Figure 20. Illustrative Example 2 - Evaluation of Advanced Space and Water Heating Technologies Relative to Solar PV System**

### 3.2.3 Summary of Optimization Process

Illustrative examples 1 and 2 provide an overview for the optimization process in a limited set of conditions. In the actual software, the multiple-step approach includes all end-uses and all efficiency options at each step and selects the single most cost-effective measure at each step before starting over for the new energy consumption profiles. For example, the optimized process for a ZNE home may have six steps, adding five efficiency measures before adding a solar PV system, as shown in the illustrative Figure 21. The number of optimization steps and selected efficiency options will vary with each home size, location, utility rates, orientation, and other characteristics.

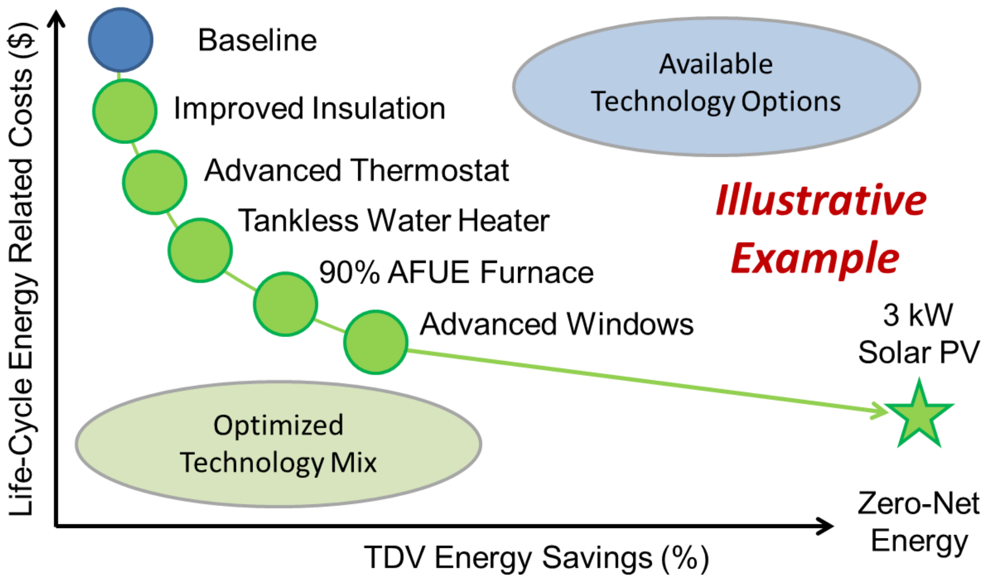


**Figure 21. Illustrative Optimization Process**

## *3.3 Post-Simulation Processing Technologies*

The BEopt simulation software can accommodate most of the advanced technologies for ZNE homes, but the software does not include some advanced technologies due to their low market adoption to date. For these systems, we estimate their potential impacts for mixed-fuel and electric-only ZNE homes by modeling the technology's performance against the hourly simulated consumption values for applicable end-uses including: space cooling, space heating, water heating, total electricity, etc. We then evaluate the technology's benefits on a $/TDV basis against alternative technologies to understand whether the advanced technology would offer more attractive savings under several cost estimates. Table 11 summarizes the key inputs and outputs for modeling post-simulation technologies.

**Table 11. Key Inputs and Key Outputs for Post-Simulation Technologies**

| Key Inputs | Key Outputs |
|---|---|
| • Technology cost and performance<br>• Baseline end-use consumption (e.g., TDV, kWh, Btu)<br>• Home design and orientation | • Energy consumption of advanced technology (e.g., TDV, kWh, Btu)<br>• $/TDV savings value |

### 3.3.1 Advanced Gas Systems

#### *3.3.1.1 mCHP*

Through the conversion or combustion of natural gas, small-scale or micro-combined-heat-and-power (mCHP) systems generate electricity at the home and capture thermal energy as a byproduct (i.e., waste heat recovery). As illustrated in Figure 22, the mCHP system can generate a net positive TDV value for mixed-fuel ZNE homes in the following ways:

- The mCHP system's electrical output can reduce on-site TDV energy consumption by offsetting the home's electricity consumption, or produce TDV energy by exporting the excess electricity to the local electrical grid.
- The mCHP system's thermal output can reduce on-site TDV energy consumption by offsetting the home's electricity and gas consumption associated with space and water heating. The home recovers or captures the waste heat from the mCHP system to satisfy a portion of the thermal load. Most ZNE homes do not feature a practical manner to export excess thermal energy, so once the homes thermal loads are satisfied, the excess thermal energy provides no additional TDV value.

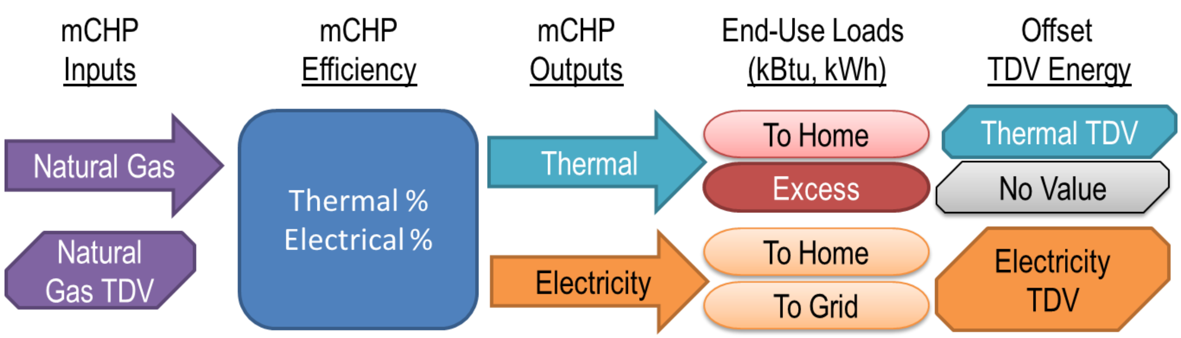


**Figure 22. Summary of TDV Energy Impacts for mCHP Systems Including Waste-Heat Recovery**

As shown in the equation below, the net value of a mCHP system on a TDV basis depends on how much the mCHP's thermal and electrical outputs offset on-site TDV consumption or export TDV energy from the home relative to the on-site natural gas consumption of the mCHP system. Compared to solar PV systems, mCHP systems offer an advantage in the ability to satisfy thermal loads at the home, but also carry the disadvantage of negative TDV values associated with fuel consumption.

$$TDV_{net} = Offset\,TDV_{thermal} + Offset\,TDV_{electric} + Export\,TDV_{electric} - Consumed\,TDV_{gas}$$

The net TDV benefit of a specific mCHP system depends on the thermal and electrical efficiencies of the mCHP system and the thermal load profile of the specific home. To understand the value of different mCHP systems for mixed-fuel ZNE homes, we developed a spreadsheet model to estimate TDV consumption and production of mCHP systems with the modeled end-use home consumption for each location. Our analysis considered both engine-based and fuel cell mCHP systems with a range of electricity and thermal performance characteristics. In addition to modeling various system capacities (based on electrical production), we evaluated each mCHP technology under a range of current and future cost projections, shown in Table 12. See Appendix E for additional details and assumptions on mCHP performance and costs.

**Table 12. Performance and Cost Assumptions for mCHP Systems**

| Category | Metric | Performance (Efficiency %) | | | | Technology Cost ($/$W_e$) | | |
|---|---|---|---|---|---|---|---|---|
| | | Output | Low | Medium | High | Low | Medium | High / Current |
| Micro-CHP Systems | Gas Engine mCHP | Electrical | 4% | 22% | 25% | $5 | $15 | $20 |
| | | Thermal | 85% | 54% | 68% | | | |
| | Fuel Cell mCHP | Electrical | 30% | 38% | 60% | $10 | $15 | $20 |
| | | Thermal | 65% | 39% | 24% | | | |

Note – Thermal efficiency assumes waste-heat recovery. See Appendix E for additional details and assumptions on mCHP performance and costs.

Our analysis first evaluated whether the mCHP system could provide a net TDV benefit for a specific mixed-fuel home in each location under the range of performance characteristics (e.g., capacity, thermal efficiency, electrical efficiency). We modeled each mCHP system at a range of capacities (0.5-5 kW) to understand how net TDV value changes once the mCHP system satisfies the home's thermal loads. We then compared the mCHP system's benefits on a $/TDV basis to a solar PV system to understand whether the mCHP system may offer a lower cost to reach ZNE status. We evaluated each system under three cost assumptions outlined in Table 12, with current cost estimated as the high scenario ($20/W electric).

### *3.3.1.2 Gas Heat Pumps*

In place of conventional HVAC and water heating systems, gas heat pumps could potentially offer reduced TDV energy consumption for mixed-fuel ZNE homes. Gas-fired heat pumps provide space and water heating with thermal efficiency (heating COP > 1) greater than gas-fired water heaters and furnaces, while also providing space cooling. Additionally, the system can recover waste heat in cooling mode to offset water heating loads. As illustrated in Figure 23, gas heat pumps can generate a net positive TDV value for mixed-fuel ZNE homes by generating the same thermal output of conventional equipment with a lower TDV value.

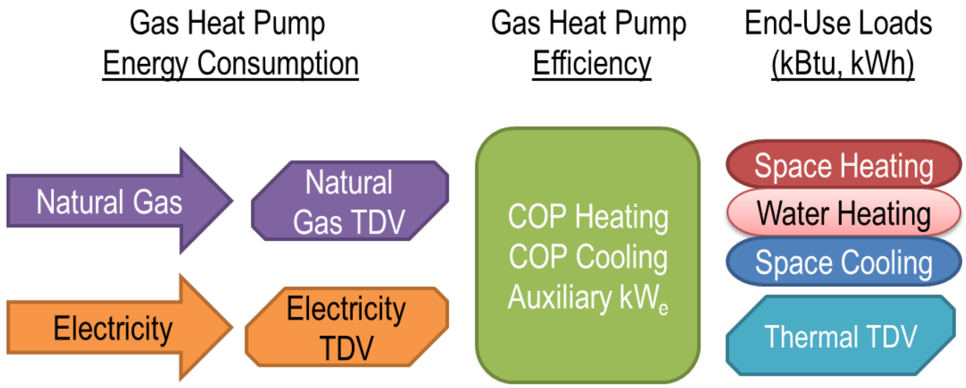


**Figure 23. Gas Heat Pump TDV Impacts**

As shown in the equation below, the net value of a gas heat pump on a TDV basis depends on how much the system's thermal outputs offset the home's TDV consumption relative to the gas heat pump's natural gas and electricity consumption. For the mixed-fuel ZNE home, the gas heat pump would offset the consumption for a non-condensing furnace, SEER 14 air conditioner, and standard efficiency storage water heater.

$$TDV_{net} = Offset\,TDV_{thermal} - (Consumed\,TDV_{gas} + Consumed\,TDV_{electric})$$

The net TDV benefit of a specific gas heat pump depends on the heating and cooling efficiencies (COPs) and the thermal load profile of the specific home. To understand the value of different gas heat pumps for mixed-fuel ZNE homes, we developed a spreadsheet model to estimate TDV consumption with the simulated end-use home consumption for each region. Our analysis considered both engine-based and thermally activated[33] gas heat pumps with a range of heating and cooling COPs, shown in Table 13. Where applicable, we examined cooling-only, heating-only, and combined heating-and-cooling operation. See Appendix E for additional details and assumptions for gas heat pump performance and costs.

[33] We considered several thermally activated technologies including absorption, adsorption, and Vulleumier heat pumps. Appendix E contains additional details.

**Table 13. Performance and Cost Assumptions for Gas-Fired Heat Pumps**

| Category | Metric | Performance (Heating / Cooling COP) | | | | | | Incremental Cost ($/kBtu-hr.) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | | Medium | | High | | Low | Medium | High |
| | | Heating | Cooling | Heating | Cooling | Heating | Cooling | | | |
| Gas-Fired Heat Pumps | Engine Based | 1.2 | 1.1 | 1.5 | 1.2 | n/a | n/a | $56 | $67 | $78 |
| | Both Heating & Cooling | 1.3 | 0.6 | 1.6 | 0.8 | 2.2 | 1.2 | | | |
| | Heating Only | 1.2 | – | 1.4 | – | 1.6 | – | | | |
| | Cooling Only | – | 0.6 | – | 0.7 | – | 0.8 | | | |

Note - Assumes 0.023 kW electric per KW thermal consumption for heating and 0.046 kW electric per KW thermal consumption for cooling. Thermal efficiency assumes waste-heat recovery. See Appendix E for additional details and assumptions for gas heat pump performance and costs.

Our analysis evaluated whether the gas heat pump could provide a net TDV energy savings for a specific mixed-fuel home in each location under a range of operating modes and efficiencies. Then we compared the gas heat pump's benefits on a $/TDV basis to a higher efficiency HVAC system to understand whether the gas heat pump may offer a lower cost to reach ZNE status. We evaluated each system under three cost assumptions outlined in Table 13, with current cost estimated as the high scenario ($78/kBtu-hr incremental cost).

### 3.3.2 Advanced Electrical Systems

#### *3.3.2.1 Electric Battery (Modeled as Demand Response)*

Traditionally featured in off-grid homes, home energy storage systems with electric batteries have received increased interest in recent years due to the decreasing cost of batteries, increased adoption of on-site solar PV systems, and prevalence of TOU and/or tiered electricity rates. Under most scenarios, the electric batteries charge during low- and mid-peak hours using the solar PV system and reduce the home's grid-supplied electricity consumption during peak hours when electricity rates are highest. By reducing energy consumption of grid-supplied electricity, the batteries offset TDV consumption for the home in a similar process to efficiency measures.

BEopt does not offer an electric battery option, but does contain a similar system for load reductions with a demand-response (DR) controller. We modelled the electric battery system as a demand-response system to offset the equivalent of 10 kWh per day and compared it to other technology options on a $/TDV-conserved basis. Table 14 provides several estimates for a 5kW, 10kWh battery system.

**Table 14. Cost Assumptions for Electric Battery Systems**

| Category | System Cost ($/kWh) | | | |
|---|---|---|---|---|
| | Current | Medium-High | Medium-Low | Low |
| **Electric Battery System** | $750[1] | $600[1] | $300[1] | $100[2] |

1 – Wang, Ucilia. 2014. "Coming to Your Home: A Battery the Size of a Fridge." Forbes Green Tech Online. December 3, 2013.
2 – Ayre, James. 2014. "Tesla's Gigafactory May Hit $100/kWh Holy Grail of EV Batteries, Report Predicts." Cleantechnica.com. September 5, 2014.

### 3.3.3 On-Site Renewable Energy Systems

#### *1.1.1.1 Solar PV Systems*

BEopt offers solar PV systems as standard technology options with discrete sizes from 0-12 kW in 0.5 kW increments. Figure 24 shows our assumed costs ($/W-DC) for solar PV systems. For ZNE homes, homebuilders optimize costs by designing solar PV systems a meet the exact needs of the home and can install systems in increments smaller than 0.5 kW. To account for this, we scale the optimized solar PV system size to accurately match the needs of the home. For example, if the BEopt simulation selects a 5 kW system for a home that only requires a 4.75 kW system to meet TDV requirements, we adjust the solar PV system's outputs to 4.75 kW. This scaling does not affect the optimization process because the per capacity output of a solar PV system is consistent for a given location and orientation, and per capacity costs are very similar over a +/- 0.5 kW capacity range.

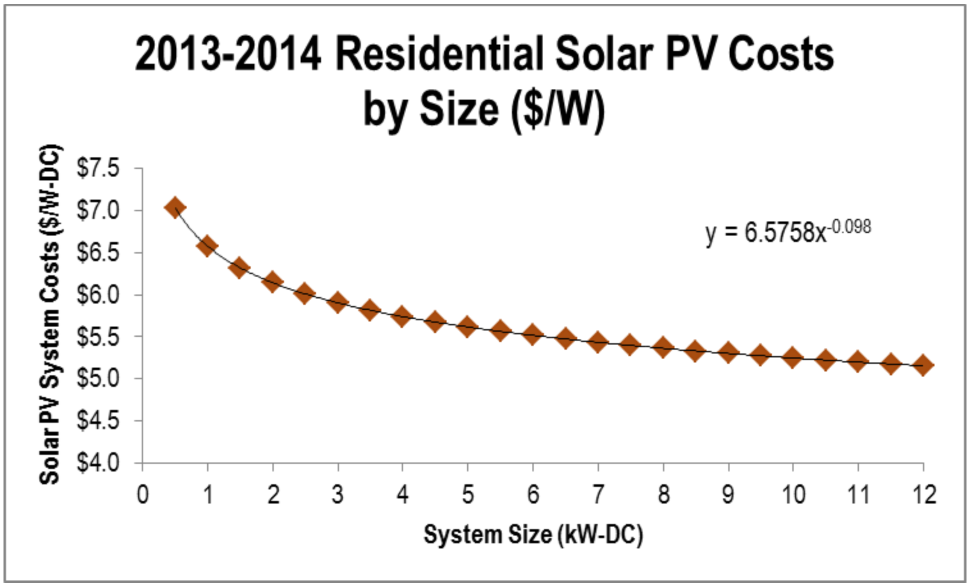


**Figure 24. Estimated California Solar PV System Costs by Size**

Source: CSI data for residential systems 2013-2014, accessed October 2014.[28]

### *3.3.3.1 Solar Thermal*

BEopt also offers solar hot water systems as standard technology options in 40 sq.ft. and 60 sq.ft. sizes, and we incorporated an additional 25 sq.ft. capacity. Table 15 provides the cost assumptions for the solar water heater with closed loop, flat-plate collectors and storage tank, not including any backup water heater. Each applicable simulation included these solar thermal options for domestic hot water pre-heating. For solar thermal technologies other than water heating (e.g., solar absorption cooling), we used the thermal outputs of the modeled solar thermal system to offset natural gas consumption of the advanced technology.

**Table 15. Cost Assumptions for Solar Thermal System**

| Category | Solar Thermal System Installed Cost | | |
|---|---|---|---|
| | 25 sq.ft. | 40 sq.ft. | 64 sq.ft. |
| Total System Cost | $6,000[1] | $7,179[2] | $7,554[2] |
| Per Capacity Cost ($/sq.ft.) | $240[1] | $179[2] | $118[2] |

1 – Estimate based on DOE Building Integrated Solar Roadmap[34]

2 – BEopt standard technology costs

[34] Goetzler et al. 2014. "Research & Development Needs for Building-Integrated Solar Technologies." Navigant Consulting, Inc. for U.S. Department of Energy Building Technologies Office. January 2014.

## 3.4 Calculation of Economic Metrics

The BEopt software provides most of the economic results of interest as direct outputs of the simulations, but we conducted additional economic analyses for some areas including:

- Homeowner mortgage payments
- Utility program goals through avoided cost and TRC estimates
- Life-cycle benefit-cost analysis.

### 3.4.1 Mortgage Payment Calculation

We estimated the incremental annual mortgage payments for ZNE homes using an amortization calculator from Wells Fargo[35], assuming 4.12% annual percentage rate (APR) for a 30 year mortgage. The calculator provided the total annual mortgage payment, as well as the principal and interest payments. We then estimated the homeowner's total annual cost by adding the net-present-value (NPV) of each ZNE home's life-cycle cost and utility bills assuming a 4.12% interest rate, and 3% discount rate over 30 years.  The equation below shows the homeowner annual cost calculation:

$$\text{Homeowner Annual Cost (\$)} = \text{Capital Recovery Factor} \times \left( \text{Net-Present Value of Life-Cycle Costs (\$)} + \text{Net-Present Value of ZNE Utility Bills (\$)} \right)$$

Appendix F contains assumptions for incremental mortgage analysis.

### 3.4.2 Avoided Cost and TRC Calculation

To understand how ZNE homes would be evaluated by utility energy efficiency programs, we estimated the avoided cost and TRC test values using the 2013-2014 E3 Calculator for SCG territory[36]. Within the E3 calculator, we entered the electricity and natural gas savings and NPV of the incremental life-cycle cost for each ZNE home design and location, assuming 85% net-to-gross, 2013 installation year, and 30 year lifetime[37]. Because the TRC test permits non-IOU incentives to reduce the cost of measures, we also calculated TRC values assuming a 30% and 10% federal tax credit for the upfront solar PV systems.

### 3.4.3 Life-Cycle Benefit-Cost Calculation

We evaluated the life-cycle benefits and costs for ZNE homes using the CEC Codes & Standards life-cycle methodology. The CEC methodology compares the NPV of life-cycle incremental cost of ZNE homes against the NPV of TDV energy savings as estimated by the CEC Energy Division[38]. The

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[35] Wells Fargo Home Loan Amortization Calculator. Accessed November 2014. Available at: https://www.wellsfargo.com/mortgage/tools/amortization

[36] E3. "Energy Efficiency Calculator-Draft 2013-2014 E3 Calculator Files." 2012. Available at: https://ethree.com/public_projects/cpuc4.php.

[37] We used NPV of incremental life-cycle costs consistent with Title 24 methodology. Utility efficiency programs commonly consider only the upfront incremental cost of the measure. Appendix G includes TRC results under both methodologies.

[38] Architectural Energy Corporation. 2011. "Life-Cycle Cost Methodology – 2013 California Building Energy Efficiency Standards." January 14, 2011. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/2011-01-14_LCC_Methodology_2013.pdf

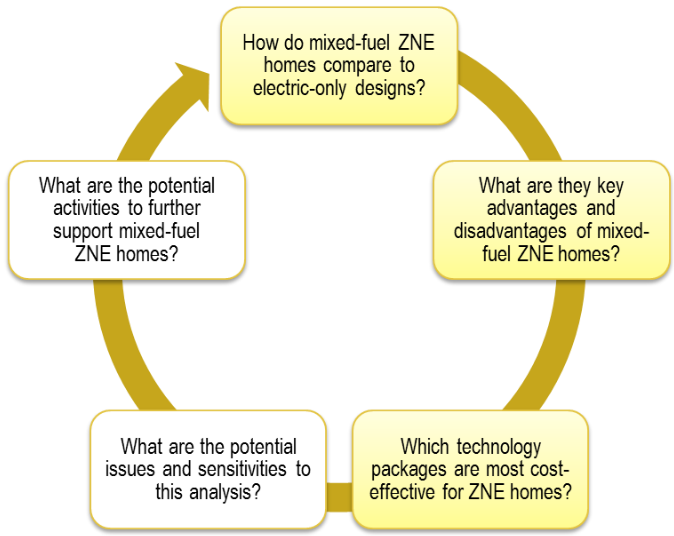
incremental costs include all associated costs over the life of the home, including upfront purchase, equipment replacement, maintenance, etc. This method assumes 3% discount rate, 30 year lifetime, and net present TDV value of $0.1732 per TDV-kBtu.

# 4. Technology Evaluation

## 4.1 Section Summary

This section summarizes the technical results of the analysis and answers the following key questions:

1. **How do mixed-fuel ZNE homes compare to electric-only designs?**
2. **What are the key advantages and disadvantages of mixed-fuel ZNE homes compared to electric-only ZNE homes?**
3. **Which technology packages are most cost-effective for ZNE homes, both now and in the future?**




## 4.2 Simulation Results

Navigant conducted building simulations for each home design, location, and suite of technology options to identify the measure combinations that provide the lowest life-cycle cost for new single-family homes to reach ZNE status. This section:

- Summarizes the technical results of the modeling study, focusing on the energy consumption and technology choices for baseline homes and ZNE homes optimized on a TDV basis.
- Discusses general observations regarding the selection of certain technology combinations relative to other measures.

While this section discusses technology costs and economic value of energy savings and/or production, Section 5 discusses the economic results of the modeling study.

Note – unless specifically noted, we present results for the Home B house size (2,500 sq.ft., two-story) for ease of reading. Section 4.2.7 discusses the results for Home A (1,800 sq.ft., single-story) and Home C (3,200 sq.ft., two-story).

### 4.2.1 Energy Consumption and Savings for Baseline and Optimized ZNE Homes

Table 16 provides the electricity, natural gas, and TDV energy consumption of baseline and optimized mixed-fuel and electric-only homes. Mixed-fuel homes generally have lower annual TDV energy consumption than electric-only homes due to the lower hourly TDV value of natural gas compared to electricity (See Figure 11). In each home configuration, electricity and TDV energy consumption increases substantially as HVAC loads increase from the moderate coastal region (Los Angeles), to inland regions (Pasadena, Riverside), and more extreme regions (Bakersfield, Palm Springs). As expected, natural gas consumption increases in colder regions (Bakersfield) and decreases for warmer regions (Palm Springs).

Further discussed below, the electric-only homes in Bakersfield experiences lower TDV consumption than the mixed-fuel homes in the region because the electric-only home selected a solar thermal water heating system when the other locations selected HPWHs. Title 24 allows both options for compliance of baseline home designs.

**Table 16. Annual Energy Consumption of Baseline and Optimized ZNE Homes by Location – Home B**

| Category | Location | Baseline Energy Consumption | | | Optimized Energy Consumption | | |
|---|---|---|---|---|---|---|---|
| | | Electricity (kWh) | Natural Gas (Therms) | TDV (MMBtu) | Electricity (kWh) | Natural Gas (Therms) | TDV (MMBtu) |
| Mixed-Fuel | Los Angeles | 4,206 | 285 | 100 | 4,200 | 235 | 93 |
| | Pasadena | 4,369 | 269 | 101 | 4,341 | 211 | 91 |
| | Riverside | 4,590 | 290 | 109 | 4,537 | 235 | 98 |
| | Bakersfield | 5,073 | 373 | 133 | 4,968 | 292 | 116 |
| | Palm Springs | 6,908 | 209 | 145 | 6,169 | 171 | 120 |
| Electric-Only | Los Angeles | 7,679 | – | 105 | 7,588 | – | 104 |
| | Pasadena | 7,702 | – | 106 | 7,570 | – | 104 |
| | Riverside | 8,133 | – | 112 | 7,945 | – | 108 |
| | Bakersfield | 9,258 | – | 131 | 7,579 | – | 108 |
| | Palm Springs | 9,555 | – | 148 | 9,297 | – | 137 |

Figure 25 and Figure 26 provide the baseline and optimized TDV energy consumption for mixed-fuel and electric-only ZNE homes, as well as the size for the solar PV system. For the Home B design (2,500 sq.ft.), new homes can reach ZNE goals with moderate efficiency savings and 3-5 kW solar PV systems, with mixed-fuel requiring 3.5-4.3 kW and electric-only requiring 3.8-5.0 kW. This suggests that reaching ZNE status over Title 24-2016 and other proposed codes is technically possible for both mixed-fuel and electric-only homes with current technologies.

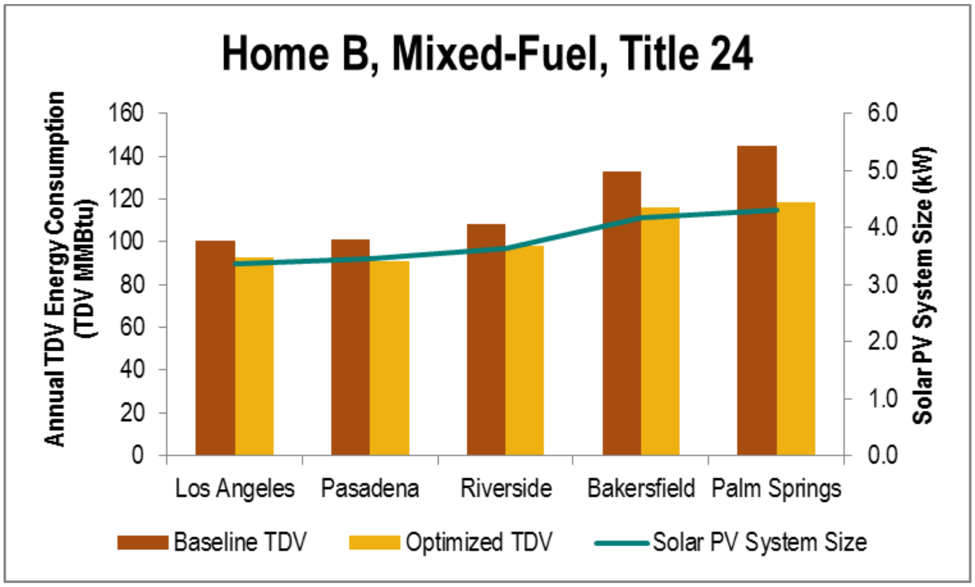



**Figure 25. TDV Energy Consumption and PV System Size for Mixed-Fuel ZNE Homes**

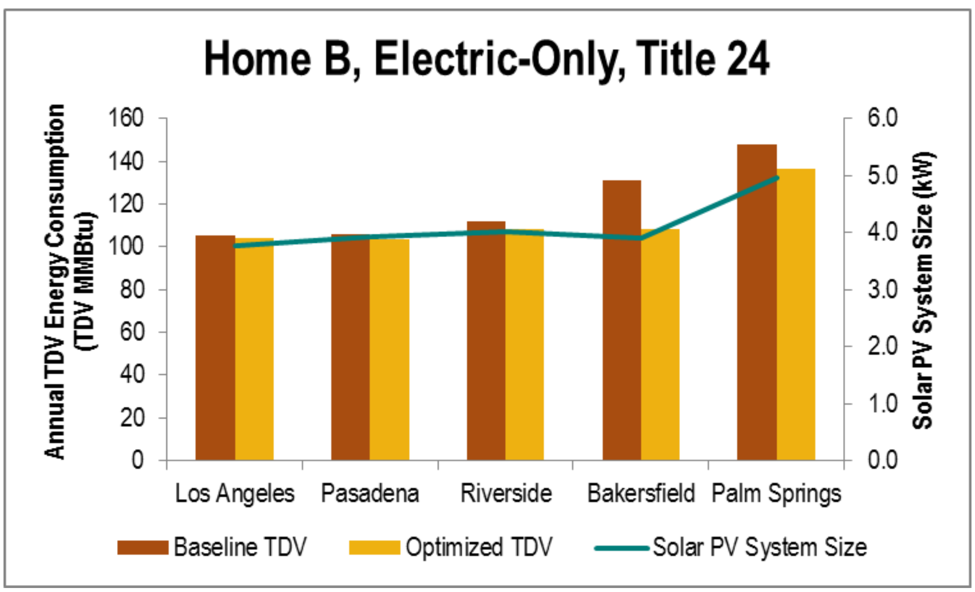



**Figure 26. TDV Energy Consumption and PV System Size for Electric-Only ZNE Homes**

ZNE homes combine both TDV savings from efficiency measures and TDV production from on-site renewable energy systems to offset the home's energy consumption. As seen in Table 17, the optimized ZNE Homes primarily reduced their net TDV consumption through solar PV systems (91% average TDV savings) with only moderate savings from efficiency measures (9% average TDV savings). With the exception of the electric-only Bakersfield scenario, mixed-fuel ZNE homes achieved greater savings than electric-only ZNE homes before adding solar PV capacity (8-18% vs. 1-8%). These values also provide an estimate for each ZNE home's HERS rating before adding solar PV systems, compared to a Title 24-2016 baseline. By definition, both mixed-fuel and electric-only homes achieve a HERS rating of zero when they reach ZNE goal on a TDV basis.

**Table 17. TDV Savings Values for Optimized ZNE Homes by Location – Home B**

| Category | Location | TDV Savings (MMBtu, Year 1) | | | | |
|---|---|---|---|---|---|---|
| | | Total TDV Savings to ZNE | Efficiency Measures | Solar PV | TDV Savings % Efficiency Measures | TDV Savings % Solar PV |
| Mixed-Fuel | Los Angeles | 100.3 | 7.6 | 92.7 | 8% | 92% |
| | Pasadena | 101.0 | 9.9 | 91.1 | 10% | 90% |
| | Riverside | 108.6 | 10.5 | 98.1 | 10% | 90% |
| | Bakersfield | 132.6 | 16.8 | 115.8 | 13% | 87% |
| | Palm Springs | 144.6 | 25.9 | 118.7 | 18% | 82% |
| Electric-Only | Los Angeles | 105.2 | 1.2 | 104.0 | 1% | 99% |
| | Pasadena | 106.1 | 2.4 | 103.7 | 2% | 98% |
| | Riverside | 112.1 | 3.7 | 108.5 | 3% | 97% |
| | Bakersfield | 130.9 | 22.6 | 108.3 | 17% | 83% |
| | Palm Springs | 148.0 | 11.3 | 136.7 | 8% | 92% |

As shown in Figure 27, mixed-fuel ZNEs generally have similar baseline TDV energy consumption values to electric-only homes. In most regions, mixed-fuel homes exhibit slightly lower TDV energy consumption and at worst (Bakersfield), have slightly higher consumption. This suggests that the choice of fuel availability does not substantially impact TDV energy consumption for homes built to Title 24-2016.

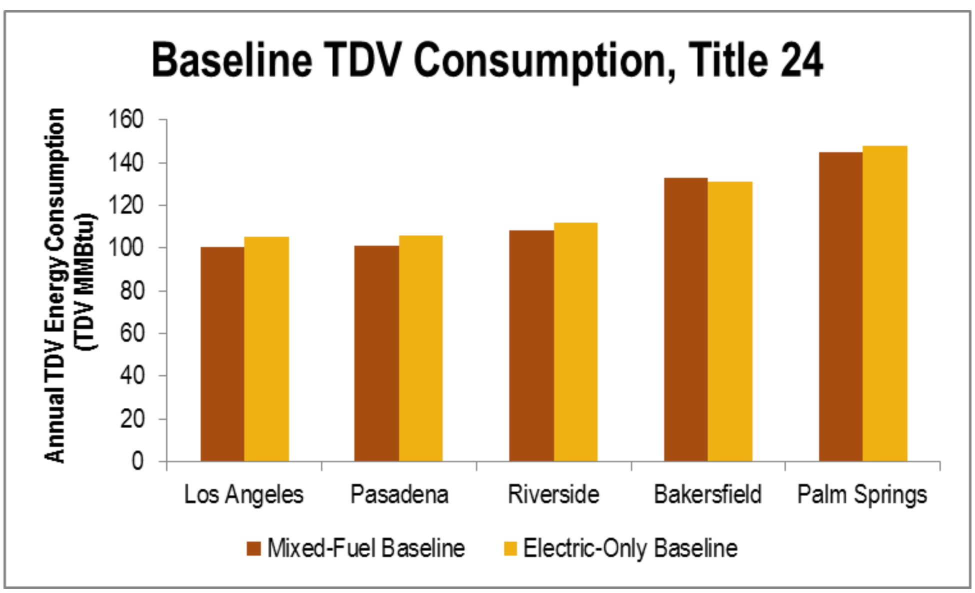



**Figure 27. Baseline TDV Energy Consumption for Mixed-Fuel and Electric-Only ZNE Homes**

Figure 28 provides a side-by-side comparison of optimized TDV consumption and PV system size for optimized mixed-fuel and electric-only ZNE homes. With comparable baseline TDV consumption and shared reliance on electricity production from solar PV systems to reach ZNE goal, optimized mixed-fuel and electric-only ZNEs have similar TDV consumption and solar PV system sizes. In most regions, optimized mixed-fuel ZNE homes have 10-13% less TDV consumption than electric-only homes and subsequently require smaller solar PV systems. For Bakersfield, where the electric-only ZNE home uses a solar thermal system in place of a HPWH, mixed-fuel ZNE homes have 7% greater TDV consumption than electric-only homes. Nevertheless, the results suggest that mixed-fuel and electric-only ZNEs require similar approaches to reach ZNE status.

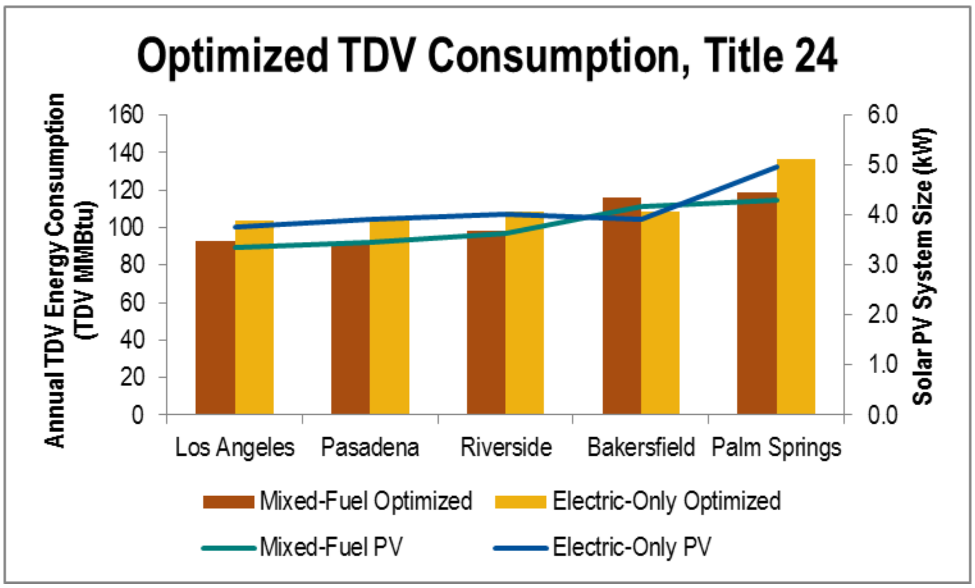



**Figure 28. Optimized TDV Energy Consumption and PV System Size for Mixed-Fuel and Electric-Only ZNE Homes**

By definition, ZNE homes produce as much on-site TDV energy as they consume. Because mixed-fuel ZNE homes consume both natural gas and electricity, the solar PV system for mixed-fuel homes must generally produce more electricity (kWh) than the home consumes annually[39], as shown in Table 18. Because the TDV value for electricity changes substantially throughout the day and year (see Figure 9), annual electricity consumption on a kWh basis can differ from annual TDV consumption depending on the home's load curves. As shown in Table 18, optimized electric-only ZNE homes produced less electricity on a kWh basis than they consume. In these cases, the solar electricity exported to the electrical grid during high TDV periods more than offsets nighttime energy consumption.

[39] Note – there is the possibility that the solar PV system could produce enough TDV energy on a kwh basis to offset the additional TDV consumption, but requires different operating schedules and characteristics.

**Table 18. Annual Energy Consumption of Optimized ZNE Homes by Location – Home B**

| Category | Location | Gross Annual Energy Consumption | | | Solar PV Production (kWh) | Net Annual Energy Consumption | | |
|---|---|---|---|---|---|---|---|---|
| | | Electricity (kWh) | Natural Gas (Therms) | TDV (MMBtu) | | Electricity (kWh) | Natural Gas (Therms) | TDV (MMBtu) |
| Mixed-Fuel | Los Angeles | 4,200 | 235 | 93 | 5,269 | -1,069 | 235 | 0 (ZNE) |
| | Pasadena | 4,341 | 211 | 91 | 5,211 | -870 | 211 | |
| | Riverside | 4,537 | 235 | 98 | 5,666 | -1,129 | 235 | |
| | Bakersfield | 4,968 | 292 | 116 | 6,599 | -1,631 | 292 | |
| | Palm Springs | 6,169 | 171 | 120 | 7,008 | -839 | 171 | |
| Electric-Only | Los Angeles | 7,588 | – | 104 | 5,914 | 1,674 | – | 0 (ZNE) |
| | Pasadena | 7,570 | – | 104 | 5,930 | 1,640 | – | |
| | Riverside | 7,945 | – | 108 | 6,264 | 1,681 | – | |
| | Bakersfield | 7,579 | – | 108 | 6,171 | 1,408 | – | |
| | Palm Springs | 9,297 | – | 137 | 8,070 | 1,227 | – | |

### 4.2.2 End-Use Loads for ZNE Homes

Figure 29 and Figure 30 illustrates various end-use loads within baseline and optimized ZNE homes on a TDV energy basis. Generally, Title 24 requirements and prescriptive measures address the following end-use loads when under the compliance definition: water heating, lighting, HVAC (i.e., space heating, space cooling, ventilation, and associated fans, pumps, etc.), major kitchen and laundry appliances, and an allowance for common miscellaneous plus loads (e.g., TVs, computers, etc.). Water heating loads show consistency across all regions while HVAC loads increase for more inland regions. For both mixed-fuel and electric-only configurations, HVAC and water heating efficiency measures reduced the TDV energy consumption for optimized ZNE homes. The TDV consumption for the majority of end-uses (e.g., miscellaneous electric loads, large appliances, lighting), did not decrease due to a lack of available efficiency options (e.g., high-efficacy lighting as baseline) or poor economics ($/TDV-offset) relative to an incrementally larger solar PV system (e.g., laundry equipment).

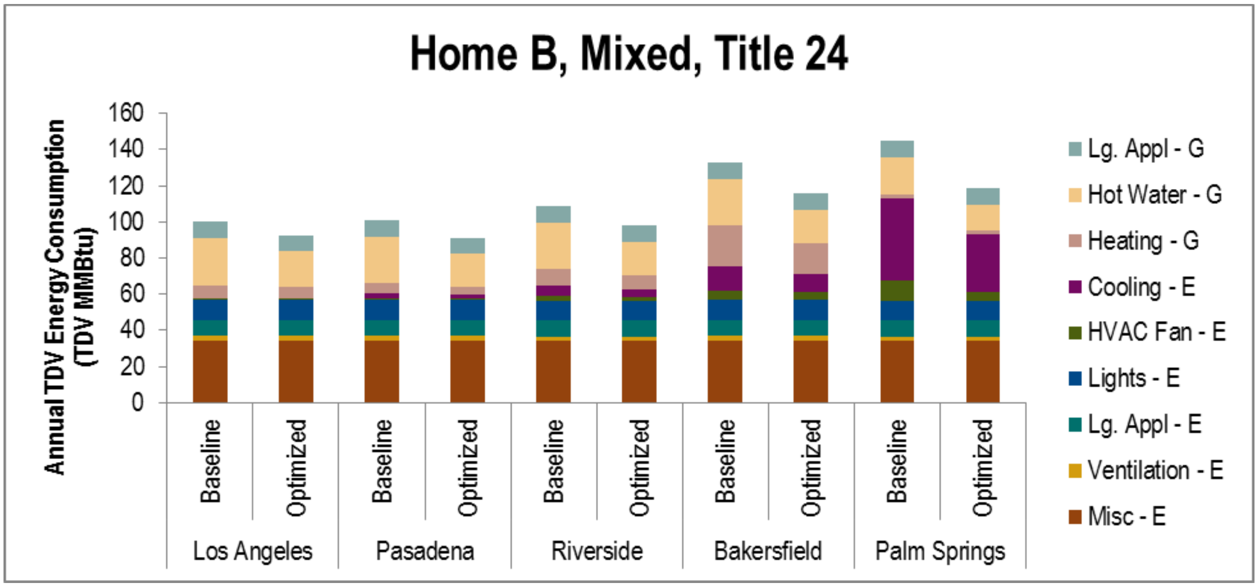



**Figure 29. End-Use TDV Energy Consumption for Mixed-Fuel ZNE Homes**

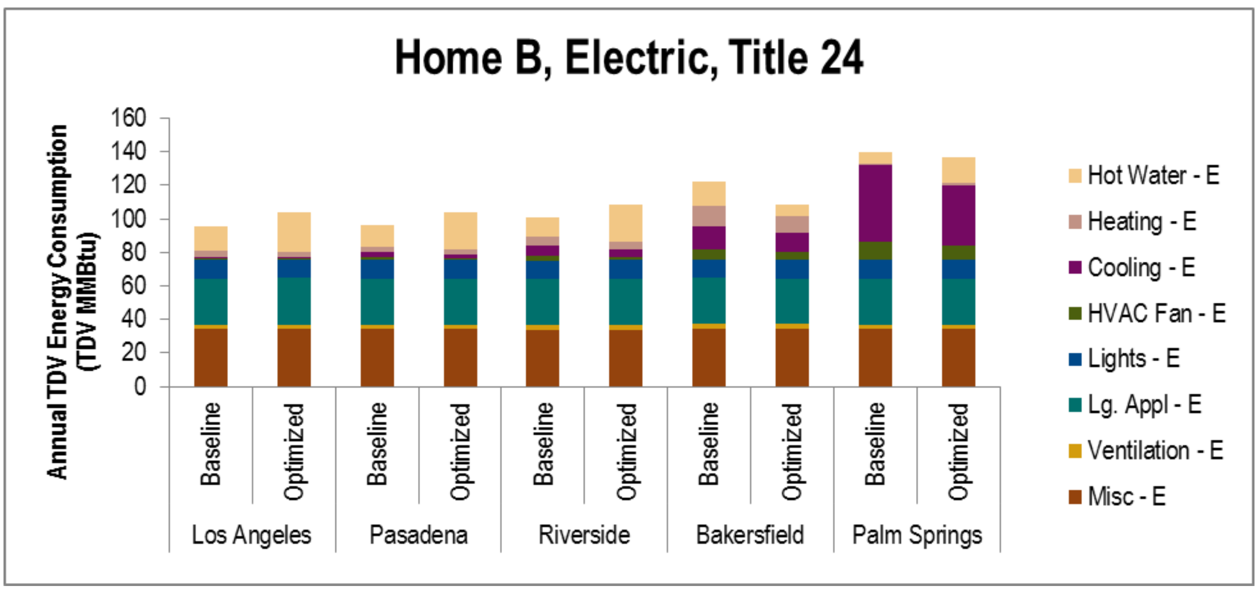



**Figure 30. End-Use TDV Energy Consumption for Electric-Only ZNE Homes**

Note – Hot water TDV consumption increases for most Electric-Only homes because each Electric-Only home starts with a combined electric-storage water heater and solar thermal system and then selects whether it is more cost effective to switch to a HPWH and slightly larger solar PV system. In every region except Bakersfield, the optimized Electric-Only home chose the HPWH option.

Appendix G provides further breakdown of each home's end-use consumption, including breakdown of Title 24 loads (space heating, ventilation, air conditioning, water heating) and HERS loads (Title 24 loads plus interior lighting, kitchen appliances, laundry appliances, miscellaneous loads).

#### 4.2.3 Selected Technology Options for ZNE Homes

Table 19 provides a summary overview for the efficiency measures selected for mixed-fuel and electric-only homes in each region and Table 20 provides a detailed list for each home. The cost-effective efficiency options outlined in Table 19 and Table 20 generally fall in the following categories:

- **Reducing HVAC Loads**: Particularly in inland regions with larger HVAC-related consumption, advanced thermostats and condensing furnaces can offer economically attractive TDV savings, relative to solar PV. By providing both space heating and space cooling savings over a long lifetime, advanced windows are economically attractive for each region and fuel configuration.
- **Gas Water Heating**: Each mixed-fuel ZNE selected a non-condensing gas tankless water heater over a baseline, non-condensing gas storage water heater due to its lifetime energy savings and moderately longer expected life. As noted in Section 2.1.1.3, Title 24-206 may adopt tankless water heaters as the basis for the ACM's energy budget, essentially lowering the TDV consumption of the mixed-fuel baseline home and incremental cost, but not the optimized cost (See Section 4). Each ZNE home adopts an advanced hot water distribution system to reduce standby losses.
- **Electric Water Heating**: Under Title 24, homes using electric water heaters can either use an electric storage water heater with solar thermal system (with 50% solar fraction) or a HPWH. The combination solar water heater offers substantial TDV savings relative to the HPWH, but a high incremental cost. Except for Bakersfield, each electric-only ZNE home selected the HPWH and additional solar PV capacity in place of the solar water heater. In Bakersfield, the relatively cold weather contributed to the selection of solar water heater, as the HPWH located in the garage experienced higher energy consumption than other regions. Each ZNE home adopts a homerun hot water distribution system to reduce standby losses.
- **Pool Heating**: For each mixed-fuel ZNE home with a non-Title 24 pool heating end-use, the condensing model showed attractive economics due to the potential savings relative to incremental costs.

In general, efficiency measures that reduce water heating and HVAC end-use TDV consumption provide attractive economics relative to additional solar PV capacity. California building codes and federal appliance standards have substantially reduced the consumption for a baseline home and raised minimum appliance efficiency, limiting the potential opportunity for cost-effective efficiency measures. As shown previously in Figure 8, Title 24 codes have progressively lowered baseline HVAC and water heating energy consumption, especially for moderate climates. In Figure 29 and Figure 30, both mixed-fuel and electric-only baseline homes show relatively small HVAC and water heating loads, which limits the potential energy and utility cost savings for any one measure. With lower per unit savings, few measures can offer an attractive payback, especially when compared to an incrementally larger solar PV system that can address all end-uses. As discussed in Section 2.1.1.1 above, the $/TDV value of solar PV depends on the orientation of the home, and therefore, more efficiency options are attractive in non-optimally orientated ZNE homes.

Homebuilders can design ZNE homes without incorporating efficiency measures, but relying solely on solar PV systems is less attractive than first adding cost-effective efficiency measures. Mixed-fuel ZNE homes without efficiency measures require an additional 0.2-0.9 kW PV capacity (7-22% increase), with

$877-$3,969 higher costs (6-16% increase). The additional solar PV capacity would also increase the required roof area by 7-22%, and could pose constraints on homebuilders. This issue is further discussed in Section 4.2.6.

**Table 19. Summary of Selected High Efficiency Building Features by Location – Home B**

| Category | Metric | Mixed-Fuel Selection | | | | | Electric-Only Selection | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LA | PA | RV | BK | PS | LA | PA | RV | BK | PS |
| General Operation | Heating Set Point | | | | ✓ | | | | ✓ | ✓ | |
| | Cooling Set Point | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | * | ✓ |
| | Interior Shading | | | | | | | | | | |
| Walls | Wood Stud | | | | | | | | | | |
| | Wall Sheathing | | | | * | | | | | ✓ | |
| Ceiling/Roofs | Unfinished Attic | * | ✓ | | * | | * | ✓ | | ✓ | |
| Foundation/Floors | Interzonal Floor | | | | | | | | | ✓ | |
| Windows & Doors | Windows | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Airflow | Mechanical Ventilation | | | | | | | | | | |
| Space Conditioning | Central Air Conditioner | | | | | ✓ | | | n/a | | |
| | Furnace | * | ✓ | ✓ | ✓ | | | | n/a | | |
| | Air-Source Heat Pump | | | n/a | | | | | | | |
| Water Heating | Water Heater | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | |
| | Distribution | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Solar Water Heating | | | | | | | | | ✓ | |
| Major Appliances | Kitchen & Laundry | | ✓ | | | | | | | ✓ | |
| Miscellaneous | Pool Heater[40] | ✓ | ✓ | ✓ | ✓ | ✓ | | | n/a | | |
| On-Site Generation | PV System | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | mCHP System | | | | | | | | n/a | | |

Location abbreviations: Los Angeles (LA), Pasadena (PA), Riverside (RV), Bakersfield (BK), Palm Springs (PS)
✓ denotes selection of high-efficiency option in North orientation
* denotes selection made in another orientation
n/a denotes high efficiency options are not available for fuel configuration.

[40] Pool heaters are "exogenous" loads not covered by Title 24, but common for new homes in SCG regions. Section 4.2.5 discusses the impacts of exogenous loads for ZNE homes.

**Table 20. Specific High Efficiency Building Features by Location – Home B**

| Home Design | Location | | | | |
|---|---|---|---|---|---|
| | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| **Mixed-Fuel** | Attic Insulation (R60)<br>Adv. Windows<br>Condensing Furnace*<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)<br>Adv. Windows<br>Condensing Furnace<br>HW Distribution<br>Tankless WH<br>Cooking Range<br>Solar PV System | Adv. Thermostat (Cooling)<br>Adv. Windows<br>Condensing Furnace<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Attic Insulation (R60)<br>Wall Sheathing (R15)<br>Advanced Windows<br>Condensing Furnace<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Advanced Windows<br>SEER 18 AC<br>HW Distribution<br>Tankless WH<br>Solar PV System |
| **Electric-Only** | Attic Insulation (R60)<br>Adv. Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling*)<br>Attic Insulation (R60)<br>Floor Insulation (R30)<br>Wall Sheathing (R15)<br>Advanced Windows<br>HW Distribution<br>Solar Water Heater<br>ESTAR Dishwasher<br>Solar PV System | Adv. Thermostat (Cooling)<br>Advanced Windows<br>HW Distribution<br>Solar PV System |

Note – table identifies selections for North orientation. * denotes selection made in another orientation

### 4.2.4 Impacts of Home Orientation for ZNE Homes

As discussed in Section 2.1.1.1, building orientation has a substantial effect on solar PV system output and a negligible impact on home energy consumption for the sample home designs. Because the TDV consumption remains relatively constant in each direction, the required solar PV capacity to reach ZNE goals substantially increases in non-optimal orientations. Table 21 summarizes the increase in solar PV system size moving from optimal North-facing home with a South-facing solar PV system on the back roof. Compared to a North-facing home, home orientations facing South, East, and West experience the following impacts:

- The South-facing home with North-facing solar is most disadvantaged orientation for solar PV, with system capacity increases from 44-58% relative to North-facing homes. In the Northern Hemisphere, the sun travels across the Southern sky, reducing the solar insolation for a North-facing PV system.
- The West-facing home with East-facing solar is a moderately disadvantaged orientation for solar PV, with system capacity increases from 21-35% relative to North-facing homes. The sun tracks from East to West throughout the day, with the lowest hourly insolation in the morning, in the direction of the East-facing PV system.
- The East-facing home with West-facing solar is a slightly disadvantaged orientation for solar PV, with system capacity increases from 11-18% relative to North-facing homes. Because the West-facing solar system captures the high hourly insolation of the afternoon sun, the East-facing home loses a smaller portion of solar PV production.

**Table 21. Orientation Impact on Solar PV System Size for ZNE Locations**

| Category | Location | North PV System (kW) | Solar PV System Size Increase from North-Facing Home (%) | | |
|---|---|---|---|---|---|
| | | | East | South | West |
| Mixed-Fuel | Los Angeles | 3.4 | 12% | 49% | 23% |
| | Pasadena | 3.4 | 16% | 55% | 28% |
| | Riverside | 3.6 | 18% | 58% | 29% |
| | Bakersfield | 4.2 | 13% | 44% | 25% |
| | Palm Springs | 4.3 | 18% | 50% | 27% |
| Electric-Only | Los Angeles | 3.8 | 11% | 48% | 24% |
| | Pasadena | 3.9 | 14% | 52% | 26% |
| | Riverside | 4.0 | 14% | 52% | 25% |
| | Bakersfield* | 3.9 | 23%* | 64%* | 35%* |
| | Palm Springs | 5.0 | 18% | 49% | 21% |

* Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations. Similar to solar PV systems, solar water heating technologies lose effectiveness in non-optimal orientations. 58%

### 4.2.5 Impacts of Non-Title 24 Loads on ZNE Homes

While the current definition of a ZNE home excludes certain end-uses, non-Title 24 or "exogenous" loads could have a substantial impact on current and future ZNE home designs. Title 24 regulations cover only a subset of the end-use loads for single-family homes and several common products such as pool heaters and pool pumps do not factor into the ACM "energy budget". Nevertheless, ZNE stakeholders should be aware of the impacts these loads have on ZNE homes and how specific ZNE definitions affect the feasibility of ZNE homes. In this evaluation, we conducted simulations for optimized ZNE homes that included pool heating, pool pump, and in-home transportation loads:

- Mixed-fuel ZNE homes used a condensing or non-condensing gas pool heater, electric pool pump, and an in-home refueling system for a NGV.
- Electric-only ZNE homes used a heat pump pool heater, electric pool pump, and in-home charging system for an EV.

Figure 31 illustrates the TDV energy consumption impacts for mixed-fuel and electric-only ZNE homes with and without these exogenous loads. In each case, the exogenous loads significantly increase the ZNE homes TDV energy consumption, ranging from 100-200%, with mixed-fuel configurations generally experiencing a larger increase.

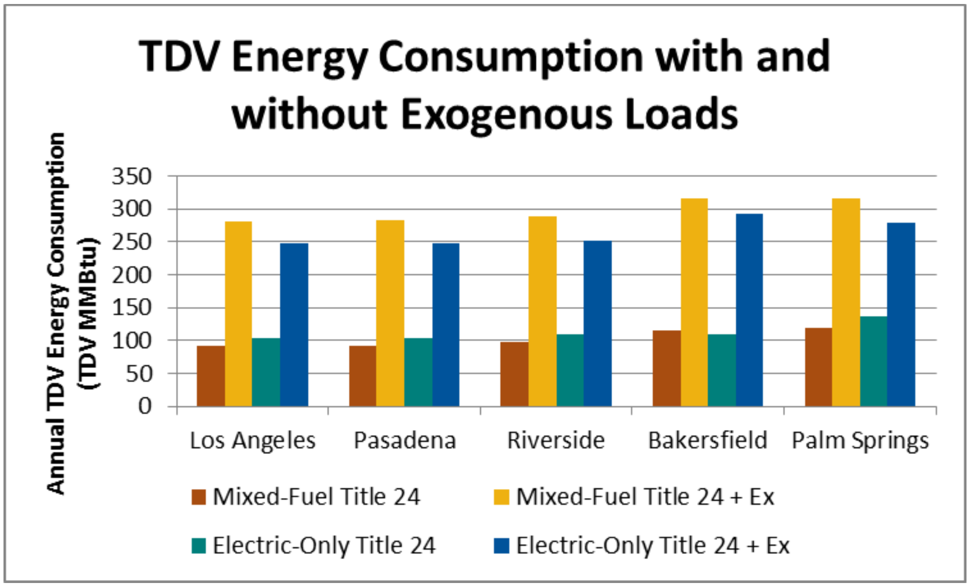



**Figure 31. Comparison of Mixed-Fuel and Electric-Only ZNE Homes with and without Exogenous Loads**

Figure 32 provides a comparison of the exogenous loads between mixed-fuel and electric-only ZNE homes. Because we applied these loads consistently to each ZNE home, i.e., same pool size and driving habits, the results for Home B accurately represent those for other regions and home sizes.

- **Transportation**: Most of the TDV energy consumption for advanced transportation systems consists of the natural gas or electrical "fuel" itself. EV's have a higher fuel consumption but lower ancillary loads compared to the NGV. The NGV refueling system consumes no natural gas but has a substantial electricity load due to the compressor.
- **Pool Heating and Operation**: The choice of fuel type significantly affects the TDV consumption of the pool heater. For both fuel configurations, pool pumps significantly increase the home's TDV energy consumption. Electric-only homes using heat pump pool heaters have lower TDV energy consumption than gas-fired pool heaters for mixed-fuel homes. In each mixed-fuel location, a condensing gas pool pump proved economically attractive relative to a larger solar PV system.

Appendix D provides additional details on the transportation related loads.

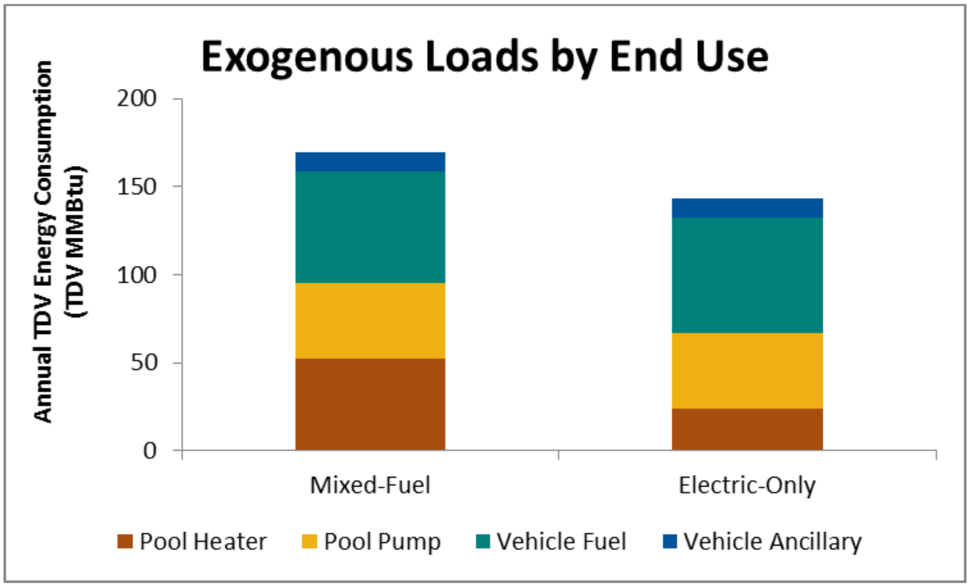



**Figure 32. Breakdown of Exogenous Loads by End-Use**

### 4.2.6 Impacts of Available Roof Space for ZNE Homes

In all cases, ZNE homes will require a solar PV system of a given size to offset the remaining TDV energy consumption. Because the vast majority of residential solar PV systems are installed on the home's roof, the size of the solar PV system relative to the available roof space is a key consideration for technical feasibility and market adoption of ZNE homes. Table 22 summarizes the available roof space and corresponding potential solar PV capacity at for each representative home design. Our analysis includes estimates for 100%, 75%, and 50% of roof availability to account for non-optimal building design or conditions. Several factors commonly reduce the roof's solar availability by interrupting or shading the roof, including: window/roof gables, chimneys/flues, overhanging trees, and neighboring buildings.

**Table 22. Available Roof Space and Corresponding Solar PV Capacity for Each Home Design**

| Metric | Home A | Home B | Home C |
|---|---|---|---|
| **Conditioned Floor Area** | 1,800 sq.ft. | 2,500 sq.ft. | 3,200 sq.ft. |
| **Rough Dimensions / Floors** | 40 x 50 sq.ft. / 1 floor | 27 x 50 sq.ft. / 2 floors | 34 x 50 sq.ft. / 2 floors |
| **Available Roof Dimensions (Back of House)** | 50 x 22.4 ft. | 50 x 15.1 ft. | 50 x 19.0 ft. |
| **Available Roof Area (Back of House)** | 1,118 sq.ft. | 755 sq.ft. | 950 sq.ft. |
| **100% of Available Solar PV System @ 14 W/sq.ft.*** | 15.7 kW | 10.6 kW | 13.3 kW |
| **75% of Available Solar PV System @ 14 W/sq.ft.*** | 11.7 kW | 7.9 kW | 10.0 kW |
| **50% of Available Solar PV System @ 14 W/sq.ft.*** | 7.8 kW | 5.3 kW | 6.7 kW |

* 14 W/sq.ft. estimated from solar PV panel specifications from Sharp (ND-250QCS, ND-235QCS), and Yingli (YL250P-29b, YL240P-29b).

Figure 33 and Figure 34 illustrate how the solar PV systems required for mixed-fuel and electric-only ZNE homes compares to the system size allowed by the available roof space. The impacts for solar PV availability generally follow the following trends:

- **Title 24 Loads**: In each location, the solar PV system required for both mixed-fuel and electric-only ZNE homes with Title 24 loads easily fits on a North-facing home with 50% roof availability. For a South-facing home, the ZNE homes generally require between 50-75% roof availability. These results suggest that homes under current ZNE definitions could reasonably meet ZNE goals even with solar availability for the back roof as low as 75%.
- **Title 24 + Exogenous Loads**: In each location, the solar PV system requires at least 75% roof availability for a North-facing home when including exogenous loads. For a South-facing ZNE home, the required solar PV system exceeds the available roof space by a wide margin (>1 kW). These results suggest that ZNE homes including exogenous loads in their ZNE definition could have difficulty siting the required solar PV systems. In these cases, a home builder could add solar capacity in another location (e.g., front roof, ground, or community solar system) or incorporate other efficiency measures to reduce the required solar PV system size.

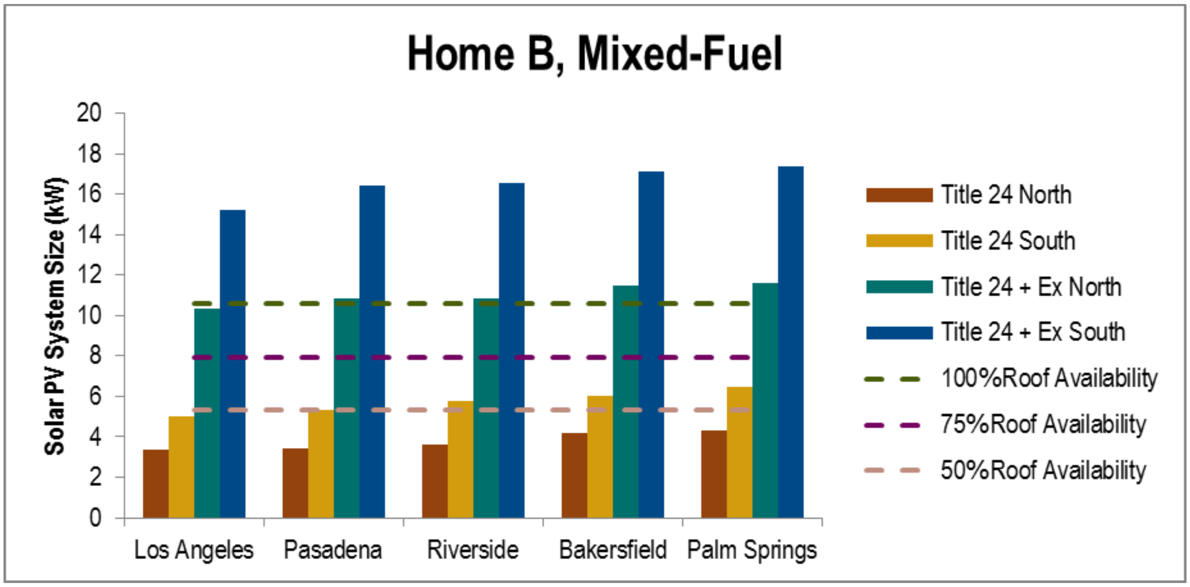



Figure 33. Solar PV System for Mixed-Fuel ZNE Homes Relative to Available Roof Area

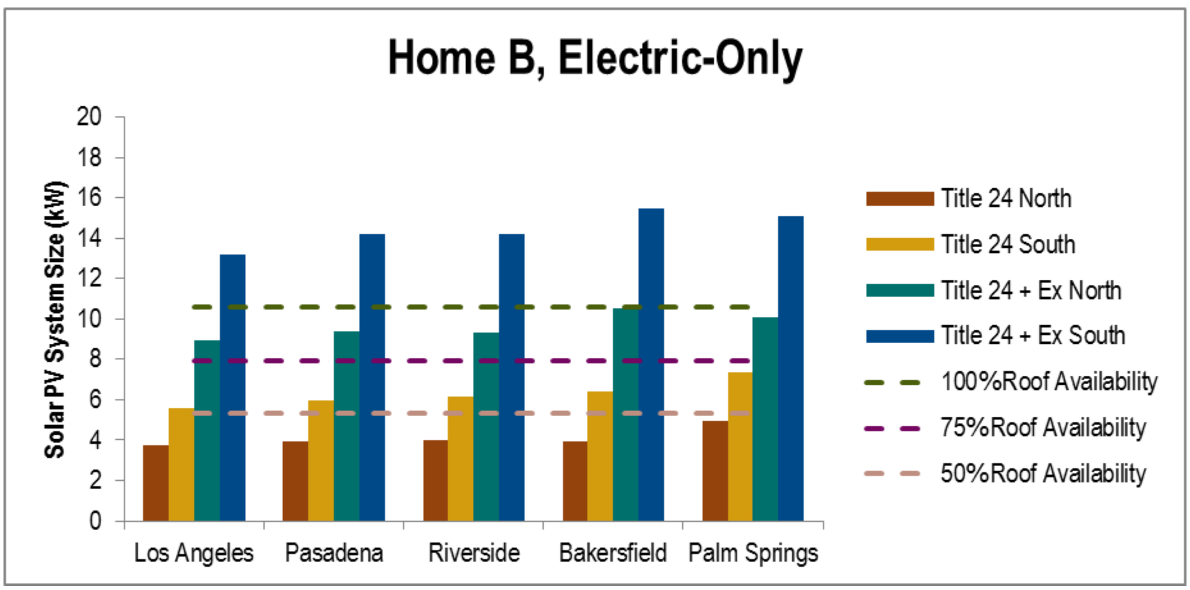



Figure 34. Solar PV System for Electric-Only ZNE Homes Relative to Available Roof Area

### 4.2.7 Impacts of ZNE Home Size

While this section provides the technical results for the 2,500 sq.ft., two-story ZNE home configuration, i.e., Home B, these results are generally consistent for other ZNE home configurations e.g., 1,800 and 3,200 sq.ft. Figure 35 and Figure 36 outline the required solar PV system sizes for each mixed-fuel and electric-only ZNE home configuration, respectively. For each home configuration, mixed-fuel ZNE homes have lower optimized TDV energy consumption than electric-only homes, and subsequently require smaller solar PV systems to reach ZNE goals. Solar PV system size increases for more inland locations and for non-optimized home orientation, and each home's solar PV system fits within 75% or less of the available roof space. Each home size selected a similar mix of efficiency measures, i.e., targeting HVAC and water heating loads, with some variation in milder regions. For example, HVAC loads for Home C sufficiently large that some additional HVAC related measures become economically attractive for more mild locations. Appendix G contains full technical results for each home design.

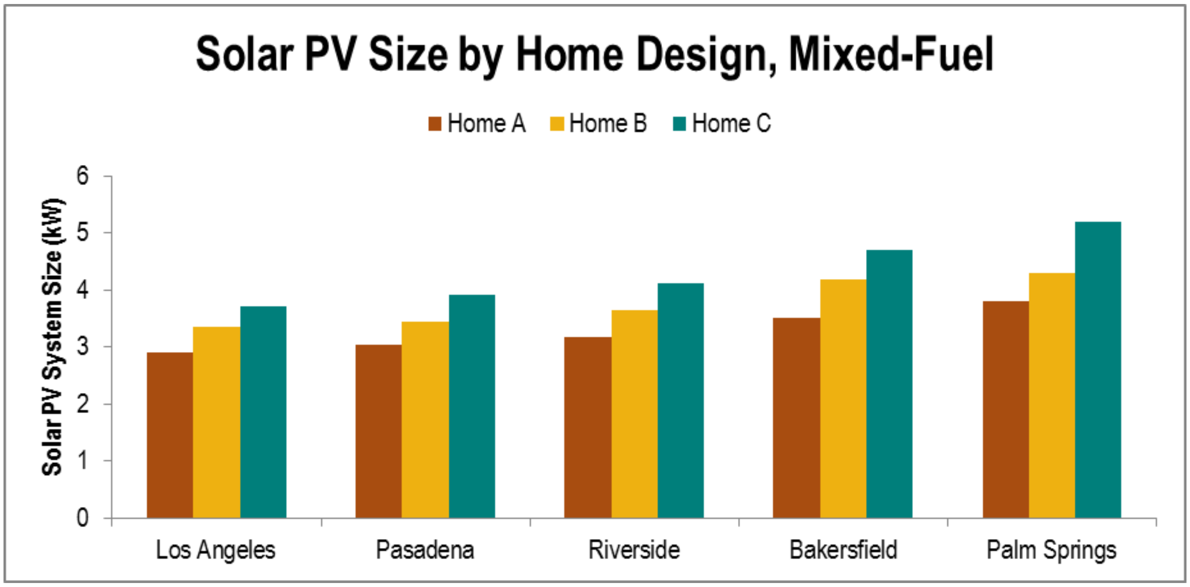



**Figure 35. Solar PV System Size by Home Size for Mixed-Fuel ZNE Homes**

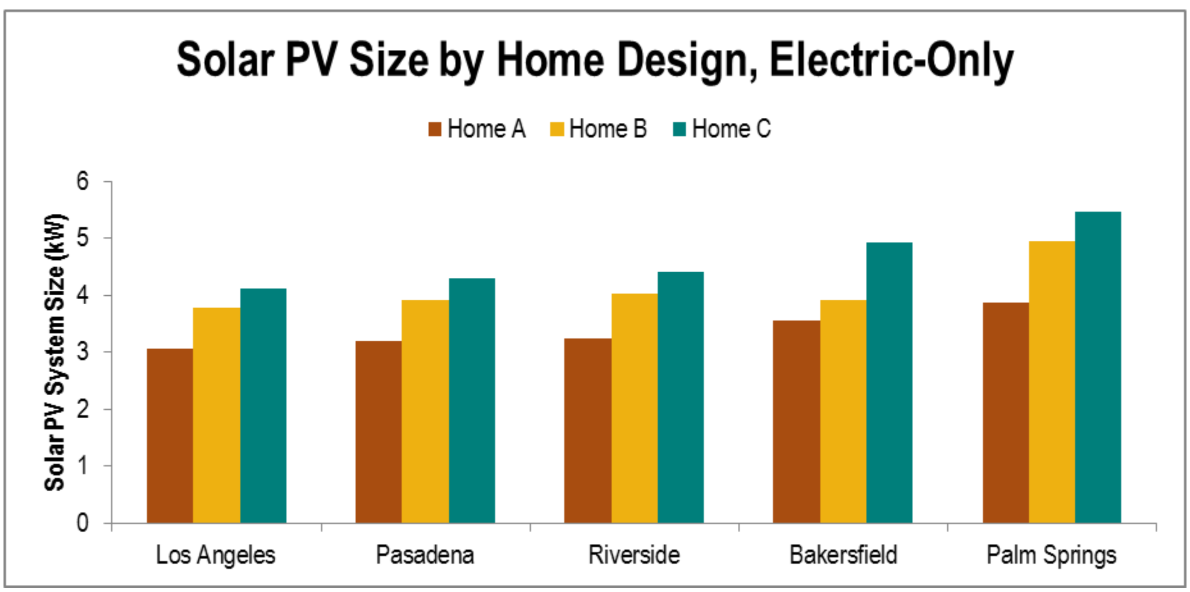



**Figure 36. Solar PV System Size by Home Size for Electric-Only ZNE Homes**

## 4.3 Advanced Technologies

### 4.3.1 Micro-CHP Systems for ZNE Homes

Table 23 provides the net TDV output for engine and fuel cell mCHP systems for a mixed-fuel ZNE home in Los Angeles under a range of efficiency and capacity assumptions. For both technologies the thermal efficiency of the mCHP system is less than the efficiency of baseline space and water heating systems (~80%), but the substantially larger hourly TDV values of the generated electricity can produce a net TDV benefit. On a net TDV basis, engine and fuel cell mCHP systems have the following impacts:

- **Engine mCHP**: With the exception of 0.5kW high-efficiency model, each engine mCHP configuration has a negative net TDV impact. This result signifies that the TDV value for the energy consumed is greater than the TDV value for the electricity and usable energy produced in most engine mCHP combinations. For the 0.5 kW, high-efficiency model, the small mCHP's thermal output generally matches the ZNE home's consumption and is therefore rarely wasted, and TDV value of the electricity production outweighs the mCHP's natural gas TDV consumption.
- **Fuel Cell mCHP**: For each efficiency class, fuel cell mCHP systems with 0.5-1 kW capacity provide net TDV value similar to the 0.5 kW high-efficiency engine mCHP system above. For these sizes, the mCHP system's thermal output generally matches the demands of the home and is seldom wasted. Medium and high-efficiency fuel cell mCHP systems continue to provide net TDV benefit at higher capacities due to their higher electrical efficiencies. In these cases, the TDV benefit from electricity production outweighs the negative TDV energy value of the fuel cell's natural gas consumption.

**Table 23. Summary of TDV Energy Impacts for mCHP Systems – Los Angeles**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -520 | -1073 | -1627 | -2181 | -3288 | -5502 |
| | Medium | 22% | 54% | -10 | -49 | -90 | -131 | -213 | -378 |
| | High | 25% | 68% | 4 | -21 | -48 | -75 | -130 | -238 |
| Fuel Cell | Low | 30% | 65% | 18 | 8 | -4 | -16 | -41 | -91 |
| | Medium | 38% | 39% | 29 | 36 | 41 | 45 | 52 | 65 |
| | High | 60% | 24% | 38 | 72 | 100 | 127 | 178 | 277 |

Note - Highlight denotes positive TDV energy benefit

Engine and fuel cell mCHP systems can provide net TDV benefits for ZNE homes under certain performance conditions. For configurations where mCHP systems show net positive TDV values, the mCHP system acts similarly to an efficiency measure or solar PV system in offsetting the ZNE home's TDV consumption. Systems with lower electrical efficiencies only provide net TDV value while thermal loads are met, while systems with higher electrical efficiencies can provide net TDV value independent of thermal loads. For most locations, the inflection point for self-sustaining mCHP is 35-38% electrical efficiency. These results are generally consistent for other ZNE home locations and home designs. One exception is the low-efficiency, 1.5 kW fuel cell mCHP systems, which shows net TDV benefit for Bakersfield due to the larger space heating loads.

However, beyond technical feasibility, for mCHP systems to be adopted, they must also provide attractive economics for ZNE homes relative to other technology options. As discussed previously, solar PV systems provide the majority of TDV benefit for ZNE homes. To displace solar PV capacity for ZNE homes, mCHP systems must show lower $/TDV production for the 30 year life of the home. Because the lifetime for solar PV systems (25 years) is substantially longer than the useful life than mCHP systems (15 years), we compared the purchase costs of the two technologies on a net present value basis[41].

Table 24 and Table 25 below provide the $/TDV values for engine and fuel cell mCHP systems compared to an optimally oriented solar PV system for a mixed-fuel ZNE home in Los Angeles under a range of efficiency, capacity, and cost assumptions. Compared to solar PV systems for North-facing ZNE homes, engine and fuel cell mCHP systems have the following impacts:

- **Engine mCHP**: Under these assumptions, engine mCHP systems would not compare favorably to solar PV systems for any capacity, efficiency, or cost configuration. For the configuration where engine mCHPs did provide net TDV benefits, i.e., high-efficiency 0.5 kW, the engine mCHP system at low costs ($5/W) offers $/TDV values over three times greater than the solar PV system.
- **Fuel Cell mCHP**: Under current/high cost scenario ($20/W), fuel cell mCHP systems are not cost competitive with solar PV systems on a $/TDV basis. If fuel cell mCHP costs decrease to the low cost scenario ($10/W), medium- and high-efficiency systems become cost competitive for select capacities.

**Table 24. Summary of $/TDV Cost-Effectiveness for Engine-Based mCHP Systems – Los Angeles**

| mCHP Costs ($/W) | | mCHP Efficiency Class | Solar PV Costs | Engine-Based mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | $20/W | Low | $375 | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 |
| | | Medium | | -$1,633 | -$673 | -$549 | -$502 | -$462 | -$435 |
| | | High | | $3,863 | -$1,576 | -$1,027 | -$874 | -$760 | -$689 |
| Medium | $15/W | Low | $375 | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 |
| | | Medium | | -$1,225 | -$505 | -$412 | -$376 | -$347 | -$326 |
| | | High | | $2,897 | -$1,182 | -$770 | -$655 | -$570 | -$517 |
| Low | $5/W | Low | $375 | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 |
| | | Medium | | -$408 | -$168 | -$137 | -$125 | -$116 | -$109 |
| | | High | | $966 | -$394 | -$257 | -$218 | -$190 | -$172 |

Note - Highlight denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase.

[41] Assumes only upfront purchase and subsequent replacement costs, and does not include any assumptions for reduced purchase costs in future, residual value, efficiency degradation, operating costs, maintenance costs, or component replacement (e.g., inverter).

**Table 25. Summary of $/TDV Cost-Effectiveness for Fuel Cell mCHP Systems – Los Angeles**

| mCHP Costs ($/W) | | mCHP Efficiency Class | Solar PV Costs | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | $20/W | Low | $375 | $917 | $3,928 | -$13,307 | -$4,072 | -$2,401 | -$1,808 |
| | | Medium | | $567 | $906 | $1,193 | $1,445 | $1,889 | $2,545 |
| | | High | | $429 | $455 | $491 | $519 | $555 | $592 |
| Medium | $15/W | Low | $375 | $688 | $2,946 | -$9,981 | -$3,054 | -$1,801 | -$1,356 |
| | | Medium | | $425 | $680 | $895 | $1,084 | $1,417 | $1,909 |
| | | High | | $322 | $342 | $368 | $389 | $416 | $444 |
| Low | $10/W | Low | $375 | $459 | $1,964 | -$6,654 | -$2,036 | -$1,201 | -$904 |
| | | Medium | | $283 | $453 | $597 | $722 | $945 | $1,272 |
| | | High | | $214 | $228 | $245 | $260 | $277 | $296 |

Note - Highlight denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase.

Unlike solar PV systems, the orientation of the home does not affect the performance and $/TDV value for the mCHP systems. If the home faces any direction other than North, the TDV output of the solar PV system decreases, requiring more solar PV capacity to meet the home's TDV consumption. This increases the $/TDV value for solar PV systems, and lowers the cost-effectiveness threshold for other technologies. Compared to solar PV systems for South-facing ZNE homes, engine and fuel cell mCHP systems provide the following impacts:

- **Engine mCHP**: Similar to optimally oriented homes, engine mCHP systems are not cost competitive relative to solar PV systems under any capacity, efficiency, or cost configuration.
- **Fuel Cell mCHP**: Similar to optimally oriented homes, fuel cell mCHP systems are not cost competitive with solar PV systems under current/high cost scenario ($20/W), but high-efficiency fuel cell mCHP systems are competitive for 0.5-1.5 kW capacities under the medium and low cost scenarios ($10-15/W).

See Appendix E for additional details and assumptions on mCHP systems.

### 4.3.2 Impacts of Gas Heat Pumps for ZNE Homes

Table 26 provides the net TDV output for different gas heat pump systems for a mixed-fuel ZNE home in Bakersfield under a range of efficiency and capacity assumptions. The baseline systems consist of 80% AFUE furnace, 0.6 EF storage water heater, and SEER 14 air conditioner (estimated COP of 3.5[42]). Compared to these values, each gas heat pump technology offers improved heating COP and decreased cooling COP before accounting for auxiliary consumption[43]. On a net TDV basis, different gas heat pump systems have the following impacts:

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[42] Goetzler et al. 2014. "Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies." Navigant Consulting Inc. for U.S. Department of Energy, Building Technologies Office. March 2014.
[43] Assumes 0.023 kW electric per KW thermal consumption for heating and 0.046 kW electric per KW thermal consumption for cooling. See 9.2E.2.

- **Gas-fired air conditioner (cooling-only):** In each efficiency class, thermally activated heat pumps operating in cooling-only mode do not provide net TDV savings over conventional systems. Even with the significant difference in hourly TDV value between electricity and natural gas, the lower cooling COP values relative to electrically driven systems (0.6 vs. 3.5) result in net negative TDV values except for the highest peak hours of the year. Cooling-only heat pumps may provide substantial operating cost benefits to homeowners, but would require additional solar PV capacity to make up the TDV shortfall.
- **Gas-fired heat pump (reversible operation)**: In each efficiency class, thermally activated heat pumps operating with both heating and cooling operation provide net TDV energy savings. For the Bakersfield location, the system provides 20-50% TDV savings on HVAC and water heating and overcomes a cooling season disadvantage with improved performance in the heating season.
- **Gas-fired heat pump (heating-only)**: In each efficiency class, thermally activated heat pumps operating in heating-only mode provide substantial net TDV energy savings. For the Bakersfield location, the system provides 50-60% TDV savings on HVAC and water heating.
- **Gas engine-driven heat pump**: In each efficiency class, the engine heat pump operating in combined heating-and-cooling operation provides net TDV benefits over conventional systems. The cooling mode penalty is less for the engine-driven system due to the higher COP the engine-driven vapor-compression system relative to absorption or adsorption cooling systems.
- **Solar Thermal Heat Pump**: Integrating a solar hot water system with a gas heat pump reduced natural gas consumption by 40-60% or greater, providing additional TDV savings. For cooling-only mode, an absorption chiller combined with solar water heater resulted in positive TDV values.

**Table 26. Summary of TDV Energy Impacts for Gas Heat Pumps - Bakersfield**

| Gas Heat Pump Category | Location | Technology Efficiency | | TDV Savings |
|---|---|---|---|---|
| | | Heating COP | Cooling COP | |
| **Engine-Based** | Low | 1.2 | 1.1 | 20 |
| | Medium | 1.5 | 1.2 | 26 |
| | High | n/a | n/a | n/a |
| **Absorption (Reversible)** | Low | 1.3 | 0.6 | 13 |
| | Medium | 1.6 | 0.8 | 23 |
| | High | 2.2 | 1.2 | 33 |
| **Absorption (Heating Only)** | Low | 1.2 | n/a | 32 |
| | Medium | 1.4 | n/a | 36 |
| | High | 1.6 | n/a | 39 |
| **Absorption (Cooling Only)** | Low | n/a | 0.6 | -6 |
| | Medium | n/a | 0.7 | -4 |
| | High | n/a | 0.8 | -3 |

In addition to technical feasibility, for gas heat pumps to be adopted, they must also provide attractive economics to ZNE homes relative to other technology options. As discussed previously, many mixed-fuel home locations selected condensing furnaces during the optimization process. To displace condensing furnaces for ZNE homes, gas heat pumps must show lower $/TDV savings. Because the lifetime for condensing furnaces (12-15 years) closely matches the useful life of gas heat pumps (12-15 years), we compared the original incremental costs.

Table 27 provides the $/TDV values for gas heat pump technologies compared to condensing furnace for a mixed-fuel ZNE home in Bakersfield under a range of efficiency and cost assumptions. Gas heat pump costs assume incremental costs per capacity over a standard-efficiency central furnace and split-system air conditioner. Compared to condensing furnaces, heating-only absorption technologies under current/high cost scenario ($78/kBtu-hr) are cost competitive and could offer cost-effective TDV savings. These costs assume capacities over 120,000 kBtu-hr whereas the sample ZNE home projects a necessary capacity less than half this amount. Further technology developments will improve the cost and performance of gas heat pumps, particularly for smaller capacities suitable for most single-family homes.

**Table 27. Summary of $/TDV Cost-Effectiveness for Gas Heat Pumps**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings by Cost and Efficiency | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| **Engine-Based** | $43 | $56 | $42 | n/a | $67 | $51 | n/a | $78 | $59 | n/a |
| **Absorption (Reversible)** | $43 | $83 | $48 | $33 | $100 | $57 | $40 | $116 | $66 | $47 |
| **Absorption (Heating Only)** | $43 | $35 | $31 | $29 | $42 | $38 | $35 | $49 | $44 | $40 |
| **Absorption (Cooling Only)** | $43 | -$178 | -$264 | -$400 | -$213 | -$316 | -$478 | -$248 | -$368 | -$557 |

Note - Highlight denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase.

Incorporating an additional solar hot water system with a gas heat pump can improve TDV energy savings, but at a substantially higher system costs ($6,000-$7,000 for 40 sq.ft. solar hot water system). With this additional incremental cost over other HVAC and water heating technologies, thermally activated heat pumps combined with solar thermal systems are not cost-effective. Even with dramatic cost reductions of >50%, solar thermal systems would be too expensive relative to other options.

See Appendix E for additional details and assumptions on gas heat pumps.

### 4.3.3 Impacts of Demand Response and On-Site Energy Storage for ZNE Homes

For decades, electric utilities have offered DR programs to reduce a home's electrical consumption during peak demand hours. For example, a DR-enabled thermostat can modify the HVAC system's operating schedule based on a signal from the utility so the home draws less power from the electricity grid. Electric batteries located at the home can operate in a similar manner by deferring the consumption of grid-supplied electricity consumption during peak demand hours. On a TDV basis, this strategy exchanges peak electricity (high TDV) with off-peak electricity (low TDV). When coupled with a solar PV system, the battery storage can time-shift the solar electricity to achieve a greater TDV offset than would normally occur. For example, a battery would charge using solar PV electricity generated at 1pm and discharge at 5pm when the TDV value is higher.

Table 28 summarizes the TDV energy savings and cost-effectiveness for on-site energy storage under several cost scenarios. As modeled for a 10 kWh, 5 kW electric battery storage system, on-site energy storage can provide meaningful TDV energy reductions by shifting the consumption of grid-supplied electricity to hours with lower TDV values. Actual kWh and utility cost savings are minor without any additional utility incentives or other payment systems that credit customer-sited load reductions. Under current cost projections, battery storage systems are not cost-effective compared to incrementally larger solar PV systems, but future cost reductions could improve their economic attractiveness for ZNE homes.

**Table 28. TDV Energy Savings and Cost-Effectiveness of On-Site Energy Storage Systems – Home B**

| Location | TDV Energy Savings for 10kWh System (MMBtu) | $/TDV Savings at Various Cost Projections | | | Solar PV $/TDV Savings |
|---|---|---|---|---|---|
| | | $600/kWh | $300/kWh | $100/kWh | |
| **Los Angeles** | 4.9 | $1,220 | $610 | $203 | $254 |
| **Pasadena** | 6.0 | $1,000 | $500 | $168 | $217 |
| **Riverside** | 7.4 | $806 | $403 | $134 | $213 |
| **Bakersfield** | 10.2 | $587 | $294 | $98 | $203 |
| **Palm Springs** | 9.2 | $650 | $325 | $108 | $240 |

## *4.4 Additional Technical Analyses*

Following presentation of interim results, SCG staff requested further investigation on certain topics and the sensitivity of major assumptions on the technical results. Appendix H provides the full results of these additional technical analyses:

- **Comparison of 2016 vs. 2013 TDV Values:** Navigant performed a sensitivity study to understand the impacts of using 2016 TDV values when optimizing energy efficiency and renewable building technologies, rather than 2013 values. In general, using 2016 TDV values increases electricity and natural gas consumption by 1.5–3.5% for both mixed-fuel and electric-only ZNE homes and the value of solar PV systems (TDV/kW) changes by -1.0–1.5%, but the general findings of this Phase 1 report are consistent throughout. This suggests the Phase 1 results, using 2013 TDV values, will be applicable under future TDV definitions.
- **List of Measures Proposed for Title 24-2019:** Navigant reviewed the proposed measures for Title 24-2019 provided by SCG staff and performed additional analyses to determine the impacts for Phase 1 results. Navigant and SCG determined that 3 technologies could be eligible for

inclusion in Title 24-2019 due to current estimates for savings, cost, market acceptance, and potential barriers: controllable electrical receptacles, evaporative cooling as a baseline cooling system, and fault detection and diagnostic system / charge indicator display (FDD/CID) for HVAC systems. Navigant conducted additional simulations to understand the potential impacts of these technologies, while each provided meaningful TDV energy savings for ZNE homes, only the FDD/CID technology has a clear regulatory and market pathway towards inclusion in Title 24-2019. If included, FDD/CID would have a similar impact for both mixed-fuel and electric-only homes since the majority of savings come occur from space cooling, which is common for both home designs.

- **Sensitivity to Optimization by First Costs Only:** In Phase 1, the optimization software selected building technologies based on full life-cycle costs, including original purchase, energy savings, and replacement costs. To model first costs only, we conducted additional simulations by setting the lifetime of each technology to 30 years. In general, the software selected additional HVAC, water heating, and solar PV technologies in place of building envelope measures. When evaluated on first costs only, mixed-fuel ZNE homes still maintain advantages over electric-only designs, but the gap is narrowed. The incremental first cost advantage changes from $2,000 to $500-$1,500 and the solar PV advantage changes from 0.5 kW to 0.0–0.2 kW.
- **Cost-Effective "Near-ZNE" Building Technologies:** While single-family homes will require solar PV systems to meet ZNE goals starting in 2020, builders can incorporate select packages of building technologies today and provide homeowners cost-effective savings before ZNE building codes come in effect. Navigant conducted additional analysis to identify cost-effective building technologies for mixed-fuel homes in each location and evaluate their energy savings, incremental cost, payback, and TRC values. Appendix H provides further details, but the list of cost-effective measures includes: advanced windows, tankless water heaters, condensing furnaces, advanced thermostats, and higher efficiency cooling systems. In the next several years before 2020 codes take effect, builders could advertise these homes as "near-ZNE" or "ZNE-ready" since they will already incorporate the major efficiency measures applicable to a ZNE home.

## 4.5 Observations

### 4.5.1 Comparison between Mixed-Fuel and Electric-Only ZNE Homes

- On a TDV basis, mixed-fuel ZNE homes almost always have 5-15% lower TDV energy consumption than electric-only designs. For both mixed-fuel and electric-only homes, many end-uses (e.g., lighting, fan consumption, miscellaneous electric loads, etc.) are the same in each configuration. Stringent Title 24 codes and federal minimum efficiency standards have substantially reduced HVAC, water heating, lighting, and other end-uses, while non-regulated home appliances or "plug loads" have few efficiency options available today.

- Because solar PV systems can offset home electricity consumption during peak TDV hours and PV has experienced substantial price reductions in recent years, ZNE homes offset the majority of their TDV energy consumption (91% average) with a moderately sized solar PV system (3-5 kW). The size of the solar PV system depends on both the fuel configuration and home location, with electric-only homes and homes located in inland regions requiring larger systems. PV system size increases by around 1 kW between Los Angeles (CZ 6) and Palm Springs (CZ 15), and by around 0.5 kW between mixed-fuel and electric-only ZNE homes for the same location.

- While stringent Title 24, Title 20, and federal appliance standards limit the cost effectiveness of non-PV technologies in optimized ZNE configurations, several efficiency measures relating to HVAC loads and water heating can provide cost-effective TDV savings. Technologies such as advanced thermostats, improved insulation, and advanced windows reduce thermal loads, while condensing furnaces reduce the thermal and electrical energy to satisfy the home's thermal 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 attractive cost savings, but are less cost effective on a $/TDV basis than solar PV systems for the life of the home.

#### 4.5.2 Impacts of Home Size, Orientation, and Non-Title 24 Loads

- The ZNE home's orientation substantially affects the solar PV system output and the required system size to reach ZNE goals. Compared to an optimal South-facing solar PV system on the ZNE home's back roof, a North-facing solar PV system must be 44-58% larger, with East-facing systems at 21-35% and West facing systems at 11-18%. Nevertheless, ZNE can accommodate the required solar PV system in any orientation as long as at least 50-75% of the back roof is available. Of course, if they are willing to sacrifice aesthetics, homebuilders can orient the solar PV system in different ways, regardless the direction the house faces.

- Incorporating non-Title 24 or exogenous loads, such as transportation- and pool-related loads, into the energy-budget for a ZNE home increases TDV consumption by 100-200%. For both ZNE home designs, these exogenous loads substantially increase the required solar PV system size to 9-10 kW which approaches roof availability limits. In these instances, homebuilders may need to install solar PV systems in alternative locations, or move to a community-based solar approach.

- ZNE home size has a substantial impact on the technical results, with mixed-fuel ZNE homes have lower optimized TDV energy consumption and solar PV systems compared to electric-only ZNE homes for each home size. Each home (1,800 sq.ft., 2,500 sq.ft., 3,200 sq.ft.) selected a similar mix of HVAC and water heating measures, with larger homes selecting more HVAC measures due to their larger HVAC loads.

#### 4.5.3 Impacts of Advanced Technologies

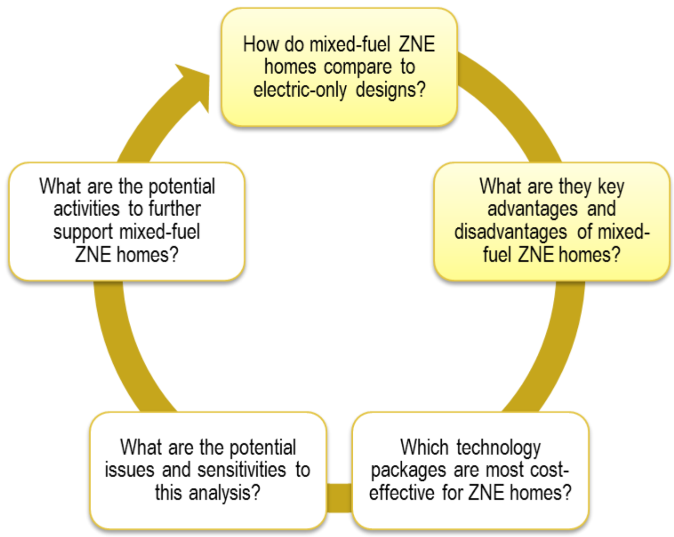
- Under current cost and performance scenarios, gas heat pumps and mCHP systems can provide net energy savings on a TDV basis but are less cost-effective than solar PV systems. On a technical basis, heating-only or reversible gas heat pumps and 0.5-1kW fuel cell mCHP systems can substantially reduce HVAC and water heating consumption and displace a portion of the solar PV system capacity. Adding a solar thermal system to thermally activated heat pumps improves TDV energy savings, but carries too high of a system cost, relative to other available options. The economics for these technologies improves under future cost projections, but PV and other technologies will also likely experience cost reductions.

- On-site energy storage systems, such as electric batteries can reduce a home's TDV energy consumption by shifting grid-supplied electricity consumption to hours with lower TDV values. At current costs, electric batteries can provide TDV energy savings for ZNE homes, but are less cost-effective than solar PV systems. Future projections for battery costs may partly close this gap relative to solar PV systems.

# 5. Economic Evaluation

## 5.1 Section Summary

This section summarizes the economic results of the analysis and answers the following key questions:




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

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

## 5.2 Simulation Results

After analyzing the technical results of the building simulation study, Navigant evaluated the economic impacts of the optimized mixed-fuel and electric-only homes compared to a Title 24-2016 code-compliance electric-only home in each location. This section:

- Summarizes the economic results of the modeling study, focusing on the total and incremental cost to reach ZNE goal, annual utility bill savings, simple payback, and annual GHG emissions savings of ZNE homes compared to a baseline electric-only home.
- Discusses general observations regarding the economic impacts of optimized mixed-fuel and electric-only homes compared to a baseline electric-only home from customer, utility, and regulatory perspectives.

Note – unless specifically noted, we present results for the Home B house size (2,500 sq.ft., two-story) for ease of reading. Section 5.2.4 discusses the results for Home A (1,800 sq.ft., single-story) and Home C (3,200 sq.ft., two-story).

### 5.2.1 Incremental Cost for ZNE Goal, Utility Cost Impacts, and Homeowner Payback

Figure 37 summarizes the installed costs for baseline and optimized mixed-fuel and electric-only ZNE homes in each location. These cost estimates include the major building features summarized in Table 19, including major building materials (e.g., roofing, wall frame, window, flooring, and insulation) and major end-use appliances (e.g., HVAC, water heating, kitchen, laundry, lighting, and solar PV systems), but excludes construction and land costs. Baseline home costs do not differ significantly among locations, while optimized ZNE home costs generally increase in more inland regions. Baseline costs for both mixed-fuel and electric-only homes range from $85,000 to $89,000, with a maximum difference between the fuel configurations for a home in the same location of less than 1% ($800). The cost for optimized ZNE homes range from $105,000 to $121,000, with mixed-fuel ZNE homes averaging 3.4% ($3,696) less than an electric-only configuration. These results suggest mixed-fuel ZNE homes have comparable first costs to electric-only homes meeting current and future Title 24 building codes.

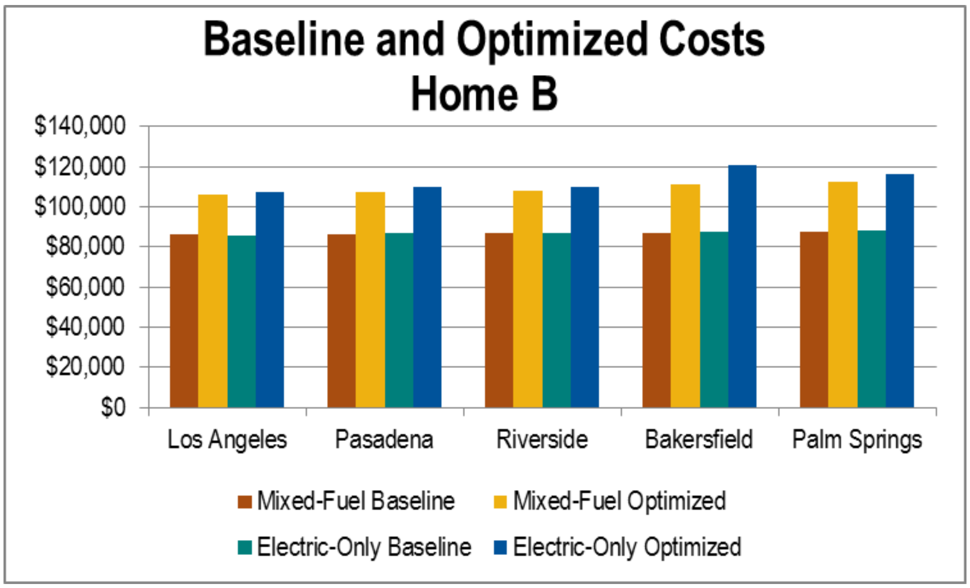



**Figure 37. Baseline and Optimized Costs for Mixed-Fuel and Electric-Only ZNE Homes**

Figure 38 compares the incremental cost for mixed-fuel and electric-only homes to reach ZNE goals compared to a Title 24-2016 code-compliance electric-only home. In each location, mixed-fuel ZNE homes have lower incremental cost than electric-only homes to reach ZNE status compared to electric-only baseline home, with an average of 9% ($2,200) lower incremental cost for all regions except Bakersfield. This trend aligns with the technical results of Section 4. In both mixed-fuel and electric-only homes, solar PV systems provided the majority of TDV savings, with electric-only ZNE homes requiring slightly larger solar PV systems in most locations. In most locations, the larger solar PV system size contributes to larger incremental cost for electric-only ZNE homes.

The incremental cost for electric-only ZNE home in Bakersfield is substantially higher than other locations. As noted in Section 4, the electric-only ZNE home for Bakersfield selected a solar water heating system in place of a HPWH. Solar water heaters have a substantial upfront cost, as illustrated in Figure 38, but provided a lower cost of conserved energy on a TDV basis for Bakersfield compared to a HPWH and larger solar PV system.

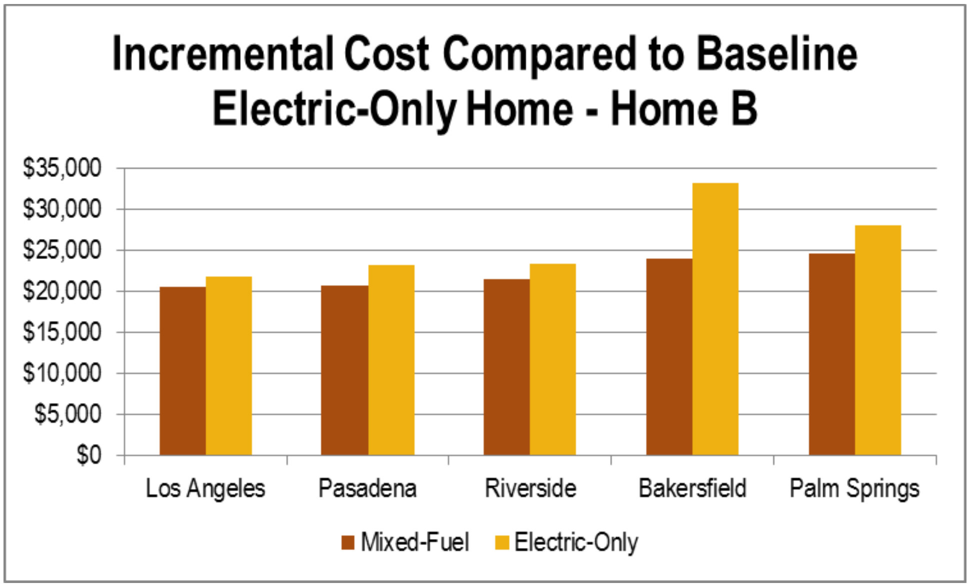



**Figure 38. Incremental Cost for Mixed-Fuel and Electric-Only ZNE Homes Compared to Electric-Only Baseline Home**

Table 29 compares the annual utility bills and net savings for optimized mixed-fuel and electric-only homes relative to a baseline electric-only home in each location. For most locations and home designs, ZNE homes significantly reduce utility bills to less than $25 per month. The values displayed in Table 29 include monthly connection charges, consumption charges, as well as any net electricity production credited at the retail cost of electricity on a net metering basis. Annual net electricity production is credited by net surplus compensation rates, where applicable. ZNE homes in several locations experience net negative utility bills because they produce excess electricity annually or more electricity during higher rate periods. The electric-only ZNE home in Bakersfield does not have substantial utility cost savings relative to TDV savings due to the selection of solar water heater.

**Table 29. Annual Utility Bills and Savings by Location – Home B**

| Location | Electric-Only Baseline Home | Mixed-Fuel ZNE Homes | | Electric-Only ZNE Homes | |
|---|---|---|---|---|---|
| | Annual Utility Cost | Optimized Utility Cost | Utility Cost Savings | Optimized Utility Cost | Utility Cost Savings |
| **Los Angeles** | $1,182 | $304 | $878 | $239 | $943 |
| **Pasadena** | $1,495 | $49 | $1,446 | $17 | $1,478 |
| **Riverside** | $1,588 | $64 | $1,524 | $82 | $1,506 |
| **Bakersfield** | $2,165 | $256 | $1,909 | $771 | $1,394 |
| **Palm Springs** | $1,980 | $45 | $1,935 | ($31) | $2,011 |

Note - includes monthly connection charges, consumption charges, as well as any net electricity production credited, but does not include additional taxes, riders, or tariffs.

Note – utility rates include monthly connection and consumption charges in each rate schedule, but do not consider additional riders, fees, or taxes. Annual net electricity production is credited by net surplus compensation rates, where applicable. Extra charges tied to consumption will also decrease for ZNE homes. Appendix A contains details on the utility rates for each location.

While Title 24 regulations will require all new homes to reach ZNE status starting in 2020, prospective homeowners will want to know the expected payback for their investment in ZNE. Figure 39 outlines the expected simple payback for mixed-fuel and electric-only ZNE homes relative to a baseline electric-only home in each location. Without assuming fuel escalation or maintenance costs in future years and excluding incentives, mixed-fuel ZNE homes can offer homeowners simple paybacks ranging from 13 to 23 years compared to baseline electric-only homes. Due to higher incremental costs, electric-only ZNE homes offer longer payback periods ranging from 14 to 24 years.

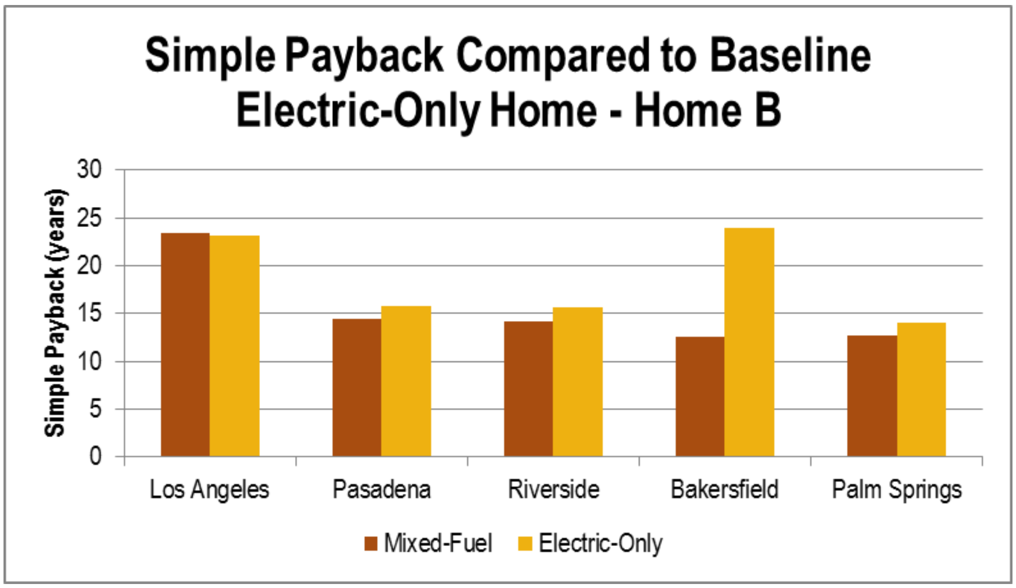



**Figure 39. Simple Payback for Optimized ZNE Home Compared to Baseline Electric-Only Home – Home B**

Note – Mixed-Fuel ZNE homes in Los Angeles have higher payback partially due to how different utilities compensate net surplus electricity consumption at the end of the year. SCE and PG&E provide a net surplus compensation rate of $0.04-$0.05 per kWh while LADWP does not. Because Mixed-Fuel ZNE homes must generate excess electricity to offset natural gas consumption, utilities that do not compensate excess electricity production leave Mixed-Fuel ZNE homeowners with slightly higher utility costs, and lower annual utility savings.

The majority of prospective ZNE home owners will mortgage the upfront cost of the ZNE home, including any incremental costs over a baseline unit. Without additional incentives, financing the necessary efficiency measures and solar PV systems is the easiest way for the average home owner to reach ZNE status. Through this method, the incremental ZNE costs are spread over the life of the home, resulting in low annual payments, among other benefits. Table 30 provides the annual incremental mortgage cost , assuming a 4.12 % APR, 30 year mortgage, and homeowner annual costs , assuming a 4.12% interest rate, and 3% discount rate for utility costs over 30 years. Compared to a baseline electric-only home, mixed-fuel ZNE homes have lower incremental annual mortgage payments and homeowner annual costs than electric-only ZNE homes. Appendix F contains assumptions for incremental mortgage analysis.

**Table 30. Incremental Mortgage Payments and Homeowner Annual Costs – Home B**

| Category | Location | Incremental Cost | Incremental Annual Mortgage Payment | Annual Utility Costs | Homeowner Annual Costs |
|---|---|---|---|---|---|
| Mixed-Fuel | Los Angeles | $20,547 | $1,193 | $304 | $2,776 |
| | Pasadena | $20,793 | $1,208 | $49 | $2,496 |
| | Riverside | $21,539 | $1,251 | $64 | $2,558 |
| | Bakersfield | $23,973 | $1,392 | $256 | $3,237 |
| | Palm Springs | $24,572 | $1,427 | $45 | $3,025 |
| Electric-Only | Los Angeles | $21,830 | $1,268 | $239 | $2,835 |
| | Pasadena | $23,278 | $1,352 | $17 | $2,621 |
| | Riverside | $23,423 | $1,360 | $82 | $3,028 |
| | Bakersfield | $33,315 | $1,935 | $771 | $4,105 |
| | Palm Springs | $28,058 | $1,630 | -$31 | $3,163 |

Assumes 4.12 % APR, 30 year mortgage, for a homeowner with 4.12 % interest rate, and 3% discount rate. Homeowner annual cost accounts for the NPV of life-cycle costs and utility bills over 30 years.

### 5.2.2 Economic Impacts of Building Orientation

As described in Section 4.2.4, ZNE homes facing North with their solar PV system on the South-facing back roof maximize the solar output for their location. In other orientations, the solar PV system receives less energy throughout the day such that ZNE homes require a larger solar PV system to reach ZNE goals. With less electricity output per capacity, the larger solar PV system does not provide any additional utility savings or other benefits, but only increases the incremental costs to achieve ZNE goals. Because the cost of the solar PV system comprises the largest incremental cost, ZNE homes with non-optimal orientations carry substantially larger incremental costs, paybacks, and mortgage payments.

Table 31 outlines the incremental cost and payback for mixed-fuel and electric-only ZNE homes compared to baseline electric-only homes in each orientation. Because the utility cost savings remain consistent across each orientation, increases to incremental cost have a direct correlation to the simple payback[44]. Increases for mixed-fuel and electric-only ZNE homes range from 10-16% for East, 42-50% for South, and 19-25% for West. The electric-only ZNE home in Bakersfield shows different results due to the baseline choice of a South-facing solar water heating system, and then a HPWH in the other orientations. Without incentives or financing, the payback for South and West homes approaches the 25-30 year expected lifetime, and exceed that timeframe in some cases.

[44] Percentage increases for incremental cost and payback will be similar to the percentage increases for solar PV systems (See Table 21), but will not directly coincide because each orientation carries different efficiency measures within the incremental cost.

**Table 31. Incremental Costs and Simple Payback for ZNE Homes in Each Orientation – Home B**

| Category | Location | North Home (South PV) | | | East Home (West PV) | | | South Home (North PV) | | | West Home (East PV) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Solar PV Size (kW) | Incremental Cost | Payback | Percent Increase | Incremental Cost | Payback | Percent Increase | Incremental Cost | Payback | Percent Increase | Incremental Cost | Payback |
| Mixed-Fuel | Los Angeles | 3.4 | $20,547 | 23 | 13% | $23,020 | 26 | 43% | $29,075 | 33 | 21% | $24,747 | 28 |
| | Pasadena | 3.4 | $20,793 | 14 | 10% | $22,937 | 16 | 45% | $30,337 | 21 | 20% | $25,067 | 17 |
| | Riverside | 3.6 | $21,539 | 14 | 15% | $24,819 | 16 | 50% | $32,249 | 21 | 25% | $26,833 | 18 |
| | Bakersfield | 4.2 | $23,973 | 13 | 11% | $26,672 | 14 | 45% | $34,994 | 18 | 22% | $29,317 | 15 |
| | Palm Springs | 4.3 | $24,572 | 13 | 16% | $28,564 | 15 | 49% | $36,888 | 19 | 21% | $30,000 | 16 |
| Electric-Only | Los Angeles | 3.8 | $21,830 | 23 | 10% | $23,981 | 26 | 42% | $31,048 | 35 | 21% | $26,498 | 29 |
| | Pasadena | 3.9 | $23,278 | 16 | 10% | $25,676 | 17 | 42% | $33,049 | 25 | 20% | $27,885 | 20 |
| | Riverside | 4.0 | $23,423 | 16 | 13% | $26,414 | 17 | 45% | $34,060 | 24 | 22% | $28,539 | 20 |
| | Bakersfield | 3.9 | $33,315 | 24 | -11% | $29,766 | 26 | 12% | $37,173 | 42 | -1% | $33,125 | 28 |
| | Palm Springs | 5.0 | $28,058 | 14 | 16% | $32,496 | 16 | 43% | $40,096 | 22 | 19% | $33,361 | 18 |

* Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

These results suggest that the economic success for a ZNE home project largely depends on the solar PV system orientation and should be considered early in the design process. Where possible, the solar PV system should face South or West and may require increasing the solar PV system's tilt or placement of the solar PV panels on the front roof, garage, porch, or other surface that provides near-optimal orientation with minimal shade. If the ZNE home designs cannot optimally orient the solar PV system, other options could be considered including community-based solar systems. In this configuration, multiple ZNE homes share the benefits of a larger solar PV system located in a common space, such as a community center, commercial buildings, school, carport, etc. As discussed in the 2013 Integrated Energy Policy Report[8], anticipated additions to the ZNE Code Building definition will incorporate specific "development entitlements" to allow for community-based renewable energy generation systems.

### 5.2.3 Economic Impacts of Exogenous Loads

As discussed in Section 4.2.5, incorporating pool-related and vehicle-related building loads increases home energy consumption by 100-200%, and consequently ZNE homes require larger solar PV systems. As shown in Table 32, the larger solar PV systems raise the incremental cost to reach ZNE goals relative to a baseline electric-only home, but the simple payback does not substantially differ because the large solar PV system contributes to larger utility cost savings. Because the exogenous loads for electric-only homes are smaller than those for mixed-fuel ZNE, electric-only ZNEs require smaller solar PV systems and have lower incremental costs. Similar to Table 31, altering the orientation of ZNE homes with exogenous loads increases required solar PV size, incremental cost, and payback.

**Table 32. Economic Impacts of ZNE Homes Exogenous Loads – Home B**

| Category | Location | ZNE Home w/ Title 24 Loads | | | ZNE Home w/ Title 24 + Exogenous Loads | | |
|---|---|---|---|---|---|---|---|
| | | Solar PV Size (kW) | Incremental Cost ($) | Payback (Years) | Solar PV Size (kW) | Incremental Cost ($) | Payback (Years) |
| Mixed-Fuel | Los Angeles | 3.4 | $20,547 | 23 | 10.2 | $59,349 | 38 |
| | Pasadena | 3.4 | $20,793 | 14 | 10.7 | $62,295 | 16 |
| | Riverside | 3.6 | $21,539 | 14 | 10.7 | $61,747 | 16 |
| | Bakersfield | 4.2 | $23,973 | 13 | 11.4 | $64,940 | 14 |
| | Palm Springs | 4.3 | $24,572 | 13 | 11.5 | $65,176 | 16 |
| Electric-Only | Los Angeles | 3.8 | $21,830 | 23 | 8.9 | $47,441 | 21 |
| | Pasadena | 3.9 | $23,278 | 16 | 9.4 | $49,534 | 12 |
| | Riverside | 4.0 | $23,423 | 16 | 9.3 | $49,549 | 11 |
| | Bakersfield | 3.9 | $33,315 | 24 | 10.6 | $54,135 | 14 |
| | Palm Springs | 5.0 | $28,058 | 14 | 10.1 | $52,715 | 11 |

Note – exogenous loads include pool- and vehicle-related energy consumption not covered under Title 24 building codes.

### 5.2.4 Economic Impacts of ZNE Home Size

As discussed in Section 4.2.7, ZNE homes of different sizes show generally consistent results, with TDV energy consumption and solar PV system size varying with home size. Consequently, the economics for Home A (1,800 sq.ft., single-story) and Home C (3,200 sq.ft., two-story) follow similar trends to Home B (2,500 sq.ft., two-story). In each case, mixed-fuel ZNE homes have lower incremental costs than electric-only ZNE homes when compared to an electric-only baseline home due to the lower solar PV requirements, as shown in Table 33. Similar to Home B, other mixed-fuel ZNE home sizes have slightly higher annual utility costs and shorter payback periods than electric-only ZNE homes when compared to electric-only baseline home. Appendix G contains full economic results for each Home design.

**Table 33. Comparison of ZNE Home Incremental Cost by Home Size**

| Location | Home A (1,800 sq.ft., single-story)) | | Home B (2,500 sq.ft., single-story)) | | Home C (3,200 sq.ft., single-story)) | |
|---|---|---|---|---|---|---|
| | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only |
| **Los Angeles** | $17,031 | $18,054 | $20,547 | $21,830 | $19,805 | $23,670 |
| **Pasadena** | $17,779 | $18,744 | $20,793 | $23,278 | $20,903 | $24,732 |
| **Riverside** | $18,551 | $19,297 | $21,539 | $23,423 | $21,948 | $25,395 |
| **Bakersfield** | $20,799 | $22,380 | $23,973 | $33,315 | $25,213 | $27,361 |
| **Palm Springs** | $21,936 | $22,200 | $24,572 | $28,058 | $27,228 | $30,562 |

### 5.2.5 Lifetime Energy, Utility Cost, and Greenhouse Gas Savings

Table 34, Table 35, and Table 36 show the annual and lifetime TDV, energy, and utility cost savings, relative to an electric-only baseline home. Evaluated from the same baseline electric-only home, mixed-fuel and electric-only ZNE homes achieve the same TDV energy savings since they both achieve ZNE by definition. These results are consistent across different building orientations.

**Table 34. TDV Savings Values for Optimized ZNE Homes Compared to Electric-Only Baseline Home – Home B**

| Category | Location | Annual TDV Savings (MMBtu, Year 1) | Total TDV Savings (MMBtu, Year 1-30) |
|---|---|---|---|
| **Mixed-Fuel** | Los Angeles | 105.2 | 3,156 |
| | Pasadena | 106.1 | 3,183 |
| | Riverside | 112.1 | 3,363 |
| | Bakersfield | 130.9 | 3,927 |
| | Palm Springs | 148.0 | 4,440 |
| **Electric-Only** | Los Angeles | 105.2 | 3,156 |
| | Pasadena | 106.1 | 3,183 |
| | Riverside | 112.1 | 3,363 |
| | Bakersfield | 130.9 | 3,927 |
| | Palm Springs | 148.0 | 4,440 |

**Table 35. Lifetime Net Energy Savings of Optimized ZNE Homes Compared to Electric-Only Baseline Home – Home B**

| Category | Location | Net Annual Energy Savings | | | | Lifetime Energy Savings (30 Years) | |
|---|---|---|---|---|---|---|---|
| | | Electricity Savings (kWh) | PV Production (kWh) | Total Electricity Savings (kWh) | Natural Gas (Therms) | Total Electricity Savings (kWh) | Total Natural Gas (Therms) |
| **Mixed-Fuel** | Los Angeles | 3479 | 5,269 | 8,748 | -235 | 262,440 | -7,050 |
| | Pasadena | 3361 | 5,211 | 8,572 | -211 | 257,160 | -6,330 |
| | Riverside | 3596 | 5,666 | 9,262 | -235 | 277,860 | -7,050 |
| | Bakersfield | 4290 | 6,599 | 10,889 | -292 | 326,670 | -8,760 |
| | Palm Springs | 3386 | 7,008 | 10,394 | -171 | 311,820 | -5,130 |
| **Electric-Only** | Los Angeles | 91 | 5,914 | 6,005 | – | 180,150 | – |
| | Pasadena | 132 | 5,930 | 6,062 | – | 181,860 | – |
| | Riverside | 188 | 6,264 | 6,452 | – | 193,560 | – |
| | Bakersfield* | 1,679 | 6,171 | 7,850 | – | 235,500 | – |
| | Palm Springs | 258 | 8,070 | 8,328 | – | 249,840 | – |

* Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

**Table 36. Lifetime Utility Cost Savings of Optimized ZNE Homes Compared to Electric-Only Baseline Home – Home B**

| Category | Location | Annual Utility Cost Savings | Lifetime Utility Cost Savings (30 Years) |
|---|---|---|---|
| **Mixed-Fuel** | Los Angeles | $878 | $26,328 |
| | Pasadena | $1,446 | $43,389 |
| | Riverside | $1,524 | $45,734 |
| | Bakersfield | $1,909 | $57,267 |
| | Palm Springs | $1,935 | $58,063 |
| **Electric-Only** | Los Angeles | $943 | $28,290 |
| | Pasadena | $1,478 | $44,340 |
| | Riverside | $1,506 | $45,180 |
| | Bakersfield | $1,394 | $41,820 |
| | Palm Springs | $2,011 | $60,330 |

Table 37 provides the annual GHG emissions and savings for ZNE homes in each location relative to a baseline electric-only home. In addition to reduced utility bills, ZNE homes also support personal, statewide, and national environmental goals by reducing the associated GHG emissions of new homes by 55-87% relative to a baseline electric-only home. These estimates assume carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on U.S. Energy Information Administration estimates for California region and 2,205 lbs per metric ton conversion factor[45]. If evaluated on national average carbon emission factors of 1.53 lbs/kWh and 14.15 lbs/therm[46], the savings percentages for mixed-fuel homes would more closely match those of electric-only homes. California's electric generation portfolio is already substantially less carbon intensive than the most of the U.S. average, and will continue to decrease with statewide targets for reduced carbon emissions. Efforts to reduce the carbon intensity of natural gas (e.g., biogas) would decrease the emissions factor for natural gas, and improve the savings percentage of mixed-fuel homes.

[45] EIA resources eGrid Database, available at: http://www.epa.gov/cleanenergy/energy-resources/egrid/ and Voluntary Reporting of Greenhouse Gases Program Fuel Carbon Dioxide Emission Coefficients, available at: http://www.eia.gov/oiaf/1605/coefficients.html

[46] National average from BEopt software, referencing ANSI/ASHRAE Standard 105-2014, Appendix J.

**Table 37. Annual GHG Emissions and Savings Compared to Electric-Only Baseline Home – Home B**

| Category | Location | Annual GHG Emissions (metric tons/year) | | |
|---|---|---|---|---|
| | | Annual Savings | Net Consumption | Net Savings (%) |
| Mixed-Fuel | Los Angeles | 1.2 | 1.0 | 55% |
| | Pasadena | 1.3 | 0.9 | 59% |
| | Riverside | 1.3 | 0.9 | 59% |
| | Bakersfield | 1.5 | 1.1 | 57% |
| | Palm Springs | 2.0 | 0.7 | 75% |
| Electric-Only | Los Angeles | 1.7 | 0.5 | 78% |
| | Pasadena | 1.7 | 0.5 | 79% |
| | Riverside | 1.8 | 0.5 | 79% |
| | Bakersfield* | 2.2 | 0.4 | 85% |
| | Palm Springs | 2.3 | 0.3 | 87% |

Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.
* Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

### 5.2.6 Impacts for Utility and Regulatory Cost-Benefit Analyses

Table 38 estimates the cost-benefit ratio for ZNE homes from a utility programmatic perspective using the TRC test. The TRC test estimates the value of a measure's electricity and gas savings as the avoided costs to the California utility over the life of the measure and compares it against the cost of the measure. Assuming the energy savings of Table 35, incremental life-cycle costs, 85% net-to-gross, 2013 installation year, and 30 year lifetime, mixed-fuel and electric-only homes show TRC values under one in each location. Despite the net natural gas consumption relative to electric-only baseline home, mixed-fuel ZNE homes show higher TRC values than electric-only ZNE homes for each location, with a range of 0.42-0.46 for mixed-fuel and 0.33-0.38 for electric-only. As discussed further in Section 5.3, available federal tax credits raise the TRC values, but still well below 1.0. TRC values would decrease for non-optimized orientations with higher incremental costs in a similar manner to the payback increases in Table 31

These results reflect the Title 24 methodology using incremental life-cycle costs rather than upfront incremental costs. If evaluated only on upfront incremental costs, as common for utility program, TRCs range from 0.86-0.96 for mixed-fuel and 0.57-0.74 for electric-only ZNE homes. While the TRC values less than one suggest the measures may not meet utility program goals for cost-effective energy savings, these TRC values may be acceptable compared to other residential measures. The residential sector average TRC for SCG measures was 0.85 in 2013 and 0.96 between 2010-2012[47].

[47] Provided by SCG to Navigant as part of SCG's Portfolio of the Future assignments.

The fact that ZNE homes featuring solar PV systems have TRC values less than zero is consistent with the overall TRC values for the California Solar Initiative (CSI) program. In a 2011 report, Energy and Environmental Economics, Inc.[48] discussed the cost-effectiveness of solar PV for residential homes in California, saying "From a societal (or TRC) perspective, we do not expect solar PV to be cost-effective during the analysis period [2008-2020], particularly in the residential sector." The report points out how the CSI program was a policy initiative and includes non-economic benefits that are not considered in the TRC calculation. Additionally, the report discusses community-based solar PV systems using virtual net-metering as a pathway for smaller or non-optimal homes to achieve greater cost-effectiveness.

**Table 38. TRC Values for Optimized ZNE Homes by Location Compared to Electric-Only Baseline Home – Home B**

| Category | Location | Net Incremental Life-Cycle Cost | Lifetime Net Avoided Costs | | TRC Test |
|---|---|---|---|---|---|
| | | | Electricity (kWh) | Natural Gas (Therms) | |
| **Mixed-Fuel** | Los Angeles | $34,703 | $17,637 | -$2,912 | 0.42 |
| | Pasadena | $35,036 | $18,072 | -$2,615 | 0.44 |
| | Riverside | $35,673 | $18,474 | -$2,912 | 0.44 |
| | Bakersfield | $42,158 | $21,986 | -$3,619 | 0.44 |
| | Palm Springs | $42,705 | $21,712 | -$2,119 | 0.46 |
| **Electric-Only** | Los Angeles | $36,677 | $12,106 | - | 0.33 |
| | Pasadena | $37,375 | $12,780 | - | 0.34 |
| | Riverside | $42,118 | $12,869 | - | 0.31 |
| | Bakersfield | $45,857 | $15,850 | - | 0.35 |
| | Palm Springs | $45,987 | $17,396 | - | 0.38 |

Note - Assumes the energy savings of Table 35, incremental life-cycle costs, 85% net-to-gross, 2013 installation, 30 year lifetime, and no incentives.

Table 39 estimates the benefit-cost analysis for ZNE homes from a regulatory perspective using methodology adopted for CEC Codes & Standards life-cycle analyses. This methodology compares the net present value of all associated costs and benefits for the measure relative to a baseline electric-only home. Life-cycle costs represent the incremental upfront and replacement costs for a mixed-fuel or electric-only ZNE home relative to a baseline electric-only home for each location. Assuming a 3% discount rate, $0.1732 per TDV-kBtu, and 30 year lifetime, mixed-fuel and electric-only ZNE homes show positive life-cycle costs ranging from $23,394-$27,824 for mixed-fuel and $25,760-$32,256 for electric-only ZNE homes.

[48] Energy and Environmental Economics. 2011. "California Solar Initiative Cost-Effectiveness Evaluation." California Public Utilities Commission. April 2011.

**Table 39. Lifetime TDV Benefit-Cost Analysis for Optimized ZNE Homes Compared to Electric-Only Baseline Home – Home B**

| Category | Location | NPV Life-Cycle Cost | Annual TDV Savings (MMBtu TDV) | NPV Benefits @ $0.1732/TDV-kBtu | Net Life-Cycle Costs |
|---|---|---|---|---|---|
| Mixed-Fuel | Los Angeles | $41,580 | 105 | $18,186 | $23,394 |
| | Pasadena | $41,979 | 106 | $18,359 | $23,620 |
| | Riverside | $42,742 | 112 | $19,398 | $23,344 |
| | Bakersfield | $50,513 | 131 | $22,689 | $27,824 |
| | Palm Springs | $51,168 | 148 | $25,634 | $25,534 |
| Electric-Only | Los Angeles | $43,946 | 105 | $18,186 | $25,760 |
| | Pasadena | $44,782 | 106 | $18,359 | $26,423 |
| | Riverside | $50,465 | 112 | $19,398 | $31,067 |
| | Bakersfield | $54,945 | 131 | $22,689 | $32,256 |
| | Palm Springs | $55,100 | 148 | $25,634 | $29,466 |

Assumes 3% discount rate, $0.1732 per TDV-kBtu, and 30 year lifetime.

## *5.3 Impact of Incentives*

To accelerate the adoption of emerging technologies and boost residential efficiency, the federal government and several California utilities offer incentives for energy savings, solar technologies, and mCHP systems. Table 40 provides an overview of available incentives for California new homes. The available programs generally follow one or more of the following incentive structures:

- **Prescriptive Rebate by Capacity**: Homeowners, or their contractor, receive a cash rebate for installing technologies based on the system's nameplate or effective capacity. For example, the CSI program's solar PV incentive provided rebates ($/W) based on an effective capacity estimate, accounting for factors such as home location, panel efficiency, inverter efficiency, roof orientation, roof tilt, etc.
- **Prescriptive Rebate by Estimated Savings**: Homeowners, or their contractor, receive a cash rebate for achieving certain energy savings goals based on building simulation modeling results. For example, the California Advanced Homes Program provides rebates based on the home's estimated kWh, therm, and kW savings projected by Micropas or EnergyPro simulated software.
- **Tax Credit by Capacity**: Homeowners, or their contractors, receive a credit on their annual income taxes for installing technologies based on the system's nameplate or effective capacity. For example, the federal Residential Renewable Energy Tax Credit provides a credit worth 30% of the total installed cost for solar PV systems and other technologies that a homeowner could use to reduce their federal income tax liability.

**Table 40. Available Incentives for ZNE Homes and Advanced Technologies**

| Utility | Program Name | Incentive Structure | Amount | Notes |
|---|---|---|---|---|
| SCE | Self Generation Incentive Program | Rebate | • mCHP $0.46/W (engine-based) to $1.83/W (fuel cell)<br>• Energy Storage $1.62/W (must do 2 hr. discharge) | Carries a 5-10% annual decline rate |
| PG&E/SCE | California Solar Initiative (CSI) Solar PV | Rebate | Closed | |
| PG&E/SCG | CSI Solar Thermal | Rebate | $18.59/therm | Gas only |
| PG&E/SCE | CSI Solar Thermal | Rebate | $0.54/kWh | Electric only |
| PG&E, SCE | New Solar Homes | Rebate | • Built to code - $0.75/W,<br>• 15% better than code Tier 1 -$1/W,<br>• 30% better than code Tier 2 - $1.5/W | |
| PG&E, SCE, SCG | California Advanced Homes Program | Rebate | • 15% better than code, ($1.72/therm, $0.43/kWh, $75/kW)<br>• 45% better than code ($5.14/therm, $1.29/kWh, $225/kW)<br>• Additional incentives for technologies and other efficiency levels. | Expires end of 2014 |
| LADWP | Solar Incentive Program | Rebate | Ranges from $0.3-0.4/W | |
| Federal | Residential Renewable Energy Tax Credit | Tax Credit | • 30% on solar electric, solar water heating,<br>• $500 per 0.5 kW fuel cells | Expires 2016 |

Our technical analysis of ZNE homes has not considered these incentives during the optimization process due to the uncertain impact they will have on future residential homes. As shown in Table 40, the majority of available incentives expire in the next several years. Some incentives will cease as their planned funding is fully allocated or when they reach their target completion date. Others such as the federal tax credit may extend the current program design, reduce their incentive levels (e.g., from 30% to 10%), or modify their structure (e.g., performance based approach). Additionally, new incentives may be offered targeting emerging technologies (e.g., on-site battery storage).

Nevertheless, understanding how incentives can impact the incremental costs and payback for ZNE homes provides insight into the future economics of potential ZNE homebuyers. Table 41 provides the net incremental cost and payback for mixed-fuel and electric-only ZNE homes, assuming a 30% or 10% federal tax credit on the solar PV system. Compared to an average incremental ZNE cost of approximately, $22,000, the 30% federal tax credit for solar PV systems reduces ZNE incremental cost by an average of $6,500 while a 10% tax credit reduces ZNE incremental cost by close to $2,200. Because the solar PV system comprises the majority of a ZNE home's incremental cost, percentage based incentives levels have a nearly direct correlation to total ZNE incremental cost. For example, the 30% federal tax credit lowers the average ZNE incremental cost by 29%. Similarly, ZNE incremental costs will follow similar trends for capacity based incentives ($/W) when compared to prevailing solar PV cost per capacity.

**Table 41. Incremental Cost and Payback with Federal Incentives – Home B**

| Category | Location | PV System Size (kW) | Annual Utility Savings | No Incentive | | 30% Federal Tax Credit | | 10% Federal Tax Credit | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Incremental Cost | Simple Payback | Incremental Cost | Simple Payback | Incremental Cost | Simple Payback |
| Mixed-Fuel | Los Angeles | 3.4 | $878 | $20,547 | 23 | $14,666 | 17 | $18,587 | 21 |
| | Pasadena | 3.4 | $1,446 | $20,793 | 14 | $14,771 | 10 | $18,786 | 13 |
| | Riverside | 3.6 | $1,524 | $21,539 | 14 | $15,208 | 10 | $19,429 | 13 |
| | Bakersfield | 4.2 | $1,909 | $23,973 | 13 | $16,810 | 9 | $21,585 | 11 |
| | Palm Springs | 4.3 | $1,935 | $24,572 | 13 | $17,213 | 9 | $22,119 | 11 |
| Electric-Only | Los Angeles | 3.8 | $943 | $21,830 | 23 | $15,253 | 16 | $19,638 | 21 |
| | Pasadena | 3.9 | $1,478 | $23,278 | 16 | $16,545 | 11 | $21,034 | 14 |
| | Riverside | 4.0 | $1,506 | $23,423 | 16 | $16,534 | 11 | $21,127 | 14 |
| | Bakersfield | 3.9 | $1,394 | $33,315 | 24 | $26,582 | 19 | $31,071 | 22 |
| | Palm Springs | 5.0 | $2,011 | $28,058 | 14 | $19,633 | 10 | $25,250 | 13 |

Incentives and tax credits awarded outside of utility incentive programs also act as a net benefit for TRC calculations. Table 42 provides estimated TRC values for mixed-fuel and electric-only homes, assuming a 30% and 10% federal tax credit on the solar PV system.

**Table 42. TRC Values with Federal Incentives – Home B**

| Category | Location | Baseline TRC | TRC w/ 30% Federal Tax Credit | TRC w/ 10% Federal Tax Credit |
|---|---|---|---|---|
| Mixed-Fuel | Los Angeles | 0.42 | 0.49 | 0.45 |
| | Pasadena | 0.44 | 0.52 | 0.46 |
| | Riverside | 0.44 | 0.51 | 0.46 |
| | Bakersfield | 0.44 | 0.51 | 0.46 |
| | Palm Springs | 0.46 | 0.54 | 0.48 |
| Electric-Only | Los Angeles | 0.33 | 0.39 | 0.35 |
| | Pasadena | 0.34 | 0.40 | 0.36 |
| | Riverside | 0.31 | 0.35 | 0.32 |
| | Bakersfield | 0.35 | 0.39 | 0.36 |
| | Palm Springs | 0.38 | 0.45 | 0.40 |

Note - Assumes energy savings of Table 35, NPV of incremental life-cycle costs, 85% net-to-gross, 2015 installation, and 30 year lifetime

## 5.4 Observations

### 5.4.1 Economic Impacts from Homeowner Perspective

- For each location, mixed-fuel and electric-only ZNE homes have comparable baseline and optimized costs for applicable building features. As noted in the technical evaluation, mixed-fuel and electric-only homes have similar TDV consumption values, share the majority of the end-use loads, and have a similar set of efficiency and renewable measures to reach ZNE goals. The incremental cost for ZNE homes range from $20,000-28,000 compared to a baseline electric-only home. Incremental costs range from $20,500-$24,600 for mixed-fuel and $21,800-$28,000 for electric-only ZNE homes. Mixed-fuel homes typically offer an average 9% reduction in incremental cost ($2,200) compared to electric-only ZNE homes, based on the smaller solar PV system size (approximately 0.5 kW). These results are generally consistent for other ZNE home sizes.
- Optimized, mixed-fuel ZNE homes have slightly higher annual utility bills than electric-only ZNE homes, and therefore offer lower utility cost savings. Relative to a baseline electric-only home, simple paybacks for mixed-fuel ZNE homes range from 13 to 23 years without additional incentives. Due to higher incremental costs and lower annual utility cost savings, electric-only ZNE homes offer longer payback periods ranging from 14 to 24 years.
- Mixed-fuel and electric-only ZNE homes show similar results when financing the incremental ZNE costs over a baseline electric-only home. For an assumed 4.12% APR 30-year mortgage, the incremental annual mortgage payment ranges from $1,200 to $1,425 for mixed-fuel ZNE homes and $1,250 to $1,900 for electric-only ZNE homes.

- Including exogenous loads or non-optimal solar PV orientation reduces the economic attractiveness of ZNE homes. ZNE homes with exogenous loads have higher incremental costs due to the larger solar PV system requirements. In each case, altering the solar PV orientation increases the incremental cost and payback period due to the required larger solar PV system.

**5.4.2 Utility and Regulatory Perspectives**

- Both mixed-fuel and electric-only ZNE homes offer substantial site energy, TDV energy, and GHG savings over the 30 year life of the home compared to a baseline electric-only home. Because the ZNE goal for both mixed-fuel and electric-only ZNE homes is the same electric-only ZNE homes provide the same TDV energy savings relative to a baseline electric-only home. GHG emissions for electric-only ZNE homes are lower than mixed-fuel ZNE homes based on the relatively low carbon intensity of electricity in California.
- From a utility programmatic perspective, the electricity and natural gas savings for ZNE homes carry TRC values less than one, excluding incentives, meaning their NPV of life-cycle incremental costs exceed the avoided fuel costs to the utility. Mixed-fuel ZNE homes show higher TRC values relative to a baseline electric-only home for each location, with a range of 0.42-0.46 for mixed-fuel ZNE homes and 0.33-0.38 for electric-only ZNE homes.
- For life-cycle benefit-cost analysis, ZNE homes in all locations have life-cycle incremental costs exceeding 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.

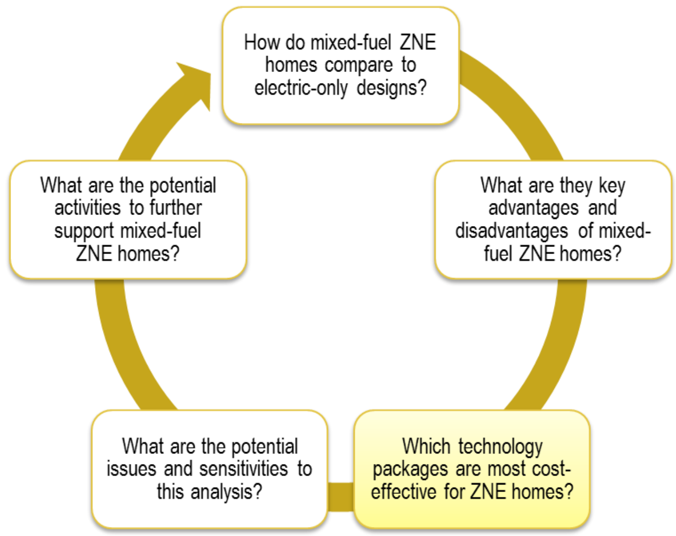
**5.4.3 Impact of Incentives**

- The economic attractiveness for ZNE homes can significantly improve with federal, state, or utility incentives. While many incentive programs expire in the next few years, the 30% federal tax credit may be extended or revised to a 10% incentive level. With a 30% tax credit, the payback for ZNE homes decreased by 3-6 years and a 10% federal tax credit decreases system payback by 1-2 years.

# 6. Next Steps for Advanced Technologies

## 6.1 Section Summary

This section summarizes the evaluation of advanced technologies under current and projected cost and performance metrics. This section answers the following key question:




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

## 6.2 Technology Roadmap

ZNE homes incorporate a wide variety of technologies, including those that are readily available today (e.g., high efficacy lighting, condensing furnaces), those gaining wider acceptance (e.g., HPWH, solar PV systems), and emerging technologies that require cost, performance, or market breakthroughs (e.g., on-site batteries, mCHP systems). Because Title 24 ZNE regulations are expected to begin in 2020, technology advancements over the next five years can significantly improve the technical and economic attractiveness of certain technologies and ZNE homes in general. Additionally, SCG, CEC, and others can consider conducting RD&D activities to improve the cost-effectiveness of current technologies or develop advanced technologies suitable for ZNE homes in California.

To understand how future technology developments may impact ZNE homes, we performed the following analyses:

- Compared the landscape of ZNE technology options on the basis of life-cycle cost vs. TDV energy savings under current cost and performance estimates to understand the full range of options that builders could use to achieve ZNE goals today.
- Evaluated the development status of select advanced technologies to estimate current cost and performance characteristics as well as those projected over the 2020-2030 timeframe.
- Developed cost and performance targets for select natural gas technologies to achieve competitiveness or maintain their current status compared to future advances in solar PV systems, electric heat pump water heaters, and electric air-source heat pumps.

### 6.2.1 Comparison of Current Technology Landscape for ZNE Homes

By extracting data on individual technologies from the building simulation study, we plotted the life-cycle cost vs. TDV energy savings for different technologies to understand the full range of options that builders could use to achieve ZNE goals. While the Phase 1 report outlines the technologies that showed lower cost-of-conserved energy than a solar PV system, other technologies can still provide cost-effective savings even if they are not the most optimal choice. This section contains figures and tables showing how different technologies within major end-use categories compare on a life-cycle cost vs. TDV savings basis, including:

- **Water heating–** storage, tankless, heat pump, condensing, heat recovery, solar water heater, etc.
- **Space heating–** furnace, boiler, condensing, heat pump, combined space/water heater, etc.
- **Space cooling–** standard a/c, ground-source, engine-driven, thermally activated, etc.
- **Building envelope–** windows, ceiling insulation, attic insulation, wall insulation, floor insulation.

The analysis included the mixed-fuel and electric-only home designs, in 3 locations (Los Angeles, Palm Springs, Bakersfield), with 2,500 sq.ft. home size (Home B) and South-facing PV orientation. The analysis assumes current cost and performance characteristics for each technology and provides the basis for developing performance and cost targets further discussed in Section 6.2.3.

Each of the following figures provides a comparison of each technology to other available options, and a slightly larger solar PV system, and shows the following relationships:

- Any technology that has lower life-cycle costs than the baseline system would be a potential option towards ZNE goals.
- Any technology below the solar PV line would provide more cost-effective energy savings than a slightly larger solar PV system.

For example, in the illustrative example in Figure 40, standard efficiency tankless water heater show greatest cost-effectiveness, but condensing tankless water heaters is also attractive.

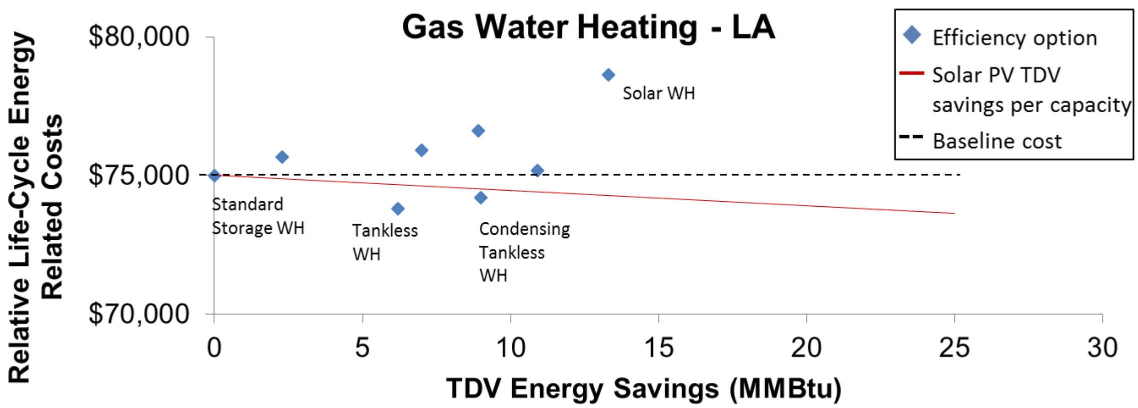



**Figure 40. Illustrative Example of Technology Cost vs. Savings Figure for Gas Water Heating Technologies in Los Angeles**

*6.2.1.1 Water Heating – Natural Gas*

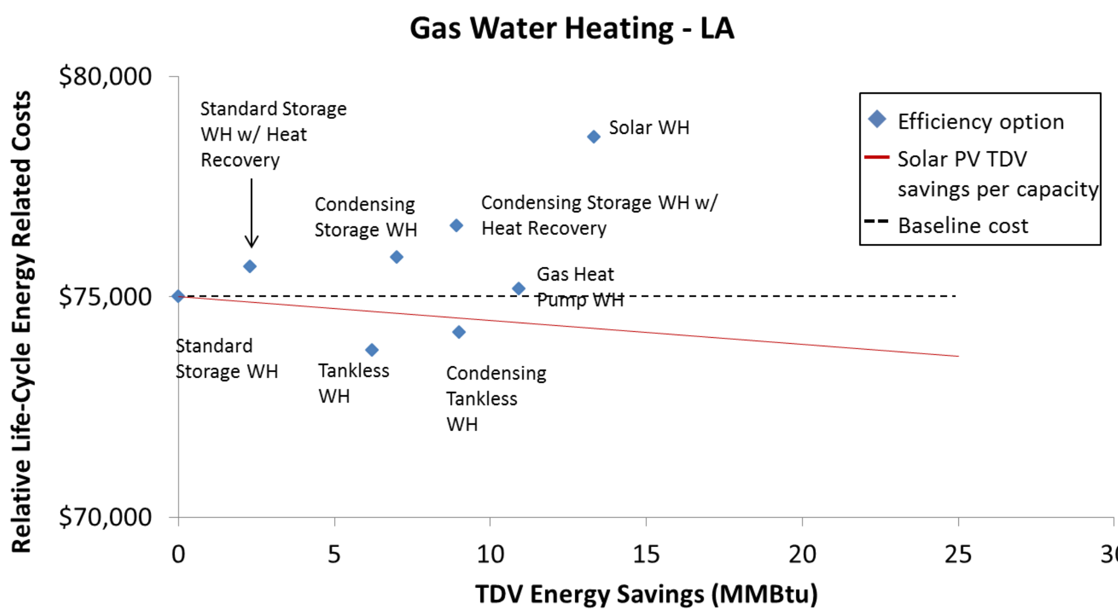



**Figure 41. Technology Cost vs. Savings Figure for Gas Water Heating Technologies in Los Angeles**

**Table 43. Technology Cost vs. Savings for Gas Water Heating Technologies in Los Angeles**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard WH | 0.0 | $75,010 |
| Tankless | 6.2 | $73,799 |
| Tankless Condensing | 9.0 | $74,210 |
| Standard WH + Heat Recovery | 2.3 | $75,685 |
| Solar WH and Standard | 13.3 | $78,626 |
| Condensing | 7.0 | $75,905 |
| Gas HPWH | 10.9 | $75,196 |
| Condensing + Heat Recovery | 8.9 | $76,622 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

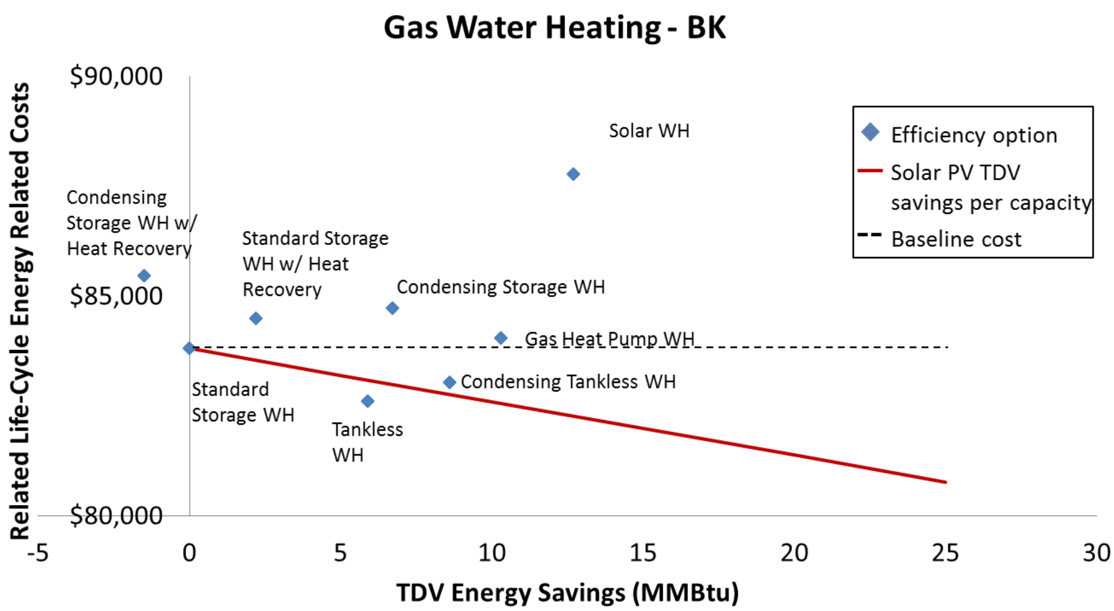



**Figure 42. Technology Cost vs. Savings Figure for Gas Water Heating Technologies in Bakersfield**

**Table 44. Technology Cost vs. Savings for Gas Water Heating Technologies in Bakersfield**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard WH | 0.0 | $83,808 |
| Tankless | 5.9 | $82,614 |
| Tankless Condensing | 8.6 | $83,046 |
| Standard WH + Heat Recovery | 2.2 | $84,491 |
| Solar WH and Standard | 12.7 | $87,772 |
| Condensing | 6.7 | $84,733 |
| Gas HPWH | 10.3 | $84,043 |
| Condensing + Heat Recovery | -1.5 | $85,458 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

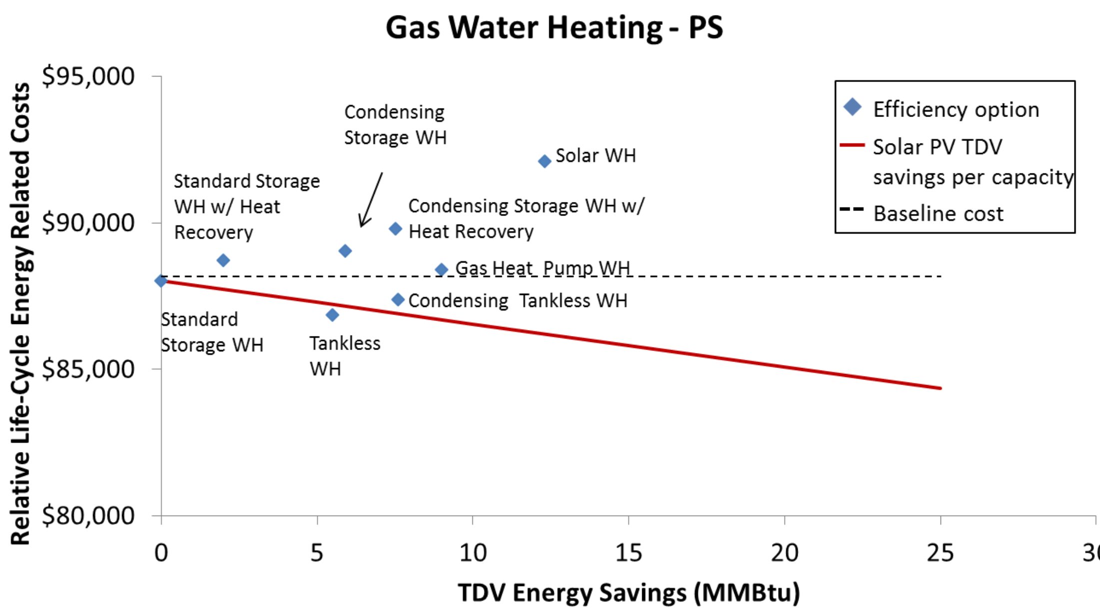



**Figure 43. Technology Cost vs. Savings Figure for Gas Water Heating Technologies in Palm Springs**

**Table 45. Technology Cost vs. Savings for Gas Water Heating Technologies in Palm Springs**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard WH | 0.0 | $88,019 |
| Tankless | 5.5 | $86,863 |
| Tankless Condensing | 7.6 | $87,368 |
| Standard WH + Heat Recovery | 2.0 | $88,717 |
| Solar WH and Standard | 12.3 | $92,103 |
| Condensing | 5.9 | $89,036 |
| Gas HPWH | 9.0 | $88,413 |
| Condensing + Heat Recovery | 7.5 | $89,787 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

#### *6.2.1.2 Water Heating – Electric*

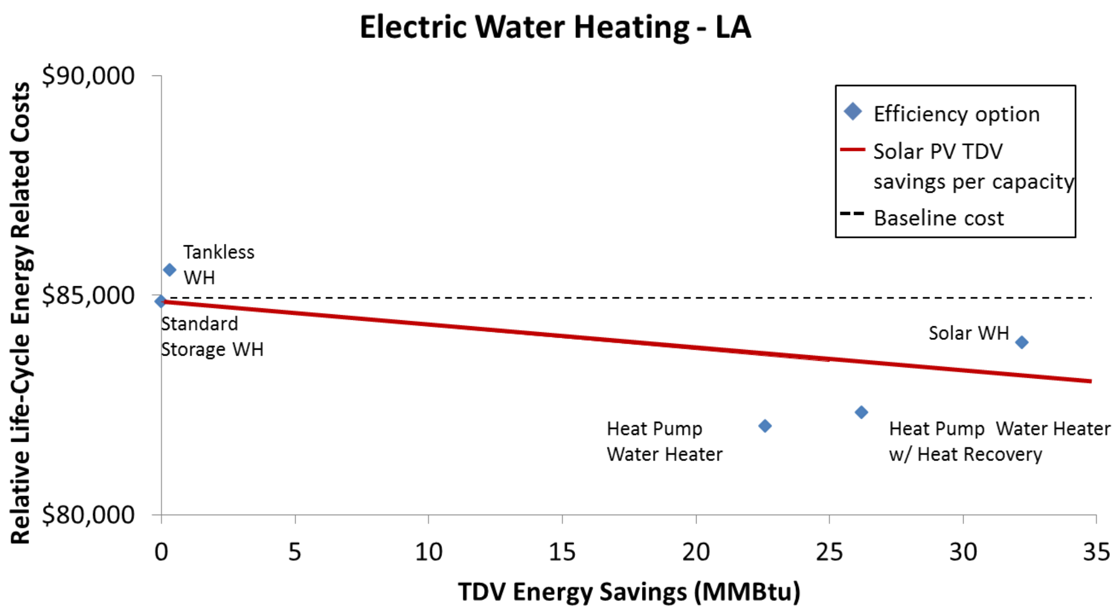



**Figure 44. Technology Cost vs. Savings Figure for Electric Water Heating Technologies in Los Angeles**

**Table 46. Technology Cost vs. Savings for Electric Water Heating Technologies in Los Angeles**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard Elec. | 0.0 | $84,862 |
| Tankless | 0.3 | $85,589 |
| HPWH | 22.6 | $82,029 |
| HPWH + Heat Recovery | 26.2 | $82,339 |
| Solar WH and Standard | 32.2 | $83,936 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

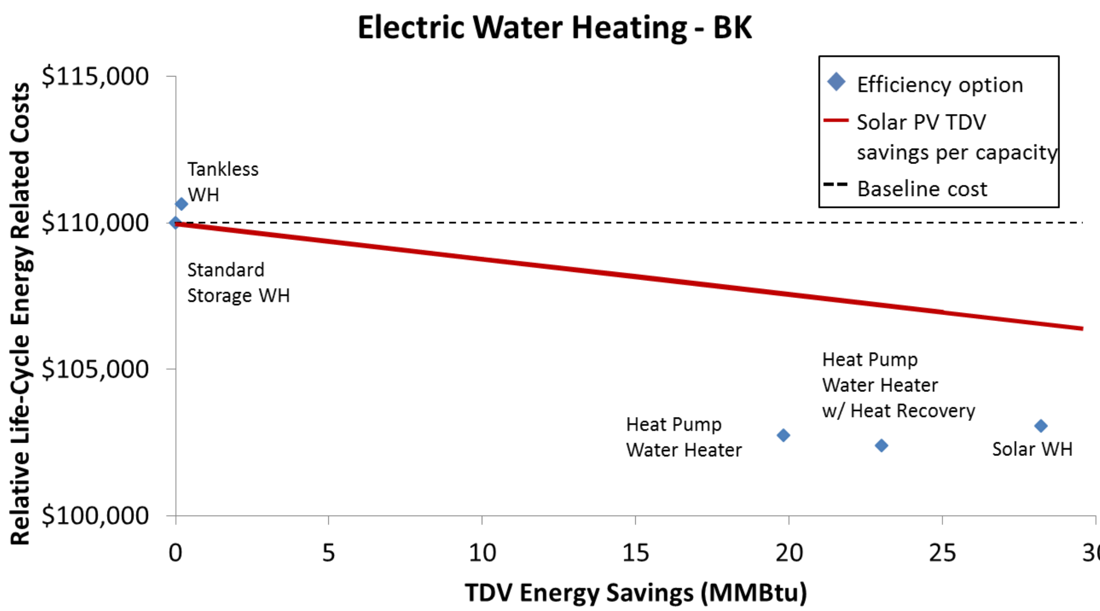



**Figure 45. Technology Cost vs. Savings Figure for Electric Water Heating Technologies in Bakersfield**

**Table 47. Technology Cost vs. Savings for Electric Water Heating Technologies in Bakersfield**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard Elec. | 0.0 | $110,008 |
| Tankless | 0.2 | $110,653 |
| HPWH | 19.8 | $102,754 |
| HPWH + Heat Recovery | 23.0 | $102,409 |
| Solar WH and Standard | 28.2 | $103,075 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

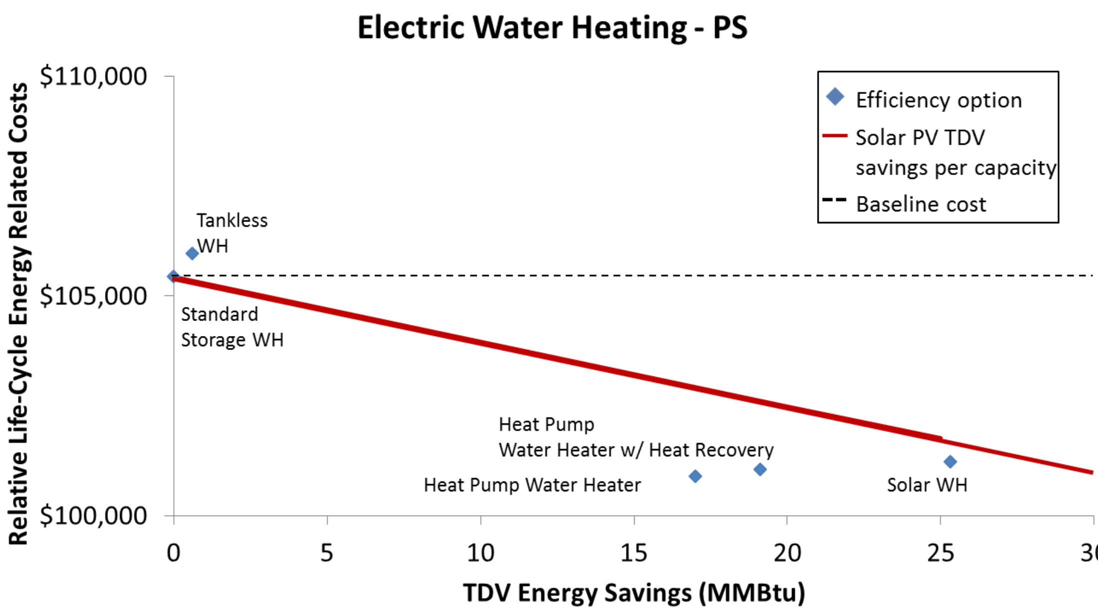



**Figure 46. Technology Cost vs. Savings Figure for Electric Water Heating Technologies in Palm Springs**

**Table 48. Technology Cost vs. Savings for Electric Water Heating Technologies in Palm Springs**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard Elec. | 0.0 | $105,441 |
| Tankless | 0.6 | $105,962 |
| HPWH | 17.0 | $100,901 |
| HPWH + Heat Recovery | 19.1 | $101,051 |
| Solar WH and Standard | 25.3 | $101,240 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

### *6.2.1.3 Space Heating – Natural Gas*

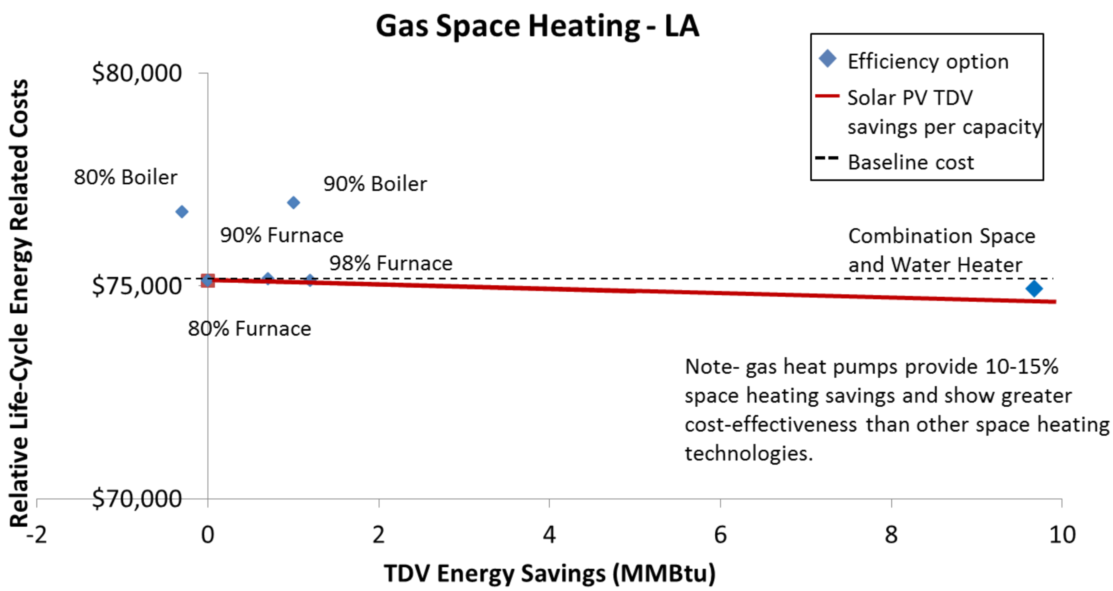



**Figure 47. Technology Cost vs. Savings Figure for Gas Space Heating Technologies in Los Angeles**

**Table 49. Technology Cost vs. Savings for Gas Space Heating Technologies in Los Angeles**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard 80% | 0.0 | $75,142 |
| Condensing 90% | 0.7 | $75,166 |
| Condensing 98% | 1.2 | $75,130 |
| Boiler 80% | -0.3 | $76,745 |
| Boiler 95% | 1.0 | $76,959 |
| Combi Furnace-WH | 9.8 | $74,600 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

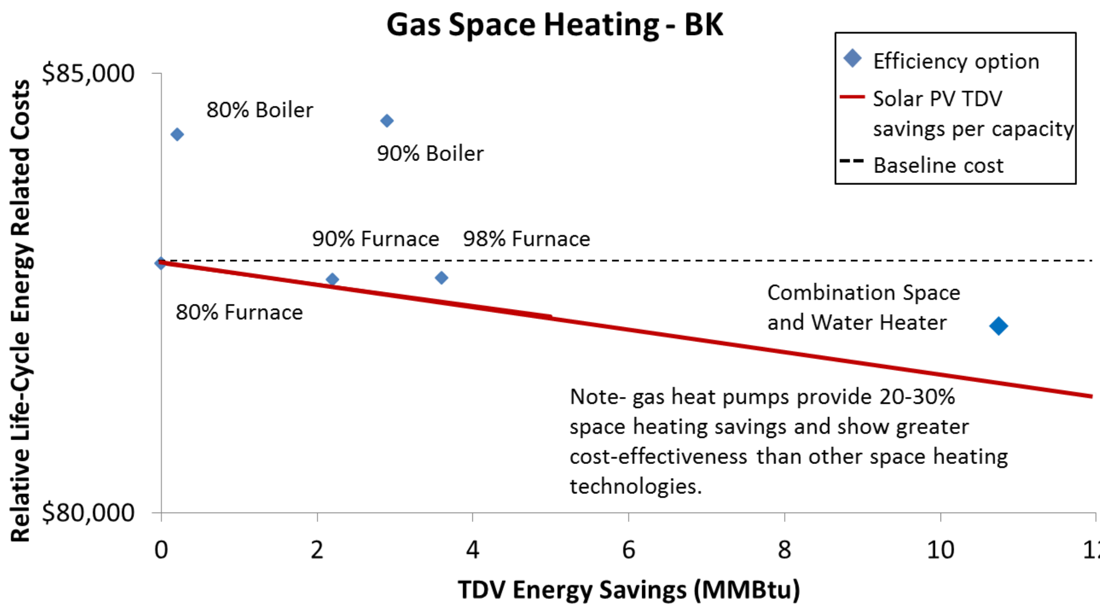



**Figure 48. Technology Cost vs. Savings Figure for Gas Space Heating Technologies in Bakersfield**

**Table 50. Technology Cost vs. Savings for Gas Space Heating Technologies in Bakersfield**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard 80% | 0.0 | $82,841 |
| Condensing 90% | 2.2 | $82,657 |
| Condensing 98% | 3.6 | $82,671 |
| Boiler 80% | 0.2 | $84,305 |
| Boiler 95% | 2.9 | $84,465 |
| Combi Furnace-WH | 10.9 | $82,088 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

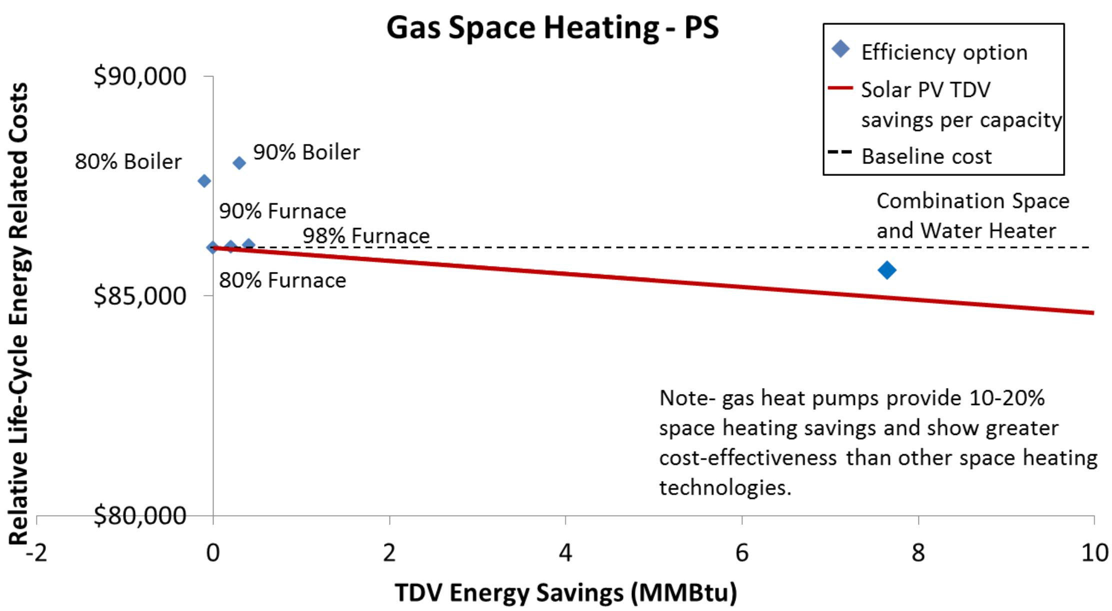



**Figure 49. Technology Cost vs. Savings Figure for Gas Space Heating Technologies in Palm Springs**

**Table 51. Technology Cost vs. Savings for Gas Space Heating Technologies in Palm Springs**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Standard 80% | 0.0 | $86,098 |
| Condensing 90% | 0.2 | $86,130 |
| Condensing 98% | 0.4 | $86,160 |
| Boiler 80% | -0.1 | $87,621 |
| Boiler 95% | 0.3 | $88,026 |
| Combi Furnace-WH | 7.8 | $85,686 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

*6.2.1.4 Space Heating – Electric*

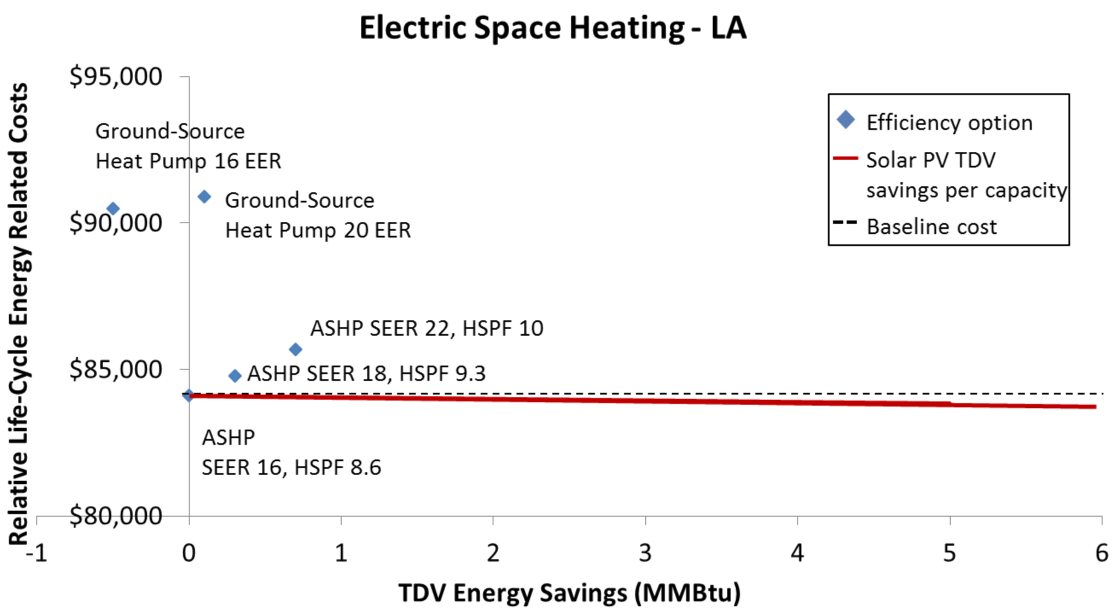



**Figure 50. Technology Cost vs. Savings Figure for Electric Space Heating Technologies in Los Angeles**

**Table 52. Technology Cost vs. Savings for Electric Space Heating Technologies in Los Angeles**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| ASHP SEER 16 | 0.0 | $84,109 |
| ASHP SEER 18 | 0.3 | $84,777 |
| ASHP SEER 22 | 0.7 | $85,694 |
| GSHP 16 | -0.5 | $90,488 |
| GSHP 20 | 0.1 | $90,909 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

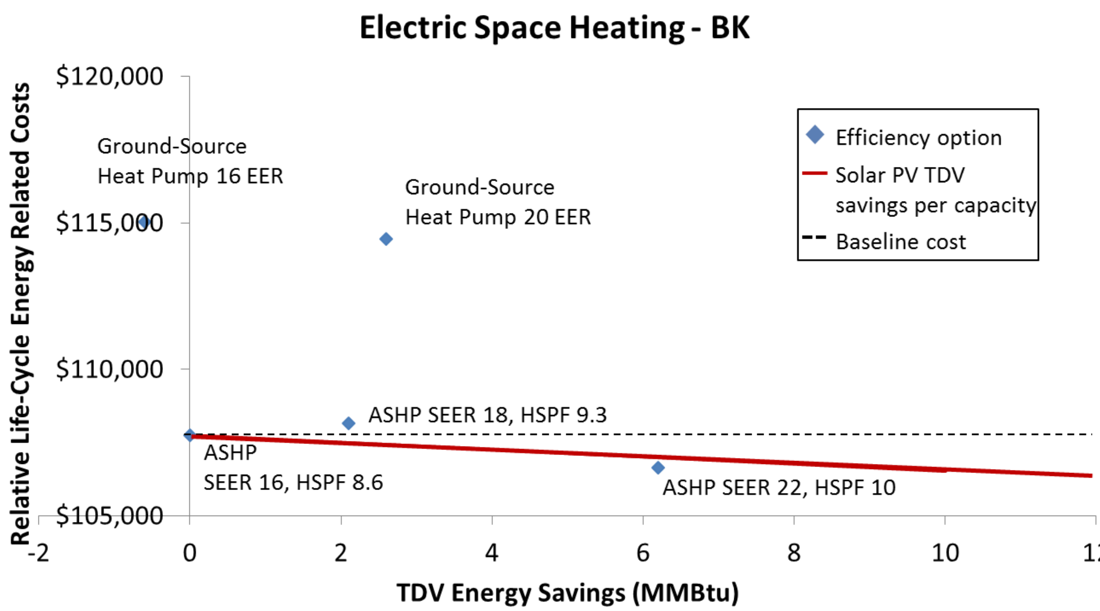



**Figure 51. Technology Cost vs. Savings Figure for Electric Space Heating Technologies in Bakersfield**

**Table 53. Technology Cost vs. Savings for Electric Space Heating Technologies in Bakersfield**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| ASHP SEER 16 | 0.0 | $107,750 |
| ASHP SEER 18 | 2.1 | $108,154 |
| ASHP SEER 22 | 6.2 | $106,649 |
| GSHP 16 | -0.6 | $115,046 |
| GSHP 20 | 2.6 | $114,452 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

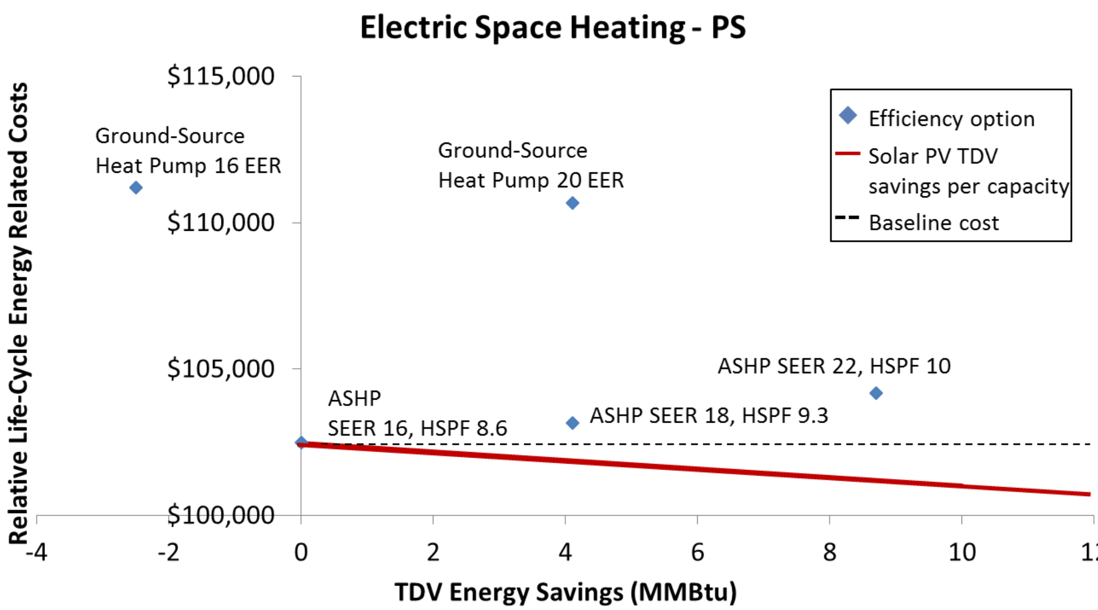



**Figure 52. Technology Cost vs. Savings Figure for Electric Space Heating Technologies in Palm Springs**

**Table 54. Technology Cost vs. Savings for Electric Space Heating Technologies in Palm Springs**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| ASHP SEER 16 | 0.0 | $102,484 |
| ASHP SEER 18 | 4.1 | $103,158 |
| ASHP SEER 22 | 8.7 | $104,179 |
| GSHP 16 | -2.5 | $111,185 |
| GSHP 20 | 4.1 | $110,681 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

*6.2.1.5 Space Cooling*

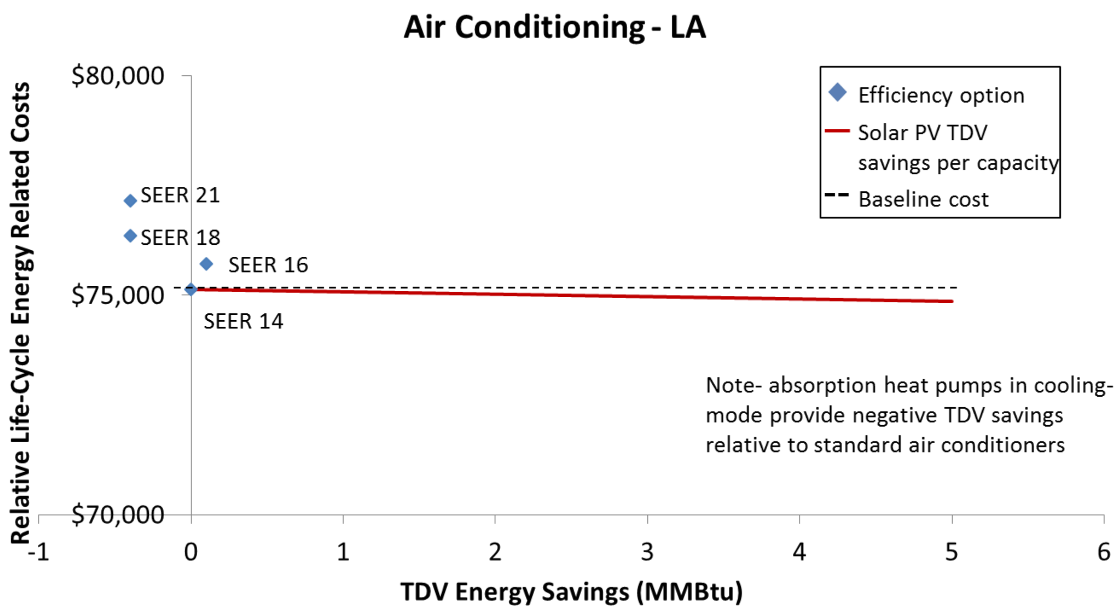



**Figure 53. Technology Cost vs. Savings Figure for Space Cooling Technologies in Los Angeles**

**Table 55. Technology Cost vs. Savings for Space Cooling Technologies in Los Angeles**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| SEER 14 | 0.0 | $75,142 |
| SEER 16 | 0.1 | $75,728 |
| SEER 18 | -0.4 | $76,367 |
| SEER 21 | -0.4 | $77,165 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

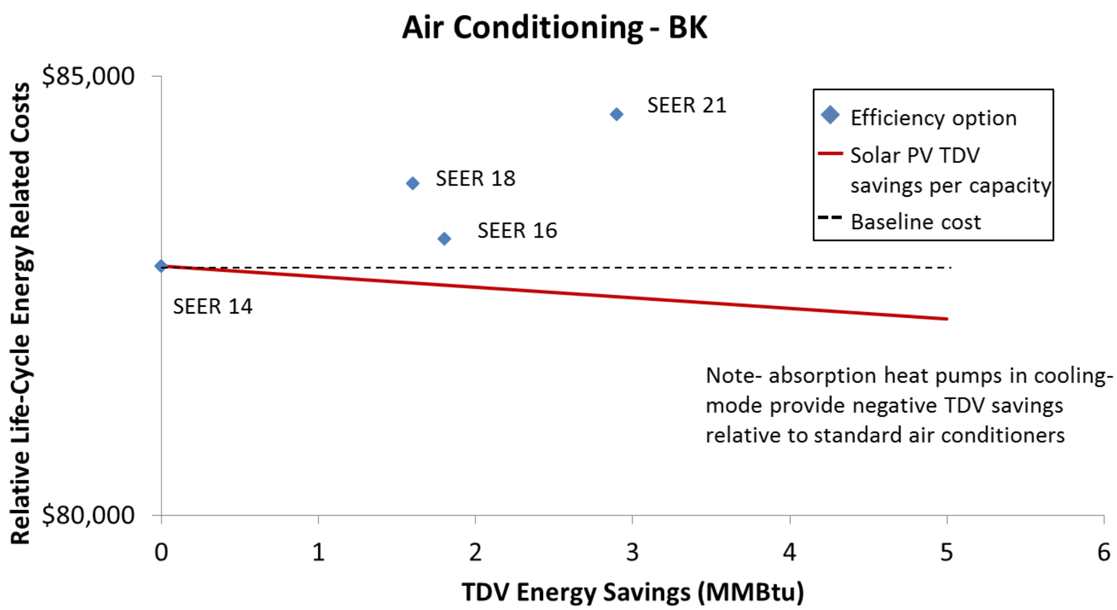



**Figure 54. Technology Cost vs. Savings Figure for Space Cooling Technologies in Bakersfield**

**Table 56. Technology Cost vs. Savings for Space Cooling Technologies in Bakersfield**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| SEER 14 | 0.0 | $82,841 |
| SEER 16 | 1.8 | $83,147 |
| SEER 18 | 1.6 | $83,777 |
| SEER 21 | 2.9 | $84,571 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

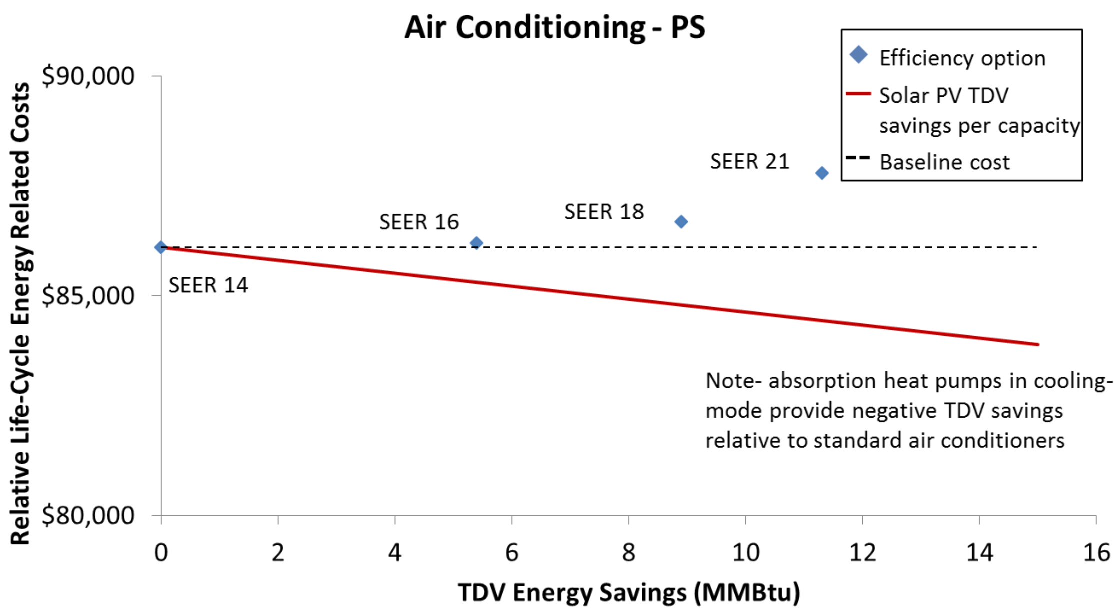



**Figure 55. Technology Cost vs. Savings Figure for Space Cooling Technologies in Palm Springs**

**Table 57. Technology Cost vs. Savings for Space Cooling Technologies in Palm Springs**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| SEER 14 | 0.0 | $86,098 |
| SEER 16 | 5.4 | $86,209 |
| SEER 18 | 8.9 | $86,692 |
| SEER 21 | 11.3 | $87,800 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

*6.2.1.6 Building Envelope – Natural Gas Heating*

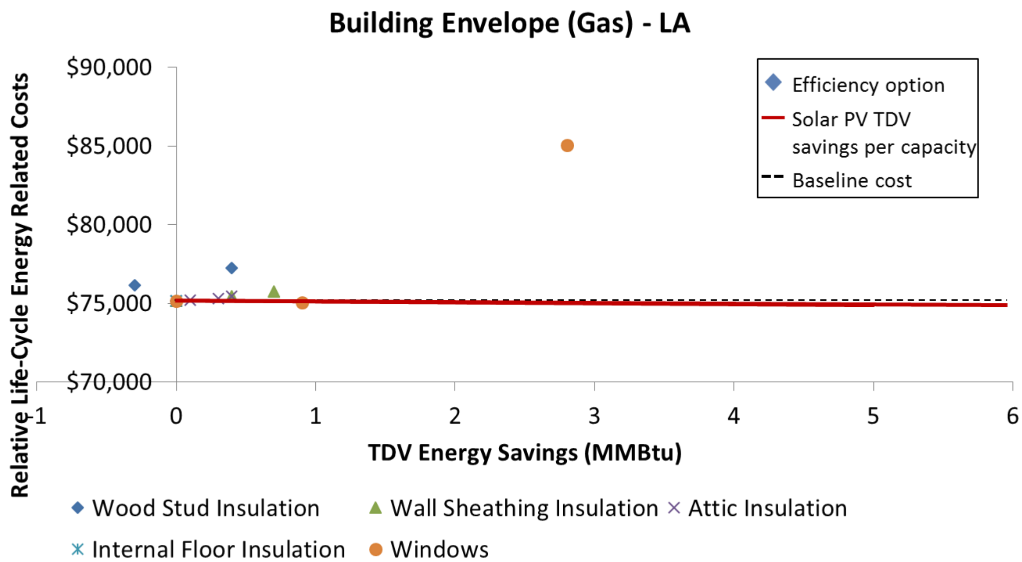



**Figure 56. Technology Cost vs. Savings Figure for Building Envelope (Gas Heating) Technologies in Los Angeles**

**Table 58. Technology Cost vs. Savings for Building Envelope (Gas Heating) Technologies in Los Angeles**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Wood Stud - R21 | 0.0 | $75,142 |
| Wood Stud - R23 | -0.3 | $76,155 |
| Wood Stud - R36 | 0.4 | $77,246 |
| Wall Sheathing - R5 | 0.0 | $75,142 |
| Wall Sheathing - R10 | 0.4 | $75,440 |
| Wall Sheathing - R15 | 0.7 | $75,747 |
| Attic - R38 | 0.0 | $75,142 |
| Attic - R44 | 0.1 | $75,219 |
| Attic - R49 | 0.3 | $75,286 |
| Attic - R60 | 0.4 | $75,438 |
| Internal Floor - R19 | 0.0 | $75,142 |
| Internal Floor - R30 | 0.0 | $75,160 |
| Internal Floor - R38 | 0.0 | $75,175 |
| Windows - Base | 0.0 | $75,142 |
| Windows - Stage 2 | 0.9 | $75,081 |
| Windows - Stage 3 | 2.8 | $85,081 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

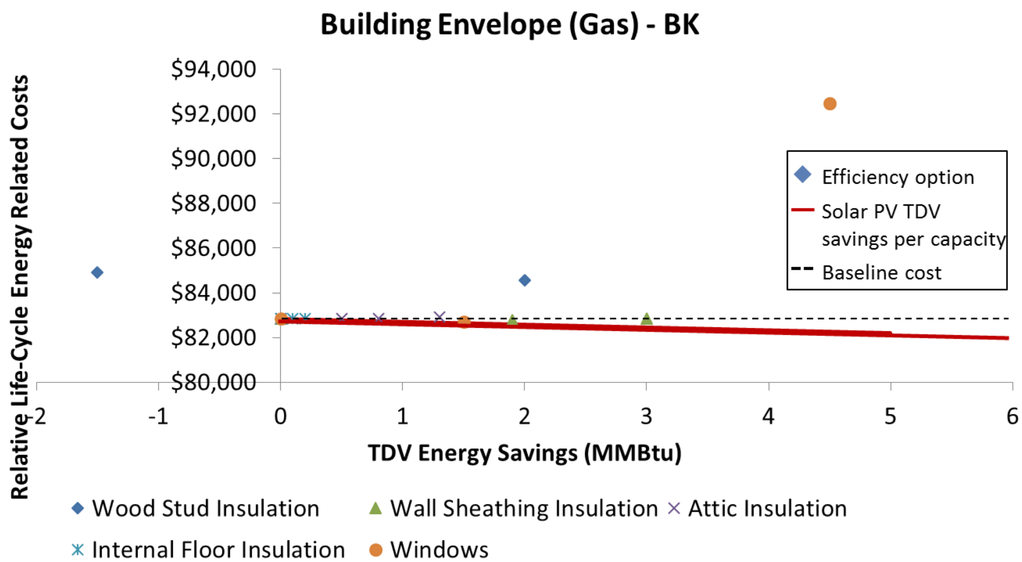



**Figure 57. Technology Cost vs. Savings Figure for Building Envelope (Gas Heating) Technologies in Bakersfield**

**Table 59. Technology Cost vs. Savings for Building Envelope (Gas Heating) Technologies in Bakersfield**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Wood Stud - R21 | 0.0 | $82,841 |
| Wood Stud - R23 | -1.5 | $84,913 |
| Wood Stud - R36 | 2.0 | $84,553 |
| Wall Sheathing - R5 | 0.0 | $82,841 |
| Wall Sheathing - R10 | 1.9 | $82,770 |
| Wall Sheathing - R15 | 3.0 | $82,865 |
| Attic - R38 | 0.0 | $82,841 |
| Attic - R44 | 0.5 | $82,839 |
| Attic - R49 | 0.8 | $82,858 |
| Attic - R60 | 1.3 | $82,934 |
| Internal Floor - R19 | 0.0 | $82,841 |
| Internal Floor - R30 | 0.1 | $82,833 |
| Internal Floor - R38 | 0.2 | $82,836 |
| Windows - Base | 0.0 | $82,841 |
| Windows - Stage 2 | 1.5 | $82,700 |
| Windows - Stage 3 | 4.5 | $92,469 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

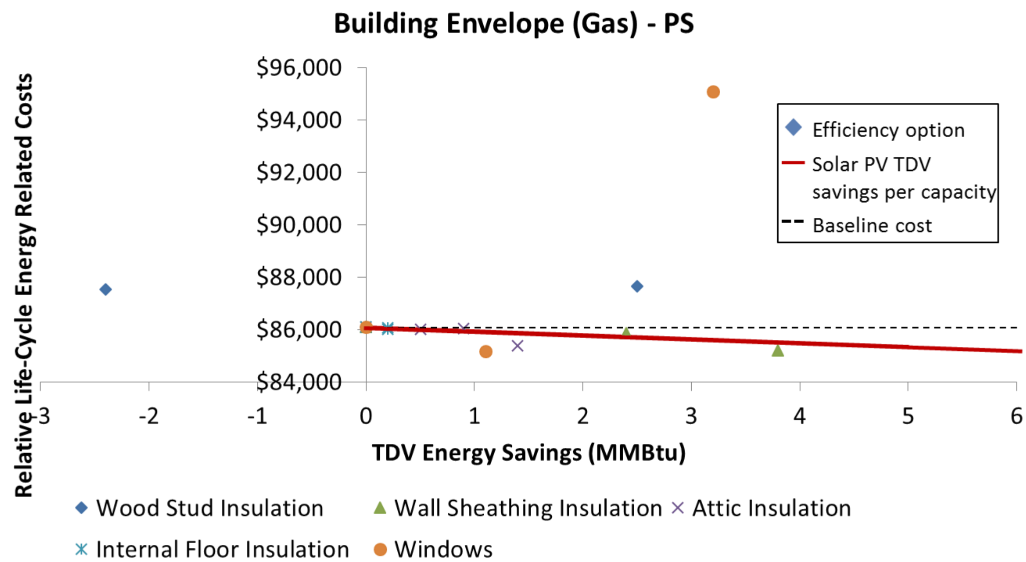



**Figure 58. Technology Cost vs. Savings Figure for Building Envelope (Gas Heating) Technologies in Palm Springs**

**Table 60. Technology Cost vs. Savings for Building Envelope (Gas Heating) Technologies in Palm Springs**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Wood Stud - R21 | 0.0 | $86,098 |
| Wood Stud - R23 | -2.4 | $87,541 |
| Wood Stud - R36 | 2.5 | $87,663 |
| Wall Sheathing - R5 | 0.0 | $86,098 |
| Wall Sheathing - R10 | 2.4 | $85,877 |
| Wall Sheathing - R15 | 3.8 | $85,198 |
| Attic - R38 | 0.0 | $86,098 |
| Attic - R44 | 0.5 | $86,023 |
| Attic - R49 | 0.9 | $86,039 |
| Attic - R60 | 1.4 | $85,390 |
| Internal Floor - R19 | 0.0 | $86,098 |
| Internal Floor - R30 | 0.2 | $86,085 |
| Internal Floor - R38 | 0.2 | $86,014 |
| Windows - Base | 0.0 | $86,098 |
| Windows - Stage 2 | 1.1 | $85,189 |
| Windows - Stage 3 | 3.2 | $95,104 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

*6.2.1.7 Building Envelope – Electric Heating*

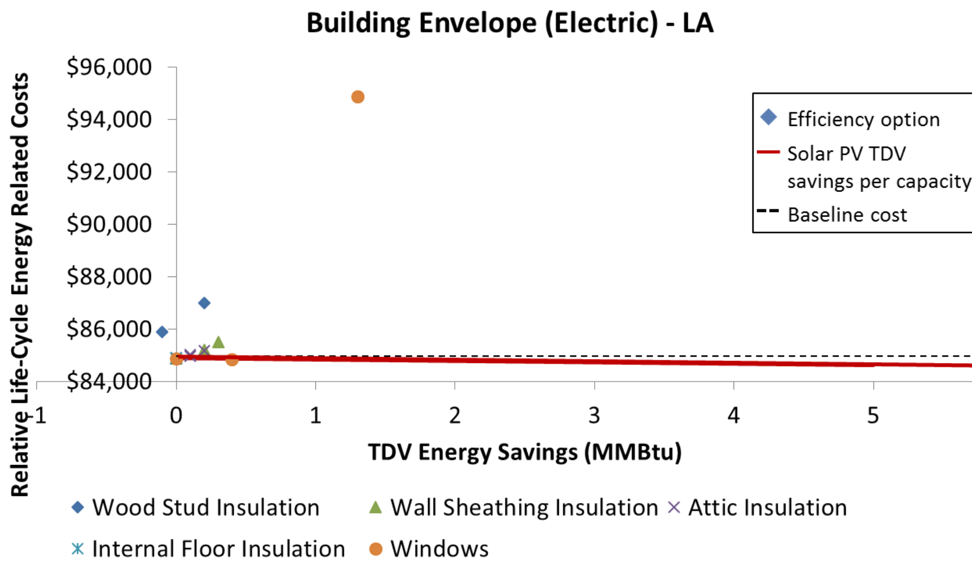



**Figure 59. Technology Cost vs. Savings Figure for Building Envelope (Electric Heating) Technologies in Los Angeles**

**Table 61. Technology Cost vs. Savings for Building Envelope (Electric Heating) Technologies in Los Angeles**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Wood Stud - R21 | 0.0 | $84,882 |
| Wood Stud - R23 | -0.1 | $85,888 |
| Wood Stud - R36 | 0.2 | $86,999 |
| Wall Sheathing - R5 | 0.0 | $84,882 |
| Wall Sheathing - R10 | 0.2 | $85,193 |
| Wall Sheathing - R15 | 0.3 | $85,508 |
| Attic - R38 | 0.0 | $84,882 |
| Attic - R44 | 0.1 | $84,963 |
| Attic - R49 | 0.1 | $85,034 |
| Attic - R60 | 0.2 | $85,190 |
| Internal Floor - R19 | 0.0 | $84,882 |
| Internal Floor - R30 | 0.0 | $84,899 |
| Internal Floor - R38 | 0.0 | $84,914 |
| Windows - Base | 0.0 | $84,882 |
| Windows - Stage 2 | 0.4 | $84,840 |
| Windows - Stage 3 | 1.3 | $94,873 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

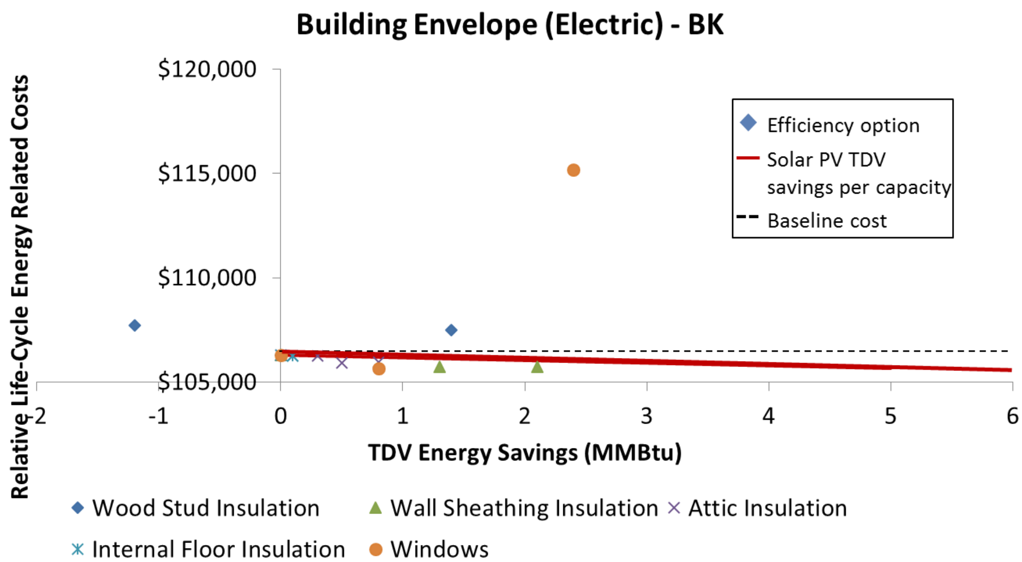



**Figure 60. Technology Cost vs. Savings Figure for Building Envelope (Electric Heating) Technologies in Bakersfield**

**Table 62. Technology Cost vs. Savings for Building Envelope (Electric Heating) Technologies in Bakersfield**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Wood Stud - R21 | 0.0 | $106,276 |
| Wood Stud - R23 | -1.2 | $107,722 |
| Wood Stud - R36 | 1.4 | $107,502 |
| Wall Sheathing - R5 | 0.0 | $106,276 |
| Wall Sheathing - R10 | 1.3 | $105,731 |
| Wall Sheathing - R15 | 2.1 | $105,746 |
| Attic - R38 | 0.0 | $106,276 |
| Attic - R44 | 0.3 | $106,247 |
| Attic - R49 | 0.5 | $105,903 |
| Attic - R60 | 0.8 | $105,948 |
| Internal Floor - R19 | 0.0 | $106,276 |
| Internal Floor - R30 | 0.1 | $106,256 |
| Internal Floor - R38 | 0.1 | $106,255 |
| Windows - Base | 0.0 | $106,276 |
| Windows - Stage 2 | 0.8 | $105,645 |
| Windows - Stage 3 | 2.4 | $115,178 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

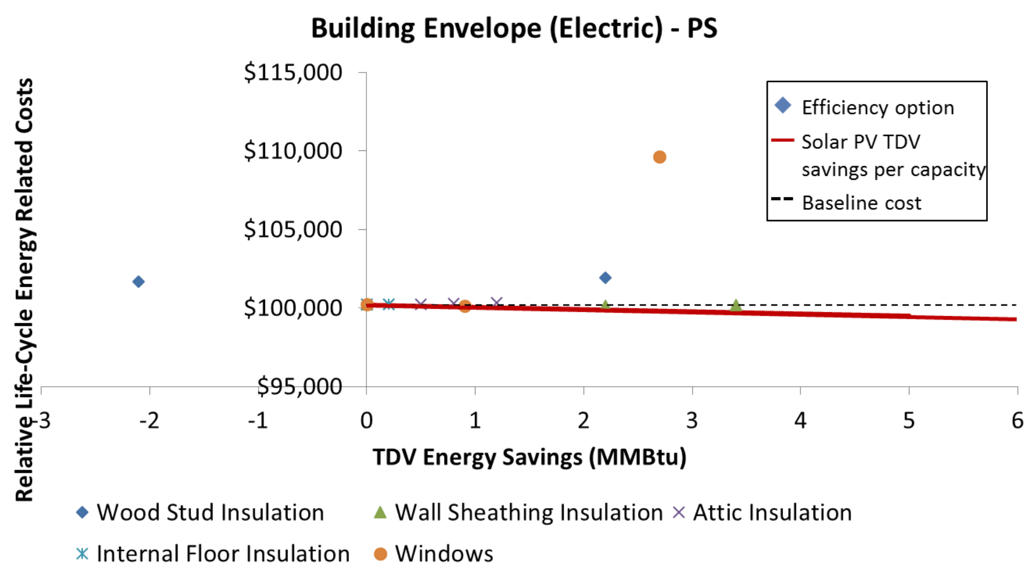



**Figure 61. Technology Cost vs. Savings Figure for Building Envelope (Electric Heating) Technologies in Palm Springs**

**Table 63. Technology Cost vs. Savings for Building Envelope (Electric Heating) Technologies in Palm Springs**

| Technology | TDV Savings (MMBtu) | Life-Cycle Cost ($) |
|---|---|---|
| Wood Stud - R21 | 0.0 | $100,261 |
| Wood Stud - R23 | -2.1 | $101,694 |
| Wood Stud - R36 | 2.2 | $101,928 |
| Wall Sheathing - R5 | 0.0 | $100,261 |
| Wall Sheathing - R10 | 2.2 | $100,138 |
| Wall Sheathing - R15 | 3.4 | $100,205 |
| Attic - R38 | 0.0 | $100,261 |
| Attic - R44 | 0.5 | $100,259 |
| Attic - R49 | 0.8 | $100,277 |
| Attic - R60 | 1.2 | $100,355 |
| Internal Floor - R19 | 0.0 | $100,261 |
| Internal Floor - R30 | 0.2 | $100,250 |
| Internal Floor - R38 | 0.2 | $100,254 |
| Windows - Base | 0.0 | $100,261 |
| Windows - Stage 2 | 0.9 | $100,118 |
| Windows - Stage 3 | 2.7 | $109,626 |

For further explanation, please refer to the example at the beginning of Section 6.2.1.

### 6.2.2 Development Status for Advanced Technologies

Beyond traditional efficiency measures in the areas of space heating, water heating, and space cooling, several advanced energy efficiency and renewable energy technologies will offer substantial TDV energy impacts for ZNE homes. Table 64 outlines the advanced technologies included in this analysis, their current status and applicable ZNE home configurations. Some of these technologies have been on the market for decades and have experienced substantial cost breakthroughs (e.g., solar PV systems), while others are emerging into the market outside California (e.g., gas heat pumps). These advanced technologies will change the way that a ZNE home is designed and the net consumption pattern of each home on the electrical and natural gas grids. Even for those already on the market, each advanced technology requires further development to meet the performance, capacity, and cost thresholds needed for ZNE homes in California.

**Table 64. Current Status and ZNE Home Applicability of Advanced Technologies**

| Advanced Technology | ZNE Home Applicability | | Current Applicability | Notes |
|---|---|---|---|---|
| | Mixed-Fuel | Electric-Only | | |
| **Solar PV System** | ✓ | ✓ | High | • Residential solar PV is increasingly popular in California due to decreased costs, available incentives and new financing options. |
| **Electric Heat Pumps for Space and Water Heating** | n/a | ✓ | High | • Current baseline for electric-only homes and projected to reduce costs in upcoming years |
| **mCHP** | ✓ | n/a | Low | • Current technologies have limited applicability in California due to emissions requirements.<br>• Greater adoption with larger homes in colder climates |
| **Gas Heat Pumps** | ✓ | n/a | Low | • Current products are only offered in capacities suitable for larger homes.<br>• Greater adoption in colder climates |
| **DR / Energy Storage** | ✓ | ✓ | Medium/Low | • Utilities have offered DR programs for many years.<br>• Some solar integration companies in California offer customer-sited energy storage systems with solar PV installations. |
| **Alternative Vehicles** | ✓ | ✓ | Medium/Low | • Southern California is a leader in EV adoption, but their market penetration is still low.<br>• NGVs are still rare for non-fleet vehicles. |
| **Solar Thermal** | ✓ | ✓ | Medium | • Residential solar thermal is prevalent in California due to available incentives. |

#### *6.2.2.1 Solar PV Systems*

As discussed in previous sections, we project solar PV systems to offset the majority of TDV energy for ZNE homes. Through incremental cost and performance improvements over several decades and the availability of customer incentives, on-site solar PV systems have emerged as a cost-effective energy solution throughout California. As shown in Figure 62, researchers at Lawrence Berkeley National Laboratory (LBNL) estimate the installed cost per capacity for residential solar PV systems have decreased by over 5% annually since the late 1990s.

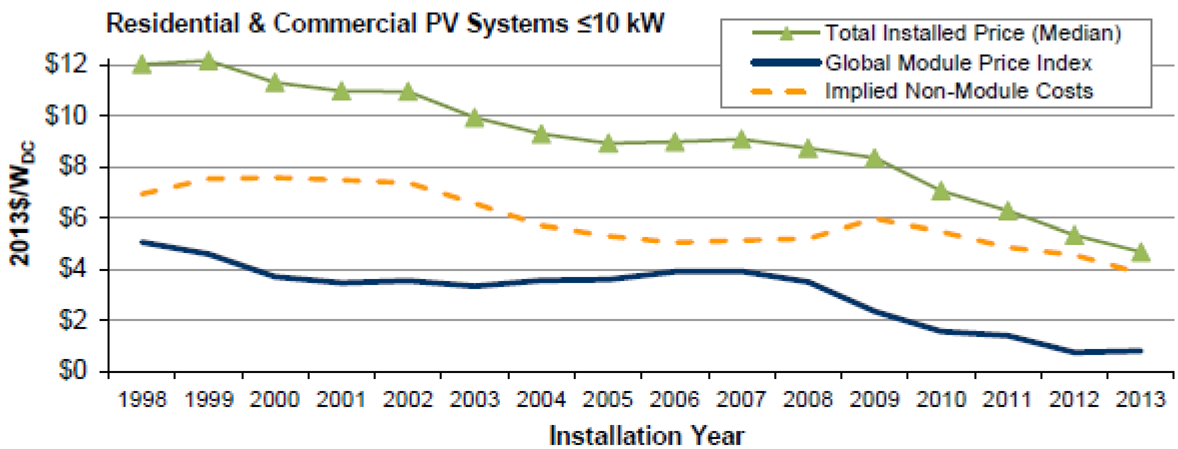



**Figure 62. Historical Solar PV Cost Trends**

Source: Barbose et al. 2014[49]

While technology and manufacturing advancements for solar PV panel or module have contributed to this steep price decline, the solar industry is also addressing the non-module or "soft" costs of solar PV installations. Future cost reductions will come from mounting systems, inverters, and other balance-of-system components as well as improved operations, installation methods, and permitting processes. If successful, these efforts could enable the recent cost reduction trends to continue in the future. Figure 63 outlines the cost per capacity curve for future years assuming 5% annual cost reductions. If the industry can continue this trend, residential solar PV system installed costs would decrease in California from $5-6 today[28] to $4-5/W-DC in 2020, $3-4/W-DC in 2025, and $2-3/W-DC in 2030.

[49] Barbose et al. 2014. "Tracking the Sun VII - An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2013." Lawrence Berkeley National Laboratory. September 2014.

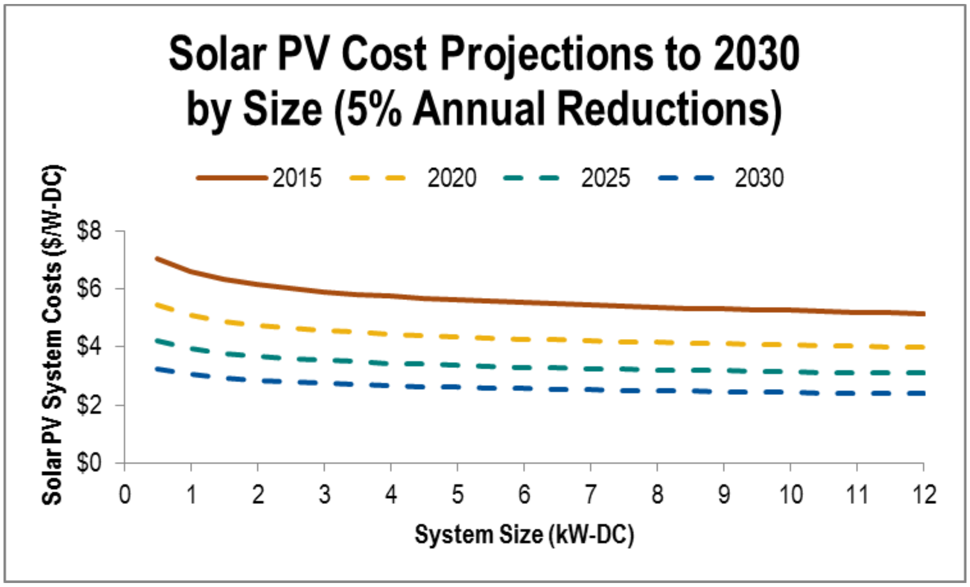



**Figure 63. Projected Solar PV System Costs to 2030 by Size**

If the industry experiences a 2.5-5.0% annual cost reduction, the cost of a 5kW system ($28,000 in 2014) would decrease by 14-23% in 2020, 26-40% in 2025, 37-54% in 2030, as shown in Figure 64. While 5% annual reductions may be an optimistic projection, 2.5% annual reductions over the next 15 years may provide a more accurate representation based on technology and operational improvements to the soft costs of solar PV systems[50]. Additionally, the installation cost for new homes is generally less than the cost for retrofitting existing homes.

[50] Few publications provide cost projections for solar PV systems longer than 1-3 years due to the rapid price decrease in recent years, and the uncertainty of incentive availability going forward. Researchers for the U.S. DOE's SunShot initiative compiled analyst predictions on residential solar PV price trends, which showed installed costs ranging from $1.75-3.50/W-DC in 2020, $1.5-3.25/W-DC in 2025, and $1.25-3/W-DC in 2030. Feldman et al. 2014. "Photovoltaic System Pricing Trends – Historical, Recent, and Near-Term Projections." September 22, 2014. Available at http://www.nrel.gov/docs/fy14osti/62558.pdf.

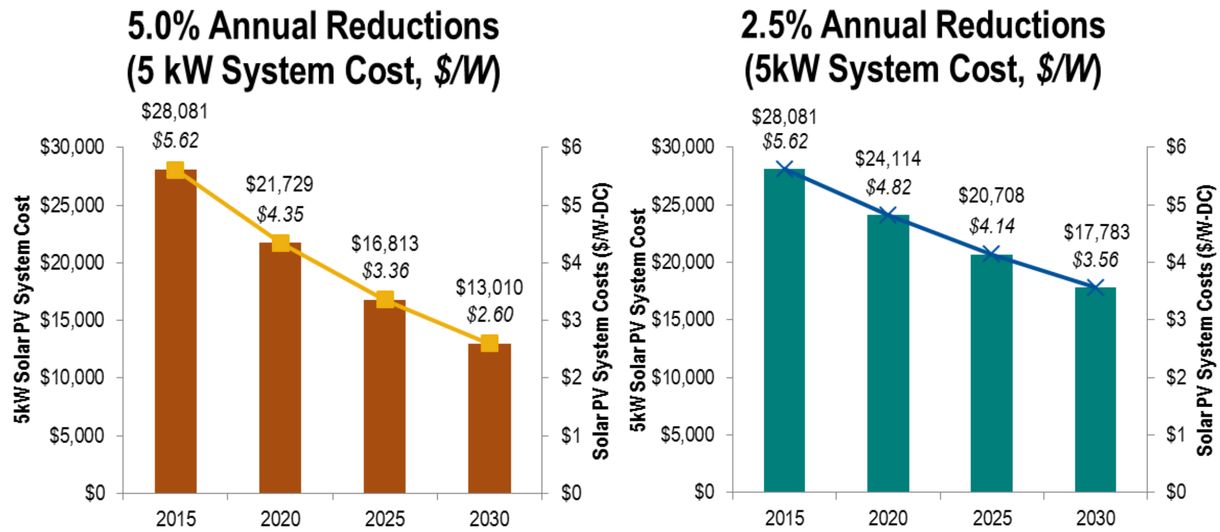



**Figure 64. Projected Solar PV System Costs to 2030 – 5 kW System Size**

Table 65 provides a summary of potential incremental cost reductions by solar PV cost reductions in 2020 (14%) and 2030 (37%) compared to 2015. Appendix G contains additional details on TRC impacts and other home designs.

**Table 65. Incremental Cost and Payback with Current and Future Solar PV Cost Projections – Home B**

| Category | Location | PV System Size (kW) | 2015 Solar PV Costs | | 2020 Solar PV Cost Projections (14% lower) | | 2020 Solar PV Cost Projections (37% lower) | |
|---|---|---|---|---|---|---|---|---|
| | | | Incremental Cost | Simple Payback | Incremental Cost | Simple Payback | Incremental Cost | Simple Payback |
| Mixed-Fuel | Los Angeles | 3.4 | $20,547 | 23 | $17,777 | 20 | $13,358 | 15 |
| | Pasadena | 3.4 | $20,793 | 14 | $17,957 | 12 | $13,432 | 9 |
| | Riverside | 3.6 | $21,539 | 14 | $18,557 | 12 | $13,801 | 9 |
| | Bakersfield | 4.2 | $23,973 | 13 | $20,599 | 11 | $15,217 | 8 |
| | Palm Springs | 4.3 | $24,572 | 13 | $21,106 | 11 | $15,577 | 8 |
| Electric-Only | Los Angeles | 3.8 | $21,830 | 23 | $18,756 | 20 | $13,852 | 15 |
| | Pasadena | 3.9 | $23,278 | 16 | $20,091 | 14 | $15,007 | 10 |
| | Riverside | 4.0 | $23,423 | 16 | $20,159 | 13 | $14,953 | 10 |
| | Bakersfield | 3.9 | $33,315 | 24 | $30,138 | 22 | $25,070 | 18 |
| | Palm Springs | 5.0 | $28,058 | 14 | $24,122 | 12 | $17,842 | 9 |

* Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

Under current cost assumptions, solar PV systems already account for the largest TDV savings of ZNE homes. Even as available incentive programs end, solar PV's economic advantage over other technologies on a TDV basis only increases as the price per capacity continues to decrease from $200-250/TDV-offset to $125-175/TDV-offset. Because mixed-fuel ZNE homes have the option of selecting natural gas efficiency measures or increasing the size of the solar PV system, many natural gas technologies will require cost reductions over the next 5-10 years to remain competitive with falling solar PV prices. Section 6.2.3 discusses the cost thresholds and necessary advancements for natural gas technologies to compete against a slightly larger solar PV system.

#### *6.2.2.2 Electric Heat Pumps for Space and Water Heating*

For electric-only homes, the modeling analysis showed space and water heating loads are served most effectively by vapor-compression heat pump systems. These technologies offer high efficiency operation with COPs greater than 1 and have increased their market penetration in recent years due to improved performance, reduced cost, and contractor and homeowner familiarity with products. Future cost reductions for air-source heat pump HVAC systems (ASHPs) and heat pump water heaters (HPWHs) will have a significant impact on the cost of electric-only ZNE homes. Table 66 outlines the anticipated cost reductions for ASHPs and HPWHs over the next 5-10 years from DOE BTO R&D activities[51,52].

**Table 66. Projected Heat Pump Technology Cost Reductions for Los Angeles**

| Year | Air-Source Heat Pump (2 ton) | | Heat Pump Water Heater (50 gallon) | | Total Cost Reduction | % Cost Reduction |
|---|---|---|---|---|---|---|
| | Product Cost | Cost Reduction | Product Cost | Cost Reduction | | |
| 2015 | $3,666 | - | $1,094 | - | - | - |
| 2020 | $3,006 | $660 | $891 | $203 | $863 | 18% |
| 2025 | $2,694 | $972 | $790 | $304 | $1,276 | 27% |

Notes: Product costs from DEER, cost reductions for 2015-2020 from DOE BTO HVAC[51] and Water Heating[52] Roadmaps and projected for 2020-2025 at 50% of 2015-2020 reduction.

Because these technologies are baseline features in electric-only ZNE homes, cost reductions in ASHPs and HPWHs have a direct impact on the total cost of a ZNE home. In combination, advances in these systems would decrease the cost of an electric-only ZNE home in Los Angeles by $863 (18%) in 2020 and $1,276 (27%) in 2025. For less moderate climates with higher HVAC loads, cost reductions are greater. As electric heat pumps reduce their cost in future years, gas-fired technologies for space and/or water heating must also reduce their cost to maintain the cost advantage and competitiveness of mixed-fuel homes. Section 6.2.3 discusses the cost thresholds and necessary advancements for natural gas

[51] Goetzler et al. 2014. "Research and Development Roadmap for Emerging HVAC Technologies." Navigant Consulting, Inc. for U.S. Department of Energy Building Technologies Office. September 2014.

[52] Goetzler et al. 2014. "Research and Development Roadmap for Emerging Water Heating Technologies." Navigant Consulting, Inc. for U.S. Department of Energy Building Technologies Office. September 2014.

technologies in mixed-fuel ZNE homes to remain competitive against heat pump cost reductions for electric-only ZNE homes.

#### *6.2.2.3 mCHP Systems*

Discussed in Section 4.3.1, engine-based and fuel cell mCHP systems can provide TDV benefits for a mixed-fuel ZNE home, but are not economically attractive on a TDV basis compared to an incrementally larger solar PV system. By 2030, technology cost for medium- and high-efficiency mCHP systems could improve from a price of $20/W-electric today to $5/We for engine-based systems and $10/We for fuel cells[53]. Under these medium- and low-cost assumptions, mCHP systems could become attractive relative to current solar PV costs with an electrical efficiency of at least 35% under a higher heating value (HHV). Relative to projected solar PV costs for 2020-2030, mCHP systems must achieve the low cost assumptions.

California emissions standards pose an additional barrier to mCHP adoption. As a stationary electrical generation source, mCHP systems will also need to comply with strict California emissions requirements, e.g., 0.07 NOx, 0.10 CO, 0.02 VOCs, on a pounds per MWh basis[54]. With current technologies, fuel cell mCHP systems generally pass these requirements while engine-based systems exceed these limits without expensive emissions control systems. Even when incorporating the secondary thermal output adjustment, the emissions for engine-based systems will have difficulty reaching these targets unless the cost of emission controls substantially decreases.

Nevertheless, several current trends suggest the potential for successful mCHP introduction at acceptable product cost and electrical efficiencies, including:

- Increasing acceptance of fuel cells for commercial and industrial CHP applications. Advances in the core technology for larger systems will improve residential-scale systems, but the improvements will not be linear. Economies of scale will not necessarily hold as the balance-of-system components generally accounts for a larger percentage of product costs.
- Multiple U.S. and worldwide R&D programs to develop residential and light-commercial mCHP systems including:
    - Japan's ENE-FARM program[55]
    - Germany's Callux program[56]
    - EU's ene-field program[57]

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[53] Estimates based on summary of current technology costs from Staffell and Green. 2012. "The Cost of Domestic Fuel Cell Micro-CHP Systems." July 2012. Available at: https://spiral.imperial.ac.uk/bitstream/10044/1/9844/6/Green%202012-08.pdf
[54] California Air Resources Board. 2006. "Amendments to the Distributed Generation Certification Regulation." California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 8, Article 3, Sections 94200-94214.
[55] Tokyo Gas. 2014. "Comfortable Housing and Lifestyle - Residential Sector." Available at: http://www.tokyo-gas.co.jp/techno/stp1/00h1_e.html.
[56] Callux Project. 2014. "Callux, Practical Tests for Fuel Cells in a Domestic Setting." Available at: http://www.callux.net/home.English.html.
[57] Ene-field. 2014. Available at: http://enefield.eu/.

  - U.S. DOE's ARPA-e REBELS fuel cell program[58] and GENSETS FOA specification[59] for 1kWe for non-fuel cell systems with 40% electrical efficiency and $3/We costs
  - A.O. Smith's mCHP system demonstration for light-commercial buildings[60].
- Planned introduction of light-duty vehicles using next-generation fuel cells by Toyota, Honda, and Hyundai in the next several years[61,62].

Through these efforts, mCHP technologies may achieve higher efficiencies and lower costs based on wide-spread investment in new energy systems. Fuel cell based systems provide clearest path for incorporating mCHP in ZNE homes based on their generally higher electrical efficiencies and limited emissions barriers. Fuel cell mCHP systems require breakthroughs over the next 10-15 years to directly compete with solar PV systems, but even at current efficiencies, there is a positive TDV impact. Section 6.2.3 discusses the cost thresholds, performance targets, and necessary advancements for fuel cell mCHP systems.

#### *6.2.2.4 Gas Heat Pumps*

As discussed in Section 4.3.2, gas heat pumps can provide TDV benefits for a mixed-fuel ZNE home in certain situations, but are not economically attractive on a TDV basis compared to an incrementally larger solar PV system. On a TDV basis, gas heat pumps providing space heating offer an attractive proposition for homes with larger space or water heating loads, especially when considering pool heating loads. By 2030, the incremental cost for gas heat pumps over conventional space and water heating systems could improve from $78/kBtu-hr today to $56/kBtu-hr. Under these medium- and low-cost assumptions, heat-only or reversible gas heat pumps systems could become attractive relative to other efficiency options, such as condensing furnaces, in locations with substantial heating loads, such as Bakersfield. Unlike solar PV systems, costs for these space heating measures are not projected to decrease continuously.

Gas heat pump technologies may achieve high efficiencies and low costs with federal and utility support and the introduction of products from established European manufacturers to the US market. Initial adopters could include homes in colder areas (Bakersfield), larger homes, and homes with large water heating loads (i.e., pool heaters). Nevertheless, the current capacity of most systems offered today is too large for most ZNE homes in Southern California. Further product development is needed to create smaller-capacity gas heat pumps at suitable performance and cost for most single-family homes. Section 6.2.3 discusses the cost thresholds, performance targets, and necessary advancements for gas heat pump systems.

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[58] ARPA-e. 2014. Reliable Electricity Based on Electrochemical Systems – REBELS Program. Available at: http://arpa-e.energy.gov/?q=arpa-e-site-page/view-programs

[59] ARPA-e. 2014. Generators for Small Electrical and Thermal Systems – GENSETS Program. Available at: https://arpa-e-foa.energy.gov/FileContent.aspx?FileID=6cef1c18-5fb6-40dc-9f39-c00d52b06ec6

[60] Petrarca, Mark. 2014. "A.O. Smith, DOE Energy into Cooperative Agreement to Evaluate Commercial Hot Water, Power Generation System." October 30, 2014.

[61] Hurst and Gartner. 2014. "Light Duty Natural Gas Vehicles - Natural Gas Passenger Cars, Light Duty Pickup Trucks, SUVs, Vans, and Light Commercial Vehicles: Global Market Analysis and Forecasts." Navigant Research. Published 1Q 2014.

[62] Chang, Kenneth. 2014. "A Road Test of Alternative Fuel Visions." New York Times Online. November 18, 2014.

### 6.2.2.5 Demand Response and Energy Storage

As discussed in Section 4.3.3, residential DR and energy storage systems offset TDV consumption by time-shifting the home's energy consumption from high TDV periods to lower TDV periods. While Title 24 may require DR capabilities for additional appliances, similar to thermostat requirements, homebuilders could potentially receive a TDV credit for incorporating on-site electric batteries. Many solar integration companies now offer California homeowners on-site battery systems (5kW, 10kWh) as part of their solar PV package. Beyond utility bill savings for the customer, these companies are hoping to take advantage of California's new regulations and utility programs to incorporate energy storage into the California electrical grid.

For ZNE homes, electric batteries offer modest TDV energy savings, but are not cost-effective compared to solar PV systems under current cost estimates of $600-$750/kWh. At the $100/kWh goal cited for Tesla and Solar City's Gigafactory, on-site electric batteries would have lower cost of conserved TDV energy than solar PV systems at current costs. Additionally, batteries would offer an efficiency option for many miscellaneous electric loads, where no conventional efficiency measures currently exist.

### 6.2.2.6 Electric and Natural Gas Vehicles

As discussed in Section 4.2.5, incorporating the energy consumption of alternative vehicles substantially increases ZNE home consumption, often doubling the TDV consumption of standard Title 24 loads. While Title 24 does not cover in-home refueling or recharging today, increased market adoption of electric or NGVs could cause their inclusion in future building codes. Navigant Research projects light-duty vehicles using natural gas in California to increase from 40,000 in 2014 to 105,000 by 2023[63]. Even larger increases are projected for plug-in EVs, with annual sales in California increasing from 40,000 in 2014 to 140,000 by 2023[64].

Should future building codes cover transportation energy, each ZNE home will require additional solar PV to offset the increased TDV consumption. The solar PV size and subsequent incremental cost will largely depend on which portion of the transportation system is applicable to building codes. For example, if the building codes only consider the consumption of the charging/refueling station, then the ZNE home only requires modest solar PV capacity additions. The NGV refueling station carries such a larger solar PV requirement due to the high electricity consumption of the compressor in addition to the natural gas fuel itself.

Without inclusion under future building codes, incorporating in-home NGV refueling or EV charging stations should not add substantial cost to a new ZNE. Unlike a retrofit application, the homebuilder can design the home's natural gas and/or electrical infrastructure to reach the garage. The price for EV chargers has substantially dropped in recent years and industry groups are working toward $500 NGV refueling stations[63] compared to the current $5,500.

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[63] Hurst and Gartner. 2014. "Light Duty Natural Gas Vehicles - Natural Gas Passenger Cars, Light Duty Pickup Trucks, SUVs, Vans, and Light Commercial Vehicles: Global Market Analysis and Forecasts." Navigant Research. Published 1Q 2014.

[64] Shepard and Gartner. 2014. "Electric Vehicle Geographic Forecasts - Plug-In Electric Vehicle Sales Forecasts for North America and Select European and Asia Pacific Cities by State/Province, Metropolitan Area, City, and Selected Utility Service Territories." Navigant Research. Published 2Q 2014.

#### 6.2.2.7 Solar Thermal Technologies

In general, solar thermal technologies did not provide cost-effective TDV savings relative to other HVAC, water heating, and on-site renewable measures. Solar hot water systems do provide TDV energy savings for domestic water heating and can improve the performance of thermally activated gas heat pumps, but the high costs of solar thermal systems limits their potential benefits for ZNE homes. Similar to solar PV systems, the output for solar thermal systems depends on the home's orientation, such that the TDV energy savings diminish when not optimally oriented towards the South.

Solar hot water systems have not achieved the same rapid cost reductions in recent years as solar PV systems. Recent studies[65,66] have outlined potential pathways to reduce the cost of solar how water systems, but several barriers exist for HVAC and water heating loads. Even under the most optimistic projections with 50% cost reduction (e.g., $3,000 for 40 sq.ft. system), solar hot water systems are not cost-competitive with other options on a $/TDV-offset basis, such as gas-fired tankless water heaters. Section 6.2.3 discusses the necessary cost thresholds for solar thermal systems to compete over the next 5-10 years with the falling price of solar PV systems and other technologies. Nevertheless, solar hot water systems may provide an attractive alternative or supplemental heating source for gas-fired pool heaters. Current solar pool heating systems cost substantially less, although their thermal performance is well below those for HVAC and water heating loads.

### 6.2.3 Cost and Performance Targets for Gas Technologies

In future years, cost reductions for certain renewable and electric technologies could reduce the first cost advantage and relative attractiveness of mixed-fuel ZNE homes. As noted in Section 6.2.2.1, anticipated cost reductions for solar PV systems will not only reduce the cost advantage that mixed-fuel ZNE homes offer by way of smaller system size requirements, but also lower the attractiveness of gas-fired efficiency measures. Further developments of electric heat pump technologies will reduce the first cost of electric-only ZNE homes relative to mixed-fuel designs, and combined with solar PV cost reductions could put mixed-fuel homes at a disadvantage.

To ensure that mixed-fuel ZNE homes remain competitive to electric-only designs in future years, we developed cost thresholds for individual gas technologies to maintain competitiveness against future solar PV and heat pump cost reductions in 2015, 2020, and 2025. Comparing these future cost thresholds against current technology costs helps identify areas where SCG, CEC, and others can target for future RD&D activities. Our analysis consists of three steps:

- Comparison of gas technologies against future solar PV systems for mixed-fuel ZNE homes i.e., selection of efficiency vs. solar PV savings for mixed-fuel ZNE home
- Comparison of gas technologies for mixed-fuel ZNE homes against electric-only ZNE homes with future solar PV and heat pump systems i.e., mixed-fuel vs. electric-only ZNE home designs in future years.

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[65] Goetzler et al. 2014. "Research & Development Needs for Building-Integrated Solar Technologies." Navigant Consulting Inc. for the U.S. Department of Energy, Building Technologies Office. January 2014.
[66] Hudon et al. 2012. "Low-Cost Solar Water Heating Research and Development Roadmap." National Renewable Energy Laboratory. August 2012.

- Identification of key RD&D focus areas i.e., what costs thresholds do gas technologies need to meet to be competitive against solar PV savings and electric-only ZNE designs.

#### *6.2.3.1 Mixed-Fuel ZNE Technologies Compared to Solar PV Systems*

As described in Section 3.2, the optimization process compares the cost of TDV energy savings for various efficiency technologies against the cost of TDV energy production for a slightly larger solar PV system. Without cost reductions, the attractiveness of certain efficiency technologies will decrease as the cost of solar PV systems continues to decrease. To understand how various gas technologies will compared to future solar PV costs, we developed specific cost thresholds for gas-fired water heating, space heating, solar water heating, mCHP, and heat pump technologies and compared them to current technology costs. These thresholds compared the value of the energy savings from each gas technology to that provided by an incrementally larger solar PV system. Table 68, Table 69, and Table 70 outline the cost thresholds and necessary cost reductions for projects solar PV costs in 2015, 2020, and 2025. Because solar PV systems have longer lifetimes than many of the individual technologies, each cost threshold considers the NPV of equipment replacement over 30 year period (similar to the process described in Section 3.2), and then equates to an initial technology cost. Future solar PV costs assume 14% reductions in 2020 and 26% reduction in 2025 as shown in Figure 64.

#### *How to Interpret the Following Tables*

Table 68, Table 69, and Table 70 provide cost thresholds for gas technologies to be more cost-effective than a larger solar PV system with 2015-2025 cost projections. Each table shows the following relationships:

- Current cost of selected gas technologies
- Cost thresholds in 2015-2025 where the gas technology shows greater cost-effectiveness relative to a slightly larger solar PV system in 2015-2025.
- Required cost reduction (%) for the gas technology to meet the cost threshold for that year.

Table 67 below provides an illustrative example to help explain Table 68, Table 69, and Table 70:

**Table 67. Gas Technology Cost Thresholds Compared to Solar PV Costs in Future Years - Excerpt**

| Gas Technology | Current Cost | | Technology Cost Threshold | | | Necessary Cost Reduction* | | |
|---|---|---|---|---|---|---|---|---|
| | Initial Cost | Incremental Cost | 2015 | 2020 | 2025 | 2015 | 2020 | 2025 |
| Standard WH | $762 | - | - | - | - | - | - | - |
| Tankless WH | $871 | $109 | $2,088 | $1,910 | $1,756 | N/A | N/A | N/A |
| Solar WH | $7,941 | $7,179 | $5,489 | $4,895 | $4,384 | 31% | 38% | 45% |

*N/A signifies that current technology cost are lower than technology cost threshold.
** incremental cost includes both baseline water heater and furnace

- The tankless water heater has a current cost of $871, which is lower than the cost thresholds in 2015-2025. Therefore, tankless water heaters are a more cost-effective option than incrementally larger solar PV in future years as long as tankless water heaters remain those thresholds.

- Conversely, the solar water heater has current cost higher than the future cost thresholds ($7,941 vs. $5,489 for 2015) and would require cost reductions of 31% in 2015 to 45% in 2025 to become more cost-effective than a slightly larger solar PV system.

**Table 68. Gas Technology Cost Thresholds Compared to Solar PV Costs in Future Years – Los Angeles**

| Gas Technology | Current Cost | | Technology Cost Threshold | | | Necessary Cost Reduction* | | |
|---|---|---|---|---|---|---|---|---|
| | Initial Cost | Incremental Cost | 2015 | 2020 | 2025 | 2015 | 2020 | 2025 |
| Standard WH | $762 | - | - | - | - | - | - | - |
| Tankless WH | $871 | $109 | $2,088 | $1,910 | $1,756 | N/A | N/A | N/A |
| Tankless Condensing WH | $1,582 | $820 | $2,674 | $2,413 | $2,189 | N/A | N/A | N/A |
| Standard WH + HR | $1,362 | $600 | $1,189 | $1,129 | $1,077 | 13% | 17% | 21% |
| Solar WH | $7,941 | $7,179 | $5,489 | $4,895 | $4,384 | 31% | 38% | 45% |
| Condensing WH | $2,091 | $1,329 | $2,084 | $1,898 | $1,737 | 0% | 9% | 17% |
| Gas HPWH | $1,928 | $1,166 | $2,814 | $2,524 | $2,275 | N/A | N/A | N/A |
| Condensing + HR | $2,691 | $1,929 | $2,444 | $2,206 | $2,002 | 9% | 18% | 26% |
| Furnace 80% | $346 | - | - | - | - | N/A | N/A | N/A |
| Furnace 90% | $449 | $103 | $470 | $453 | $438 | N/A | N/A | 3% |
| Furnace 98% | $467 | $122 | $552 | $523 | $498 | N/A | N/A | N/A |
| Combi Furnace-WH | $2,049 | $942** | $3,234 | $2,942 | $2,692 | N/A | N/A | N/A |
| mCHP (mid Eff 0.5kW) | $10,000 | $10,000 | $5,902 | $5,068 | $4,352 | 41% | 49% | 56% |
| mCHP (mid Eff 1.0 kW) | $20,000 | $20,000 | $7,326 | $6,291 | $5,403 | 63% | 69% | 73% |
| mCHP (high Eff 0.5kW) | $10,000 | $10,000 | $7,733 | $6,641 | $5,703 | 23% | 34% | 43% |
| mCHP (high Eff 1.0kW) | $20,000 | $20,000 | $14,653 | $12,582 | $10,806 | 27% | 37% | 46% |
| Gas Heat Pump (engine Low) | $3,058 | $1,950** | $4,081 | $3,669 | $3,317 | N/A | N/A | N/A |
| Gas Heat Pump (engine high) | $3,058 | $1,950** | $4,813 | $4,299 | $3,857 | N/A | N/A | N/A |
| Gas Heat Pump (reversible low) | $3,058 | $1,950** | $4,264 | $3,827 | $3,452 | N/A | N/A | N/A |
| Gas Heat Pump (reversible high) | $3,058 | $1,950** | $5,749 | $5,102 | $4,547 | N/A | N/A | N/A |
| Gas Heat Pump (heat only low) | $3,058 | $1,950** | $4,101 | $3,687 | $3,332 | N/A | N/A | N/A |
| Gas Heat Pump (heat only high) | $3,058 | $1,950** | $5,017 | $4,473 | $4,007 | N/A | N/A | N/A |

*N/A signifies that current technology cost are lower than technology cost threshold.
** incremental cost includes both baseline water heater and furnace
For further explanation, please refer to the example at the beginning of Section 6.2.3.1.

**Table 69. Gas Technology Cost Thresholds Compared to Solar PV Costs in Future Years – Bakersfield**

| Gas Technology | Current Cost | | Technology Cost Threshold | | | Necessary Cost Reduction* | | |
|---|---|---|---|---|---|---|---|---|
| | Initial Cost | Incremental Cost | 2015 | 2020 | 2025 | 2015 | 2020 | 2025 |
| Standard WH | $762 | - | - | - | - | - | - | - |
| Tankless WH | $871 | $109 | $2,021 | $1,852 | $1,706 | N/A | N/A | N/A |
| Tankless Condensing WH | $1,582 | $820 | $2,576 | $2,328 | $2,116 | N/A | N/A | N/A |
| Standard WH + HR | $1,362 | $600 | $1,167 | $1,110 | $1,060 | 14% | 19% | 22% |
| Solar WH | $7,941 | $7,179 | $5,268 | $4,705 | $4,221 | 34% | 41% | 47% |
| Condensing WH | $2,091 | $1,329 | $2,012 | $1,835 | $1,684 | 4% | 12% | 19% |
| Gas HPWH | $1,928 | $1,166 | $2,705 | $2,431 | $2,195 | N/A | N/A | N/A |
| Condensing + HR | $2,691 | $1,929 | Net negative savings | | | Net negative savings | | |
| Furnace 80% | $346 | - | - | - | - | - | - | - |
| Furnace 90% | $539 | $124 | $788 | $735 | $690 | N/A | N/A | N/A |
| Furnace 98% | $584 | $170 | $1,045 | $956 | $880 | N/A | N/A | N/A |
| Combi Furnace-WH | $2,166 | $990** | $3,632 | $3,294 | $3,004 | N/A | N/A | N/A |
| mCHP (mid Eff 0.5kW) | $10,000 | $10,000 | $5,676 | $4,874 | $4,186 | 43% | 51% | 58% |
| mCHP (mid Eff 1.0 kW) | $20,000 | $20,000 | $7,906 | $6,789 | $5,830 | 60% | 66% | 71% |
| mCHP (high Eff 0.5kW) | $10,000 | $10,000 | $7,704 | $6,615 | $5,681 | 23% | 34% | 43% |
| mCHP (high Eff 1.0kW) | $20,000 | $20,000 | $14,191 | $12,186 | $10,465 | 29% | 39% | 48% |
| Gas Heat Pump (engine Low) | $3,127 | $1,950** | $5,294 | $4,721 | $4,229 | N/A | N/A | N/A |
| Gas Heat Pump (engine high) | $3,127 | $1,950** | $6,591 | $5,835 | $5,186 | N/A | N/A | N/A |
| Gas Heat Pump (reversible low) | $3,127 | $1,950** | $3,956 | $3,572 | $3,243 | N/A | N/A | N/A |
| Gas Heat Pump (reversible high) | $3,127 | $1,950** | $8,031 | $7,071 | $6,248 | N/A | N/A | N/A |
| Gas Heat Pump (heat only low) | $3,127 | $1,950** | $7,646 | $6,740 | $5,964 | N/A | N/A | N/A |
| Gas Heat Pump (heat only high) | $3,127 | $1,950** | $9,065 | $7,959 | $7,010 | N/A | N/A | N/A |

*N/A signifies that current technology cost are lower than technology cost threshold.
** incremental cost includes both baseline water heater and furnace
For further explanation, please refer to the example at the beginning of Section 6.2.3.1.

**Table 70. Gas Technology Cost Thresholds Compared to Solar PV Costs in Future Years – Palm Springs**

| Gas Technology | Current Cost | | Technology Cost Threshold | | | Necessary Cost Reduction* | | |
|---|---|---|---|---|---|---|---|---|
| | Initial Cost | Incremental Cost | 2015 | 2020 | 2025 | 2015 | 2020 | 2025 |
| Standard WH | $762 | - | - | - | - | - | - | - |
| Tankless WH | $871 | $109 | $1,941 | $1,784 | $1,648 | N/A | N/A | N/A |
| Tankless Condensing WH | $1,582 | $820 | $2,372 | $2,153 | $1,965 | N/A | N/A | N/A |
| Standard WH + HR | $1,362 | $600 | $1,127 | $1,076 | $1,032 | 17% | 21% | 24% |
| Solar WH | $7,941 | $7,179 | $5,167 | $4,618 | $4,146 | 35% | 42% | 48% |
| Condensing WH | $2,091 | $1,329 | $1,860 | $1,705 | $1,572 | 11% | 18% | 25% |
| Gas HPWH | $1,928 | $1,166 | $2,443 | $2,205 | $2,001 | N/A | N/A | N/A |
| Condensing + HR | $2,691 | $1,929 | $2,156 | $1,959 | $1,790 | 20% | 27% | 33% |
| Furnace 80% | $415 | - | - | - | - | - | - | - |
| Furnace 90% | $539 | $124 | $456 | $450 | $445 | 15% | 17% | 17% |
| Furnace 98% | $584 | $169 | $476 | $468 | $460 | 18% | 20% | 21% |
| Combi Furnace-WH | $2,166 | $989** | $2,005 | $1,780 | $1,587 | 7% | 18% | 27% |
| mCHP (mid Eff 0.5kW) | $10,000 | $10,000 | $4,688 | $4,026 | $3,457 | 53% | 60% | 65% |
| mCHP (mid Eff 1.0 kW) | $20,000 | $20,000 | $5,503 | $4,726 | $4,058 | 72% | 76% | 80% |
| mCHP (high Eff 0.5kW) | $10,000 | $10,000 | $7,542 | $6,476 | $5,562 | 25% | 35% | 44% |
| mCHP (high Eff 1.0kW) | $20,000 | $20,000 | $13,657 | $11,727 | $10,071 | 32% | 41% | 50% |
| Gas Heat Pump (engine Low) | $3,127 | $1,950** | $3,452 | $3,023 | $2,655 | N/A | 3% | 15% |
| Gas Heat Pump (engine high) | $3,127 | $1,950** | $4,492 | $3,916 | $3,421 | N/A | N/A | N/A |
| Gas Heat Pump (reversible low) | $3,127 | $1,950** | Net negative savings | | | Net negative savings | | |
| Gas Heat Pump (reversible high) | $3,127 | $1,950** | $5,083 | $4,423 | $3,857 | N/A | N/A | N/A |
| Gas Heat Pump (heat only low) | $3,127 | $1,950** | $2,453 | $2,165 | $1,918 | 22% | 31% | 39% |
| Gas Heat Pump (heat only high) | $3,127 | $1,950** | $3,044 | $2,673 | $2,354 | 3% | 15% | 25% |

*N/A signifies that current technology cost are lower than technology cost threshold.
** incremental cost includes both baseline water heater and furnace
For further explanation, please refer to the example at the beginning of Section 6.2.3.1.

Several key findings emerge when comparing the current cost of various gas technologies against future solar PV system costs to reach ZNE goals for a mixed-fuel home design:

- Both standard and condensing tankless water heaters are a very attractive option for achieving TDV energy savings for mixed-fuel ZNE homes compared to additional solar PV capacity and are substantially below their cost thresholds.
- Condensing storage water heaters (50 gallons) require 5-25% cost reduction from $2,091 to around $1,600 to be more cost-effective than additional solar PV capacity in future years. If a ZNE home did not wish to use a tankless water heater, condensing storage would be an attractive option at around $500 lower cost.
- Heat recovery systems for storage heaters require additional development to reduce costs to around $300 from the current estimate of $600 added onto a conventional storage water heating system.
- Solar water heaters require cost reductions of 30-50% below current cost estimates of $7,179 for a 40 sq.ft. system with standard gas storage water heater to compete against additional solar PV capacity. Even then, the technology would still be less cost-effective than a tankless water heater in achieving TDV energy savings.
- Condensing furnaces are an attractive option for many climate regions relative to additional solar PV capacity, but products with capacities below 30-40 kBtu/hr may not be widely available from multiple manufacturers.
- Combination water and space heaters carry a wide range of cost thresholds depending on the location and solar PV cost projection, from $1,500-$3,000. This technology has large potential for TDV energy savings relative to a conventional furnace and storage water heater configuration.
- Fuel cell mCHP systems at 0.5-1.0kW sizes with medium to high efficiency require cost reductions of 25-50% from $20/We to approximately $10/We to become cost-effective relative to solar PV systems.
- Engine or absorption-based gas heat pumps can offer cost-effective TDV energy savings by covering space and water heating loads, but current products are significantly oversized relative to the 30-40 kBtu/hr capacity to satisfy thermal loads for ZNE homes. The per-capacity cost projections of $78/kBtu-hr incremental cost for gas heat pumps assume capacities of 120 kBtu/hr and will most likely increase for smaller sizes.

Because the cost of technologies can change over time due to non-energy factors such as environmental regulations, incorporation of new features, product safety requirements, etc., these thresholds can provide guidance for not only R&D activities on new technologies (i.e., lowering cost), but also understanding how future cost increases would affect competitiveness (i.e., increasing costs). For example, gas heat pumps for space and/or water heating are not yet available in the capacities needed for ZNE homes and the current cost projections may not hold for initial products. Nevertheless, these cost thresholds are based on the technology's savings relative to a solar PV system and can therefore provide a target to the products needed for ZNE homes.

#### *6.2.3.2 Mixed-Fuel ZNE Homes Compared to Electric-Only ZNE homes with Future Technology Costs*

Mixed-fuel ZNE homes exhibit lower incremental costs today than an electric-only home design due to the combination of lower TDV energy consumption requiring a smaller solar PV system as well as lower technology costs for certain end-uses. As discussed in Section 6.2.2.2, the cost of solar PV systems and electric heat pump space and water heating technologies is projected to decrease by 15-30% from 2015-2025. To understand how the advantage for mixed-fuel ZNE homes will change with future electric technology cost reductions, we compared mixed-fuel homes using various gas-fired space and water heating technologies to electric-only ZNE homes incorporating future technology costs. Where specific gas technologies showed higher incremental cost, we identified the cost thresholds those technologies would need to meet to remain competitive with electric-only designs.

***How to Interpret the Following Tables***

Table 71 below provides an illustrative example to help explain Table 72, Table 73, and Table 74:

**Table 71. Cost Comparison of Individual Mixed-Fuel Technologies Relative to Projected Electric Technology Cost Reductions in Future Years – Excerpt**

| Gas Technology | 2015 Incremental Cost | | 2020 Incremental Cost | | 2025 Incremental Cost | | Technology Current Cost | Gas Technology Cost Target | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | | 2015 | 2020 | 2025 |
| Tankless WH | $18,626 | $21,762 | $16,719 | $18,694 | $14,735 | $16,039 | $871 | N/A | N/A | N/A |
| Solar WH | $24,336 | $21,762 | $22,620 | $18,694 | $20,802 | $16,039 | $7,941 | $5,367 | $4,867 | $4,015 |

Note- incremental costs compared to a baseline electric-only home. N/A signifies that current technology cost are lower than technology cost target. Highlight denotes where mixed-fuel incremental cost is higher than electric-only homes.

- For example, a Mixed-Fuel ZNE home with a tankless water heater will continue to show lower incremental costs than an Electric-Only ZNE home over 2015-2025, even with cost reductions in solar PV and electric heat pump technologies.
- Conversely, a Mixed-Fuel ZNE home using a solar thermal system will require cost reductions to match the incremental cost for an Electric-Only ZNE home over 2015-2025. Because solar PV is steadily decreasing, the cost threshold for solar thermal travels lower as well, making it even more difficult to remain competitive.

Table 72, Table 73, and Table 74 outline the incremental cost for mixed-fuel and electric-only ZNE homes with future cost reductions to solar PV, ASHP, and HPWH systems in 2015, 2020, and 2025 and specific gas technology cost thresholds to reach parity with electric-only designs.

Note - both mixed-fuel and electric-only ZNE homes benefit from future solar PV cost reductions through lower incremental costs. Each gas technology is evaluated individually, with a separate TDV energy consumption and requirements for a solar PV system. Elsewhere in this report, mixed-fuel ZNE homes using combinations of technologies (e.g., tankless water heater, condensing furnace) are compared to electric-only designs.

**Table 72. Cost Comparison of Individual Mixed-Fuel Technologies Relative to Projected Electric Technology Cost Reductions in Future Years – Los Angeles**

| Gas Technology | 2015 Incremental Cost | | 2020 Incremental Cost | | 2025 Incremental Cost | | Technology Current Cost | Gas Technology Cost Target | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | | 2015 | 2020 | 2025 |
| Standard WH | $19,699 | $21,762 | $17,625 | $18,694 | $15,496 | $16,039 | $762 | N/A | N/A | N/A |
| Tankless WH | $18,626 | $21,762 | $16,719 | $18,694 | $14,735 | $16,039 | $871 | N/A | N/A | N/A |
| Tankless Condensing WH | $18,787 | $21,762 | $16,957 | $18,694 | $15,040 | $16,039 | $1,582 | N/A | N/A | N/A |
| Standard WH + HR | $19,868 | $21,762 | $17,854 | $18,694 | $15,779 | $16,039 | $1,362 | N/A | N/A | N/A |
| Solar WH | $24,336 | $21,762 | $22,620 | $18,694 | $20,802 | $16,039 | $7,941 | $5,367 | $4,867 | $4,015 |
| Condensing WH | $19,690 | $21,762 | $17,804 | $18,694 | $15,839 | $16,039 | $2,091 | N/A | N/A | N/A |
| Gas HPWH | $18,784 | $21,762 | $17,003 | $18,694 | $15,129 | $16,039 | $1,928 | N/A | N/A | N/A |
| Condensing + HR | $19,924 | $21,762 | $18,091 | $18,694 | $16,170 | $16,039 | $2,691 | N/A | N/A | $2,560 |
| Furnace 80% | $19,699 | $21,762 | $17,625 | $18,694 | $15,496 | $16,039 | $346 | N/A | N/A | N/A |
| Furnace 90% | $19,686 | $21,762 | $17,628 | $18,694 | $15,514 | $16,039 | $449 | N/A | N/A | N/A |
| Furnace 98% | $19,629 | $21,762 | $17,582 | $18,694 | $15,477 | $16,039 | $467 | N/A | N/A | N/A |
| Combi Furnace-WH | $18,708 | $21,762 | $16,906 | $18,694 | $15,014 | $16,039 | $2,049 | N/A | N/A | N/A |

Note- incremental costs compared to a baseline electric-only home. N/A signifies that current technology cost are lower than technology cost target. Highlight denotes where mixed-fuel incremental cost is higher than electric-only homes.

For further explanation, please refer to the example at the beginning of Section 6.2.3.2.

**Table 73. Cost Comparison of Individual Mixed-Fuel Technologies Relative to Projected Electric Technology Cost Reductions in Future Years – Bakersfield**

| Gas Technology | 2015 Incremental Cost | | 2020 Incremental Cost | | 2025 Incremental Cost | | Technology Current Cost | Gas Technology Cost Target | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | | 2015 | 2020 | 2025 |
| Standard WH | $23,079 | $24,489 | $20,790 | $21,036 | $18,346 | $18,049 | $762 | N/A | N/A | $465 |
| Tankless WH | $22,091 | $24,489 | $19,957 | $21,036 | $17,646 | $18,049 | $871 | N/A | N/A | N/A |
| Tankless Condensing WH | $22,291 | $24,489 | $20,228 | $21,036 | $17,981 | $18,049 | $1,582 | N/A | N/A | N/A |
| Standard WH + HR | $23,278 | $24,489 | $21,045 | $21,036 | $18,650 | $18,049 | $1,362 | N/A | $1,353 | $760 |
| Solar WH | $27,898 | $24,489 | $25,941 | $21,036 | $23,785 | $18,049 | $7,941 | $4,533 | $3,036 | $2,205 |
| Condensing WH | $23,168 | $24,489 | $21,053 | $21,036 | $18,761 | $18,049 | $2,091 | N/A | $2,074 | $1,379 |
| Gas HPWH | $22,313 | $24,489 | $20,297 | $21,036 | $18,088 | $18,049 | $1,928 | N/A | N/A | $1,888 |
| Condensing + HR | $23,428 | $24,489 | $21,361 | $21,036 | $19,110 | $18,049 | $2,691 | N/A | $2,366 | $1,629 |
| Furnace 80% | $23,079 | $24,489 | $20,790 | $21,036 | $18,346 | $18,049 | $415 | N/A | N/A | $118 |
| Furnace 90% | $22,862 | $24,489 | $20,620 | $21,036 | $18,218 | $18,049 | $539 | N/A | N/A | $370 |
| Furnace 98% | $22,672 | $24,489 | $20,464 | $21,036 | $18,090 | $18,049 | $584 | N/A | N/A | $542 |
| Combi Furnace-WH | $21,870 | $24,489 | $19,891 | $21,036 | $17,715 | $18,049 | $2,166 | N/A | N/A | N/A |

Note- incremental costs compared to a baseline electric-only home. N/A signifies that current technology cost are lower than technology cost target. Highlight denotes where mixed-fuel incremental cost is higher than electric-only homes.

For further explanation, please refer to the example at the beginning of Section 6.2.3.2.

**Table 74. Cost Comparison of Individual Mixed-Fuel Technologies Relative to Projected Electric Technology Cost Reductions in Future Years – Palm Springs**

| Gas Technology | 2015 Incremental Cost | | 2020 Incremental Cost | | 2025 Incremental Cost | | Technology Current Cost | Gas Technology Cost Target | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | Mixed-Fuel | Electric-Only | | 2015 | 2020 | 2025 |
| Standard WH | $24,641 | $27,439 | $22,325 | $23,570 | $19,729 | $20,222 | $762 | N/A | N/A | N/A |
| Tankless WH | $23,737 | $27,439 | $21,564 | $23,570 | $19,091 | $20,222 | $871 | N/A | N/A | N/A |
| Tankless Condensing WH | $24,057 | $27,439 | $21,939 | $23,570 | $19,514 | $20,222 | $1,582 | N/A | N/A | N/A |
| Standard WH + HR | $24,883 | $27,439 | $22,618 | $23,570 | $20,065 | $20,222 | $1,362 | N/A | N/A | N/A |
| Solar WH | $29,546 | $27,439 | $27,551 | $23,570 | $25,232 | $20,222 | $7,941 | $5,834 | $3,960 | $2,932 |
| Condensing WH | $24,892 | $27,439 | $22,728 | $23,570 | $20,263 | $20,222 | $2,091 | N/A | N/A | $2,050 |
| Gas HPWH | $24,156 | $27,439 | $22,073 | $23,570 | $19,678 | $20,222 | $1,928 | N/A | N/A | N/A |
| Condensing + HR | $25,201 | $27,439 | $23,078 | $23,570 | $20,649 | $20,222 | $2,691 | N/A | N/A | $2,265 |
| Furnace 80% | $24,641 | $27,439 | $22,325 | $23,570 | $19,729 | $20,222 | $415 | N/A | N/A | N/A |
| Furnace 90% | $24,728 | $27,439 | $22,418 | $23,570 | $19,826 | $20,222 | $539 | N/A | N/A | N/A |
| Furnace 98% | $24,755 | $27,439 | $22,447 | $23,570 | $19,857 | $20,222 | $584 | N/A | N/A | N/A |
| Combi Furnace-WH | $24,131 | $27,439 | $22,027 | $23,570 | $19,613 | $20,222 | $2,166 | N/A | N/A | N/A |

Note- incremental costs compared to a baseline electric-only home. N/A signifies that current technology cost are lower than technology cost target. Highlight denotes where mixed-fuel incremental cost is higher than electric-only homes.
For further explanation, please refer to the example at the beginning of Section 6.2.3.2.

Improvements in solar PV and heat pump system costs will impact the relative advantage and competitiveness of mixed-fuel ZNE homes. Some gas technologies (e.g., tankless water heaters) are not substantially affected by future cost reductions in electric technologies. For many technologies and locations, cost reductions by 2025 will put mixed-fuel ZNE homes at a disadvantage relative to electric-only designs (e.g., condensing water heaters and furnaces). For these technologies, additional RD&D would be needed to reduce the cost of these products or alternatives should be considered. For example, a mixed-fuel ZNE home in Bakersfield using a tankless water heater or combination space and water heater is still a competitive with an electric-only home whereas a condensing storage water heater would not.

### *6.2.3.3 Key RD&D Focus Areas for Gas Technologies*

Specific gas technologies must not only compete with other efficiency and renewable energy measures available for each mixed-fuel home, but also with available technologies for electric-only ZNE home designs. By comparing various gas technologies against the future cost of solar PV and electric heat pump systems, we can identify which gas technologies offer the greatest likelihood of success for mixed-fuel ZNE homes and which required additional RD&D to improve their cost effectiveness. Table 75 summarizes the competitive positioning of gas-fired space and water heating technologies compared to future solar PV systems for mixed-fuel homes, and then future electric-only home designs.

**Table 75. Competitive Position of Gas Technologies Compared to Future Electric Technology Costs**

| Gas Technology | Compared to Solar PV for Mixed-Fuel Home | | | Compared to Electric-Only Home (Solar PV, ASHP, HPWH) | | |
|---|---|---|---|---|---|---|
| | 2015 | 2020 | 2025 | 2015 | 2020 | 2025 |
| Standard WH | - | - | - | ■ | ■ | □ |
| Tankless WH | ■ | ■ | ■ | ■ | ■ | ■ |
| Tankless Condensing WH | ■ | ■ | ■ | ■ | ■ | ■ |
| Standard WH + HR | ☒ | ☒ | ☒ | ■ | □ | □ |
| Solar WH | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ |
| Condensing WH | ☒ | ☒ | ☒ | ■ | □ | □ |
| Gas HPWH | ■ | ■ | ■ | ■ | ■ | □ |
| Condensing + HR | ☒ | ☒ | ☒ | ■ | □ | ☒ |
| Furnace 80% | - | - | - | ■ | ■ | □ |
| Furnace 90% | □ | □ | □ | ■ | ■ | □ |
| Furnace 98% | □ | □ | □ | ■ | ■ | □ |
| Combi Furnace-WH | □ | □ | □ | ■ | ■ | ■ |

■ denotes the gas technology at current cost is competitive relative to future solar PV or electric options in all locations

□ denotes the gas technology at current cost is sometimes competitive relative to future solar PV or electric options in some locations and requires RD&D to reach cost and performance targets

☒ denotes the gas technology at current cost is not competitive relative to future solar PV or electric options for any locations and requires RD&D to reach cost and performance targets

In examining Table 75, every gas technology besides tankless water heaters require at least some additional RD&D to remain competitive, even the baseline technology configuration of a standard storage water heater and 80% AFUE furnace. This suggests that while gas technologies can cost-effectively meet ZNE goals in the near term, SCG, CEC, and other partners should continue efforts to improve the performance and cost-effectiveness of gas technologies for space heating, water heating, and on-site generation for mixed-fuel ZNE homes. Table 76 summarizes the cost thresholds where the technology shows competitiveness against future cost reductions in solar PV systems and electric-only home designs as well as performance characteristics for the analyzed gas technologies. These values can assist SCG and partners prioritize focus areas for RD&D initiatives, benchmark the performance of new products, and other activities to support mixed-fuel ZNE homes. Note – the values represent the range of cost targets identified through each analysis.

**Table 76. Summary of Gas Technology Cost Threshold Ranges and Attributes**

| Gas Technology | Current Cost | Range of Cost Thresholds | | | Performance Attributes and Notes |
|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | |
| Standard WH | $762 | - | - | $465-$762 | • Modeled as 50 gallon storage water heater with EF of 0.60 |
| Tankless WH | $871 | $1,941-$2,088 | $1,784-$1,910 | $1,648-$1,756 | • Modeled as tankless water heater with EF of 0.82 |
| Tankless Condensing WH | $1,582 | $2,372-$2,674 | $2,153-$2,413 | $1,965-$2,189 | • Modeled as tankless water heater with EF of 0.96 |
| Standard WH + HR | $1,362 | $1,127-$1,189 | $1,076-$1,353 | $760-$1,077 | • Modeled as 50 gallon storage water heater with EF of 0.60 and heat recovery device |
| Solar WH | $7,941 | $4,533-$5,834 | $3,036-$4,895 | $2,205-$4,384 | • Modeled as 40 sq.ft. solar thermal panel and 50 gallon gas-fired storage water heater |
| Condensing WH | $2,091 | $1,860-$2,084 | $1,705-$2,074 | $1,379-$2,050 | • Modeled as 50 gallon storage water heater with EF of 0.80 |
| Gas HPWH | $1,928 | $2,443-$2,814 | $2,205-$2,524 | $1,888-$2,275 | • Modeled as 50 gallon storage water heater with EF of 1.15 |
| Condensing + HR | $2,691 | $2,444-$2,691 | $2,366-$2,691 | $2,560-$2,691 | • Modeled as 50 gallon condensing storage water heater with EF of 0.80 and heat recovery device |
| Furnace 80% | $346 | - | - | $118-$346 | • Modeled capacity as 20-25 kBtu/hr with 80% AFUE |
| Furnace 90% | $539 | $456-$788 | $450-$735 | $370-$690 | • Modeled capacity as 20-25 kBtu/hr with 90% AFUE |
| Furnace 98% | $584 | $476-$1,045 | $468-$956 | $460-$880 | • Modeled capacity as 20-25 kBtu/hr with 98% AFUE |
| Combi Furnace-WH | $2,166 | $2,005-$3,632 | $1,780-$3,294 | $1,587-$3,004 | • Modeled as a tankless condensing water heater with EF of 0.96 and condensing furnace (20-25 kBtu/hr) with 98% AFUE |
| mCHP System (0.5kW) | $10,000 | $4,688-$7,733 | $4,026-$6,641 | $3,457-$5,703 | • Modeled as 0.5-1.0 kW fuel cell with medium (38%) and high (60%) electrical efficiency |

| Gas Technology | Current Cost | Range of Cost Thresholds | | | Performance Attributes and Notes |
|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | |
| Gas Heat Pump | $3,127 | $2,453-<br>$9,065 | $2,165-<br>$7,959 | $1,918-<br>$7,010 | • Modeled as 25-30 kBtu/hr gas heat pump system with low and high efficiencies for different technologies (COP Heat/Cool)and operating modes: engine (1.2/1.1-1.5/1.2), absorption reversible (1.3/0.6-2.2/1.2), and absorption heat-only (1.2/0.0-1.6/0.0) |

## *6.3 Observations*

### 6.3.1 Comparison of Current Technology Landscape for ZNE Homes

- Because California's proposed ZNE building codes represent such a large shift in the building industry, many stakeholders believe that a new home will need the most advanced and expensive features to comply with code. Each ZNE home will combine a mix of traditional and emerging technologies to reach ZNE goals, and several traditional efficiency measures can provide more cost-effective TDV energy savings even with the steadily decreasing cost of solar PV systems.

### 6.3.2 Development Status for Advanced Technologies

Several advanced energy efficiency and renewable energy technologies will offer substantial TDV energy impacts for ZNE homes. These advanced technologies typically carry a substantial cost premium due to their low production volumes, but should improve their cost effectiveness as future R&D advancements improve performance and market adoption increases. In future years, lower cost and/or improved performance can alter the economic attractiveness of a technology relative to alternatives. In some cases, the technology would provide more cost-effective TDV savings and become a more attractive technology option for ZNE homes. These advanced technologies could impact ZNE home design and economics in the following manner:

- **Solar PV Systems**: Future reductions in the soft costs of solar PV systems may reduce their installation costs by as much as 14-23% in 2020 and 37-54% in 2030. Under these projections, the incremental cost and payback of a ZNE home decreases by a similar percentage, because solar PV consists the largest portion of ZNE costs. Other economic factors such as payback and TRC values improve due to the lower incremental cost. The lower solar PV costs will also reduce the relative economic attractiveness of other traditional and advanced technologies compared to solar PV.
- **Electric Heat Pumps for Space and Water Heating**: Most electric-only ZNE homes will use electric air-source heat pumps and heat pump water heaters to satisfy HVAC and water heating loads. With the support of research organizations, these heat pump technologies will continue to improve performance and reduce upfront cost. As electric heat pumps reduce their cost in future years, gas-fired technologies for space and/or water heating must also reduce their cost to maintain the cost advantage and competitiveness of mixed-fuel homes.

- **Micro-CHP Systems**: mCHP systems can provide TDV benefits with the efficiencies of current technologies, but require cost reductions from $20/W-electric to $5-10/W-electric to become economically attractive. Current efforts to develop mCHP systems for residential, industrial, and transportation applications suggest future cost reductions are possible. Although future price decreases for solar PV systems will counterbalance these improvements, ZNE homes with higher space and water heating loads or those with limited solar resource could benefit from 0.5-1 kW mCHP systems.
- **Gas Heat Pumps**: Gas-fired heat pumps offering heating-only or reversible operation could provide TDV benefits for mixed-fuel ZNE homes. Future cost reductions increase the attractiveness of these technologies for ZNE homes with larger thermal demand, especially as the cost for competing space and water heating technologies is not expected to substantially decrease. Because current products are designed for colder regions, manufacturers must develop lower capacity gas heat pumps to serve ZNE homes in Southern California.
- **Demand Response and Energy Storage**: Technologies that shift a ZNE home's electricity consumption, such as DR or electric batteries, can reduce the net annual TDV consumption of a home by 5-10%. Title 24 will most likely not allow demand-response capabilities as a measure to reduce a home's TDV consumption, but an on-site electric battery system might comply if it meets certain storage and discharge requirements. Under projected cost reductions, electric batteries could provide cost-effective TDV savings compared to solar PV systems.
- **Alternative Vehicles**: EVs and NGVs could have a significant impact on ZNE home designs if future ZNE standards include the energy consumption of the on-site charging/refueling station and/or the vehicle itself within the home's energy budget. In this case, the ZNE home would require additional solar PV to offset the added TDV consumption, significantly increasing costs and potentially creating issues with the available roof space.
- **Solar Thermal**: Without a major cost breakthrough, solar hot water systems will not provide cost-effective savings for domestic water heating or thermally activated heat pumps. Solar hot water systems can provide large TDV energy savings and lower in natural gas consumption, but carry too high an incremental cost relative to other options, even with large cost reductions.

### 6.3.3 Cost and Performance Targets for Gas Technologies

- In future years, cost reductions for solar PV and electric heat pump systems could reduce the first cost advantage and relative attractiveness of mixed-fuel ZNE homes. Anticipated cost reductions for solar PV systems will not only reduce the cost advantage that mixed-fuel ZNE homes offer by way of smaller system size requirements, but also lower the attractiveness of gas-fired efficiency measures. Further developments of electric heat pump technologies will reduce the first cost of electric-only ZNE homes relative to mixed-fuel designs, and combined with solar PV cost reductions could put mixed-fuel homes at a disadvantage.
- While many gas technologies can cost-effectively meet ZNE goals in the today, SCG, CEC, and other partners should continue efforts to improve the performance and cost-effectiveness of gas

technologies for space heating, water heating, and on-site generation for mixed-fuel ZNE homes. We identified cost thresholds for each gas technology compared to competing technologies over the period of 2015-2025. These values can assist SCG and partners prioritize focus areas for RD&D initiatives, benchmark the performance of new products, and other activities to support mixed-fuel ZNE homes.

# 7. Customer and Builder Perspectives

## 7.1 Section Summary

The success of ZNE building codes will ultimately depend on whether the ZNE homes meet the needs of prospective homeowners. This section summarizes available information from past research studies regarding customer and builder perspectives on ZNE homes and discusses their impacts on ZNE adoption, technology selection, and other factors. We include this section to provide a market perspective to the technical results of this study by using findings from past research studies. Information in this section was provided by:

- Kirk Morales, Project Manager Clean Energy Strategy at SCG[67]
- SCG Visions 2014 Home Preference Survey (SCG 2015)
- SCG Builder Preference Survey[68]
- CALMAC Residential ZNE Market Characterization Study (Pande et al. 2015).

## 7.2 Customer and Builder Perspectives on ZNE Homes

While this Phase I Technology Report focuses on the technical and economic comparison between mixed-fuel and electric-only ZNE homes, ZNE efforts must engage the building community and their customers, i.e., prospective homeowners. As discussed in previous sections, mixed-fuel ZNE homes offer numerous advantages, including lower incremental cost, smaller PV size, etc. but these advantages may decrease as the price of solar PV systems continues to decrease. With this trend, the non-economic consumer benefits of natural gas appliances will become a key differentiator for builders, prospective homebuyers, and other stakeholders in the Southern California real estate market. To better understand these issues, we interviewed Kirk Morales, Project Manager Clean Energy Strategy at SCG[67] and reviewed available literature on market preferences from past research studies.

### 7.2.1 Customer Perspectives on Natural Gas Appliances

Beyond those features specified by building and safety codes, homeowner preferences for certain features, appliances, and amenities have a large impact on how real estate professionals design, price and market a home. Prospective homebuyers drive the design of new homes either directly in the case of custom or semi-custom production homes, or indirectly with spec homes. Where applicable, natural gas appliances can offer several key advantages over electrical appliances that past research studies suggest that homebuyers prefer such as lower operating costs, greater comfort, and improved performance. Two recent market research studies have characterized customers' preferences for natural gas appliances:

- **SCG Visions 2014 Home Preference Survey (SCG 2015)**
  - Percentage of homebuyers and renters responding that natural gas was the preferred source of energy for the following appliances:

[67] Interview conducted on March 25, 2015.

[68] Results of survey provided over the phone from Kirk Morales during interview on March 25, 2015.

    - 95% cooking
    - 83% space heating
    - 91% water heating
    - 82% clothes drying
    - 95% fireplaces.
- **CALMAC Residential ZNE Market Characterization Study (Pande et al. 2015)**
    - 88% of homeowners prefer at least one natural gas appliance over an electric appliance, if given the option.

These two research studies suggest that customers overwhelming prefer natural gas appliances for certain applications, and not only for large end-uses such as space and water heating, but also the smaller "lifestyle" end-uses of cooking and fireplaces. Builders who offer mixed-fuel ZNE homes could have a marketing advantage over those offering electric-only features by meeting the preferences of Southern California homebuyers suggested by past research studies. Further, because homebuyers do not have a clear understanding of the ZNE home definition[69], a homebuilder offering natural gas appliances creates an opportunity to interact with the homebuyer and gain their trust by explaining the definition and characteristics of a mixed-fuel ZNE home. As shown in these past research studies, customer preferences for natural gas appliances should act as a compelling drive for mixed-fuel ZNE homes even if the technical and economic advantages decrease with lower solar PV costs.

#### 7.2.2 Builder Perspectives on Natural Gas Appliances

Builders have numerous and often competing factors to consider when designing a home, such as meeting state building codes, customer preferences for certain amenities, and their own construction costs. Ultimately, the builder would like to design a code-compliant home meeting all of the customer's preferences at the lowest cost, but tradeoffs typically occur to resolve conflicting factors. While customers may prefer natural gas appliances, mixed-fuel homes could carry extra infrastructure costs compared to electric-only designs. Above standard requirements and electrical connections, mixed-fuel homes require an additional natural gas distribution systems within the home, from the street to the home, and for a new community, from the larger distribution network to the street. With only a small incremental cost difference between individual mixed-fuel and electric-only ZNE homes, the value of mixed-fuel ZNE homes compared to electric-only ZNE homes could diminish if infrastructure costs prove too burdensome.

In a recent survey of Southern California builders conducted by SCG[70], builders ranked their top concerns from a set of 6 factors (1 – highest concern, 6 – lowest concern):

1. Title 24 and Title 20 building codes
2. Customer preferences of natural gas vs. electric appliances
3. First cost of appliances and other building technologies

[69] Section 5.4.2 of Pande et al. (2015).

[70] Results of survey provided over the phone from Kirk Morales during interview on March 25, 2015.

4. Operating costs
5. Utility allowances for infrastructure costs
6. Utility services.

This list suggests that if a mixed-fuel ZNE home design meets code and does not have significantly higher first cost or operating costs, than builders will likely wish to continue constructing mixed-fuel ZNE homes to meet customer preferences even though there may be added infrastructure cost and complexity. As evidenced in this report, ZNE homes with natural gas appliances show lower first cost and similar costs compared to electric-only designs, so builders will likely embrace mixed-fuel ZNE homes and market natural gas features to their prospective customers. SCG is currently researching the feasibility of expanding an existing multi-family program and offer single-family builders the option to use elevated pressure service of rather than 0.33 psi[71]. Elevated gas pressure of 2 psi can lower installation cost and complexity by allowing the use of smaller-diameter flexible gas piping with manifold or parallel branch pipe layouts. The flexible gas piping reduces the number of fittings by changing direction easily within walls and floors or around appliances, and the smaller diameter allows more length for each roll of pipe. Additionally, the elevated pressure layout can more readily integrate future expansion for pool heaters and other technologies.

## *7.3 Observations*

While ZNE policies have been set in motion through a top-down approach using Title 24 building codes, the ultimate success of the ZNE building movement depends on broad market support from builders and their customers. Builders will design homes that meet Title 24 ZNE codes, are cost-effective, and meet customer preferences, but their fuel choice for each home will depend on the comparison between mixed-fuel and electric-only designs. In previous sections of this study, we identified that mixed-fuel ZNE home designs not only meet Title 24 codes, but also provide attractive technical and economic advantages over electric-only designs. Further, several past research studies referenced in this section identified an overwhelming customer preference for natural gas appliances, and builders' likely willingness to meet these customer demands, even if it increases infrastructure cost and complexity during construction. By combining these technical, economic, and market advantages, SCG can conduct educational outreach and support to the real estate community so they can better understand the large role that natural gas can play in the residential ZNE future. SCG efforts such as the ABC Green Home 2.0 demonstration home and marketing materials will provide great visibility and begin the conversation on natural gas' role for ZNE homes[72].

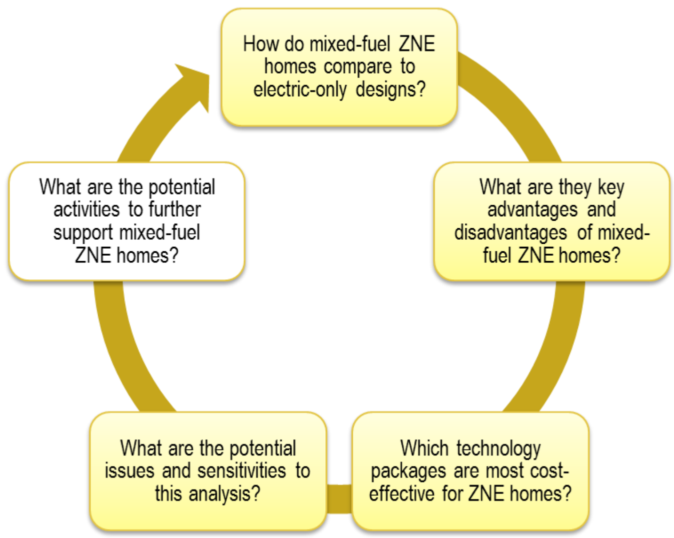
[71] http://www.socalgas.com/for-your-business/builder-services/elevated-pressure.shtml
[72] Information and flyer provided by Kirk Morales in March 25, 2015 interview.

# 8. Summary of Results

## 8.1 Section Summary

This section summarizes the technical and economic results of the analysis, the evaluation of advanced technologies, as well as potential sensitivities to the analysis results. This section answers the following key questions:

1. **How do mixed-fuel ZNE homes compare to electric-only designs?**
2. **What are they key advantages and disadvantages of mixed-fuel ZNE homes compared to electric-only ZNE homes?**
3. **Which technology packages are most cost-effective for ZNE homes, both now and in the future?**
4. **What are the potential issues and sensitivities to this analysis that SCG and other stakeholders should monitor in the future?**




## 8.2 Project Summary

California's goal to reduce energy consumption and GHG emissions through ZNE building standards will have a profound impact on the residential building industry over the next several decades. ZNE building codes provide substantial benefits for the state of California, but require upfront planning to accommodate the significant changes in current practice. Prospective homebuyers, residential builders, utilities, and other stakeholders must adjust to new terminology and processes as well as shift their perceptions of utility-customer interaction. Compared to traditional single-family homes, ZNE homes will consume significantly less energy and include on-site electricity production as well as other advanced technologies. SCG's investigation into the value and benefits of ZNE homes using natural gas appliances through this project can support internal program development and outreach efforts to policy stakeholders and residential building partners.

During this project, we used building simulations to investigate the optimum approach for mixed-fuel and electric-only homes to reach ZNE goals and answer the five key questions outlined in Figure 65.We developed baseline home designs compliant with future Title 24 building codes and conducted an extensive building simulation study to identify the most cost-effective ZNE home features when optimized for TDV energy savings. The simulation software BEopt optimized 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. Where applicable, we outlined potential activities that SCG and other stakeholders could pursue to further support the adoption of mixed-fuel ZNE homes.

The remainder of Section 8 and Section 9 summarizes the results to the five key questions outlined in Figure 65.

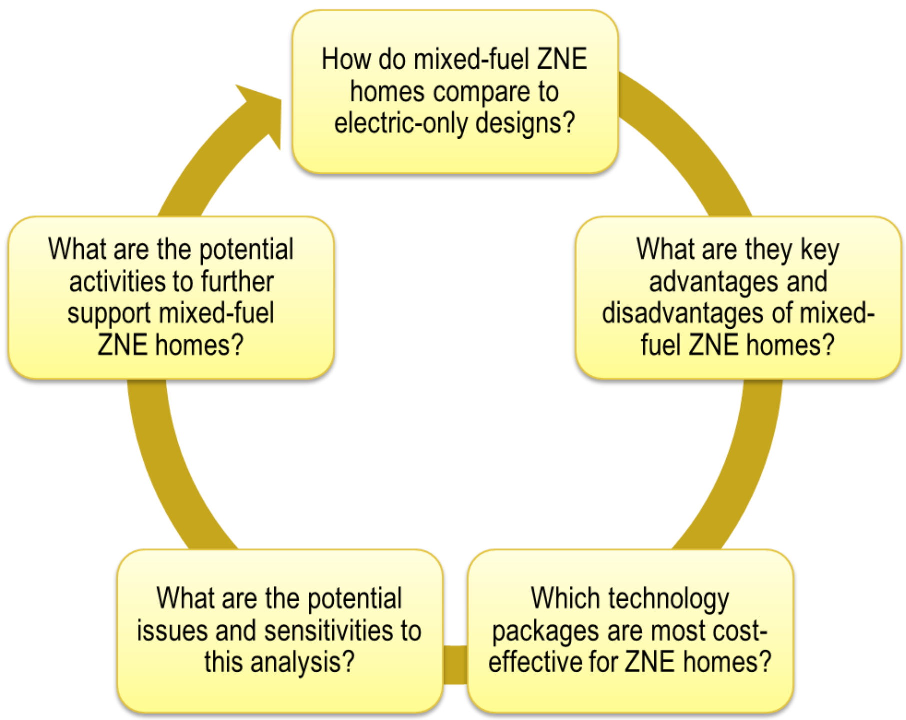



**Figure 65. Key Questions for Mixed-Fuel ZNE Home Analysis in Phase I**

## *8.3 Summary of Key Findings and Results*

Through this building simulation 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. As outlined in Figure 66, both mixed-fuel and electric-only home designs share common characteristics to reaching ZNE goals with similar cost and performance compared to a baseline electric-only home. 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 TRC values. These results suggest SCG and other stakeholders should conduct outreach efforts to communicate the value and benefits of ZNE homes using natural gas appliances to the residential building community.

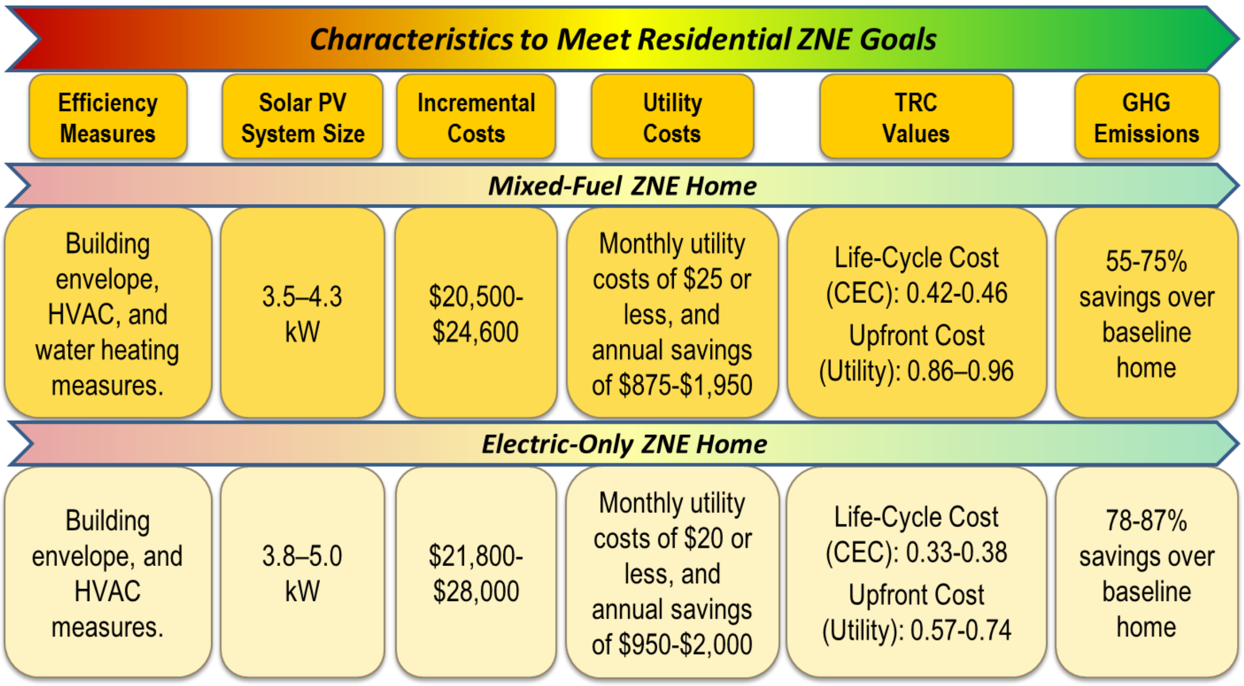



**Figure 66. Common Characteristics to Meet Residential ZNE Goals for Mixed-Fuel and Electric-Only Homes**

### 8.3.1 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. As outlined in Table 77, our analysis revealed that mixed-fuel ZNE homes always lower costs to the homebuilder and homeowner, and have improved TRC results to an all-electric solution. These results are generally consistent across home sizes relevant for single-family new construction, i.e., 1,800-3,200 sq.ft.

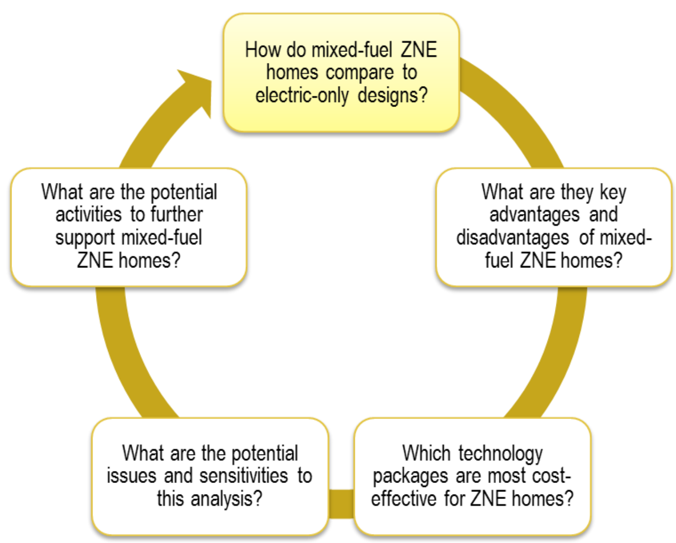


**Table 77. Key Characteristics for Mixed-Fuel and Electric-Only ZNE Homes**

| | Topic | Comments |
|---|---|---|
| Technical | TDV energy consumption | Mixed-fuel ZNE homes almost always have 5-15% lower TDV energy consumption than electric-only designs. |
| | Selection of advanced technologies | 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 of TDV savings. |
| | Required solar PV system sizes and roof areas | • Solar PV sizes range from 3.5-4.3 kW for mixed-fuel and 3.8-5.0 for electric-only ZNE homes.<br>• 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% of the roof space is available for worst-case North-facing orientations. |
| Economic | Incremental costs to reach ZNE goals | Incremental costs 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. |
| | 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. |
| | GHG emission 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 exceeding 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. |

Note – Unless stated, results reflect optimally oriented ZNE homes i.e., North-facing homes with South-facing solar PV systems.

### 8.3.2 What are the 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**

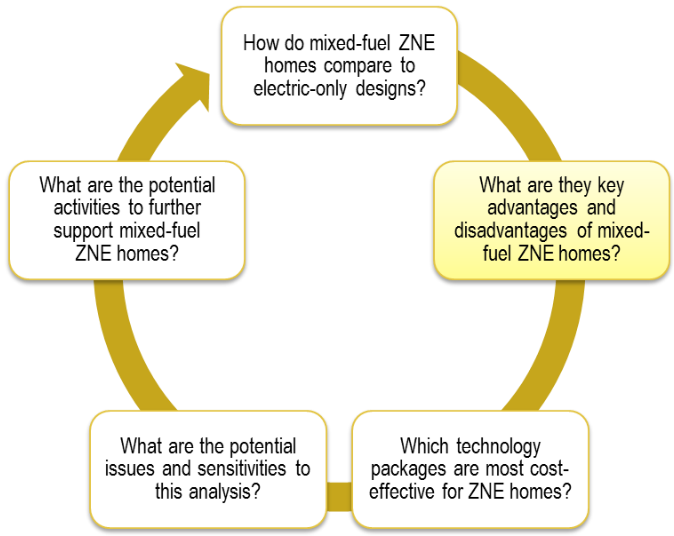


Table 78, most of the key advantages for mixed-fuel homes have significant value for homeowners, homebuilders, and regulators. Beyond technical and economic advantages, several past research studies suggest the market for new homes overwhelmingly prefers natural gas appliances, further increasing the attractiveness for mixed-fuel ZNE homes. These results suggest that SCG and other stakeholders should continue to promote the use of natural gas appliances for ZNE homes among homebuilders and advocate their inclusion and consideration during regulatory and policy proceedings. Highlighting the key advantages in promotional materials will help SCG communicate value and cost-effectiveness of mixed-fuel ZNE homes to the residential building community.

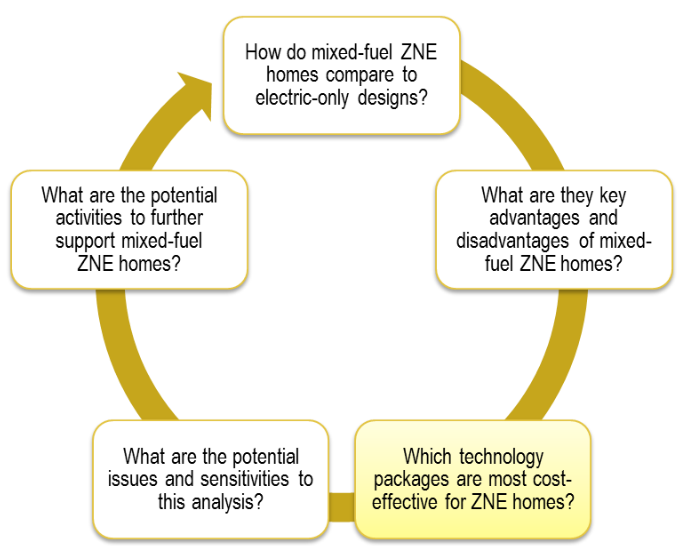
**Table 78. Key Advantages and Disadvantages of Mixed-Fuel and Electric-Only ZNE Homes**

| | Key Differences | Comments | Impacts for Stakeholders | Significant Impact |
|---|---|---|---|---|
| Advantages for Mixed-Fuel ZNE Home | Required solar PV size and roof area | Mixed-fuel ZNE homes require an approximately 0.5 kW smaller solar PV system, requiring less roof space compared to electric-only ZNE homes. | Less required roof space for the solar PV system provides builders flexibility in home design. | ✓ |
| | Incremental cost | With a smaller solar PV system, mixed-fuel homes carry a lower incremental cost (average of $2,200 or 9%) to reach ZNE goals compared to electric-only ZNE homes. | Homebuilders and prospective buyers experience reduced construction and purchase price. | ✓ |
| | Payback | With lower incremental costs and comparable utility savings, mixed-fuel ZNE homes in most regions offer quicker payback by 1-2 years than electric-only ZNE homes when compared to baseline electric-only homes. | When ZNE homes become the new standard, payback will not actually exist because ZNE standards will be the new baseline. | - |
| | TRC values | Mixed-fuel ZNE homes show higher TRC values than electric-only ZNE homes for each location (0.42-0.46 vs. 0.33-0.38) relative to baseline electric-only homes. | Utility program staff can use TRC values to demonstrate cost-effectiveness of mixed-fuel ZNE homes to regulators. | ✓ |

Note – Unless stated, results reflect optimally oriented ZNE homes i.e., North-facing homes with South-facing s PV systems.

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

While stringent Title 24, Title 20, 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 67, 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 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 mCHP and electric battery systems create net positive TDV benefits when the TDV value of their thermal and electricity outputs exceeds their energy inputs. 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 of an incremental cost over other technologies currently. As shown in Table 79, projected cost and performance developments over the next decade may significantly improve the economic attractiveness of these technologies. Fuel cell mCHP systems at small capacities, gas heat pumps, and customer-sited electric batteries could become complementary features to solar PV systems in ZNE homes. Nevertheless, experts project per unit cost of solar PV systems to continue historical reductions, which continues to lower the cost-effectiveness bar for these advanced technologies.

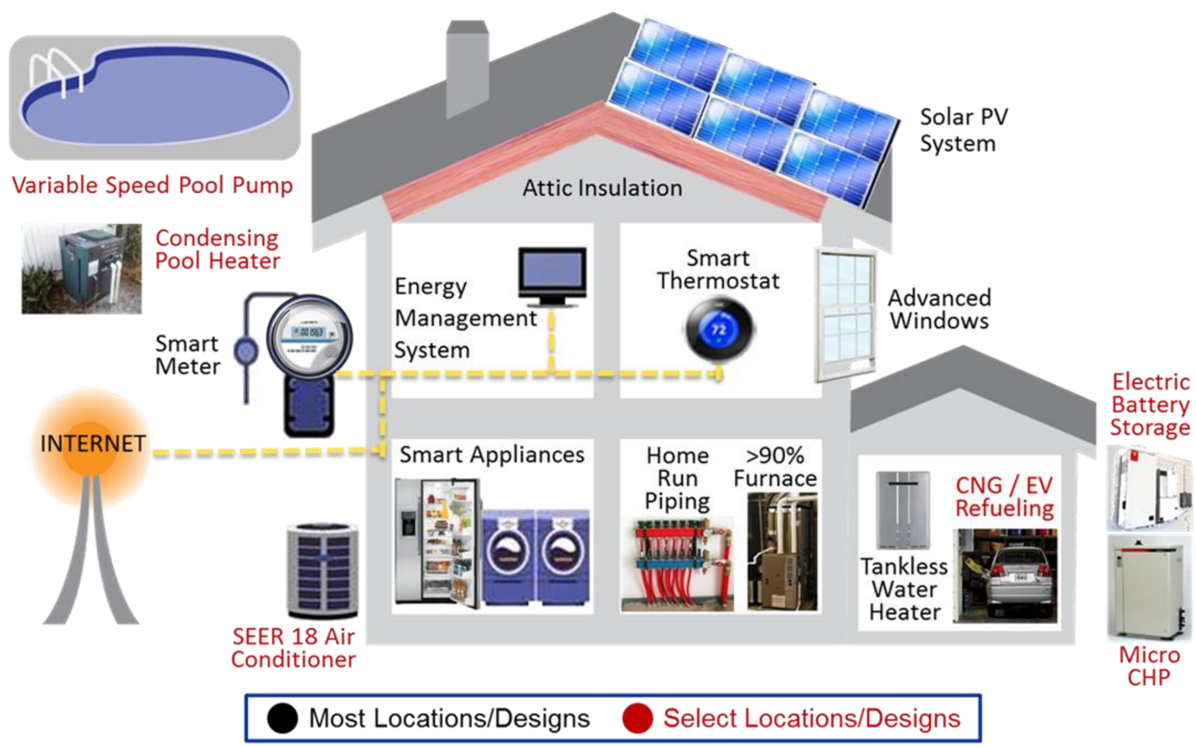


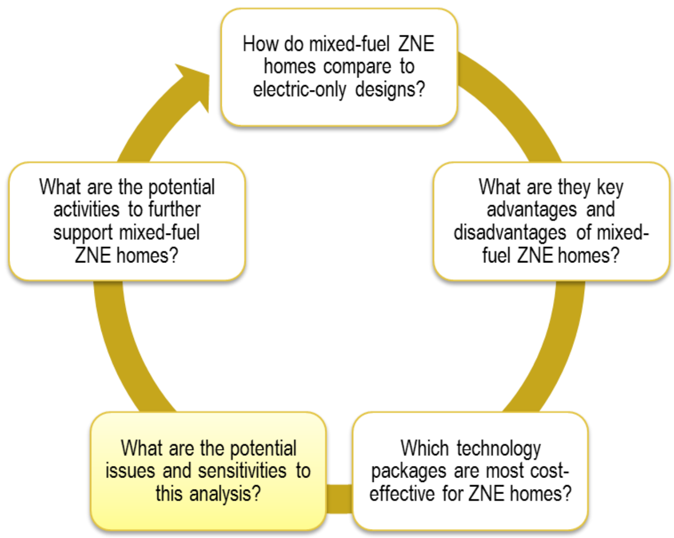

**Figure 67. Building Technologies in Future Mixed-Fuel ZNE Homes**

**Table 79. Potential Impacts of Advanced Technologies for Current and Future ZNE Homes**

| Technology Type | Current Impact | Future Impact | Notes |
|---|---|---|---|
| **Solar PV System** | High | High | • Solar PV systems should continue as the primary technology to achieve ZNE goals, even as incentives decrease over the next several years.<br>• Future improvements in “soft costs” will reduce the cost for solar PV installations, and therefore overall cost for ZNE homes. |
| **Electric Heat Pumps for Space and Water Heating** | High | High | • Current baseline for electric-only homes and projected to reduce costs in upcoming years<br>• Several gas-fired technologies will require further cost reductions to maintain competitiveness with advances in heat pump technology |
| **mCHP** | Low | Medium | • Fuel cell mCHP systems can offset TDV energy consumption with today’s technology, but require cost reductions from $20/W to $10-15/W to compete with solar PV systems.<br>• Most ZNE homes would offset a portion of the solar PV system with a 0.5-1 kW mCHP system to satisfy space and water heating loads. |
| **Gas Heat Pumps** | Low | Medium | • Gas heat pumps in heating-only or reversible operating modes can provide TDV energy savings over conventional gas appliances.<br>• Future cost reductions will improve the economic attractiveness, but manufacturers need to develop products at smaller capacities to suit the smaller thermal loads of California ZNE homes. |
| **Demand Response / Energy Storage** | Medium / Low | Medium / High | • By shifting when a ZNE home consumes grid-supplied electricity, DR or electric battery systems could modestly reduce the home’s TDV energy consumption.<br>• While DR is available today, electric battery systems require cost reductions from $750-600/kWh to $100-300/kWh to compete with solar PV systems. |
| **Alternative Vehicles** | Medium / Low | Medium / High | • If included under future ZNE building codes, the energy consumption associated with EVs and NGVs could have a significant impact on ZNE home design.<br>• The higher TDV energy consumption would require ZNE homes to have a larger solar PV system, potentially creating issues with available roof space. |
| **Solar Thermal** | Medium | Medium | • Solar hot water systems can provide large TDV energy savings and lower in natural gas consumption, but carry too high an incremental cost relative to other options.<br>• Without a major cost breakthrough, solar hot water systems will not provide cost-effective savings for domestic water heating or thermally activated heat pumps. |

### 8.3.4 What are the potential issues and sensitivities to this analysis that SCG and other 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, 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 SCG and other 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 reduce the available roof space, then additional measures are 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 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 may differ.
- **Adjustment in Miscellaneous Load Calculations for Energy Budget**: These findings suggest that miscellaneous electric loads or "plug loads" account for an increasing proportion of overall

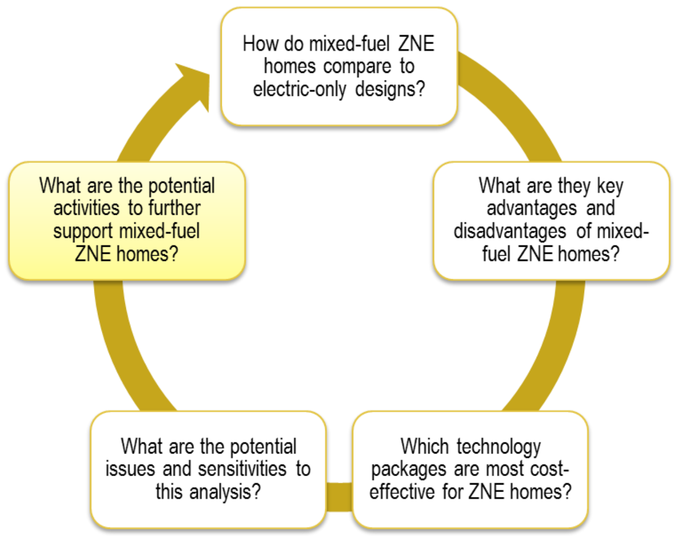
energy consumption. If Title 24 adjusts plug load assumptions, or building codes drive plug load reductions, the required solar PV size and comparison between fuel types will change.

- **Relative Utility Rates, TDV Values, and 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. 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 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.

SCG, CEC, and other 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. As suggested by past research studies, homebuilders will likely continue to  design 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 evidenced by 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.

# 9. Recommended Activities

This section summarizes Navigant's recommended activities identified during this analysis and answers the following key question:




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

Based on our review of the Phase I results, we recommend SCG and other stakeholders consider the following activities to further support the adoption of mixed-fuel ZNE homes.

- **Technology RD&D Activities** support the research, development, and demonstration (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.
- **Policy 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.

## *9.1 Recommended Technology RD&D Activities*

1. ***Support the development of the next generation of gas-fired appliances and technologies for California ZNE homes through RD&D activities.***

   This study found that mixed-fuel ZNE homes using natural gas appliances on the market today had similar or better attractiveness in many characteristics compared to an electric-only home design. Nevertheless, future cost reductions and efficiency improvements for air-source heat pumps, electric heat pump water heaters, solar PV systems, and other electrical technologies could reduce the future attractiveness of mixed-fuel ZNE homes. SCG and other stakeholders should continue to develop the next generation of gas-fired appliances and ensure the technical and economic competitiveness of mixed-fuel home designs in California's ZNE landscape. Through existing collaboration with CEC's Natural Gas R&D program and other research organizations, SCG and other partners can provide financial and technical support for manufacturers to develop, demonstrate, and commercialize their advanced technologies. Table

80 highlights the most important cost thresholds in order to maintain the competitiveness of mixed-fuel ZNE homes with future cost reductions for solar PV and electric heat pump systems.

**Table 80. Gas Technology Cost Threshold Ranges and Attributes – Gas Appliances**

| Gas Technology | Current Cost | Range of Cost Thresholds | | | Performance Attributes and Notes |
|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | |
| Tankless WH | $871 | $1,941-$2,088 | $1,784-$1,910 | $1,648-$1,756 | • Modeled as tankless water heater with EF of 0.82 |
| Tankless Condensing WH | $1,582 | $2,372-$2,674 | $2,153-$2,413 | $1,965-$2,189 | • Modeled as tankless water heater with EF of 0.96 |
| Standard WH + HR | $1,362 | $1,127-$1,189 | $1,076-$1,353 | $760-$1,077 | • Modeled as 50 gallon storage water heater with EF of 0.60 and heat recovery device |
| Solar WH | $7,941 | $4,533-$5,834 | $3,036-$4,895 | $2,205-$4,384 | • Modeled as 40 sq.ft. solar thermal panel and 50 gallon gas-fired storage water heater |
| Condensing WH | $2,091 | $1,860-$2,084 | $1,705-$2,074 | $1,379-$2,050 | • Modeled as 50 gallon storage water heater with EF of 0.80 |
| Gas HPWH | $1,928 | $2,443-$2,814 | $2,205-$2,524 | $1,888-$2,275 | • Modeled as 50 gallon storage water heater with EF of 1.15 |
| Furnace 90% | $539 | $456-$788 | $450-$735 | $370-$690 | • Modeled capacity as 20-25 kBtu/hr with 90% AFUE |
| Furnace 98% | $584 | $476-$1,045 | $468-$956 | $460-$880 | • Modeled capacity as 20-25 kBtu/hr with 98% AFUE |
| Combi Furnace-WH | $2,166 | $2,005-$3,632 | $1,780-$3,294 | $1,587-$3,004 | • Modeled as a tankless condensing water heater with EF of 0.96 and condensing furnace (20-25 kBtu/hr) with 98% AFUE |

2. ***Support the development of fuel cell mCHP systems for California ZNE homes through RD&D activities.***

This study found that fuel cell mCHP can provide TDV energy savings for mixed-fuel ZNE homes but require additional technology development before they become cost-effective relative to other technology options. Over the next decade, these gas-fired technologies should continue to improve and could reach necessary cost-effectiveness thresholds, but will require additional RD&D funding from state and national governments, and other research organizations. SCG and other stakeholders should continue to support the development mCHP technologies with high electrical efficiencies in 0.5-1.0 kW range and evaluate their prospects for ZNE homes in Southern California. If promising, SCG and other stakeholders should support the market expansion of these technologies by conducting field demonstrations in relevant residential environments. Table 81 highlights target cost thresholds for 0.5-1.0 kW mCHP systems at medium and high efficiency categories.

**Table 81. Gas Technology Cost Threshold Ranges and Attributes – mCHP**

| mCHP Technology | Current Cost | Range of Cost Thresholds | | | Performance Attributes and Notes |
|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | |
| Medium Eff. 0.5 kW | $10,000 | $4,688-$5902 | $4,026-$5,068 | $3,457-$4,352 | • Modeled as 0.5 kW fuel cell with 38% electrical and 39% thermal efficiency and includes heat recovery |
| Medium Eff. 1.0 kW | $20,000 | $5,503-$7906 | $4,726-$6,789 | $4,058-$5,830 | • Modeled as 1.0 kW fuel cell with 38% electrical and 39% thermal efficiency and includes heat recovery |
| High Eff. 0.5 kW | $10,000 | $7,542-$7733 | $6,476-$6,641 | $5,562-$5,703 | • Modeled as 0.5 kW fuel cell with 60% electrical and 24% thermal efficiency and includes heat recovery |
| High Eff. 1.0 kW | $20,000 | $13,657-$14,653 | $11,727-$12,583 | $10,071-$10,806 | • Modeled as 1.0 kW fuel cell with 60% electrical and 24% thermal efficiency and includes heat recovery |

3. ***Support the development of gas heat pumps for California ZNE homes through RD&D activities.***

   This study found that gas heat pump systems can provide TDV energy savings for space and water heating in mixed-fuel ZNE homes but require additional technology development before they become cost-effective relative to other technology options. Similar to mCHP systems, gas heat pumps could reach necessary cost-effectiveness thresholds, but will require additional RD&D funding from state and national governments, and other research organizations. SCG and other stakeholders should continue to support the development of gas heat pump technologies for residential applications and evaluate their prospects for ZNE homes in Southern California. If promising, SCG and other stakeholders should support the market expansion of these technologies by conducting field demonstrations in relevant residential environments. Table 82 highlights target cost thresholds for gas heat pumps at a range of efficiency categories and operating modes.

**Table 82. Gas Technology Cost Threshold Ranges and Attributes – Gas Heat Pumps**

| Gas Technology | Current Cost | Range of Cost Thresholds | | | Performance Attributes and Notes |
|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | |
| Engine (Low Eff.) | $3,127 | $3,452-$5,294 | $3,023-$4,721 | $2,655-$4,229 | • Modeled as 25-30 kBtu/hr gas heat pump system with heating COP of 1.2 and cooling COP of 1.1 |
| Engine (High Eff.) | | $4,492-$6,591 | $3,916-$5,835 | $3,421-$5,186 | • Modeled as 25-30 kBtu/hr gas heat pump system with heating COP of 1.5 and cooling COP of 1.2 |
| Absorption Reversible (Low Eff.) | | $3,956-$4,264 | $3,572-$3,827 | $3,234-$3,452 | • Modeled as 25-30 kBtu/hr gas heat pump system with heating COP of 1.3 and cooling COP of 0.6 |
| Absorption Reversible (High Eff.) | | $5,083-$8,031 | $4,423-$7,071 | $3,857-$6,248 | • Modeled as 25-30 kBtu/hr gas heat pump system with heating COP of 2.2 and cooling COP of 1.2 |
| Absorption Heat-Only (Low Eff.) | | $2,453-$7,646 | $2,165-$6,740 | $1,918-$5,964 | • Modeled as 25-30 kBtu/hr gas heat pump system with heating COP of 1.2 |
| Absorption Heat-Only (High Eff.) | | $3,044-$9,065 | $2,673-$7,959 | $2,354-$7,010 | • Modeled as 25-30 kBtu/hr gas heat pump system with heating COP of 1.6 |

4. ***Support the development of lower-cost and higher-efficiency NGV refueling stations.***

   Over the coming decade, alternative vehicles should continue to increase their market share as the cost of vehicles improves and automakers offer an expanded list of models. At this stage, EVs comprise the majority of alternative light-duty vehicles, while compressed NGVs are increasingly popular in the commercial and industrial segments. As more automakers offer CNG vehicles and debut fuel cell models, the in-home refueling system must improve both upfront cost and electrical efficiency to compete with EV offerings. In-home EV chargers have low parasitic energy consumption and have significantly reduced size and cost in recent years, while in-home NGV refueling systems carry a substantial cost premium ($5,500 vs. $600) as well as substantial electricity requirement for the compressor (912 kWh for compressor vs. 840 kWh for EV charger). SCG and other stakeholders should continue to support the development and demonstration of next generation in-home NGV refueling systems through RD&D activities.

## *9.2 Recommended Policy Activities*

1. ***Develop an outreach strategy and materials to educate and support builders and the real estate community on mixed-fuel ZNE homes.***

   The findings of this report suggest that ZNE homes using natural gas appliances have similar or better technical, economic, and market characteristics compared to electric-only ZNE home designs. SCG and other stakeholders should develop educational materials using the findings of this report and conduct outreach forums with partner residential builders, realtors, lenders, and other members of real estate community. These activities can overcome some of the misconceptions about ZNE homes using natural gas appliances for key stakeholders in the homebuying process and foster closer partnerships for future demonstration and deployment of advanced gas technologies.

2. ***Conduct a willingness-to-pay study for mixed-fuel and electric-only ZNE homes.***

   This Phase I Technology Report identified several key technical and economic advantages of mixed-fuel ZNE homes for both the homebuilder and homeowners, but did not investigate the market value of a mixed-fuel ZNE home relative to an electric-only design. Pande et al. (2015) surveyed builders and homeowners about prospective buyers' willingness to pay more and expected resale value for a ZNE home, but did not consider any differences on appliance or fuel type. Pande et al. (2015) and the SCG survey (SCG 2015) identified a strong market preference for natural gas appliances, and greater sales price and resale value may be another key advantage for mixed-fuel ZNE homes to builders and homeowners. SCG and other stakeholders should conduct a willingness-to-pay study focused on mixed-fuel vs. electric-only ZNE homes to determine builder and consumer thoughts on initial and future sales price for a ZNE home with natural gas or electric appliances. This willingness-to-pay study could consider additional aspects other than appliance selection such as roof aesthetics, utility bills, EV and NGV vehicle access, and other considerations between mixed-fuel and electric-only designs.

3. ***Conduct additional research analysis to ensure future building codes provide even consideration with respect to transportation- and pool-related end-use building loads.***

   In addition to standard building loads covered by Title 24, this study examined the impacts of non-Title 24 or exogenous loads on ZNE home energy consumption. While these loads are not included in building codes today, future Title 24 versions may include these loads in a home's energy budget as alternative vehicles gain popularity and ancillary loads contribute an even larger percentage of a home's energy consumption. The ACM manual already provides modeling guidelines for pool heating and pool pumps, and electric utilities have extensive data on in-home EV charging. SCG and other stakeholders should monitor the development of future building codes and whether they include portions of transportation- and/or pool-related building loads. If adopted, the technical and economic characteristics for both mixed-fuel and electric-only ZNE homes would change and potentially alter the relative attractiveness of each home design. If they occur, SCG and other stakeholders should consider the impacts of these potential code additions on both mixed-fuel and electric-only ZNE homes, especially relative to each other. If major differences emerge, SCG and other stakeholders should conduct RD&D activities to improve the cost-effectiveness of affected transportation- and pool-related technologies.

4. ***Support the inclusion of advanced technologies in Title 24 compliance software.***

   Future ZNE homes can use technologies such as on-site energy storage, mCHP, and community-based solar PV systems to offset TDV energy consumption and reach ZNE goals. Because the majority of homebuilders use the custom performance option to show building code compliance through building modeling software, incorporating advanced technologies into the compliance software is critical to their future adoption. SCG and other stakeholders should support the development of equipment modules and other capabilities for advanced technologies within Title 24 compliance software. If possible, these upgrades should begin several years before the technologies enter on the market, to ensure that the compliance software is not a barrier once technologies are ready for mainstream adoption in ZNE homes.

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# Appendix A. Utility Rate Assumptions

Table 83 summarizes the natural gas and electricity rates used for each ZNE home location in the building simulation analysis. Appendices A.1 to A.4 provide details on the tiered and TOU rate schedules throughout each day of the week and month of the year.

**Table 83. Selected ZNE Home Locations and Utility Information**

| Location | Title 24 Climate Zone | Natural Gas Utility & Rate | Electricity Utility & Rate |
|---|---|---|---|
| **Los Angeles** | 6 | SCG (GR) | LADWP (R1B) |
| **Pasadena** | 9 | | SCE (TOU-D-T) |
| **Riverside** | 10 | | SCE (TOU-D-T) |
| **Bakersfield** | 13 | | PG&E (TOU) |
| **Palm Springs** | 15 | | SCE (TOU-D-T) |

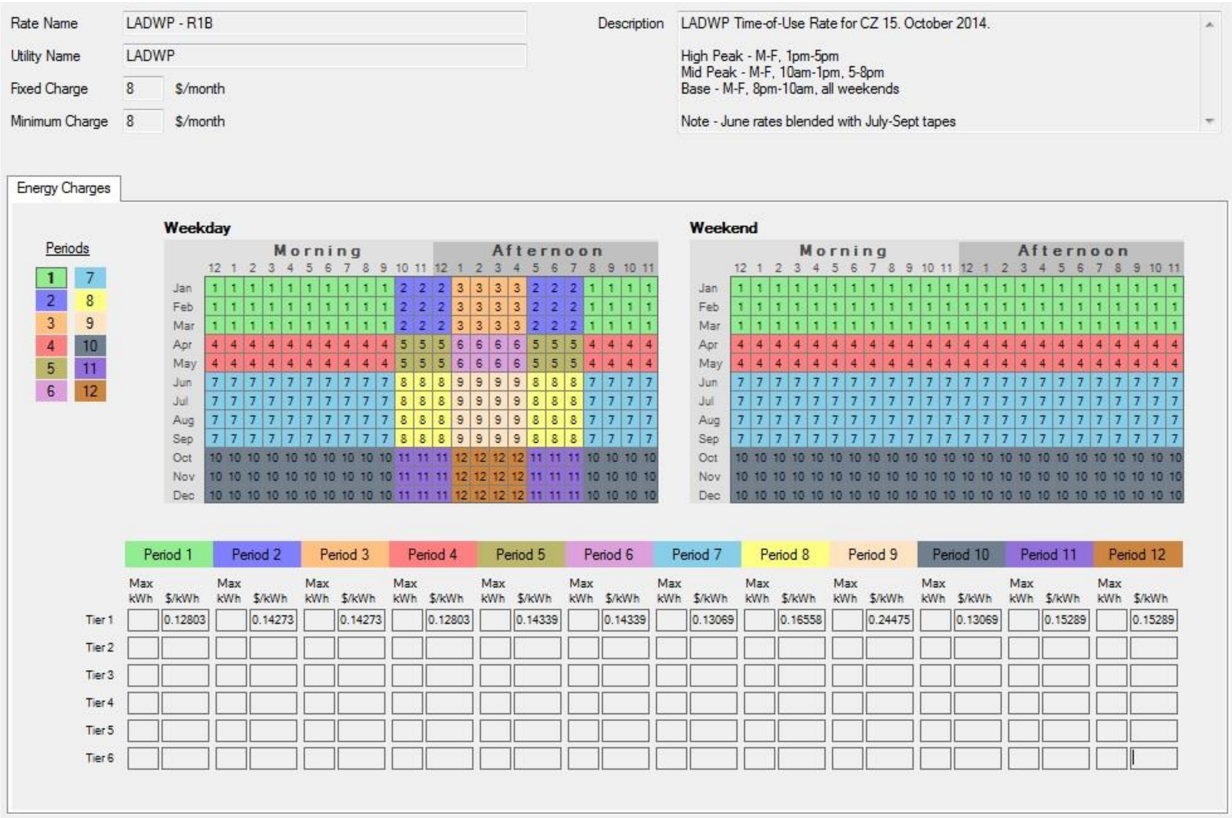
Note – Los Angeles climate zone (CZ 6) uses the LAX weather station, which is a more coastal climate than other parts of Los Angeles. Results for Pasadena or Riverside may better reflect specific portions of the Los Angeles area.

## *A.1 Southern California Gas Company – All Climate Zones*

Rate Schedule – GR
Marginal Rate – $0.89171 per therm
Fixed Charge – $4.93 per month

Note – BEopt does not allow tiered or time-of-use rates for fuels other than electricity.

## A.2 Los Angeles Department of Water & Power – Climate Zone 6



Rate Name: LADWP - R1B

Utility Name: LADWP

Fixed Charge: 8 $/month

Minimum Charge: 8 $/month

Description: LADWP Time-of-Use Rate for CZ 15. October 2014.

High Peak - M-F, 1pm-5pm
Mid Peak - M-F, 10am-1pm, 5-8pm
Base - M-F, 8pm-10am, all weekends

Note - June rates blended with July-Sept tapes

Energy Charges

Periods: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

**Weekday**

| | Morning | | | | | | | | | | | | Afternoon | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| Apr | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 4 | 4 | 4 | 4 |
| May | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 4 | 4 | 4 | 4 |
| Jun | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 |
| Jul | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 |
| Aug | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 |
| Sep | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 |
| Oct | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 10 | 10 |
| Nov | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 10 | 10 |
| Dec | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 10 | 10 |

**Weekend**

| | Morning | | | | | | | | | | | | Afternoon | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Apr | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Jul | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Aug | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Sep | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Oct | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Nov | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Dec | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

| | Period 1 | | Period 2 | | Period 3 | | Period 4 | | Period 5 | | Period 6 | | Period 7 | | Period 8 | | Period 9 | | Period 10 | | Period 11 | | Period 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh |
| Tier 1 | | 0.12803 | | 0.14273 | | 0.14273 | | 0.12803 | | 0.14339 | | 0.14339 | | 0.13069 | | 0.16558 | | 0.24475 | | 0.13069 | | 0.15289 | | 0.15289 |
| Tier 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tier 3 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tier 4 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tier 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tier 6 | | | | | | | | | | | | | | | | | | | | | | | | |

**Figure 68. LADWP Electricity Rate Schedule – Climate Zone 6**

***Net Surplus Compensation Rate*** - $0.0000 per kWh

### A.3 Southern California Edison – Climate Zones 9, 10, 15

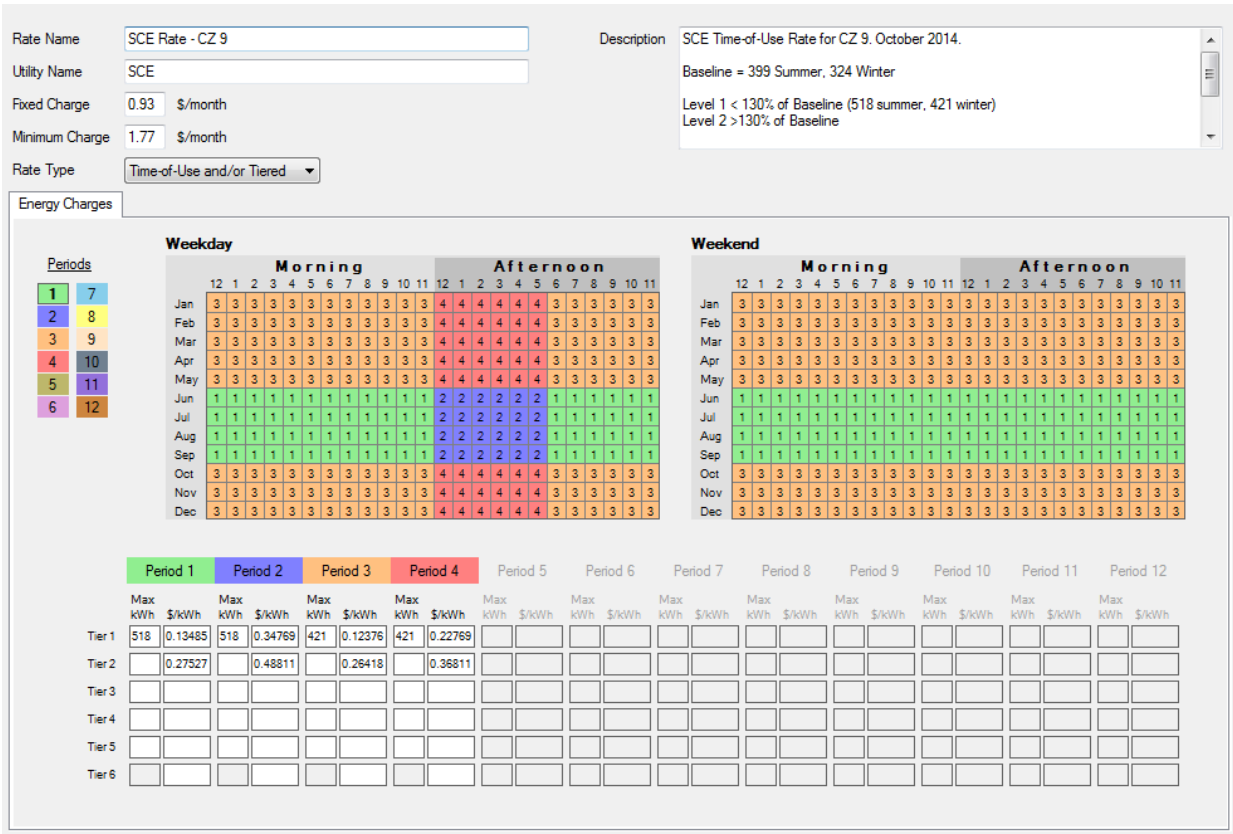



**Figure 69. SCE Electricity Rate Schedule – Climate Zone 9**

***Net Surplus Compensation Rate*** - $0.0470 per kWh

Based on 12 month average from June 2014 to May 2015

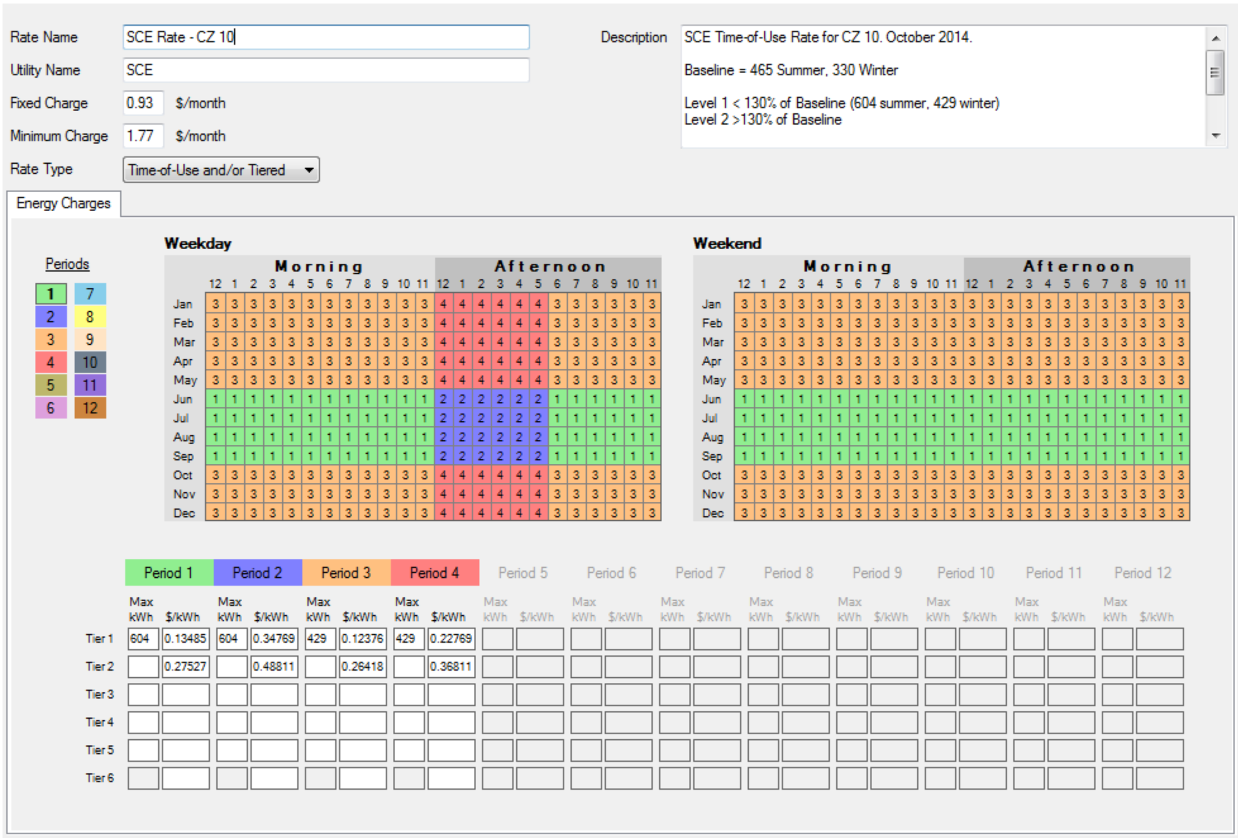



Figure 70. SCE Electricity Rate Schedule – Climate Zone 10

***Net Surplus Compensation Rate*** - $0.0470 per kWh

Based on 12 month average from June 2014 to May 2015

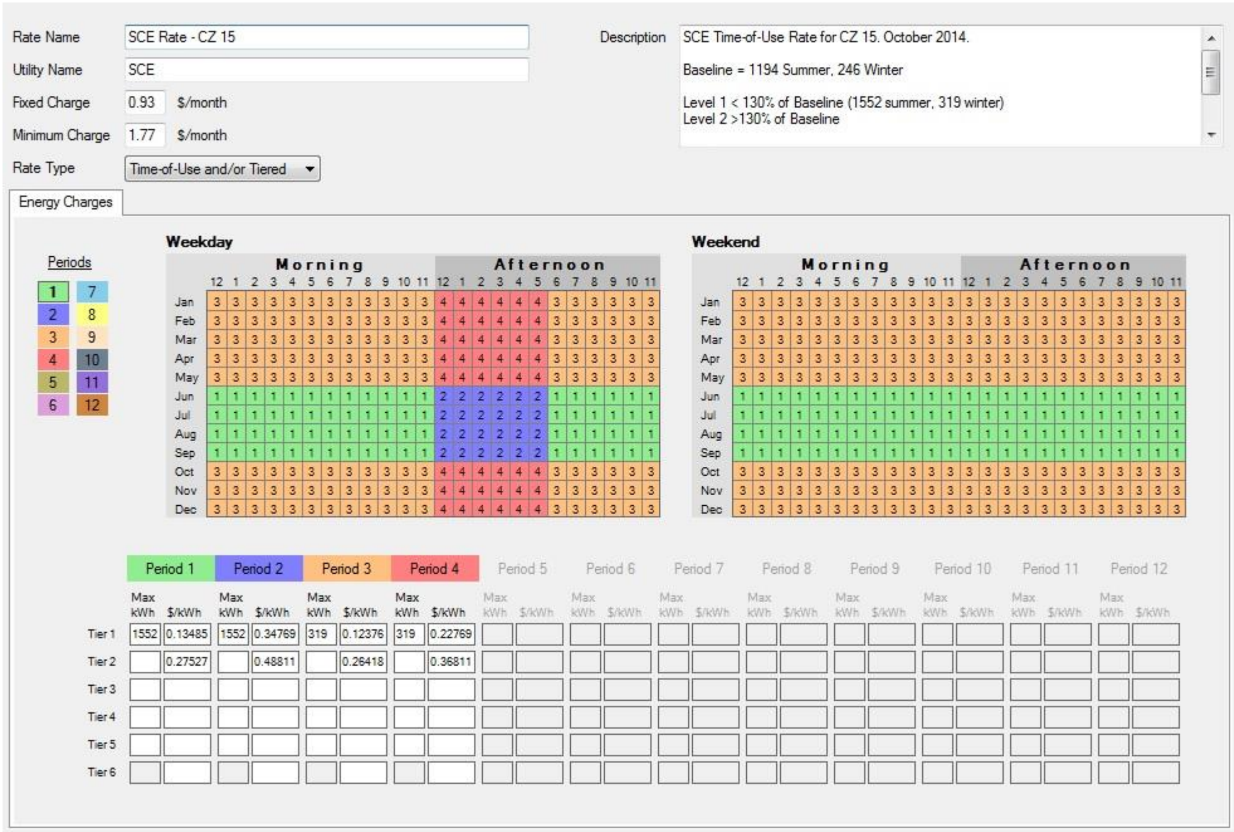
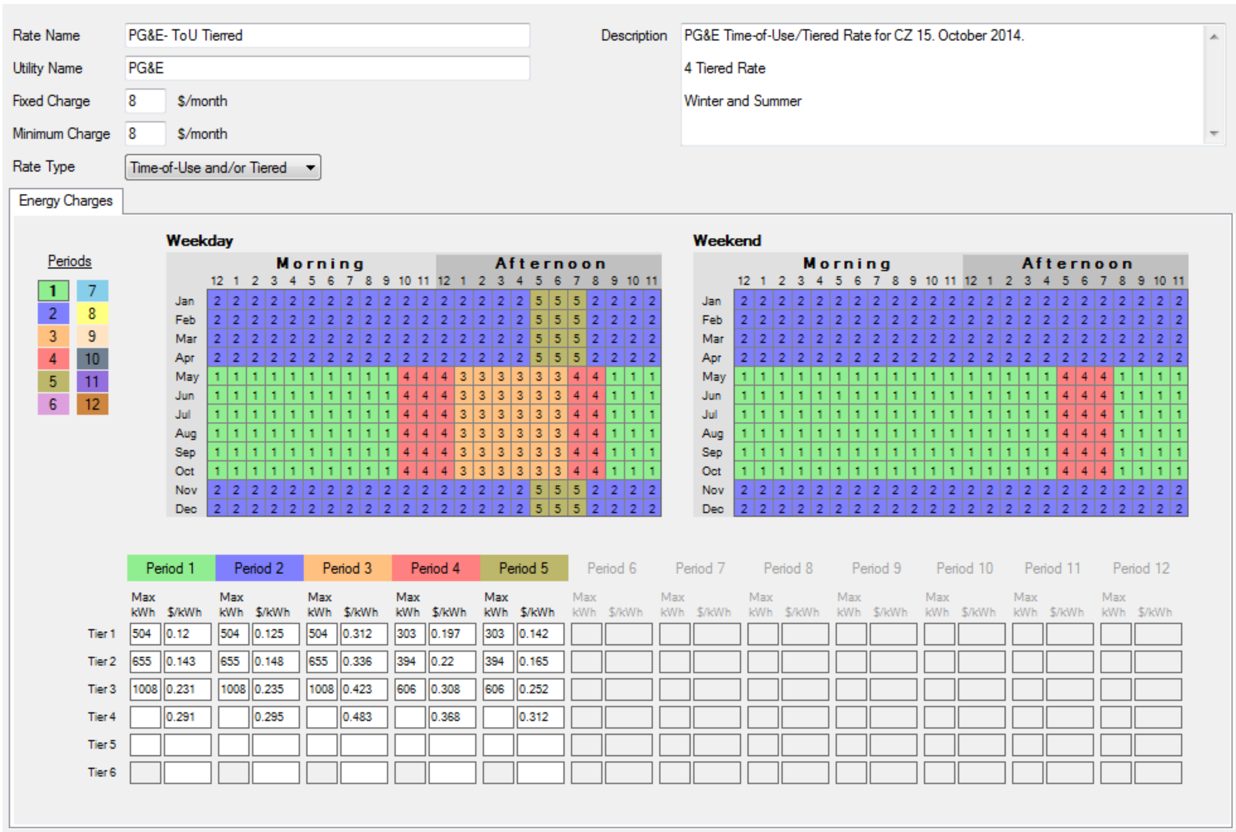



**Figure 71. SCE Electricity Rate Schedule – Climate Zone 15**

***Net Surplus Compensation Rate*** - $0.0470 per kWh

Based on 12 month average from June 2014 to May 2015

## *A.4 Pacific Gas & Electric Company – Climate Zone 13*



Rate Name: PG&E- ToU Tiered
Utility Name: PG&E
Fixed Charge: 8 $/month
Minimum Charge: 8 $/month
Rate Type: Time-of-Use and/or Tiered
Description: PG&E Time-of-Use/Tiered Rate for CZ 15. October 2014.
4 Tiered Rate
Winter and Summer

Energy Charges

Periods: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

**Weekday**

| | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Morning | | | | | | | | | | | | Afternoon | | | | | | | | | | | |
| Jan | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 5 | 5 | 2 | 2 | 2 | 2 |
| Feb | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 5 | 5 | 2 | 2 | 2 | 2 |
| Mar | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 5 | 5 | 2 | 2 | 2 | 2 |
| Apr | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 5 | 5 | 2 | 2 | 2 | 2 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 1 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 1 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 1 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 1 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 1 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 1 |
| Nov | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 5 | 5 | 2 | 2 | 2 | 2 |
| Dec | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 5 | 5 | 2 | 2 | 2 | 2 |

**Weekend**

| | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Morning | | | | | | | | | | | | Afternoon | | | | | | | | | | | |
| Jan | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Feb | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Mar | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Apr | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 1 | 1 | 1 | 1 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 1 | 1 | 1 | 1 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 1 | 1 | 1 | 1 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 1 | 1 | 1 | 1 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 1 | 1 | 1 | 1 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 1 | 1 | 1 | 1 |
| Nov | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Dec | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

| | Period 1 | | Period 2 | | Period 3 | | Period 4 | | Period 5 | | Period 6 | | Period 7 | | Period 8 | | Period 9 | | Period 10 | | Period 11 | | Period 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh | Max kWh | $/kWh |
| Tier 1 | 504 | 0.12 | 504 | 0.125 | 504 | 0.312 | 303 | 0.197 | 303 | 0.142 | | | | | | | | | | | | | | |
| Tier 2 | 655 | 0.143 | 655 | 0.148 | 655 | 0.336 | 394 | 0.22 | 394 | 0.165 | | | | | | | | | | | | | | |
| Tier 3 | 1008 | 0.231 | 1008 | 0.235 | 1008 | 0.423 | 606 | 0.308 | 606 | 0.252 | | | | | | | | | | | | | | |
| Tier 4 | | 0.291 | | 0.295 | | 0.483 | | 0.368 | | 0.312 | | | | | | | | | | | | | | |
| Tier 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tier 6 | | | | | | | | | | | | | | | | | | | | | | | | |

**Figure 72. PG&E Electricity Rate Schedule – Climate Zone 13**

***Net Surplus Compensation Rate*** - $0.0475 per kWh

Based on 12 month average from June 2014 to May 2015

# Appendix B. Key Differences between CBECC-Res and BEopt

Table 84 summarizes the key differences between the Title 24 Alternative Calculation Method (ACM) software CBECC-Res 2013 (v3)[73] and BEopt (v2.2.0.1)[74].

**Table 84. Key Differences between Modeling Tools**

| Option/Schedule | CBECC-Res | BEopt | Adjusted Y/N |
|---|---|---|---|
| **Occupancy** | 1.75 + 0.4 x NBR | 0.87 + 0.59 x NBR | N |
| **Heating Set Point** | 65°F setback schedule | 71°F | Y |
| **Cooling Set Point** | 78°F setback schedule | 76°F | Y |
| **Miscellaneous Electric Loads** | 723 + 0.706 × CFA | 1185.4 + 180.2 x NBR + 0.32 x CFA | Y |
| **Vacations** | n/a | May 26–28, Aug.12–18, Dec. 22–25 | Y |
| **Mechanical Ventilation** | Airflow (CFM) = 0.01 x CFA + 7.5 x (NBR + 1) | | Y |
| **Refrigerator** | 699 kWh/yr. | 343 kWh/yr. | Y |
| **Cooking Range** | Electric – 92 + 0.118 × CFA<br>Gas – (31+ 0.008 × CFA) × 0.43 | Electric – 250 + 83 x NBR<br>Gas – Annual Consumption | Y |
| **Dishwasher** | 0.27 x Annual Cycles/EF | 87.6 + 29.2 x NBR | Y |
| **Clothes Washer** | −64 + 0.108 × CFA | 38.8 + 12.9 x NBR | Y |
| **Clothes Dryer** | Electric – 263 + 0.254 × CFA<br>Gas – 13 + 0.010 × CFA | Electric – 538.2 + 179.4 x NBR<br>Gas – Annual Consumption | Y |
| **Appliance Schedules** | Separate hourly operating schedules, but can be adjusted | | Y |
| **Lighting** | Separate equations built up on efficacy and operating time | | Y |
| **Domestic Hot Water Draw Profile** | Separate hourly operating schedules and equations | | N |
| **Mains Water Temperature** | Separate equations based on weather conditions | | N |
| **Internal Heat Gains** | Separate equations based on occupancy, appliance, hot water assumptions | | N |
| **Non-Title 24 Loads** | User customized annual consumption and operating schedule | | Y |

CFA – Conditioned Floor Area
NBR – Number of Bedrooms

[73] CBECC-Res 2013 assumptions are based on the following resources: California Title 24-2013 Alternative Compliance Methodology (ACM) manual, California Title 24-2013 Compliance Manual, 2008 California Home Energy Rating System (HERS) Technical Manual.
[74] BEopt assumptions are based on 2014 Building America House Simulation Protocols[31]

# Appendix C. Simulation Inputs

To provide full coverage of different home consumption characteristics, advanced technology choices, etc., Navigant proposes four ZNE optimization ZNE scenarios using the technologies listed in Table 85:

- Mixed-fuel and electric-only homes with mCHP and solar PV.
- Mixed-fuel and electric-only homes with solar thermal, solar PV, mCHP, absorption chiller, and other advanced technologies, where applicable.
- Mixed-fuel and electric-only homes with non-Title 24 "exogenous" loads meeting and exceeding ZNE status.
- Mixed-fuel and electric-only homes with DR capabilities.

Because each BEopt optimization output contains >10,000 individual parametric simulations, these four provided data to analyze other specific combinations deemed valuable by SCG technical and program staff. For configurations not covered in these four scenarios, we conducted additional parametric simulations as needed.

**Table 85. Library of Standard and High Efficiency Building Features**

| Category | Metric | Baseline (* denotes new standard) | Advanced Options |
|---|---|---|---|
| **General Operation** | Heating Set Point | 65°F setback schedule | ±3°F deeper setback schedule |
| | Cooling Set Point | 78°F setback schedule | ±3°F deeper setback schedule |
| | Interior Shading | 0.5 effectiveness | n/a |
| **Walls** | Wood Stud | 2x6, R-21* | R-23, R-36 |
| | Note – other wall materials available, such as: double studs, concrete, masonry, composite panels, etc. | | |
| | Wall Sheathing | R-5 | R-10, R-15 |
| | Interzonal Walls | 2x4, R-13 | n/a |
| **Ceiling/Roofs** | Unfinished Attic | R-38* | R-44, R-49, R-60 |
| | Radiant Barrier | Yes | n/a |
| **Foundation/Floors** | Carpet | 80% carpet, 20% exposed | n/a |
| | Interzonal Floor | R-19 | R-30, R-38 |
| | Slab | n/a | n/a |
| **Thermal Mass** | Floor Mass | Wood | n/a |
| | Exterior Wall Mass | 1/2" drywall on framed | n/a |
| | Partition Wall Mass | 1/2" drywall on framed | n/a |
| | Ceiling Mass | 1/2" drywall on framed | n/a |
| **Windows & Doors** | Window Areas | 20% exterior coverage, 5% on all sides | n/a |
| | Windows | Double pane (U-0.32, SHGC-0.25) | Triple pane non-metal frame (U-0.27, SHGC-0.25), Triple pane insulated (U-0.17, SHGC-0.25) |
| **Airflow** | Air Leakage | 5 ACH 50 | n/a |
| | Mechanical Ventilation | Standalone exhaust | HRV 70%, ERV 72% |
| **Space Conditioning** | Central Air Conditioner | 14 SEER* | 16 SEER, 18 SEER, 21 SEER, 24.5 SEER |
| | Furnace | Gas 80% AFUE | Gas 90%, gas 98%, condensing gas hydronic |
| | Boiler | Gas 80% AFUE | Condensing boiler 90%, gas heat pump 1.2 COP, solar thermal heating, solar thermal cooling |
| | Air-Source Heat Pump | 14 SEER (8.2 HSPF)* | 16 SEER (8.6 HSPF), 18 SEER (9.3 HSPF), 22 SEER (10 HSPF) |
| | Mini-Split Heat Pump | n/a | n/a |
| | Ground-Source Heat Pump | 13.4 EER cooling, 3.1 COP heating | 20.2 EER cooling, 4.2 COP heating |
| | Ducts | R-8 insulation, 5% leakage* | n/a |

| Category | Metric | Baseline (* denotes new standard) | Advanced Options |
|---|---|---|---|
| Water Heating | Gas Water Heater | Gas storage (50gal) 0.60 EF | Gas storage (50gal) 0.60 EF w/ solar water heater, gas tankless* gas tankless condensing EF 0.96, gas HPWH 1.15 EF |
| | Electric Water Heater | Electric storage (50gal) 0.9 EF w/ solar water heater | Electric tankless w/ solar water heater 0.99 EF, electric HPWH 2.2 EF |
| | Combined Space and Water Heating | n/a | Modeled as condensing tankless water heater 0.96 EF and condensing furnace 98% AFUE |
| | Shower Drain Heat Recovery | n/a | Improved EF for storage water heater options |
| | Distribution | R-2, Trunk Branch, PEX | R-2, Home Run, PEX |
| | Solar Water Heating | n/a | 40 sq.ft., 60 sq.ft. |
| | SWH Azimuth | n/a | South facing roof |
| | SWH Tilt | n/a | Optimal |
| Lighting | Lighting | High-Efficacy Lighting* | n/a |
| Major Appliances | Refrigerator | kWh/yr. @ 19.6 EF * | ENERGY STAR (10% Less) |
| | Gas Cooking Range | Baseline | Advanced |
| | Electric Cooking Range | Baseline | Advanced |
| | Dishwasher | 305 kWh/yr., 5.0 gal/cycle* | 297 kWh/yr., 4.5 gal/cycle |
| | Clothes Washer | 1.57 MEF, 6.5 WF* | >2 MEF, < 6WF |
| | Clothes Dryer | Gas 3.3 EF, Elec 3.73 EF* | Gas 3.48 EF, Elec 3.93 EF |
| | Appliance Schedules | CBECC baseline | DR schedule |
| Miscellaneous | Pool Heater[75] | 82% AFUE | Gas condensing, HPWH, solar thermal |
| | Pool Pump[75] | Baseline | n/a |
| | Other Electric Loads | Baseline | n/a |
| | Other Hot Water Loads | Baseline | n/a |
| | Other Gas Loads | Baseline | n/a |
| | Transportation[75] | n/a | NGV, EV |
| | Miscellaneous Schedules | CBECC baseline | DR schedule |
| On-Site Generation | PV System | 0-15 kW | n/a |
| | PV Azimuth | South facing roof | North, East, West |
| | PV Tilt | Optimal | n/a |
| | mCHP System | n/a | Fuel cell, engine-driven, others |

[75] Exogenous or non-Title 24 building loads only included in select modeling scenarios

# Appendix D. Transportation Loads and Operating Schedules

## D.1 Electric Vehicle Energy Consumption

- EV annual consumption estimated at 5,100 kWh/yr. assuming 34 kWh/100 miles and 15,000 miles/year[76].

$$EV\ Consumption\ \left(\frac{kWh}{Yr}\right) = EV\ Consumption\ Rate\ \left(\frac{kWh}{100\ Miles}\right)x\ Annual\ Miles\ Driven\ \left(\frac{Miles}{Yr}\right)$$

- Home charging station efficiency estimated at 86.5%[77] with standby power at < 5%[78] for a total EV consumption of 5,940 kWh/yr.

$$Total\ EV\ Consumption\ \left(\frac{kWh}{Yr}\right) = \frac{EV\ Consumption\left(\frac{kWh}{Yr}\right)}{Charging\ Station\ Efficiency\ \%} + \frac{5\ (W)\ x\ 8{,}760\ \frac{Hrs}{Yr}}{1{,}000\ \left(\frac{Wh}{kWh}\right)}$$

## D.2 Natural Gas Vehicle Energy Consumption

- NGV annual consumption estimated at 577 therms/year assuming 3.2 gasoline gallons equivalent (GGE)/100 miles, 10 therms per 8.32 GGE and 15,000 miles/year[79].

$$NGV\ Gas\ Consumption\ \left(\frac{GGE}{Yr}\right) = NGV\ Consumption\ Rate\left(\frac{GGE}{100\ Miles}\right)x\ Annual\ Miles\ Driven\ \left(\frac{Miles}{Yr}\right)$$

$$NGV\ Gas\ Consumption\ \left(\frac{Therms}{Yr}\right) = NGV\ Gas\ Consumption\ \left(\frac{GGE}{Yr}\right)x\ \frac{10\ Therms}{8.32\ GGE}$$

- Home refueling station electrical consumption estimated at 912 kWh/year assuming 1.9 kWh/GGE for 480 GGE/year[80].

$$NGV\ Electricity\ Consumption\left(\frac{kWh}{Yr}\right) = NGV\ \ Gas\ Consumption\ \left(\frac{GGE}{Yr}\right)\ x\ Refueling\ Electricity\ Rate\left(\frac{2.5\ kWh}{GGE}\right)$$

[76] Estimate based on Nissan Leaf, Chevrolet Volt, and Tesla S from www.fueleconomy.gov. Accessed October 2014.
[77] Forward et al. 2013. "An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency." Efficiency Vermont. March 20, 2013.
[78] Estimate based on BlinkHQ. www.blinkhw.com . Accessed October 2014.
[79] Estimate based on Honda Civic NG from www.fueleconomy.gov. Accessed October 2014.
[80] Estimate based on Phill Refueling System. http://www.wisegasinc.com/wg-phill.htm. Accessed February 2015.

### D.3 Transportation Charging and Refueling Schedule

To understand how advanced transportation vehicles would impact ZNE home energy consumption on a TDV basis, Navigant estimated in-home charging and refueling schedules for the estimated annual consumption values. We developed these schedules using field data gathered for EVs in Los Angeles as part of *The EV Project*.[81] Without specific data for the refueling schedule of light-duty NGVs, we assumed NGVs would follow a similar overnight refueling schedule. Figure 73 and Table 86 provide the hourly load profile for advanced transportation charging/refueling, normalized to the peak weekly load). In the future, these operating schedules may differ as public charging and refueling infrastructure increases (e.g., EV charging stations in public parking lots, NGV refueling at conventional service stations).

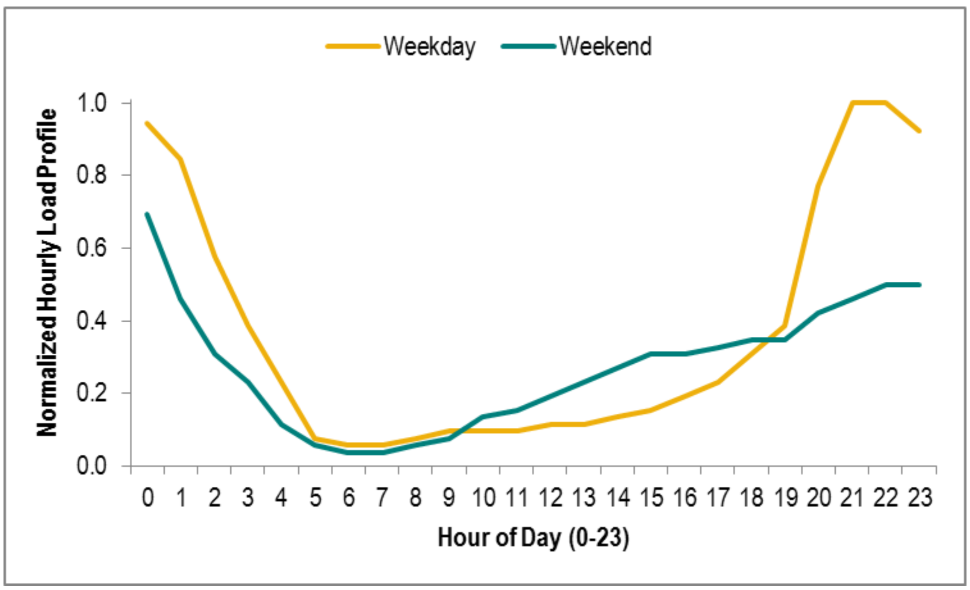



**Figure 73. Hourly Load Profile for In-Home Charging and Refueling Systems**

[81] Schey, Stephen. 2013. "Quarter 2, 2013 Quarterly Report." The EV Project. August 5, 2013. Available at: http://www.theevproject.com/cms-assets/documents/127233-901153.q2-2013-rpt.pdf

**Table 86. Advanced Vehicle Charging/Refueling Schedule**

| Hour of Day | Hourly Load Profile (Normalized to Peak Weekly Load) | |
|---|---|---|
| | Weekday | Weekend |
| 0 | 0.94 | 0.69 |
| 1 | 0.85 | 0.46 |
| 2 | 0.58 | 0.31 |
| 3 | 0.38 | 0.23 |
| 4 | 0.23 | 0.12 |
| 5 | 0.08 | 0.06 |
| 6 | 0.06 | 0.04 |
| 7 | 0.06 | 0.04 |
| 8 | 0.08 | 0.06 |
| 9 | 0.10 | 0.08 |
| 10 | 0.10 | 0.13 |
| 11 | 0.10 | 0.15 |
| 12 | 0.12 | 0.19 |
| 13 | 0.12 | 0.23 |
| 14 | 0.13 | 0.27 |
| 15 | 0.15 | 0.31 |
| 16 | 0.19 | 0.31 |
| 17 | 0.23 | 0.33 |
| 18 | 0.31 | 0.35 |
| 19 | 0.38 | 0.35 |
| 20 | 0.77 | 0.42 |
| 21 | 1.00 | 0.46 |
| 22 | 1.00 | 0.50 |
| 23 | 0.92 | 0.50 |

# Appendix E. Advanced Gas Technologies

This section outlines the performance and cost assumptions for advanced gas technologies, including:

- Fuel Cell mCHP Systems
- Engine-Based mCHP Systems
- Gas Heat Pumps

## *E.1 Assumptions and Product Data for mCHP Systems*

Table 87 outlines the performance and cost assumptions for engine-based and fuel cell mCHP systems based on data for available fuel cell mCHP (Table 88) and engine-based mCHP (Table 89) systems.

**Table 87. Performance and Cost Assumptions for mCHP Systems Including Waste-Heat Recovery**

| Category | Metric | Performance (Efficiency %) | | | | Technology Cost ($/$W_e$) | | |
|---|---|---|---|---|---|---|---|---|
| | | Output | Low | Medium | High | Low | Medium | High |
| **Micro-CHP Systems** | Gas Engine mCHP | Electrical | 4% | 22% | 25% | $5 | $15 | $20 |
| | | Thermal | 85% | 54% | 68% | | | |
| | Fuel Cell mCHP | Electrical | 30% | 38% | 60% | $10 | $15 | $20 |
| | | Thermal | 65% | 39% | 24% | | | |

Note – Thermal efficiency assumes waste-heat recovery. Costs estimates based on review of available cost data (Table 88) and Staffell and Green. 2012. "The Cost of Domestic Fuel Cell Micro-CHP Systems." July 2012. Available at: https://spiral.imperial.ac.uk/bitstream/10044/1/9844/6/Green%202012-08.pdf

**Table 88. Performance and Cost Data for Fuel Cell mCHP Systems**

| Efficiency Category | Manufacturer | Model | Electrical Capacity (kW) | Electrical Efficiency (HHV) | Thermal Efficiency (HHV) | Estimated Cost ($/W) | Source |
|---|---|---|---|---|---|---|---|
| **Low** | Toshiba-Baxi | Gamma | 1.0 | 32% | 53% | $12 | 1 |
| | Hexis | Galileo | 1.0 | 30% | 65% | $4 | 2 |
| | Elcore | 2400 | 0.3 | 30% | 60% | $40 | 3 |
| **Medium** | Viessman/Panasonic | Vitovalor | 0.75 | 37% | 49% | $39 | 4 |
| | Panasonic | ENE-FARM | 0.7-1.0 | 38% | 49% | $20 | 5 |
| | ClearEdge | CE5 | 5 | 35% | 40% | $10 | 6 |
| | Acumentrics | RP1500 | 1.5 | 34% | n/a | $20 | 7 |
| **High** | CFCL | Bluegen | 1.5 | 60% | 24% | $15 | 3 |

### *Data Sources*


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**Table 89. Performance and Cost Data for Engine mCHP Systems**

| Efficiency Category | Manufacturer | Model | Electrical Capacity (kW) | Electrical Efficiency (HHV) | Thermal Efficiency (HHV) | Estimated Cost ($/W) | Source |
|---|---|---|---|---|---|---|---|
| Low | Baxi | Ecogen | 1.0 | 4% | 85% | $12 | 1 |
| | WhisperGen | WhisperTech | 1.0 | 12% | 66% | n/a | 2 |
| | Viessmann | Vitotwin 350-F | 1.0 | 16% | 81% | $18 | 3 |
| Medium | Qnergy | QCHP7500 | 7.5 | 20% | 75% | n/a | 4 |
| | Senertec | Dachs | 5.5 | 24% | 55% | $5 | 5 |
| | Climate Energy | Freewatt | 1.2 | 22% | 54% | $21 | 6 |
| | Mararathon | EcoPower | 2.0 | 25% | 68% | $15-20 | 7 |
| High | Yanmar/ENER-G | 4y | 3.9 | 27% | 58% | n/a | 8 |
| | Yanmar | CP10WN | 10.0 | 32% | 54% | $4-5 | 9 |
| | Yanmar | CP5WN | 5.0 | 28% | 56% | $5.6-6.5 | 9 |
| | M-Co-Gen | Poweraire | 6.0 | 24% | 61% | $2 | 10 |
| | EC Power | XRGI 6 | 2.5 | 30% | 64% | $6 | 11 |
| | Vaillant | Ecopower | 1.0 | 26% | 65% | $20 | 12 |

### *Data Sources*


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## *E.2 Assumptions and Product Data for Gas Heat Pumps Systems*

Table 90 outlines the performance and cost assumptions for gas heat pump systems based on product data for available technologies (Table 91).

**Table 90. Performance and Cost Assumptions for Gas Heat Pumps**

| Category | Metric | Performance (Heating / Cooling COP) | | | | | | Incremental Cost ($/kBtu-hr)* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | | Medium | | High | | Low | Medium | High |
| | | Heating | Cooling | Heating | Cooling | Heating | Cooling | | | |
| Gas-Fired Heat Pumps | Engine-Based | 1.2 | 1.1 | 1.5 | 1.2 | n/a | n/a | $56 | $67 | $78 |
| | Both Heating & Cooling | 1.3 | 0.6 | 1.6 | 0.8 | 2.2 | 1.2 | | | |
| | Heating Only | 1.2 | – | 1.4 | – | 1.6 | – | | | |
| | Cooling Only | – | 0.6 | – | 0.7 | – | 0.8 | | | |

* Summarized in Goetzler et al. 2014. "Research & Development Roadmap for Emerging HVAC Technologies." U.S. Department of Energy, Building Technologies Office. October 2014.

**Table 91. Performance and Cost Data for Gas Heat Pump Systems**

| Thermal Outputs | Heat Pump Type | Efficiency Category | Manufacturer | Model | Heating Capacity (kBtu/hr) | Heating COP | Cooling Capacity (tons) | Cooling COP | Source |
|---|---|---|---|---|---|---|---|---|---|
| Both Heating & Cooling | Vulleumier | Medium-High | ThermoLift | n/a | 60 | 1.6-2.2 | 3 | 0.8-1.2 | 1 |
| | Engine-Based | Medium | NextAire | n/a | 72 | 1.5 | 4 | 1.2 | 2 |
| | | Low | Yamar | n/a | 72 | 1.2 | 4 | 1.1 | 3 |
| | Absorption | Low | Robur | RTAR 180/360 | 241 | 1.3 | 9.5 | 0.6 | 4 |
| Heating Only | Absorption | High | Buderus | GWPL 38 | 140 | 1.5-1.6 | n/a | n/a | 5 |
| | | Medium | FireChill | AHP40 | 135 | 1.5 | n/a | n/a | 6 |
| | | Medium | Fulton | IVS-095-A | 140 | 1.5 | n/a | n/a | 7 |
| | | Medium | Robur | GAHP-A | 124 | 1.3 | n/a | n/a | 8 |
| | | Medium | Vicot | VGAH136 | 136 | 1.5 | n/a | n/a | 9 |
| | Adsorption | Medium | Viessman | Vitosorp 200F | 34 | 1.3-1.4 | n/a | n/a | 10 |
| | | Low | Vaillant | Zeotherm vas | 34 | 1.1-1.2 | n/a | n/a | 11 |
| Cooling Only | Absorption | High | Vicot | VGAC066 | n/a | n/a | 5 | 0.8 | 12 |
| | | Medium | FireChill | ALT500 | n/a | n/a | 5 | 0.7 | 13 |
| | Adsorption | Medium | SorTech | Ecoo S-10 | n/a | n/a | 3 | 0.7 | 14 |
| | | Medium | Invensor | LTC 10 | n/a | n/a | 3 | 0.7 | 15 |

Note - Assumes 0.023 kW electric per KW thermal consumption for heating and 0.046 kW electric per KW thermal consumption for cooling.

### *Data Sources*


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## Appendix F. Mortgage Analysis Assumptions

Table 92 outlines the sample mortgage amortization table from Wells Fargo[82] for annual principal and interest payments assuming 4.12% APR and a 30 year mortgage.

**Table 92. Sample Mortgage Amortization Table**

| Year | Per 1,000, 4.12% rate | | | Normalized | | |
|---|---|---|---|---|---|---|
| | Payment | Principal | Interest | Payment | Principal | Interest |
| 1 | $58.12 | $17.25 | $40.88 | 1.00 | 0.30 | 0.70 |
| 2 | $58.12 | $17.97 | $40.15 | 1.00 | 0.31 | 0.69 |
| 3 | $58.12 | $18.73 | $39.40 | 1.00 | 0.32 | 0.68 |
| 4 | $58.12 | $19.51 | $38.61 | 1.00 | 0.34 | 0.66 |
| 5 | $58.12 | $20.33 | $37.79 | 1.00 | 0.35 | 0.65 |
| 6 | $58.12 | $21.18 | $36.94 | 1.00 | 0.36 | 0.64 |
| 7 | $58.12 | $22.07 | $36.05 | 1.00 | 0.38 | 0.62 |
| 8 | $58.12 | $23.00 | $35.12 | 1.00 | 0.40 | 0.60 |
| 9 | $58.12 | $23.97 | $34.16 | 1.00 | 0.41 | 0.59 |
| 10 | $58.12 | $24.97 | $33.15 | 1.00 | 0.43 | 0.57 |
| 11 | $58.12 | $26.02 | $32.10 | 1.00 | 0.45 | 0.55 |
| 12 | $58.12 | $27.11 | $31.01 | 1.00 | 0.47 | 0.53 |
| 13 | $58.12 | $28.25 | $29.87 | 1.00 | 0.49 | 0.51 |
| 14 | $58.12 | $29.44 | $28.69 | 1.00 | 0.51 | 0.49 |
| 15 | $58.12 | $30.67 | $27.45 | 1.00 | 0.53 | 0.47 |
| 16 | $58.12 | $31.96 | $26.16 | 1.00 | 0.55 | 0.45 |
| 17 | $58.12 | $33.30 | $24.82 | 1.00 | 0.57 | 0.43 |
| 18 | $58.12 | $34.70 | $23.42 | 1.00 | 0.60 | 0.40 |
| 19 | $58.12 | $36.16 | $21.96 | 1.00 | 0.62 | 0.38 |
| 20 | $58.12 | $37.68 | $20.45 | 1.00 | 0.65 | 0.35 |
| 21 | $58.12 | $39.26 | $18.86 | 1.00 | 0.68 | 0.32 |
| 22 | $58.12 | $40.91 | $17.22 | 1.00 | 0.70 | 0.30 |
| 23 | $58.12 | $42.63 | $15.50 | 1.00 | 0.73 | 0.27 |
| 24 | $58.12 | $44.42 | $13.71 | 1.00 | 0.76 | 0.24 |
| 25 | $58.12 | $46.28 | $11.84 | 1.00 | 0.80 | 0.20 |
| 26 | $58.12 | $48.22 | $9.90 | 1.00 | 0.83 | 0.17 |
| 27 | $58.12 | $50.25 | $7.88 | 1.00 | 0.86 | 0.14 |
| 28 | $58.12 | $52.36 | $5.77 | 1.00 | 0.90 | 0.10 |
| 29 | $58.12 | $54.56 | $3.57 | 1.00 | 0.94 | 0.06 |
| 30 | $58.12 | $56.84 | $1.28 | 1.00 | 0.98 | 0.02 |

[82] Wells Fargo Home Loan Amortization Calculator. Accessed November 2014. Available at: https://www.wellsfargo.com/mortgage/tools/amortization

# Appendix G. Simulation Results

This section summarizes the technical and economic results of the building simulation study for mixed-fuel and electric-only homes for each relevant scenario, home size, and orientation combination as well as the summarized results for certain advanced technologies.

***Appendix G.1 – Summary of Technical and Economic Results***

- Technical Results by Home Size and Scenario
- Economic Results by Home Size, Building Orientation, and Scenario
- Lifetime Energy, Utility Cost, and Greenhouse Gas Savings Over Baseline Electric-Only Homes
- End-Use Building Loads by Home Size
- Selected ZNE Building Features by Home Size
- Incremental Mortgage Payment and Homeowner Annual Costs Over Baseline Electric-Only Homes
- TRC Values by Home Size Compared to Baseline Electric-Only Homes
- Life-Cycle Cost Analysis by Home Size Compared to Baseline Electric-Only Homes
- Impacts of Incentives on Incremental Cost, Payback, and TRC Values by Home Size

***Appendix G.2 – Summary of Technical and Economic Analyses for Advanced Technologies***

- mCHP Results by Home Size and Building Orientation
- Gas Heat Pump Results by Home Size
- Energy Storage Results by Home Size

## G.1 Technical and Economic Analysis Results

### *How to Interpret the Following Tables*

Table 93 through Table 101 provide the technical results of each home design, scenario, location, and fuel type, including:

- TDV energy consumption (MMBtu) for baseline and optimized homes and the portion of TDV savings associated with efficiency and solar PV technologies
- Electricity (kWh) and natural gas (therm) consumption for baseline and optimized homes
- Annual utility costs for baseline and optimized homes
- Greenhouse gas emissions for baseline and optimized homes (metric tons per year). Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 93. Technical Results – Home B, Scenario 1 (Solar PV, Title 24 Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)*** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 100 | 93 | 8 | 93 | 4206 | 4200 | 285 | 235 | $1,011 | $304 | $878 | 2.7 | 1.0 | 1.2 |
| | PA | 101 | 91 | 10 | 91 | 4369 | 4341 | 269 | 211 | $984 | $49 | $1,446 | 2.6 | 0.9 | 1.3 |
| | RV | 109 | 98 | 11 | 98 | 4590 | 4537 | 290 | 235 | $1,047 | $64 | $1,524 | 2.8 | 0.9 | 1.3 |
| | BK | 133 | 116 | 17 | 116 | 5073 | 4968 | 373 | 292 | $1,389 | $256 | $1,909 | 3.4 | 1.1 | 1.5 |
| | PS | 145 | 120 | 26 | 119 | 6908 | 6169 | 209 | 171 | $1,539 | $45 | $1,935 | 3.0 | 0.7 | 2.0 |
| Electric-Only | LA | 105 | 104 | 1 | 103 | 7679 | 7588 | – | – | $1,182 | $239 | $943 | 2.1 | 0.5 | 1.7 |
| | PA | 106 | 104 | 2 | 102 | 7702 | 7570 | – | – | $1,495 | $17 | $1,478 | 2.1 | 0.5 | 1.7 |
| | RV | 112 | 108 | 4 | 104 | 8133 | 7945 | – | – | $1,588 | $82 | $1,506 | 2.3 | 0.5 | 1.8 |
| | BK** | 131 | 108 | 23 | 85 | 9258 | 7579 | – | – | $2,165 | $771 | $1,394 | 2.6 | 0.4 | 2.2 |
| | PS | 148 | 137 | 11 | 126 | 9555 | 9297 | – | – | $1,980 | -$31 | $2,011 | 2.6 | 0.3 | 2.3 |

* Savings compared to baseline electric-only home.

** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

*** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 94. Technical Results – Home B, Scenario 2 (Solar PV+SWH, Title 24 Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)*** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 87 | 84 | 3 | 84 | 4329 | 4749 | 179 | 158 | $934 | $233 | $852 | 2.2 | 0.8 | 1.1 |
| | PA | 88 | 85 | 3 | 85 | 4492 | 4478 | 163 | 150 | $913 | $17 | $1,292 | 2.1 | 0.7 | 0.8 |
| | RV | 95 | 91 | 4 | 91 | 4716 | 4672 | 180 | 168 | $973 | $30 | $1,344 | 2.3 | 0.7 | 1.3 |
| | BK | 120 | 107 | 13 | 107 | 5205 | 5097 | 270 | 217 | $1,328 | $206 | $1,777 | 2.9 | 0.9 | 1.5 |
| | PS | 132 | 119 | 13 | 119 | 7052 | 6823 | 109 | 97 | $1,487 | -$8 | $1,808 | 2.5 | 0.5 | 2.0 |
| Electric-Only | LA | 95 | 104 | 3 | 101 | 7025 | 7588 | – | – | $1,086 | $239 | $847 | 1.9 | 0.5 | 1.5 |
| | PA | 96 | 104 | 3 | 101 | 5521 | 6536 | – | – | $1,309 | $17 | $1,292 | 1.5 | 0.2 | 1.4 |
| | RV | 101 | 108 | 4 | 105 | 7306 | 7945 | – | – | $1,373 | $82 | $1,292 | 2.0 | 0.5 | 1.6 |
| | BK** | 122 | 108 | 13 | 96 | 8640 | 7579 | – | – | $1,983 | $771 | $1,212 | 2.4 | 0.4 | 2.0 |
| | PS | 140 | 137 | 13 | 124 | 8877 | 9297 | – | – | $1,801 | -$31 | $1,831 | 2.5 | 0.3 | 2.1 |

* Savings compared to baseline electric-only home.

** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

*** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 95. Technical Results – Home B, Scenario 3 (Solar PV+SWH, Title 24+Exogenous Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)*** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 294 | 281 | 12 | 281 | 7784 | 7781 | 1212 | 1130 | $2,393 | $1,089 | $1,543 | 8.6 | 3.7 | 1.3 |
| | PA | 295 | 283 | 12 | 283 | 7954 | 7930 | 1197 | 1122 | $2,185 | $647 | $3,906 | 8.6 | 3.6 | 1.3 |
| | RV | 302 | 288 | 15 | 288 | 8170 | 8117 | 1218 | 1137 | $2,859 | $651 | $3,978 | 8.7 | 3.6 | 1.4 |
| | BK | 326 | 316 | 10 | 316 | 8645 | 8572 | 1299 | 1258 | $3,290 | $936 | $4,515 | 9.3 | 4.0 | 1.4 |
| | PS | 338 | 316 | 22 | 316 | 10451 | 10231 | 1138 | 1066 | $3,379 | $614 | $4,119 | 8.9 | 3.3 | 2.2 |
| Electric-Only | LA | 248 | 247 | 1 | 246 | 17802 | 17711 | – | – | $2,632 | $410 | $2,222 | 4.9 | 1.0 | 3.9 |
| | PA | 249 | 248 | 1 | 247 | 17825 | 17746 | – | – | $4,554 | $230 | $4,323 | 4.9 | 1.0 | 4.0 |
| | RV | 255 | 251 | 4 | 247 | 18258 | 18072 | – | – | $4,629 | $244 | $4,385 | 5.1 | 1.0 | 4.1 |
| | BK** | 274 | 264 | 10 | 253 | 19367 | 20741 | – | – | $5,451 | $1,661 | $3,791 | 5.4 | 1.1 | 4.2 |
| | PS | 290 | 279 | 12 | 267 | 19651 | 19373 | – | – | $4,733 | $52 | $4,681 | 5.4 | 0.8 | 4.6 |

* Savings compared to baseline electric-only home.

** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

*** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 96. Technical Results – Home A, Scenario 1 (Solar PV, Title 24 Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 86 | 79 | 7 | 79 | 3672 | 3669 | 239 | 193 | $895 | $274 | $689 | 2.3 | 0.8 | 0.9 |
| | PA | 86 | 79 | 7 | 79 | 3787 | 3772 | 225 | 182 | $849 | $50 | $1,029 | 2.2 | 0.8 | 0.9 |
| | RV | 92 | 84 | 8 | 84 | 3965 | 3927 | 239 | 199 | $898 | $62 | $1,092 | 2.4 | 0.8 | 1.0 |
| | BK | 109 | 96 | 13 | 96 | 4329 | 4226 | 297 | 236 | $1,147 | $215 | $1,343 | 2.8 | 0.9 | 1.1 |
| | PS | 119 | 104 | 15 | 104 | 5736 | 5513 | 178 | 141 | $1,237 | $25 | $1,441 | 2.5 | 0.6 | 1.5 |
| Electric-Only | LA | 84 | 84 | 0 | 83 | 6140 | 6108 | - | - | $963 | $216 | $747 | 1.7 | 0.4 | 1.3 |
| | PA | 83 | 83 | 0 | 83 | 6102 | 6075 | - | - | $1,078 | $49 | $1,029 | 1.7 | 0.4 | 1.3 |
| | RV | 89 | 86 | 2 | 84 | 6442 | 6318 | - | - | $1,153 | $51 | $1,102 | 1.8 | 0.4 | 1.4 |
| | BK | 102 | 98 | 5 | 93 | 7286 | 6961 | - | - | $1,559 | $606 | $952 | 2.0 | 0.4 | 1.6 |
| | PS | 114 | 105 | 9 | 97 | 7450 | 7239 | - | - | $1,467 | -$6 | $1,473 | 2.1 | 0.3 | 1.8 |

* Savings compared to baseline electric-only home.

** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 97. Technical Results – Home A, Scenario 2 (Solar PV+SWH, Title 24 Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 79 | 72 | 7 | 72 | 3798 | 3795 | 174 | 129 | $855 | $215 | $666 | 2.0 | 0.6 | 0.9 |
| | PA | 79 | 72 | 7 | 72 | 3907 | 3892 | 160 | 119 | $812 | $17 | $925 | 1.9 | 0.6 | 1.0 |
| | RV | 84 | 77 | 7 | 77 | 4089 | 4047 | 172 | 135 | $859 | $29 | $961 | 2.0 | 0.6 | 1.0 |
| | BK | 102 | 90 | 12 | 90 | 4449 | 4343 | 231 | 178 | $1,115 | $186 | $1,237 | 2.5 | 0.7 | 1.1 |
| | PS | 111 | 98 | 14 | 98 | 5865 | 5633 | 114 | 87 | $1,213 | -$1 | $1,321 | 2.2 | 0.4 | 1.5 |
| Electric-Only | LA | 76 | 84 | -8 | 91 | 5572 | 6108 | - | - | $881 | $216 | $665 | 1.5 | 0.4 | 1.2 |
| | PA | 76 | 83 | -8 | 91 | 5522 | 6076 | - | - | $941 | $49 | $892 | 1.5 | 0.4 | 1.2 |
| | RV | 79 | 86 | -7 | 93 | 5750 | 6319 | - | - | $989 | $51 | $939 | 1.6 | 0.4 | 1.2 |
| | BK | 96 | 98 | -2 | 100 | 6773 | 6961 | - | - | $1,423 | $606 | $817 | 1.9 | 0.4 | 1.5 |
| | PS | 107 | 105 | 2 | 104 | 6896 | 7239 | - | - | $1,320 | -$6 | $1,326 | 1.9 | 0.3 | 1.6 |

* Savings compared to baseline electric-only home.

** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 98. Technical Results – Home A, Scenario 3 (Solar PV+SWH, Title 24+Exogenous Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 278 | 267 | 11 | 267 | 7253 | 7253 | 1167 | 1093 | $2,312 | $1,054 | $1,582 | 8.2 | 3.6 | 1.4 |
| | PA | 278 | 268 | 11 | 268 | 7367 | 7367 | 1154 | 1081 | $2,675 | $611 | $3,920 | 8.2 | 3.5 | 1.4 |
| | RV | 284 | 272 | 12 | 272 | 7546 | 7505 | 1168 | 1096 | $2,699 | $611 | $3,953 | 8.3 | 3.5 | 1.5 |
| | BK | 301 | 292 | 9 | 292 | 7907 | 7845 | 1224 | 1185 | $3,050 | $859 | $4,414 | 8.7 | 3.8 | 1.4 |
| | PS | 311 | 293 | 17 | 293 | 9305 | 9158 | 1106 | 1040 | $3,131 | $613 | $3,859 | 8.4 | 3.2 | 2.0 |
| Electric-Only | LA | 250 | 227 | 23 | 203 | 17822 | 16228 | - | - | $2,636 | $396 | $2,240 | 4.9 | 1.0 | 4.0 |
| | PA | 248 | 226 | 22 | 204 | 17735 | 16202 | - | - | $4,531 | $310 | $4,222 | 4.9 | 0.9 | 4.0 |
| | RV | 252 | 229 | 23 | 206 | 18030 | 16454 | - | - | $4,564 | $313 | $4,251 | 5.0 | 0.9 | 4.1 |
| | BK | 266 | 263 | 3 | 260 | 18825 | 18634 | - | - | $5,273 | $1,777 | $3,495 | 5.2 | 1.0 | 4.2 |
| | PS | 275 | 248 | 26 | 222 | 18854 | 17377 | - | - | $4,472 | $182 | $4,290 | 5.2 | 0.8 | 4.4 |

* Savings compared to baseline electric-only home.

** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

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**Table 99. Technical Results – Home C, Scenario 1 (Solar PV, Title 24 Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 110 | 102 | 8 | 102 | 4877 | 4874 | 287 | 236 | $1,108 | $294 | $990 | 2.9 | 1.0 | 1.3 |
| | PA | 111 | 103 | 7 | 103 | 5065 | 5041 | 269 | 227 | $1,116 | $37 | $1,665 | 2.8 | 1.0 | 1.4 |
| | RV | 120 | 111 | 9 | 111 | 5320 | 5264 | 293 | 252 | $1,186 | $57 | $1,740 | 3.0 | 1.0 | 1.4 |
| | BK | 147 | 130 | 17 | 130 | 5873 | 5715 | 290 | 316 | $1,614 | $266 | $2,188 | 3.2 | 1.2 | 1.6 |
| | PS | 161 | 143 | 18 | 143 | 7943 | 7723 | 205 | 169 | $1,783 | $21 | $2,193 | 3.3 | 0.7 | 2.2 |
| Electric-Only | LA | 115 | 114 | 1 | | 8409 | 8309 | - | - | $1,284 | $252 | $1,032 | 2.3 | 0.5 | 1.8 |
| | PA | 116 | 114 | 2 | | 8417 | 8315 | - | - | $1,702 | $69 | $1,633 | 2.3 | 0.5 | 1.8 |
| | RV | 123 | 119 | 4 | | 8898 | 8705 | - | - | $1,796 | $67 | $1,729 | 2.5 | 0.5 | 2.0 |
| | BK | 144 | 137 | 7 | | 10158 | 9810 | - | - | $2,453 | $1,134 | $1,319 | 2.8 | 0.6 | 2.3 |
| | PS | 163 | 150 | 13 | | 10533 | 10252 | - | - | $2,214 | $3 | $2,211 | 2.9 | 0.4 | 2.5 |

* Savings compared to baseline electric-only home.

** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 100. Technical Results – Home C, Scenario 2 (Solar PV+SWH, Title 24 Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 101 | 93 | 8 | 93 | 5009 | 5003 | 210 | 159 | $1,057 | $224 | $964 | 2.5 | 0.8 | 1.4 |
| | PA | 101 | 94 | 7 | 94 | 5193 | 5170 | 192 | 151 | $1,076 | -$3 | $1,501 | 2.5 | 0.7 | 1.4 |
| | RV | 110 | 101 | 9 | 101 | 5451 | 5396 | 212 | 173 | $1,144 | $12 | $1,559 | 2.6 | 0.8 | 1.4 |
| | BK | 138 | 121 | 16 | 121 | 6005 | 5844 | 311 | 241 | $1,579 | $228 | $2,030 | 3.3 | 1.0 | 1.7 |
| | PS | 151 | 134 | 18 | 134 | 8083 | 7831 | 125 | 94 | $1,748 | -$47 | $2,081 | 2.9 | 0.5 | 2.2 |
| Electric-Only | LA | 105 | 114 | -9 | 122 | 7755 | 8309 | - | - | $1,188 | $252 | $936 | 2.1 | 0.5 | 1.6 |
| | PA | 106 | 114 | -8 | 122 | 7717 | 8315 | - | - | $1,499 | $69 | $1,430 | 2.1 | 0.5 | 1.6 |
| | RV | 111 | 119 | -8 | 126 | 8074 | 8705 | - | - | $1,571 | $67 | $1,503 | 2.2 | 0.5 | 1.7 |
| | BK | 135 | 137 | -2 | 138 | 9534 | 9810 | - | - | $2,259 | $1,134 | $1,125 | 2.6 | 0.6 | 2.1 |
| | PS | 155 | 150 | 4 | 146 | 9854 | 10252 | - | - | $2,034 | $3 | $2,031 | 2.7 | 0.4 | 2.3 |

* Savings compared to baseline electric-only home.

** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 101. Technical Results – Home C, Scenario 3 (Solar PV+SWH, Title 24+Exogenous Loads)**

| Category | Location | TDV (MMBtu) | | | | Electricity (kWh) | | Natural Gas (Therms) | | Annual Utility Costs ($) | | | Greenhouse Gas Emissions (Metric Tons/Yr)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Optimized | Efficiency Savings | Solar PV Savings | Baseline | Optimized | Baseline | Optimized | Baseline | Optimized | Savings Over Baseline* | Baseline | Optimized | Savings Over Baseline* |
| Mixed-Fuel | LA | 282 | 271 | 12 | 271 | 8616 | 8610 | 1068 | 992 | $2,339 | $944 | $2,012 | 8.1 | 3.3 | 2.2 |
| | PA | 291 | 276 | 15 | 276 | 9085 | 9006 | 1060 | 985 | $3,060 | $418 | $4,792 | 8.1 | 3.3 | 2.3 |
| | RV | 300 | 283 | 17 | 283 | 9431 | 9325 | 1072 | 997 | $3,134 | $433 | $4,854 | 8.3 | 3.3 | 2.4 |
| | BK | 323 | 310 | 13 | 310 | 10073 | 9935 | 1130 | 1091 | $3,684 | $902 | $5,309 | 8.8 | 3.6 | 2.4 |
| | PS | 358 | 333 | 24 | 333 | 12669 | 12388 | 1022 | 953 | $3,844 | $477 | $4,940 | 8.9 | 3.0 | 3.1 |
| Electric-Only | LA | 281 | 257 | 24 | 257 | 20094 | 18438 | - | - | $2,956 | $424 | $2,532 | 5.6 | 1.1 | 4.5 |
| | PA | 280 | 280 | 1 | 280 | 20038 | 19988 | - | - | $5,209 | $98 | $5,112 | 5.6 | 1.1 | 4.4 |
| | RV | 286 | 262 | 24 | 262 | 20475 | 18845 | - | - | $5,287 | $215 | $5,072 | 5.7 | 1.0 | 4.6 |
| | BK | 307 | 275 | 32 | 275 | 21706 | 19604 | - | - | $6,211 | $1,639 | $4,572 | 6.0 | 1.1 | 4.9 |
| | PS | 324 | 294 | 30 | 294 | 21920 | 20399 | - | - | $5,417 | -$14 | $5,431 | 6.1 | 0.9 | 5.2 |

* Savings compared to baseline electric-only home.

** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

### *How to Interpret the Following Tables*

Table 102 through Table 113 provide the economic results of each home design, scenario, location, home orientation, and fuel type, including:

- Baseline, optimized, and incremental cost
- Required solar PV system size (kW) for the optimized home
- Simple payback of dividing annual utility savings by the incremental cost of the optimized home.

**Table 102. Economic Results – Home B, Scenario 1 (Solar PV, Title 24 Loads) – North, East**

| Category | Location | Baseline Cost | North | | | | East | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $86,154 | 3.4 | $105,873 | $20,547 | 23 | 3.7 | $108,346 | $23,020 | 26 |
| | Pasadena | $86,293 | 3.4 | $107,447 | $20,793 | 14 | 4.0 | $109,591 | $22,937 | 16 |
| | Riverside | $86,727 | 3.6 | $108,193 | $21,539 | 14 | 4.3 | $111,473 | $24,819 | 16 |
| | Bakersfield | $86,931 | 4.2 | $111,295 | $23,973 | 13 | 4.7 | $113,994 | $26,672 | 14 |
| | Palm Springs | $87,231 | 4.3 | $112,562 | $24,572 | 13 | 5.1 | $116,554 | $28,564 | 15 |
| Electric-Only | Los Angeles | $85,326 | 3.8 | $107,156 | $21,830 | 23 | 4.2 | $109,307 | $23,981 | 26 |
| | Pasadena | $86,654 | 3.9 | $109,932 | $23,278 | 16 | 4.5 | $112,330 | $25,676 | 17 |
| | Riverside | $86,654 | 4.0 | $110,077 | $23,423 | 16 | 4.6 | $113,068 | $26,414 | 17 |
| | Bakersfield** | $87,322 | 3.9 | $120,637 | $33,315 | 24 | 4.8 | $117,088 | $29,766 | 26 |
| | Palm Springs | $87,990 | 5.0 | $116,048 | $28,058 | 14 | 5.8 | $120,486 | $32,496 | 16 |

* Compared to baseline electric-only home.
** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

**Table 103. Economic Results – Home B, Scenario 1 (Solar PV, Title 24 Loads) – South, West**

| Category | Location | Baseline Cost | South | | | | West | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $86,154 | 5.0 | $114,401 | $29,075 | 33 | 4.1 | $110,073 | $24,747 | 28 |
| | Pasadena | $86,293 | 5.3 | $116,991 | $30,337 | 21 | 4.4 | $111,721 | $25,067 | 17 |
| | Riverside | $86,727 | 5.8 | $118,903 | $32,249 | 21 | 4.7 | $113,487 | $26,833 | 18 |
| | Bakersfield | $86,931 | 6.0 | $122,316 | $34,994 | 18 | 5.2 | $116,639 | $29,317 | 15 |
| | Palm Springs | $87,231 | 6.5 | $124,878 | $36,888 | 19 | 5.5 | $117,990 | $30,000 | 16 |
| Electric-Only | Los Angeles | $85,326 | 5.6 | $116,374 | $31,048 | 35 | 4.7 | $111,824 | $26,498 | 29 |
| | Pasadena | $86,654 | 6.0 | $119,703 | $33,049 | 25 | 4.9 | $114,539 | $27,885 | 20 |
| | Riverside | $86,654 | 6.1 | $120,714 | $34,060 | 24 | 5.0 | $115,193 | $28,539 | 20 |
| | Bakersfield | $87,322 | 6.4 | $124,495 | $37,173 | 42 | 5.3 | $120,447 | $33,125 | 28 |
| | Palm Springs | $87,990 | 7.4 | $128,086 | $40,096 | 22 | 6.0 | $121,351 | $33,361 | 18 |

* Compared to baseline electric-only home.

**Table 104. Economic Results – Home B, Scenario 2 (Solar PV+SWH, Title 24 Loads)**

| Category | Location | Baseline Cost | North | | | | South | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $92,334 | 3.0 | $109,122 | $17,242 | 20 | 4.8 | $118,579 | $26,699 | 31 |
| | Pasadena | $93,472 | 3.2 | $111,293 | $18,086 | 14 | 5.1 | $122,009 | $28,801 | 22 |
| | Riverside | $93,541 | 3.4 | $112,248 | $19,040 | 14 | 5.4 | $122,814 | $29,606 | 22 |
| | Bakersfield | $94,110 | 3.9 | $115,675 | $21,799 | 12 | 5.8 | $127,383 | $33,507 | 19 |
| | Palm Springs | $94,679 | 4.3 | $118,408 | $23,864 | 13 | 6.6 | $131,253 | $36,709 | 20 |
| Electric-Only | Los Angeles | $91,880 | 3.8 | $107,156 | $15,276 | 18 | 5.6 | $116,374 | $24,494 | 31 |
| | Pasadena | $93,208 | 3.9 | $109,932 | $16,724 | 13 | 6.0 | $119,703 | $26,495 | 18 |
| | Riverside | $93,208 | 4.0 | $110,077 | $16,869 | 13 | 6.1 | $120,714 | $27,506 | 18 |
| | Bakersfield** | $93,876 | 3.9 | $120,637 | $26,761 | 22 | 6.4 | $124,495 | $30,619 | 30 |
| | Palm Springs | $94,544 | 5.0 | $116,048 | $21,504 | 12 | 7.4 | $128,086 | $33,542 | 17 |

* Compared to baseline electric-only home.

** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

Table 105. Economic Results – Home B, Scenario 3 (Solar PV+SWH, Title 24+Exogenous Loads)

| Category | Location | Baseline Cost | North | | | | South | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| **Mixed-Fuel** | Los Angeles | $91,968 | 10.2 | $145,408 | $59,349 | 38 | 15.0 | $167,968 | $81,909 | 53 |
| | Pasadena | $93,175 | 10.7 | $149,022 | $62,295 | 16 | 16.2 | $174,652 | $87,925 | 23 |
| | Riverside | $93,244 | 10.7 | $149,142 | $61,747 | 16 | 16.3 | $175,303 | $87,908 | 22 |
| | Bakersfield | $93,813 | 11.4 | $153,003 | $64,940 | 14 | 16.9 | $178,194 | $90,131 | 20 |
| | Palm Springs | $94,382 | 11.5 | $153,908 | $65,176 | 16 | 17.2 | $180,187 | $91,455 | 22 |
| **Electric-Only** | Los Angeles | $86,059 | 8.9 | $133,500 | $47,441 | 21 | 13.2 | $153,549 | $67,490 | 32 |
| | Pasadena | $86,727 | 9.4 | $136,261 | $49,534 | 12 | 14.2 | $158,884 | $72,157 | 17 |
| | Riverside | $87,395 | 9.3 | $136,944 | $49,549 | 11 | 14.2 | $159,831 | $72,436 | 17 |
| | Bakersfield | $88,063 | 10.6 | $142,198 | $54,135 | 14 | 15.5 | $164,673 | $76,609 | 57 |
| | Palm Springs | $88,732 | 10.1 | $141,447 | $52,715 | 11 | 15.1 | $164,412 | $75,680 | 18 |

* Compared to baseline electric-only home.

**Table 106. Economic Results – Home A, Scenario 1 (Solar PV, Title 24 Loads) – North, East**

| Category | Location | Baseline Cost | North | | | | East | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $65,869 | 2.9 | $83,201 | $17,031 | 25 | 3.1 | $84,525 | $18,356 | 27 |
| | Pasadena | $66,507 | 3.0 | $84,616 | $17,779 | 17 | 3.3 | $86,278 | $19,440 | 19 |
| | Riverside | $66,507 | 3.2 | $85,388 | $18,551 | 17 | 3.5 | $87,152 | $20,314 | 19 |
| | Bakersfield | $67,145 | 3.5 | $88,305 | $20,799 | 15 | 3.8 | $89,899 | $22,393 | 17 |
| | Palm Springs | $67,644 | 3.8 | $90,109 | $21,936 | 15 | 4.2 | $93,175 | $25,001 | 17 |
| Electric-Only | Los Angeles | $66,169 | 3.1 | $84,223 | $18,054 | 24 | 3.3 | $78,943 | $12,773 | 18 |
| | Pasadena | $66,838 | 3.2 | $85,582 | $18,744 | 18 | 3.5 | $87,221 | $20,383 | 19 |
| | Riverside | $66,838 | 3.2 | $86,134 | $19,297 | 18 | 3.5 | $87,221 | $20,383 | 19 |
| | Bakersfield | $67,506 | 3.6 | $89,885 | $22,380 | 23 | 3.7 | $92,647 | $25,141 | 27 |
| | Palm Springs | $68,174 | 3.9 | $90,374 | $22,200 | 15 | 4.3 | $93,028 | $24,854 | 17 |

* Compared to baseline electric-only home.

**Table 107. Economic Results – Home A, Scenario 1 (Solar PV, Title 24 Loads) – South, West**

| Category | Location | Baseline Cost | South | | | | West | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $65,869 | 3.8 | $88,135 | $21,966 | 32 | 3.4 | $85,931 | $19,761 | 29 |
| | Pasadena | $66,507 | 4.1 | $90,018 | $23,180 | 23 | 3.6 | $87,446 | $20,608 | 20 |
| | Riverside | $66,507 | 4.3 | $91,129 | $24,292 | 22 | 3.7 | $88,327 | $21,489 | 20 |
| | Bakersfield | $67,145 | 4.5 | $93,355 | $25,849 | 19 | 4.1 | $91,464 | $23,959 | 18 |
| | Palm Springs | $67,644 | 5.0 | $96,479 | $28,306 | 20 | 4.3 | $93,426 | $25,253 | 18 |
| Electric-Only | Los Angeles | $66,169 | 4.0 | $89,171 | $23,002 | 32 | 3.6 | $87,041 | $20,871 | 29 |
| | Pasadena | $66,838 | 4.2 | $91,124 | $24,286 | 24 | 3.7 | $88,552 | $21,715 | 21 |
| | Riverside | $66,838 | 4.3 | $91,821 | $24,983 | 23 | 3.8 | $89,163 | $22,326 | 20 |
| | Bakersfield | $67,506 | 4.5 | $94,844 | $27,339 | 40 | 4.2 | $92,800 | $25,294 | 27 |
| | Palm Springs | $68,174 | 5.1 | $96,597 | $28,423 | 20 | 4.4 | $94,209 | $26,035 | 18 |

* Compared to baseline electric-only home.

**Table 108. Economic Results – Home A, Scenario 2 (Solar PV+SWH, Title 24 Loads)**

| Category | Location | Baseline Cost | North | | | | South | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $71,869 | 2.6 | $87,780 | $15,057 | 23 | 3.7 | $121,308 | $48,585 | 73 |
| | Pasadena | $72,507 | 2.8 | $89,155 | $15,763 | 17 | 3.9 | $95,146 | $21,755 | 24 |
| | Riverside | $72,507 | 2.9 | $89,897 | $16,506 | 17 | 4.1 | $96,223 | $22,831 | 24 |
| | Bakersfield | $73,145 | 3.3 | $93,069 | $19,009 | 15 | 4.4 | $98,550 | $24,491 | 20 |
| | Palm Springs | $73,644 | 3.6 | $94,985 | $20,258 | 15 | 4.9 | $101,846 | $27,119 | 21 |
| Electric-Only | Los Angeles | $72,723 | 3.1 | $84,223 | $11,500 | 17 | 4.0 | $89,171 | $16,448 | 22 |
| | Pasadena | $73,392 | 3.2 | $85,582 | $12,190 | 14 | 4.2 | $91,124 | $17,732 | 16 |
| | Riverside | $73,392 | 3.2 | $86,134 | $12,743 | 14 | 4.3 | $91,821 | $18,429 | 16 |
| | Bakersfield | $74,060 | 3.6 | $89,885 | $15,826 | 19 | 4.5 | $94,844 | $20,785 | 28 |
| | Palm Springs | $74,728 | 3.9 | $90,374 | $15,646 | 12 | 5.1 | $96,597 | $21,869 | 15 |

* Compared to baseline electric-only home.

**Table 109. Economic Results – Home A, Scenario 3 (Solar PV+SWH, Title 24+Exogenous Loads)**

| Category | Location | Baseline Cost | North | | | | South | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $73,112 | 9.8 | $124,599 | $57,953 | 37 | 12.8 | $138,600 | $71,954 | 45 |
| | Pasadena | $73,749 | 10.3 | $127,551 | $60,236 | 15 | 13.6 | $143,335 | $76,020 | 19 |
| | Riverside | $74,318 | 10.2 | $128,147 | $60,832 | 15 | 13.7 | $144,350 | $77,035 | 19 |
| | Bakersfield | $74,387 | 10.5 | $129,298 | $61,315 | 14 | 13.9 | $145,244 | $77,261 | 18 |
| | Palm Springs | $74,887 | 10.8 | $131,198 | $62,547 | 16 | 14.2 | $146,939 | $78,288 | 20 |
| Electric-Only | Los Angeles | $66,646 | 8.3 | $111,163 | $44,516 | 20 | 10.8 | $123,168 | $56,522 | 26 |
| | Pasadena | $67,315 | 8.7 | $113,666 | $46,351 | 11 | 11.5 | $127,211 | $59,897 | 14 |
| | Riverside | $67,315 | 8.6 | $113,701 | $46,386 | 11 | 11.5 | $127,361 | $60,046 | 14 |
| | Bakersfield | $67,983 | 9.6 | $117,990 | $50,008 | 14 | 12.4 | $131,219 | $63,236 | 28 |
| | Palm Springs | $68,651 | 9.1 | $116,991 | $48,340 | 11 | 12.0 | $130,489 | $61,839 | 15 |

* Compared to baseline electric-only home.

**Table 110. Economic Results – Home C, Scenario 1 (Solar PV, Title 24 Loads) – North, East**

| Category | Location | Baseline Cost | North | | | | East | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $96,863 | 3.7 | $118,464 | $19,805 | 20 | 4.1 | $120,764 | $22,106 | 22 |
| | Pasadena | $97,501 | 3.9 | $120,230 | $20,903 | 13 | 4.5 | $123,218 | $23,891 | 14 |
| | Riverside | $98,139 | 4.1 | $121,943 | $21,948 | 13 | 4.7 | $125,184 | $25,190 | 14 |
| | Bakersfield | $98,708 | 4.7 | $125,875 | $25,213 | 12 | 5.2 | $129,413 | $28,750 | 13 |
| | Palm Springs | $99,277 | 5.2 | $128,559 | $27,228 | 12 | 6.1 | $133,068 | $31,737 | 14 |
| Electric-Only | Los Angeles | $98,659 | 4.1 | $122,329 | $23,670 | 23 | 4.6 | $124,810 | $26,151 | 25 |
| | Pasadena | $99,327 | 4.3 | $124,058 | $24,732 | 15 | 4.9 | $127,132 | $27,806 | 16 |
| | Riverside | $99,995 | 4.4 | $125,390 | $25,395 | 15 | 5.0 | $128,606 | $28,611 | 16 |
| | Bakersfield | $100,663 | 4.9 | $128,023 | $27,361 | 21 | 5.6 | $132,785 | $32,122 | 23 |
| | Palm Springs | $101,331 | 5.5 | $131,893 | $30,562 | 14 | 6.4 | $136,636 | $35,306 | 16 |

* Compared to baseline electric-only home.

Table 111. Economic Results – Home C, Scenario 1 (Solar PV, Title 24 Loads) – South, West

| Category | Location | Baseline Cost | South | | | | West | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $96,863 | 5.4 | $127,553 | $28,894 | 29 | 4.6 | $123,253 | $24,594 | 25 |
| | Pasadena | $97,501 | 5.9 | $130,513 | $31,187 | 19 | 4.9 | $124,981 | $25,655 | 15 |
| | Riverside | $98,139 | 6.2 | $132,507 | $32,512 | 19 | 5.1 | $126,965 | $26,971 | 16 |
| | Bakersfield | $98,708 | 6.8 | $137,578 | $36,915 | 17 | 5.6 | $131,582 | $30,919 | 14 |
| | Palm Springs | $99,277 | 7.6 | $141,505 | $40,174 | 18 | 6.2 | $133,990 | $32,659 | 15 |
| Electric-Only | Los Angeles | $98,659 | 6.1 | $132,347 | $33,688 | 35 | 5.1 | $127,493 | $28,834 | 29 |
| | Pasadena | $99,327 | 6.5 | $135,299 | $35,972 | 24 | 5.4 | $129,497 | $30,170 | 19 |
| | Riverside | $99,995 | 6.7 | $136,975 | $36,980 | 24 | 5.5 | $130,891 | $30,896 | 19 |
| | Bakersfield | $100,663 | 6.4 | $137,836 | $37,173 | 42 | 5.3 | $133,787 | $33,125 | 28 |
| | Palm Springs | $101,331 | 7.9 | $145,607 | $44,276 | 21 | 6.0 | $134,692 | $33,361 | 18 |

* Compared to baseline electric-only home.

**Table 112. Economic Results – Home C, Scenario 2 (Solar PV+SWH, Title 24 Loads)**

| Category | Location | Baseline Cost | North | | | | South | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| Mixed-Fuel | Los Angeles | $102,863 | 3.4 | $122,726 | $17,514 | 18 | 5.3 | $132,600 | $27,387 | 28 |
| | Pasadena | $103,501 | 3.6 | $124,430 | $18,549 | 12 | 5.7 | $135,530 | $29,649 | 20 |
| | Riverside | $104,139 | 3.8 | $126,110 | $19,561 | 13 | 6.0 | $137,515 | $30,966 | 20 |
| | Bakersfield | $104,708 | 4.4 | $130,259 | $23,042 | 11 | 6.8 | $141,848 | $34,631 | 17 |
| | Palm Springs | $105,277 | 4.8 | $132,873 | $24,988 | 12 | 7.4 | $147,146 | $39,261 | 19 |
| Electric-Only | Los Angeles | $105,213 | 4.1 | $122,329 | $17,116 | 18 | 6.1 | $132,347 | $27,134 | 26 |
| | Pasadena | $105,881 | 4.3 | $124,058 | $18,178 | 13 | 6.5 | $135,299 | $29,418 | 18 |
| | Riverside | $106,549 | 4.4 | $125,390 | $18,841 | 13 | 6.7 | $136,975 | $30,426 | 18 |
| | Bakersfield | $107,217 | 4.9 | $128,023 | $20,807 | 18 | 6.4 | $137,836 | $30,619 | 30 |
| | Palm Springs | $107,885 | 5.5 | $131,893 | $24,008 | 12 | 7.9 | $145,607 | $37,722 | 17 |

* Compared to baseline electric-only home.

**Table 113. Economic Results – Home C, Scenario 3 (Solar PV+SWH, Title 24+Exogenous Loads)**

| Category | Location | Baseline Cost | North | | | | South | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback | Solar PV System Size | Total Cost | Incremental Cost Over Baseline* | Simple Payback |
| **Mixed-Fuel** | Los Angeles | $103,702 | 9.8 | $155,346 | $56,613 | 28 | 14.5 | $177,158 | $78,425 | 39 |
| | Pasadena | $104,909 | 10.4 | $159,188 | $59,787 | 12 | 15.9 | $184,364 | $84,963 | 18 |
| | Riverside | $104,978 | 10.5 | $160,214 | $60,145 | 12 | 16.2 | $186,069 | $86,000 | 18 |
| | Bakersfield | $105,546 | 11.2 | $163,792 | $63,055 | 12 | 17.0 | $190,423 | $89,686 | 17 |
| | Palm Springs | $106,115 | 12.1 | $168,600 | $67,195 | 14 | 18.1 | $196,053 | $94,648 | 19 |
| **Electric-Only** | Los Angeles | $98,733 | 9.3 | $148,528 | $49,795 | 20 | 13.7 | $169,354 | $70,622 | 29 |
| | Pasadena | $99,401 | 10.6 | $154,499 | $55,098 | 11 | 14.8 | $174,789 | $75,388 | 16 |
| | Riverside | $100,069 | 9.7 | $152,105 | $52,037 | 10 | 14.8 | $175,880 | $75,811 | 16 |
| | Bakersfield | $100,737 | 9.9 | $154,898 | $54,161 | 12 | 17.6 | $187,860 | $87,123 | 41 |
| | Palm Springs | $101,405 | 10.6 | $157,676 | $56,272 | 10 | 15.7 | $182,528 | $81,123 | 16 |

* Compared to baseline electric-only home.

***How to Interpret the Following Tables***

Table **114** through Table 116 provide the 30 year lifetime energy, cost, and greenhouse gas results of each home design, location, and fuel type, including:

- TDV energy savings
- Electricity (kWh) and natural gas (therm) savings
- Utility cost savings
- Greenhouse gas emissions savings. Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 114. Lifetime Energy, Cost, and Greenhouse Gas Savings over Baseline Electric-Only Home – Home A**

| Category | Location | Home A (1,800 sq.ft., single-story) | | | | |
|---|---|---|---|---|---|---|
| | | TDV Savings (MMBtu)* | Electricity Savings (kWh)* | Natural Gas Savings (Therms)* | Utility Cost Savings ($)* | GHG Savings*,** |
| Mixed-Fuel | Los Angeles | 2519 | 74130 | -5790 | $20,673 | 27 |
| | Pasadena | 2505 | 69900 | -5460 | $30,866 | 28 |
| | Riverside | 2656 | 75450 | -5970 | $32,746 | 29 |
| | Bakersfield | 3072 | 91800 | -7080 | $40,299 | 33 |
| | Palm Springs | 3422 | 58110 | -4230 | $43,244 | 44 |
| Electric-Only | Los Angeles | 2519 | 960 | - | $22,399 | 39 |
| | Pasadena | 2505 | 810 | - | $30,879 | 39 |
| | Riverside | 2656 | 3720 | - | $33,074 | 42 |
| | Bakersfield | 3072 | 9750 | - | $28,575 | 49 |
| | Palm Springs | 3422 | 6330 | - | $44,175 | 53 |

* Savings compared to baseline electric-only home.

** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 115. Lifetime Energy, Cost, and Greenhouse Gas Savings over Baseline Electric-Only Home – Home B**

| Category | Location | Home B (2,500 sq.ft., two-story) | | | | |
|---|---|---|---|---|---|---|
| | | TDV Savings (MMBtu)* | Electricity Savings (kWh)* | Natural Gas Savings (Therms)* | Utility Cost Savings ($)* | GHG Savings*,*** |
| Mixed-Fuel | Los Angeles | 3150 | 104370 | -7050 | $26,328 | 35 |
| | Pasadena | 3180 | 100830 | -6330 | $43,389 | 38 |
| | Riverside | 3360 | 107880 | -7050 | $45,734 | 40 |
| | Bakersfield | 3930 | 128700 | -8760 | $57,267 | 44 |
| | Palm Springs | 4440 | 101580 | -5130 | $58,063 | 59 |
| Electric-Only | Los Angeles | 3150 | 2730 | - | $28,290 | 50 |
| | Pasadena | 3180 | 3960 | - | $44,340 | 50 |
| | Riverside | 3360 | 5640 | - | $45,180 | 54 |
| | Bakersfield** | 3930 | 50370 | - | $41,820 | 65 |
| | Palm Springs | 4440 | 7740 | - | $60,330 | 69 |

* Savings compared to baseline electric-only home.
** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.
*** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

**Table 116. Lifetime Energy, Cost, and Greenhouse Gas Savings over Baseline Electric-Only Home – Home C**

| Category | Location | Home C (3,200 sq.ft., two-story) | | | | |
|---|---|---|---|---|---|---|
| | | TDV Savings (MMBtu)* | Electricity Savings (kWh)* | Natural Gas Savings (Therms)* | Utility Cost Savings ($)* | GHG Savings*,** |
| Mixed-Fuel | Los Angeles | 3454 | 106050 | -7080 | $29,698 | 40 |
| | Pasadena | 3475 | 101280 | -6810 | $49,943 | 41 |
| | Riverside | 3675 | 109020 | -7560 | $52,191 | 43 |
| | Bakersfield | 4305 | 133290 | -9480 | $65,628 | 48 |
| | Palm Springs | 4899 | 84300 | -5070 | $65,786 | 67 |
| Electric-Only | Los Angeles | 3454 | 3000 | - | $30,950 | 55 |
| | Pasadena | 3475 | 3060 | - | $48,993 | 55 |
| | Riverside | 3675 | 5790 | - | $51,867 | 59 |
| | Bakersfield | 4305 | 10440 | - | $39,581 | 68 |
| | Palm Springs | 4899 | 8430 | - | $66,334 | 76 |

* Savings compared to baseline electric-only home.
** Assumes carbon emission factors of 0.611 lbs/kWh and 11.7 lbs/therm based on EIA estimates for California region and 2,205 lbs per metric ton.

***How to Interpret the Following Tables***

Table 117 through Table 119 provide the end-use building loads for each home design, location, and fuel type on TDV Basis (MMBtu), including:

- Space Heating
- Space Cooling
- Ventilation
- HVAC Fan
- Domestic Hot Water
- Lighting
- Gas Appliances
- Electric Appliances
- Miscellaneous Loads
- Title 24 Loads – summation of space heating, ventilation, air conditioning, water heating
- HERS Loads – summation of Title 24 loads plus interior lighting, kitchen appliances, laundry appliances, miscellaneous loads

**Table 117. End-Use Building Loads – Home B**

| | | End-Use Building Loads on TDV Basis (MMBtu) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mixed-Fuel | | | | | Electric-Only | | | | |
| | | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs | Los Angeles | Pasadena | Riverside | Bakersfield* | Palm Springs |
| Baseline End-Use Consumption (TDV MMBtu) | Heating | 7.1 | 5.9 | 9.3 | 22.9 | 2.2 | 3.7 | 3.1 | 4.8 | 12.2 | 1.2 |
| | Cooling | 0.0 | 2.7 | 5.8 | 13.2 | 45.6 | 0.4 | 3.1 | 6.3 | 13.8 | 45.4 |
| | Ventilation | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| | HVAC Fan | 0.4 | 1.2 | 2.5 | 5.0 | 10.8 | 0.6 | 1.5 | 2.8 | 6.1 | 11.1 |
| | Hot Water | 26.6 | 25.4 | 25.4 | 25.3 | 20.1 | 14.7 | 12.8 | 11.6 | 14.3 | 6.6 |
| | Lighting | 11.3 | 11.3 | 11.2 | 11.3 | 11.2 | 11.3 | 11.3 | 11.2 | 11.3 | 11.2 |
| | Gas Appliances | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Electric Appliances | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 27.6 | 27.5 | 27.3 | 27.6 | 27.4 |
| | Misc. | 34.3 | 34.1 | 34.0 | 34.4 | 34.0 | 34.3 | 34.1 | 34.0 | 34.4 | 34.0 |
| | Title 24 Loads | 36.8 | 37.8 | 45.6 | 69.1 | 81.5 | 22.2 | 23.2 | 28.2 | 49.0 | 67.0 |
| | HERS Loads | 63.5 | 63.2 | 63.0 | 63.5 | 63.1 | 73.2 | 72.9 | 72.6 | 73.2 | 72.6 |
| Optimized End-Use Consumption (TDV MMBtu) | Heating | 6.4 | 4.3 | 7.5 | 16.9 | 2.2 | 3.5 | 2.7 | 4.2 | 9.4 | 1.0 |
| | Cooling | 0.0 | 1.8 | 4.1 | 10.0 | 31.7 | 0.4 | 2.2 | 4.4 | 11.6 | 35.9 |
| | Ventilation | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| | HVAC Fan | 0.4 | 0.9 | 1.9 | 4.0 | 4.6 | 0.6 | 1.1 | 2.1 | 4.8 | 9.0 |
| | Hot Water | 19.8 | 18.8 | 18.8 | 18.8 | 14.5 | 23.6 | 22.2 | 22.5 | 7.0 | 15.4 |
| | Lighting | 11.3 | 11.3 | 11.2 | 11.3 | 11.2 | 11.3 | 11.3 | 11.2 | 11.3 | 11.2 |
| | Gas Appliances | 9.1 | 8.6 | 9.1 | 9.1 | 9.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Electric Appliances | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 27.7 | 27.6 | 27.4 | 27.2 | 27.4 |
| | Misc. | 34.3 | 34.1 | 34.0 | 34.4 | 34.0 | 34.3 | 34.1 | 34.0 | 34.4 | 34.0 |
| | Title 24 Loads | 29.2 | 28.5 | 35.1 | 52.3 | 55.7 | 30.8 | 30.8 | 35.8 | 35.4 | 64.0 |
| | HERS Loads | 63.5 | 62.7 | 63.0 | 63.5 | 63.1 | 73.3 | 72.9 | 72.6 | 72.9 | 72.7 |

Title 24 loads include space heating, ventilation, air conditioning, water heating

HERS loads include Title 24 loads plus interior lighting, kitchen appliances, laundry appliances, miscellaneous loads

* Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

Table 118. End-Use Building Loads – Home A

| | | End-Use Building Loads on TDV Basis (MMBtu) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mixed-Fuel | | | | | Electric-Only | | | | |
| | | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| Baseline End-Use Consumption (TDV MMBtu) | Heating | 4.8 | 3.8 | 6.1 | 15.6 | 1.2 | 2.7 | 2.2 | 3.3 | 8.5 | 0.5 |
| | Cooling | 0.0 | 1.8 | 4.4 | 10.1 | 34.7 | 0.4 | 2.1 | 4.7 | 10.4 | 33.6 |
| | Ventilation | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| | HVAC Fan | 0.3 | 0.8 | 1.8 | 3.7 | 8.3 | 0.4 | 1.0 | 2.0 | 4.4 | 8.2 |
| | Hot Water | 26.6 | 19.5 | 19.4 | 19.3 | 15.1 | 20.0 | 18.4 | 19.0 | 19.4 | 13.3 |
| | Lighting | 8.7 | 8.7 | 8.6 | 8.7 | 8.6 | 8.7 | 8.7 | 8.6 | 8.7 | 8.6 |
| | Gas Appliances | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Electric Appliances | 12.1 | 12.1 | 12.0 | 12.1 | 12.0 | 24.5 | 24.5 | 24.3 | 24.5 | 24.4 |
| | Misc. | 27.1 | 27.0 | 26.9 | 27.2 | 26.9 | 29.2 | 29.0 | 29.0 | 29.3 | 29.0 |
| | Title 24 Loads | 33.8 | 28.0 | 33.8 | 50.8 | 61.3 | 25.6 | 25.7 | 31.1 | 44.8 | 57.6 |
| | HERS Loads | 58.4 | 58.2 | 58.0 | 58.5 | 58.1 | 62.5 | 62.2 | 61.9 | 62.5 | 62.0 |
| Optimized End-Use Consumption (TDV MMBtu) | Heating | 4.5 | 3.5 | 6.3 | 12.3 | 0.8 | 2.9 | 2.3 | 3.0 | 6.9 | 0.5 |
| | Cooling | 0.0 | 1.3 | 3.2 | 7.3 | 26.4 | 0.4 | 2.0 | 3.3 | 8.1 | 25.8 |
| | Ventilation | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| | HVAC Fan | 0.3 | 0.7 | 1.5 | 2.8 | 6.4 | 0.5 | 0.9 | 1.5 | 3.4 | 6.4 |
| | Hot Water | 14.0 | 13.3 | 13.3 | 13.3 | 10.1 | 20.0 | 18.4 | 19.0 | 19.4 | 13.3 |
| | Lighting | 8.7 | 8.7 | 8.6 | 8.7 | 8.6 | 8.7 | 8.7 | 8.6 | 8.7 | 8.6 |
| | Gas Appliances | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Electric Appliances | 12.1 | 12.1 | 12.0 | 12.1 | 12.0 | 21.9 | 21.9 | 21.7 | 21.9 | 21.7 |
| | Misc. | 27.1 | 27.0 | 26.9 | 27.2 | 26.9 | 27.0 | 26.9 | 26.8 | 27.2 | 26.9 |
| | Title 24 Loads | 20.8 | 20.8 | 26.3 | 37.8 | 45.7 | 25.8 | 25.6 | 28.9 | 39.9 | 48.1 |
| | HERS Loads | 58.4 | 58.2 | 58.0 | 58.5 | 58.1 | 57.7 | 57.5 | 57.2 | 57.7 | 57.3 |

Title 24 loads include space heating, ventilation, air conditioning, water heating
HERS loads include Title 24 loads plus interior lighting, kitchen appliances, laundry appliances, miscellaneous loads

**Table 119. End-Use Building Loads – Home C**

| | | End-Use Building Loads on TDV Basis (MMBtu) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mixed-Fuel | | | | | Electric-Only | | | | |
| | | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| Baseline End-Use Consumption (TDV MMBtu) | Heating | 7.1 | 7.2 | 11.1 | 26.9 | 2.9 | 4.4 | 3.7 | 5.5 | 14.0 | 1.4 |
| | Cooling | 0.0 | 3.0 | 6.7 | 15.1 | 51.8 | 0.4 | 3.1 | 6.6 | 14.8 | 50.2 |
| | Ventilation | 2.7 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| | HVAC Fan | 0.4 | 1.4 | 2.9 | 5.8 | 12.4 | 0.7 | 1.6 | 3.1 | 6.7 | 12.3 |
| | Hot Water | 26.6 | 25.3 | 25.3 | 25.2 | 20.1 | 23.6 | 22.2 | 22.5 | 22.6 | 15.4 |
| | Lighting | 13.9 | 13.8 | 13.8 | 13.9 | 13.8 | 13.9 | 13.8 | 13.8 | 13.9 | 13.8 |
| | Gas Appliances | 9.1 | 8.0 | 8.0 | 8.0 | 8.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Electric Appliances | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 27.6 | 27.5 | 27.3 | 27.6 | 27.4 |
| | Misc. | 34.3 | 40.3 | 40.2 | 40.7 | 40.2 | 40.5 | 40.3 | 40.2 | 40.6 | 40.2 |
| | Title 24 Loads | 36.8 | 39.9 | 48.9 | 75.9 | 90.1 | 32.1 | 33.5 | 40.7 | 61.1 | 82.2 |
| | HERS Loads | 66.1 | 70.9 | 70.7 | 71.3 | 70.7 | 82.0 | 81.6 | 81.3 | 82.1 | 81.4 |
| | | | | | | | | | | | |
| Optimized End-Use Consumption (TDV MMBtu) | Heating | 6.4 | 7.4 | 11.4 | 21.9 | 3.0 | 4.1 | 3.4 | 5.0 | 12.5 | 1.3 |
| | Cooling | 0.0 | 2.1 | 4.4 | 10.9 | 41.8 | 0.4 | 2.3 | 4.7 | 11.0 | 39.4 |
| | Ventilation | 2.7 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| | HVAC Fan | 0.4 | 1.2 | 2.3 | 4.5 | 10.3 | 0.7 | 1.3 | 2.3 | 5.3 | 9.9 |
| | Hot Water | 19.8 | 18.8 | 18.8 | 18.8 | 14.5 | 23.6 | 22.2 | 22.5 | 22.6 | 15.4 |
| | Lighting | 13.9 | 13.8 | 13.8 | 13.9 | 13.8 | 13.9 | 13.8 | 13.8 | 13.9 | 13.8 |
| | Gas Appliances | 9.1 | 8.0 | 8.0 | 8.0 | 8.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Electric Appliances | 8.7 | 8.7 | 2.9 | 8.7 | 8.7 | 27.7 | 27.6 | 27.4 | 27.6 | 27.4 |
| | Misc. | 34.3 | 40.3 | 38.3 | 40.7 | 40.2 | 40.5 | 40.3 | 40.2 | 40.6 | 40.2 |
| | Title 24 Loads | 29.2 | 32.4 | 39.8 | 58.9 | 72.5 | 31.7 | 32.1 | 37.3 | 54.4 | 68.9 |
| | HERS Loads | 66.1 | 70.9 | 63.0 | 71.3 | 70.7 | 82.1 | 81.7 | 81.4 | 82.1 | 81.4 |

Title 24 loads include space heating, ventilation, air conditioning, water heating

HERS loads include Title 24 loads plus interior lighting, kitchen appliances, laundry appliances, miscellaneous loads

### *How to Interpret the Following Tables*

Table 120 through Table 125 provide a summary of selected building features for each home design, location, and fuel type.

**Table 120. Summary of Selected ZNE Building Features – Home B**

| Category | Metric | Mixed-Fuel Selection | | | | | Electric-Only Selection | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LA | PA | RV | BK | PS | LA | PA | RV | BK | PS |
| General Operation | Heating Set Point | | | | ✓ | | | | ✓ | ✓ | |
| | Cooling Set Point | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | * | ✓ |
| | Interior Shading | | | | | | | | | | |
| Walls | Wood Stud | | | | | | | | | | |
| | Wall Sheathing | | | | * | | | | | ✓ | |
| Ceiling/Roofs | Unfinished Attic | * | ✓ | | * | | * | ✓ | | ✓ | |
| Foundation/Floors | Interzonal Floor | | | | | | | | | ✓ | |
| Windows & Doors | Windows | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Airflow | Mechanical Ventilation | | | | | | | | | | |
| Space Conditioning | Central Air Conditioner | | | | | ✓ | | | n/a | | |
| | Furnace | * | ✓ | ✓ | ✓ | | | | n/a | | |
| | Air-Source Heat Pump | | | n/a | | | | | | | |
| Water Heating | Water Heater | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | |
| | Distribution | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Solar Water Heating | | | | | | | | | ✓ | |
| Major Appliances | Kitchen & Laundry | | ✓ | | | | | | | ✓ | |
| Miscellaneous | Pool Heater[83] | ✓ | ✓ | ✓ | ✓ | ✓ | | | n/a | | |
| On-Site Generation | PV System | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | mCHP System | | | | | | | | n/a | | |

Location abbreviations: Los Angeles (LA), Pasadena (PA), Riverside (RV), Bakersfield (BK), Palm Springs (PS)
✓ denotes selection of high-efficiency option in North orientation
* denotes selection made in another orientation
n/a denotes high efficiency options are not available for fuel configuration.

[83] Pool heaters are "exogenous" loads not covered by Title 24, but common for new homes in SCG regions. Section 4.2.5 discusses the impacts of exogenous loads for ZNE homes.

**Table 121. Specific High Efficiency Building Features by Location – Home B**

| Home Design | Location | | | | |
|---|---|---|---|---|---|
| | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| **Mixed-Fuel** | Attic Insulation (R60)<br>Adv. Windows<br>Condensing Furnace*<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)<br>Adv. Windows<br>Condensing Furnace<br>HW Distribution<br>Tankless WH<br>Cooking Range<br>Solar PV System | Adv. Thermostat (Cooling)<br>Adv. Windows<br>Condensing Furnace<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Attic Insulation (R60)<br>Wall Sheathing (R15)<br>Advanced Windows<br>Condensing Furnace<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Advanced Windows<br>SEER 18 AC<br>HW Distribution<br>Tankless WH<br>Solar PV System |
| **Electric-Only** | Attic Insulation (R60)<br>Adv. Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling*)<br>Attic Insulation (R60)<br>Floor Insulation (R30)<br>Wall Sheathing (R15)<br>Advanced Windows<br>HW Distribution<br>Solar Water Heater<br>ESTAR Dishwasher<br>Solar PV System | Adv. Thermostat (Cooling)<br>Advanced Windows<br>HW Distribution<br>Solar PV System |

Note – table identifies selections for North orientation. * denotes selection made in another orientation

**Table 122. Summary of Selected ZNE Building Features – Home A**

| Category | Metric | Mixed-Fuel Selection | | | | | Electric-Only Selection | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LA | PA | RV | BK | PS | LA | PA | RV | BK | PS |
| General Operation | Heating Set Point | | | | ✓ | | | | ✓ | ✓ | |
| | Cooling Set Point | | ✓ | ✓ | ✓ | ✓ | | * | ✓ | * | ✓ |
| | Interior Shading | | | | | | | | | | |
| Walls | Wood Stud | | | | | | | | | | |
| | Wall Sheathing | | | | | * | | | | ✓ | |
| Ceiling/Roofs | Unfinished Attic | | | | ✓ | ✓ | | | | ✓ | ✓ |
| Foundation/Floors | Interzonal Floor | | | n/a | | | | | n/a | | |
| Windows & Doors | Windows | ✓ | * | * | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Airflow | Mechanical Ventilation | | | | | | | | | | |
| Space Conditioning | Central Air Conditioner | | | | | | | | n/a | | |
| | Furnace | | ✓ | | * | | | | n/a | | |
| | Air-Source Heat Pump | | | n/a | | | | | | | |
| Water Heating | Water Heater | ✓ | ✓ | ✓ | ✓ | ✓ | | | | * | |
| | Distribution | | | * | * | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Solar Water Heating | | | | | | | | | | |
| Major Appliances | Kitchen & Laundry | | | | | | | | | | |
| Miscellaneous | Pool Heater[84] | ✓ | ✓ | ✓ | | ✓ | | | n/a | | |
| On-Site Generation | PV System | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | mCHP System | | | | | | | | n/a | | |

Location abbreviations: Los Angeles (LA), Pasadena (PA), Riverside (RV), Bakersfield (BK), Palm Springs (PS)
✓ denotes selection of high-efficiency option in North orientation
* denotes selection made in another orientation
n/a denotes high efficiency options are not available for fuel configuration.

[84] Pool heaters are "exogenous" loads not covered by Title 24, but common for new homes in SCG regions. Section 4.2.5 discusses the impacts of exogenous loads for ZNE homes.

**Table 123. Specific High Efficiency Building Features by Location – Home A**

| Home Design | Location | | | | |
|---|---|---|---|---|---|
| | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| **Mixed-Fuel** | Adv. Windows<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Adv. Windows*<br>Condensing Furnace<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Adv. Windows*<br>HW Distribution*<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Attic Insulation (R60)<br>Advanced Windows<br>Condensing Furnace*<br>HW Distribution*<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Wall Sheathing (R15)*<br>Attic Insulation (R60)<br>Advanced Windows<br>HW Distribution<br>Tankless WH<br>Solar PV System |
| **Electric-Only** | Adv. Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Cooling)*<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling*)<br>Attic Insulation (R60)<br>Wall Sheathing (R15)<br>Advanced Windows<br>HW Distribution<br>Solar Water Heater*<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)<br>Advanced Windows<br>HW Distribution<br>Solar PV System |

Note – table identifies selections for North orientation. * denotes selection made in another orientation

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**Table 124. Summary of Selected ZNE Building Features – Home C**

| Category | Metric | Mixed-Fuel Selection | | | | | Electric-Only Selection | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LA | PA | RV | BK | PS | LA | PA | RV | BK | PS |
| General Operation | Heating Set Point | | | * | ✓ | | * | | ✓ | ✓ | |
| | Cooling Set Point | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| | Interior Shading | | | | | | | | | | |
| Walls | Wood Stud | | | | | | | | | | |
| | Wall Sheathing | | | | * | | | | | * | * |
| Ceiling/Roofs | Unfinished Attic | | * | | ✓ | * | | | | * | * |
| Foundation/Floors | Interzonal Floor | | | | * | * | | | | * | * |
| Windows & Doors | Windows | ✓ | * | * | ✓ | * | ✓ | ✓ | ✓ | ✓ | ✓ |
| Airflow | Mechanical Ventilation | | | | | | | | | | |
| Space Conditioning | Central Air Conditioner | | | | | | | | n/a | | |
| | Furnace | * | * | * | * | | | | n/a | | |
| | Air-Source Heat Pump | | | n/a | | | | | | | |
| Water Heating | Water Heater | ✓ | ✓ | ✓ | ✓ | ✓ | | | | * | |
| | Distribution | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Solar Water Heating | | | | | | | | | | |
| Major Appliances | Kitchen & Laundry | | | | | | | | | | |
| Miscellaneous | Pool Heater[85] | ✓ | ✓ | ✓ | | ✓ | | | n/a | | |
| On-Site Generation | PV System | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | mCHP System | | | | | | | | n/a | | |

Location abbreviations: Los Angeles (LA), Pasadena (PA), Riverside (RV), Bakersfield (BK), Palm Springs (PS)
✓ denotes selection of high-efficiency option in North orientation
* denotes selection made in another orientation
n/a denotes high efficiency options are not available for fuel configuration.

[85] Pool heaters are "exogenous" loads not covered by Title 24, but common for new homes in SCG regions. Section 4.2.5 discusses the impacts of exogenous loads for ZNE homes.

Table 125. Specific High Efficiency Building Features by Location – Home C

| Home Design | Location | | | | |
|---|---|---|---|---|---|
| | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| **Mixed-Fuel** | Adv. Windows<br>Condensing Furnace*<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)*<br>Adv. Windows*<br>Condensing Furnace*<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Heating*/Cooling)<br>Adv. Windows<br>Condensing Furnace*<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Attic Insulation (R60)<br>Wall Sheathing (R15)*<br>Advanced Windows<br>Condensing Furnace*<br>HW Distribution<br>Tankless WH<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)*<br>Floor Insulation (R30)*<br>Advanced Windows*<br>HW Distribution<br>Tankless WH<br>Solar PV System |
| **Electric-Only** | Adv. Thermostat (Heating)*<br>Adv. Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Cooling)<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Advanced Windows<br>HW Distribution<br>Solar PV System | Adv. Thermostat (Heating/Cooling)<br>Attic Insulation (R60)*<br>Floor Insulation (R30)*<br>Wall Sheathing (R15)*<br>Advanced Windows<br>HW Distribution<br>Solar Water Heater*<br>Solar PV System | Adv. Thermostat (Cooling)<br>Attic Insulation (R60)*<br>Floor Insulation (R30)*<br>Wall Sheathing (R15)*<br>Advanced Windows<br>HW Distribution<br>Solar PV System |

Note – table identifies selections for North orientation. * denotes selection made in another orientation

### *How to Interpret the Following Tables*

Table 126 provides the homeowner financial results of each home design, location, and fuel type, including:

- Upfront incremental cost for optimized home
- Annual incremental mortgage costs assuming 30 year mortgage, 4.12% interest rate, and 3% discount rate
- Homeowner annual costs estimate accounts for the NPV of life-cycle costs and utility bills over 30 years, assuming a 4.12% interest rate, and 3% discount rate for utility costs over 30 years.

**Table 126. Incremental Mortgage Payment and Homeowner Annual Costs over Baseline Electric-Only Home**

| Category | Location | Home A (1,800 sq.ft., two-story) | | | Home B (2,500 sq.ft., two-story) | | | Home C (3,200 sq.ft., two-story) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Incremental Cost* | Incremental Mortgage Cost* | Homeowner Annual Cost* | Incremental Cost* | Incremental Mortgage Cost* | Homeowner Annual Cost* | Incremental Cost* | Incremental Mortgage Cost* | Homeowner Annual Cost* |
| Mixed-Fuel | Los Angeles | $17,031 | $989 | $2,549 | $20,547 | $1,193 | $2,776 | $19,805 | $1,150 | $2,626 |
| | Pasadena | $17,779 | $1,033 | $2,326 | $20,793 | $1,208 | $2,496 | $20,903 | $1,214 | $2,384 |
| | Riverside | $18,551 | $1,077 | $2,384 | $21,539 | $1,251 | $2,558 | $21,948 | $1,275 | $2,751 |
| | Bakersfield | $20,799 | $1,208 | $2,691 | $23,973 | $1,392 | $3,237 | $25,213 | $1,464 | $3,153 |
| | Palm Springs | $21,936 | $1,274 | $2,496 | $24,572 | $1,427 | $3,025 | $27,228 | $1,581 | $3,286 |
| Electric-Only | Los Angeles | $18,054 | $1,049 | $2,589 | $21,830 | $1,268 | $2,835 | $23,670 | $1,375 | $3,244 |
| | Pasadena | $18,744 | $1,089 | $2,431 | $23,278 | $1,352 | $2,621 | $24,732 | $1,436 | $3,089 |
| | Riverside | $19,297 | $1,121 | $2,465 | $23,423 | $1,360 | $3,028 | $25,395 | $1,475 | $3,125 |
| | Bakersfield | $22,380 | $1,300 | $3,267 | $33,315 | $1,935 | $4,105 | $27,361 | $1,589 | $4,467 |
| | Palm Springs | $22,200 | $1,289 | $2,531 | $28,058 | $1,630 | $3,163 | $30,562 | $1,775 | $3,630 |

* Savings compared to baseline electric-only home. Homeowner annual cost accounts for the NPV of life-cycle costs and utility bills over 30 years.

***How to Interpret the Following Tables***

Table 127 and Table 128 provide TRC values of each home design, location, and fuel type, according to both NPV Incremental Life-Cycle Costs (CEC method) and Upfront Incremental Costs (typical method for utility efficiency programs). Values assume 85% net-to-gross, 2013 installation year, and 30 year lifetime.

**Table 127. TRC Values by Home Size Compared to Baseline Electric-Only Home (NPV Incremental Life-Cycle Costs)**

| Category | Location | Home A (1,800 sq.ft., single-story) | | | | Home B (2,500 sq.ft., two-story) | | | | Home C (3,200 sq.ft., two-story) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Net NPV Incremental Life-Cycle Cost* | Lifetime Net Avoided Costs* | | Life-Cycle TRC Test | Net Incremental Cost* | Lifetime Net Avoided Costs* | | Life-Cycle TRC Test | Net Incremental Cost* | Lifetime Net Avoided Cost* | | Life-Cycle TRC Test |
| | | | Electricity (kWh) | Natural Gas (Therms) | | | Electricity (kWh) | Natural Gas (Therms) | | | Electricity (kWh) | Natural Gas (Therms) | |
| Mixed-Fuel | LA | $31,968 | $13,979 | -$2,392 | 0.36 | $34,703 | $17,637 | -$2,912 | 0.42 | $32,725 | $18,834 | -$2,925 | 0.49 |
| | PA | $32,575 | $14,365 | -$2,256 | 0.37 | $35,036 | $18,072 | -$2,615 | 0.44 | $33,615 | $19,577 | -$2,813 | 0.50 |
| | RV | $33,209 | $14,653 | -$2,466 | 0.37 | $35,673 | $18,474 | -$2,912 | 0.44 | $38,571 | $20,020 | -$3,123 | 0.44 |
| | BK | $35,007 | $17,183 | -$2,925 | 0.41 | $42,158 | $21,986 | -$3,619 | 0.44 | $40,785 | $23,942 | -$3,916 | 0.49 |
| | PS | $35,445 | $16,734 | -$1,747 | 0.42 | $42,705 | $21,712 | -$2,119 | 0.46 | $46,853 | $23,529 | -$2,094 | 0.46 |
| Electric-Only | LA | $33,526 | $9,546 | - | 0.28 | $36,677 | $12,106 | - | 0.33 | $42,324 | $13,240 | - | 0.31 |
| | PA | $34,102 | $10,006 | - | 0.29 | $37,375 | $12,780 | - | 0.34 | $43,210 | $13,935 | - | 0.32 |
| | RV | $34,563 | $10,089 | - | 0.29 | $42,118 | $12,869 | - | 0.31 | $43,764 | $14,058 | - | 0.32 |
| | BK** | $36,625 | $11,812 | - | 0.32 | $45,857 | $15,850 | - | 0.35 | $44,893 | $16,403 | - | 0.37 |
| | PS | $36,476 | $13,329 | - | 0.37 | $45,987 | $17,396 | - | 0.38 | $52,107 | $19,130 | - | 0.37 |

* Compared to baseline electric-only home.

** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

**Table 128. TRC Values by Home Size Compared to Baseline Electric-Only Home (Upfront Incremental Cost)**

| Category | Location | Home A (1,800 sq.ft., single-story) | | | | Home B (2,500 sq.ft., two-story) | | | | Home C (3,200 sq.ft., two-story) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Net Upfront Incremental Cost* | Lifetime Net Avoided Costs* | | TRC Test | Net Upfront Incremental Cost* | Lifetime Net Avoided Costs* | | TRC Test | Net Upfront Incremental Cost* | Lifetime Net Avoided Cost* | | TRC Test |
| | | | Electricity (kWh) | Natural Gas (Therms) | | | Electricity (kWh) | Natural Gas (Therms) | | | Electricity (kWh) | Natural Gas (Therms) | |
| Mixed-Fuel | LA | $14,214 | $13,979 | -$2,392 | 0.82 | $17,149 | $17,637 | -$2,912 | 0.86 | $16,529 | $18,834 | -$2,925 | 0.96 |
| | PA | $14,838 | $14,365 | -$2,256 | 0.82 | $17,354 | $18,072 | -$2,615 | 0.89 | $17,446 | $19,577 | -$2,813 | 0.96 |
| | RV | $15,483 | $14,653 | -$2,466 | 0.79 | $17,976 | $18,474 | -$2,912 | 0.87 | $18,318 | $20,020 | -$3,123 | 0.92 |
| | BK | $17,359 | $17,183 | -$2,925 | 0.82 | $20,008 | $21,986 | -$3,619 | 0.92 | $21,042 | $23,942 | -$3,916 | 0.95 |
| | PS | $18,308 | $16,734 | -$1,747 | 0.82 | $20,508 | $21,712 | -$2,119 | 0.96 | $22,725 | $23,529 | -$2,094 | 0.94 |
| Electric-Only | LA | $15,068 | $9,546 | - | 0.63 | $18,219 | $12,106 | - | 0.66 | $19,755 | $13,240 | - | 0.67 |
| | PA | $15,644 | $10,006 | - | 0.64 | $19,428 | $12,780 | - | 0.66 | $20,641 | $13,935 | - | 0.68 |
| | RV | $16,105 | $10,089 | - | 0.63 | $19,549 | $12,869 | - | 0.66 | $21,195 | $14,058 | - | 0.66 |
| | BK** | $18,678 | $11,812 | - | 0.63 | $27,805 | $15,850 | - | 0.57 | $22,835 | $16,403 | - | 0.72 |
| | PS | $18,528 | $13,329 | - | 0.72 | $23,417 | $17,396 | - | 0.74 | $25,507 | $19,130 | - | 0.75 |

* Compared to baseline electric-only home.

** Note – The selection of water heater technology partially causes the large values for Bakersfield Electric-Only. The North orientation uses a solar thermal water heating system and HPWH for the remaining orientations.

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### *How to Interpret the Following Tables*

Table 129 through Table 131 provide the results for the Lifetime TDV Benefit-Cost Analysis for each home design, location, and fuel type, using the NPV incremental life-cycle cost values and annual TDV savings values. Values assume assuming 3% discount rate, $0.1732 per TDV-kBtu, and 30 year lifetime.

**Table 129. Lifetime TDV Benefit-Cost Analysis Compared to Baseline Electric-Only Home –Home B**

| Category | Location | Home B (2,500 sq.ft., two-story) | | | |
|---|---|---|---|---|---|
| | | NPV Life-Cycle Incremental Cost* | Annual TDV Savings (MMBtu TDV)* | Net Present Benefits @ $0.1732/TDV-kBtu* | Net Life-Cycle Costs* |
| Mixed-Fuel | Los Angeles | $41,580 | 105 | $18,186 | $23,394 |
| | Pasadena | $41,979 | 106 | $18,359 | $23,620 |
| | Riverside | $42,742 | 112 | $19,398 | $23,344 |
| | Bakersfield | $50,513 | 131 | $22,689 | $27,824 |
| | Palm Springs | $51,168 | 148 | $25,634 | $25,534 |
| Electric-Only | Los Angeles | $43,946 | 105 | $18,186 | $25,760 |
| | Pasadena | $44,782 | 106 | $18,359 | $26,423 |
| | Riverside | $50,465 | 112 | $19,398 | $31,067 |
| | Bakersfield | $54,945 | 131 | $22,689 | $32,256 |
| | Palm Springs | $55,100 | 148 | $25,634 | $29,466 |

* Compared to baseline electric-only home

**Table 130. Lifetime TDV Benefit-Cost Analysis Compared to Baseline Electric-Only Home –Home A**

| Category | Location | Home A (1,800 sq.ft., single-story) | | | |
|---|---|---|---|---|---|
| | | NPV Life-Cycle Incremental Cost* | Annual TDV Savings (MMBtu TDV)* | Net Present Benefits @ $0.1732/TDV-kBtu* | Net Life-Cycle Costs* |
| Mixed-Fuel | Los Angeles | $38,303 | 84 | $14,542 | $23,761 |
| | Pasadena | $39,030 | 83 | $14,460 | $24,570 |
| | Riverside | $39,790 | 89 | $15,332 | $24,459 |
| | Bakersfield | $41,945 | 102 | $17,737 | $24,208 |
| | Palm Springs | $42,469 | 114 | $19,759 | $22,711 |
| Electric-Only | Los Angeles | $40,170 | 84 | $14,542 | $25,628 |
| | Pasadena | $40,860 | 83 | $14,460 | $26,400 |
| | Riverside | $41,412 | 89 | $15,332 | $26,081 |
| | Bakersfield | $43,884 | 102 | $17,737 | $26,146 |
| | Palm Springs | $43,704 | 114 | $19,759 | $23,946 |

* Compared to baseline electric-only home

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**Table 131. Lifetime TDV Benefit-Cost Analysis Compared to Baseline Electric-Only Home –Home C**

| Category | Location | Home C (3,200 sq.ft., two-story) | | | |
|---|---|---|---|---|---|
| | | NPV Life-Cycle Incremental Cost* | Annual TDV Savings (MMBtu TDV)* | Net Present Benefits @ $0.1732/TDV-kBtu* | Net Life-Cycle Costs* |
| **Mixed-Fuel** | Los Angeles | $39,211 | 115 | $19,939 | $19,272 |
| | Pasadena | $40,277 | 116 | $20,060 | $20,217 |
| | Riverside | $46,214 | 123 | $21,217 | $24,997 |
| | Bakersfield | $48,867 | 144 | $24,856 | $24,011 |
| | Palm Springs | $56,138 | 163 | $28,282 | $27,856 |
| **Electric-Only** | Los Angeles | $50,711 | 115 | $19,939 | $30,773 |
| | Pasadena | $51,773 | 116 | $20,060 | $31,713 |
| | Riverside | $52,437 | 123 | $21,217 | $31,220 |
| | Bakersfield | $53,790 | 144 | $24,856 | $28,934 |
| | Palm Springs | $62,434 | 163 | $28,282 | $34,152 |

* Compared to baseline electric-only home

### *How to Interpret the Following Tables*

Table 132 through Table 134 provide the impacts of potential solar PV incentives on incremental cost, payback, and TRC values for each home design, location, and fuel type. The analysis evaluated the impacts of no tax credit on solar PV costs, a 30% federal tax credit on solar PV costs (current), and a 10% federal tax credit on solar PV costs (potentially reduced to this level after 12/31/2016).

**Table 132. Impacts of Incentives on Incremental Cost, Payback, and TRC Values – Home B**

| Category | Location | PV System Size (kW) | Simple Payback w/ Federal Incentives | | | | | | | TRC Values w/ Federal Incentives (NPV Incremental Life-Cycle Costs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Annual Utility Savings* | No Incentive | | 30% Federal Tax Credit | | 10% Federal Tax Credit | | Baseline TRC* | TRC w/ 30% Federal Tax Credit* | TRC w/ 10% Federal Tax Credit* |
| | | | | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | | | |
| Mixed-Fuel | LA | 3.4 | $878 | $20,547 | 23 | $14,666 | 17 | $18,587 | 21 | 0.42 | 0.49 | 0.45 |
| | PA | 3.4 | $1,446 | $20,793 | 14 | $14,771 | 10 | $18,786 | 13 | 0.44 | 0.52 | 0.46 |
| | RV | 3.6 | $1,524 | $21,539 | 14 | $15,208 | 10 | $19,429 | 13 | 0.44 | 0.51 | 0.46 |
| | BK | 4.2 | $1,909 | $23,973 | 13 | $16,810 | 9 | $21,585 | 11 | 0.44 | 0.51 | 0.46 |
| | PS | 4.3 | $1,935 | $24,572 | 13 | $17,213 | 9 | $22,119 | 11 | 0.46 | 0.54 | 0.48 |
| Electric-Only | LA | 3.8 | $943 | $21,830 | 23 | $15,253 | 16 | $19,638 | 21 | 0.33 | 0.39 | 0.35 |
| | PA | 3.9 | $1,478 | $23,278 | 16 | $16,545 | 11 | $21,034 | 14 | 0.34 | 0.40 | 0.36 |
| | RV | 4.0 | $1,506 | $23,423 | 16 | $16,534 | 11 | $21,127 | 14 | 0.31 | 0.35 | 0.32 |
| | BK | 3.9 | $1,394 | $33,315 | 24 | $26,582 | 19 | $31,071 | 22 | 0.35 | 0.39 | 0.36 |
| | PS | 5.0 | $2,011 | $28,058 | 14 | $19,633 | 10 | $25,250 | 13 | 0.38 | 0.45 | 0.40 |

* Compared to baseline electric-only home

**Table 133. Impacts of Incentives on Incremental Cost, Payback, and TRC Values – Home A**

| Category | Location | PV System Size (kW) | Simple Payback w/ Federal Incentives | | | | | | | TRC Values w/ Federal Incentives (NPV Incremental Life-Cycle Costs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Annual Utility Savings* | No Incentive | | 30% Federal Tax Credit | | 10% Federal Tax Credit | | Baseline TRC* | TRC w/ 30% Federal Tax Credit* | TRC w/ 10% Federal Tax Credit* |
| | | | | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | | | |
| Mixed-Fuel | LA | 2.9 | $689 | $17,031 | 25 | $11,876 | 17 | $15,313 | 22 | 0.36 | 0.42 | 0.38 |
| | PA | 3.0 | $1,029 | $17,779 | 17 | $12,420 | 12 | $15,992 | 16 | 0.37 | 0.43 | 0.39 |
| | RV | 3.2 | $1,092 | $18,551 | 17 | $12,956 | 12 | $16,686 | 15 | 0.37 | 0.43 | 0.39 |
| | BK | 3.5 | $1,343 | $20,799 | 15 | $14,681 | 11 | $18,760 | 14 | 0.41 | 0.48 | 0.43 |
| | PS | 3.8 | $1,441 | $21,936 | 15 | $15,350 | 11 | $19,740 | 14 | 0.42 | 0.50 | 0.45 |
| Electric-Only | LA | 3.1 | $747 | $18,054 | 24 | $12,650 | 17 | $16,253 | 22 | 0.28 | 0.33 | 0.30 |
| | PA | 3.2 | $1,029 | $18,744 | 18 | $13,133 | 13 | $16,874 | 16 | 0.29 | 0.34 | 0.31 |
| | RV | 3.2 | $1,102 | $19,297 | 18 | $13,595 | 12 | $17,396 | 16 | 0.29 | 0.34 | 0.31 |
| | BK | 3.6 | $952 | $22,380 | 23 | $16,186 | 17 | $20,315 | 21 | 0.32 | 0.38 | 0.34 |
| | PS | 3.9 | $1,473 | $22,200 | 15 | $15,520 | 11 | $19,974 | 14 | 0.37 | 0.43 | 0.39 |

* Compared to baseline electric-only home

**Table 134. Impacts of Incentives on Incremental Cost, Payback, and TRC Values – Home C**

| Category | Location | PV System Size (kW) | Simple Payback w/ Federal Incentives | | | | | | | TRC Values w/ Federal Incentives (NPV Incremental Life-Cycle Costs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Annual Utility Savings* | No Incentive | | 30% Federal Tax Credit | | 10% Federal Tax Credit | | Baseline TRC* | TRC w/ 30% Federal Tax Credit* | TRC w/ 10% Federal Tax Credit* |
| | | | | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | | | |
| **Mixed-Fuel** | LA | 3.7 | $990 | $19,805 | 20 | $13,382 | 14 | $17,664 | 18 | 0.49 | 0.58 | 0.51 |
| | PA | 3.9 | $1,665 | $20,903 | 13 | $14,155 | 9 | $18,654 | 11 | 0.50 | 0.60 | 0.53 |
| | RV | 4.1 | $1,740 | $21,948 | 13 | $14,877 | 9 | $19,591 | 11 | 0.44 | 0.52 | 0.46 |
| | BK | 4.7 | $2,188 | $25,213 | 12 | $17,252 | 8 | $22,559 | 10 | 0.49 | 0.59 | 0.52 |
| | PS | 5.2 | $2,193 | $27,228 | 12 | $18,514 | 8 | $24,324 | 11 | 0.46 | 0.54 | 0.48 |
| **Electric-Only** | LA | 4.1 | $1,032 | $23,670 | 23 | $16,593 | 16 | $21,311 | 21 | 0.31 | 0.36 | 0.33 |
| | PA | 4.3 | $1,633 | $24,732 | 15 | $17,374 | 11 | $22,279 | 14 | 0.32 | 0.38 | 0.34 |
| | RV | 4.4 | $1,729 | $25,395 | 15 | $17,876 | 10 | $22,889 | 13 | 0.32 | 0.38 | 0.34 |
| | BK | 4.9 | $1,319 | $27,361 | 21 | $19,051 | 14 | $24,591 | 19 | 0.37 | 0.43 | 0.39 |
| | PS | 5.5 | $2,211 | $30,562 | 14 | $21,455 | 10 | $27,526 | 12 | 0.37 | 0.43 | 0.39 |

* Compared to baseline electric-only home

### *How to Interpret the Following Tables*

Table 135 through Table 137 provide the impacts of future solar PV cost projections over the period of 2015 to 2030 on incremental cost, payback, and TRC values for each home design, location, and fuel type. The analysis assumed a 14% reduction by 2020 and 37% reduction by 2030 using a 2.5% annual cost reduction against 2014 solar PV costs. Historically, the estimated installed cost per capacity for residential solar PV systems has decreased by over 5% annually.[86]

**Table 135. Impacts of Future Solar PV Costs on Incremental Cost, Payback, and TRC Values – Home B**

| Category | Location | PV System Size (kW) | Incremental Cost and Simple Payback w/ Future Solar PV Cost Projections (2020-2030) | | | | | | | TRC Values w/ Current and Future Solar PV Cost Projections (Incremental Upfront Costs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Annual Utility Savings* | Current Solar PV Cost | | 2020 Solar PV Cost Projections (14% less) | | 2030 Solar PV Cost Projections (37% less) | | Current* | 2020 Solar PV Cost Projections (14%)* | 2030 Solar PV Cost Projections (37%)* |
| | | | | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | | | |
| Mixed-Fuel | LA | 3.4 | $878 | $20,547 | 23 | $17,777 | 20 | $13,358 | 15 | 0.86 | 0.99 | 1.32 |
| | PA | 3.4 | $1,446 | $20,793 | 14 | $17,957 | 12 | $13,432 | 9 | 0.89 | 1.03 | 1.38 |
| | RV | 3.6 | $1,524 | $21,539 | 14 | $18,557 | 12 | $13,801 | 9 | 0.87 | 1.00 | 1.35 |
| | BK | 4.2 | $1,909 | $23,973 | 13 | $20,599 | 11 | $15,217 | 8 | 0.92 | 1.07 | 1.45 |
| | PS | 4.3 | $1,935 | $24,572 | 13 | $21,106 | 11 | $15,577 | 8 | 0.96 | 1.11 | 1.51 |
| Electric-Only | LA | 3.8 | $943 | $21,830 | 23 | $18,756 | 20 | $13,852 | 15 | 0.66 | 0.77 | 1.05 |
| | PA | 3.9 | $1,478 | $23,278 | 16 | $20,091 | 14 | $15,007 | 10 | 0.66 | 0.76 | 1.02 |
| | RV | 4.0 | $1,506 | $23,423 | 16 | $20,159 | 13 | $14,953 | 10 | 0.66 | 0.76 | 1.03 |
| | BK | 3.9 | $1,394 | $33,315 | 24 | $30,138 | 22 | $25,070 | 18 | 0.57 | 0.63 | 0.76 |
| | PS | 5.0 | $2,011 | $28,058 | 14 | $24,122 | 12 | $17,842 | 9 | 0.74 | 0.86 | 1.17 |

[86] Barbose et al. 2014. "Tracking the Sun VII - An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2013." Lawrence Berkeley National Laboratory. September 2014.

* Compared to baseline electric-only home

**Table 136. Impacts of Future Solar PV Costs on Incremental Cost, Payback, and TRC Values – Home A**

| Category | Location | PV System Size (kW) | Incremental Cost and Simple Payback w/ Future Solar PV Cost Projections (2020-2030) | | | | | | | TRC Values w/ Current and Future Solar PV Cost Projections (Incremental Upfront Costs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Annual Utility Savings* | Current Solar PV Cost | | 2020 Solar PV Cost Projections (14% less) | | 2030 Solar PV Cost Projections (37% less) | | Current* | 2020 Solar PV Cost Projections (14%)* | 2030 Solar PV Cost Projections (37%)* |
| | | | | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | | | |
| Mixed-Fuel | LA | 2.9 | $689 | $17,031 | 25 | $14,603 | 21 | $10,730 | 16 | 0.80 | 0.95 | 1.29 |
| | PA | 3.0 | $1,029 | $17,779 | 17 | $15,255 | 15 | $11,229 | 11 | 0.80 | 0.95 | 1.29 |
| | RV | 3.2 | $1,092 | $18,551 | 17 | $15,916 | 15 | $11,713 | 11 | 0.77 | 0.92 | 1.25 |
| | BK | 3.5 | $1,343 | $20,799 | 15 | $17,918 | 13 | $13,321 | 10 | 0.81 | 0.95 | 1.28 |
| | PS | 3.8 | $1,441 | $21,936 | 15 | $18,834 | 13 | $13,885 | 10 | 0.80 | 0.95 | 1.29 |
| Electric-Only | LA | 3.1 | $747 | $18,054 | 24 | $15,509 | 21 | $11,448 | 15 | 0.63 | 0.74 | 1.00 |
| | PA | 3.2 | $1,029 | $18,744 | 18 | $16,102 | 16 | $11,886 | 12 | 0.64 | 0.74 | 1.01 |
| | RV | 3.2 | $1,102 | $19,297 | 18 | $16,611 | 15 | $12,327 | 11 | 0.63 | 0.73 | 0.98 |
| | BK | 3.6 | $952 | $22,380 | 23 | $19,463 | 20 | $14,809 | 16 | 0.63 | 0.73 | 0.96 |
| | PS | 3.9 | $1,473 | $22,200 | 15 | $19,054 | 13 | $14,035 | 10 | 0.72 | 0.84 | 1.14 |

* Compared to baseline electric-only home

**Table 137. Impacts of Future Solar PV Costs on Incremental Cost, Payback, and TRC Values – Home C**

| Category | Location | PV System Size (kW) | Incremental Cost and Simple Payback w/ Future Solar PV Cost Projections (2020-2030) | | | | | | | TRC Values w/ Current and Future Solar PV Cost Projections (Incremental Upfront Costs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Annual Utility Savings* | Current Solar PV Cost | | 2020 Solar PV Cost Projections (14% less) | | 2030 Solar PV Cost Projections (37% less) | | Current* | 2020 Solar PV Cost Projections (14%)* | 2030 Solar PV Cost Projections (37%)* |
| | | | | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | Incremental Cost* | Simple Payback* | | | |
| Mixed-Fuel | LA | 3.7 | $990 | $19,805 | 20 | $18,575 | 19 | $13,749 | 14 | 0.88 | 1.03 | 1.39 |
| | PA | 3.9 | $1,665 | $20,903 | 13 | $19,551 | 12 | $14,480 | 9 | 0.88 | 1.03 | 1.39 |
| | RV | 4.1 | $1,740 | $21,948 | 13 | $20,473 | 12 | $15,161 | 9 | 0.85 | 0.99 | 1.34 |
| | BK | 4.7 | $2,188 | $25,213 | 12 | $23,418 | 11 | $17,437 | 8 | 0.88 | 1.02 | 1.38 |
| | PS | 5.2 | $2,193 | $27,228 | 12 | $25,178 | 11 | $18,630 | 8 | 0.88 | 1.02 | 1.38 |
| Electric-Only | LA | 4.1 | $1,032 | $23,670 | 23 | $20,337 | 20 | $15,020 | 15 | 0.67 | 0.78 | 1.06 |
| | PA | 4.3 | $1,633 | $24,732 | 15 | $21,266 | 13 | $15,738 | 10 | 0.68 | 0.79 | 1.06 |
| | RV | 4.4 | $1,729 | $25,395 | 15 | $21,854 | 13 | $16,204 | 9 | 0.66 | 0.77 | 1.04 |
| | BK | 4.9 | $1,319 | $27,361 | 21 | $23,447 | 18 | $17,204 | 13 | 0.72 | 0.84 | 1.14 |
| | PS | 5.5 | $2,211 | $30,562 | 14 | $26,273 | 12 | $19,431 | 9 | 0.75 | 0.87 | 1.18 |

* Compared to baseline electric-only home

## G.2 Advanced Technology Results

### *How to Interpret the Following Tables*

Table 138 through Table 142 provide the TDV benefits of mCHP systems of various efficiencies and capacities for the Home B configuration in each location. The analysis assumed performance and costs detailed in Appendix E.1. Our analysis first evaluated whether the mCHP system could provide a net TDV benefit for a specific mixed-fuel home in each location under the range of performance characteristics (e.g., capacity, thermal efficiency, electrical efficiency). We modeled each mCHP system at a range of capacities (0.5-5 kW) to understand how net TDV value changes once the mCHP system satisfies the home's thermal loads. mCHP efficiency and capacity combinations highlighted in each table denotes positive TDV energy benefit. In these cases, the annual electrical and thermal output of the mCHP system on a TDV energy basis is greater than the thermal energy input on a TDV basis.

**Table 138. TDV Benefit of mCHP Systems in Los Angeles – Home B**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -520 | -1073 | -1627 | -2181 | -3288 | -5502 |
| | Medium | 22% | 54% | -10 | -49 | -90 | -131 | -213 | -378 |
| | High | 25% | 68% | 4 | -21 | -48 | -75 | -130 | -238 |
| Fuel Cell | Low | 30% | 65% | 18 | 8 | -4 | -16 | -41 | -91 |
| | Medium | 38% | 39% | 29 | 36 | 41 | 45 | 52 | 65 |
| | High | 60% | 24% | 38 | 72 | 100 | 127 | 178 | 277 |

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**Table 139. TDV Benefit of mCHP Systems in Pasadena – Home B**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -523 | -1076 | -1630 | -2184 | -3291 | -5507 |
| | Medium | 22% | 54% | -13 | -52 | -93 | -134 | -217 | -383 |
| | High | 25% | 68% | 2 | -24 | -51 | -79 | -133 | -243 |
| Fuel Cell | Low | 30% | 65% | 16 | 5 | -7 | -19 | -45 | -96 |
| | Medium | 38% | 39% | 28 | 34 | 38 | 42 | 48 | 60 |
| | High | 60% | 24% | 38 | 71 | 98 | 124 | 174 | 273 |

**Table 140. TDV Benefit of mCHP Systems in Riverside – Home B**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -519 | -1073 | -1627 | -2181 | -3289 | -5504 |
| | Medium | 22% | 54% | -11 | -49 | -90 | -131 | -214 | -380 |
| | High | 25% | 68% | 3 | -21 | -48 | -76 | -131 | -241 |
| Fuel Cell | Low | 30% | 65% | 17 | 8 | -4 | -17 | -42 | -93 |
| | Medium | 38% | 39% | 28 | 35 | 40 | 44 | 51 | 62 |
| | High | 60% | 24% | 38 | 71 | 98 | 124 | 175 | 274 |

**Table 141. TDV Benefit of mCHP Systems in Bakersfield – Home B**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -506 | -1059 | -1613 | -2167 | -3274 | -5489 |
| | Medium | 22% | 54% | -6 | -38 | -76 | -117 | -200 | -365 |
| | High | 25% | 68% | 9 | -9 | -34 | -61 | -116 | -226 |
| Fuel Cell | Low | 30% | 65% | 21 | 18 | 9 | -3 | -27 | -78 |
| | Medium | 38% | 39% | 28 | 39 | 47 | 54 | 64 | 77 |
| | High | 60% | 24% | 38 | 70 | 99 | 127 | 181 | 285 |

**Table 142. TDV Benefit of mCHP Systems in Palm Springs – Home B**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -532 | -1085 | -1639 | -2193 | -3301 | -5517 |
| | Medium | 22% | 54% | -20 | -61 | -102 | -144 | -227 | -393 |
| | High | 25% | 68% | -6 | -33 | -60 | -88 | -143 | -253 |
| Fuel Cell | Low | 30% | 65% | 8 | -3 | -16 | -29 | -55 | -106 |
| | Medium | 38% | 39% | 23 | 27 | 30 | 33 | 39 | 50 |
| | High | 60% | 24% | 37 | 67 | 92 | 117 | 166 | 263 |

### *How to Interpret the Following Tables*

Table 143 through Table 147 provide the cost-effectiveness of mCHP systems of various efficiencies and capacities for the Home B configuration in each location. The analysis assumed mCHP performance and costs detailed in Appendix E.1 and solar PV system costs for each location. We then compared the mCHP system's benefits on a $/TDV basis to a solar PV system to understand whether the mCHP system may offer a lower cost to reach ZNE status. mCHP efficiency and capacity combinations highlighted denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase. To displace solar PV capacity for ZNE homes, mCHP systems must show lower $/TDV production for the 30 year life of the home. Because the lifetime for solar PV systems (25 years) is substantially longer than the useful life than mCHP systems (15 years), we compared the purchase costs of the two technologies on a net present value basis.[87]

**Table 143. Cost-Effectiveness of mCHP Systems in Los Angeles – Home B**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $375 | $20/W | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 | $20/W | $917 | $3,928 | -$13,307 | -$4,072 | -$2,401 | -$1,808 |
| | Medium | | | -$1,633 | -$673 | -$549 | -$502 | -$462 | -$435 | | $567 | $906 | $1,193 | $1,445 | $1,889 | $2,545 |
| | High | | | $3,863 | -$1,576 | -$1,027 | -$874 | -$760 | -$689 | | $429 | $455 | $491 | $519 | $555 | $592 |
| Medium | Low | $375 | $15/W | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $688 | $2,946 | -$9,981 | -$3,054 | -$1,801 | -$1,356 |
| | Medium | | | -$1,225 | -$505 | -$412 | -$376 | -$347 | -$326 | | $425 | $680 | $895 | $1,084 | $1,417 | $1,909 |
| | High | | | $2,897 | -$1,182 | -$770 | -$655 | -$570 | -$517 | | $322 | $342 | $368 | $389 | $416 | $444 |
| Low | Low | $375 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $459 | $1,964 | -$6,654 | -$2,036 | -$1,201 | -$904 |
| | Medium | | | -$408 | -$168 | -$137 | -$125 | -$116 | -$109 | | $283 | $453 | $597 | $722 | $945 | $1,272 |
| | High | | | $966 | -$394 | -$257 | -$218 | -$190 | -$172 | | $214 | $228 | $245 | $260 | $277 | $296 |

[87] Assumes only upfront purchase and subsequent replacement costs, and does not include any assumptions for reduced purchase costs in future, residual value, efficiency degradation, operating costs, maintenance costs, or component replacement (e.g., inverter).

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Table 144. Cost-Effectiveness of mCHP Systems in Pasadena – Home B

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $321 | $20/W | -$31 | -$31 | -$30 | -$30 | -$30 | -$30 | $20/W | $1,059 | $6,101 | -$7,232 | -$3,372 | -$2,196 | -$1,717 |
| | Medium | | | -$1,309 | -$635 | -$530 | -$489 | -$454 | -$429 | | $596 | $976 | $1,290 | $1,564 | $2,039 | $2,748 |
| | High | | | $9,557 | -$1,383 | -$965 | -$837 | -$738 | -$675 | | $432 | $463 | $502 | $531 | $567 | $602 |
| Medium | Low | $321 | $15/W | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $794 | $4,576 | -$5,424 | -$2,529 | -$1,647 | -$1,288 |
| | Medium | | | -$982 | -$476 | -$398 | -$367 | -$340 | -$322 | | $447 | $732 | $967 | $1,173 | $1,529 | $2,061 |
| | High | | | $7,168 | -$1,037 | -$723 | -$627 | -$554 | -$506 | | $324 | $347 | $376 | $398 | $425 | $452 |
| Low | Low | $321 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $530 | $3,051 | -$3,616 | -$1,686 | -$1,098 | -$859 |
| | Medium | | | -$327 | -$159 | -$133 | -$122 | -$113 | -$107 | | $298 | $488 | $645 | $782 | $1,020 | $1,374 |
| | High | | | $2,389 | -$346 | -$241 | -$209 | -$185 | -$169 | | $216 | $231 | $251 | $266 | $283 | $301 |

Table 145. Cost-Effectiveness of mCHP Systems in Riverside – Home B

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $315 | $20/W | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 | $20/W | $977 | $4,244 | -$12,381 | -$3,958 | -$2,335 | -$1,758 |
| | Medium | | | -$1,494 | -$668 | -$548 | -$500 | -$460 | -$432 | | $594 | $945 | $1,235 | $1,491 | $1,941 | $2,650 |
| | High | | | $4,820 | -$1,561 | -$1,024 | -$869 | -$754 | -$681 | | $434 | $464 | $501 | $529 | $564 | $599 |
| Medium | Low | $315 | $15/W | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $733 | $3,183 | -$9,286 | -$2,968 | -$1,751 | -$1,319 |
| | Medium | | | -$1,121 | -$501 | -$411 | -$375 | -$345 | -$324 | | $446 | $709 | $926 | $1,118 | $1,456 | $1,988 |
| | High | | | $3,615 | -$1,171 | -$768 | -$651 | -$565 | -$511 | | $326 | $348 | $376 | $397 | $423 | $450 |
| Low | Low | $315 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $489 | $2,122 | -$6,191 | -$1,979 | -$1,168 | -$879 |
| | Medium | | | -$374 | -$167 | -$137 | -$125 | -$115 | -$108 | | $297 | $473 | $618 | $745 | $971 | $1,325 |
| | High | | | $1,205 | -$390 | -$256 | -$217 | -$188 | -$170 | | $217 | $232 | $251 | $265 | $282 | $300 |

**Table 146. Cost-Effectiveness of mCHP Systems in Bakersfield – Home B**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $299 | $20/W | -$32 | -$31 | -$31 | -$30 | -$30 | -$30 | $20/W | $781 | $1,852 | $5,605 | -$26,058 | -$3,583 | -$2,107 |
| | Medium | | | -$2,962 | -$862 | -$644 | -$561 | -$493 | -$450 | | $596 | $848 | $1,040 | $1,216 | $1,545 | $2,122 |
| | High | | | $1,729 | -$3,457 | -$1,434 | -$1,071 | -$849 | -$728 | | $437 | $466 | $497 | $518 | $545 | $576 |
| Medium | Low | $299 | $15/W | -$24 | -$23 | -$23 | -$23 | -$23 | -$22 | $15/W | $586 | $1,389 | $4,204 | -$19,543 | -$2,687 | -$1,580 |
| | Medium | | | -$2,221 | -$647 | -$483 | -$421 | -$370 | -$337 | | $447 | $636 | $780 | $912 | $1,158 | $1,591 |
| | High | | | $1,297 | -$2,593 | -$1,076 | -$803 | -$637 | -$546 | | $328 | $350 | $373 | $389 | $409 | $432 |
| Low | Low | $299 | $5/W | -$8 | -$8 | -$8 | -$8 | -$8 | -$7 | $10/W | $391 | $926 | $2,803 | -$13,029 | -$1,792 | -$1,053 |
| | Medium | | | -$740 | -$216 | -$161 | -$140 | -$123 | -$112 | | $298 | $424 | $520 | $608 | $772 | $1,061 |
| | High | | | $432 | -$864 | -$359 | -$268 | -$212 | -$182 | | $219 | $233 | $248 | $259 | $273 | $288 |

**Table 147. Cost-Effectiveness of mCHP Systems in Palm Springs – Home B**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $355 | $20/W | -$31 | -$30 | -$30 | -$30 | -$30 | -$30 | $20/W | $1,951 | -$9,445 | -$3,064 | -$2,273 | -$1,807 | -$1,552 |
| | Medium | | | -$819 | -$541 | -$482 | -$457 | -$435 | -$418 | | $725 | $1,235 | $1,646 | $1,992 | $2,548 | $3,315 |
| | High | | | -$2,743 | -$1,000 | -$816 | -$747 | -$689 | -$648 | | $441 | $489 | $533 | $561 | $594 | $625 |
| Medium | Low | $355 | $15/W | -$23 | -$23 | -$23 | -$22 | -$22 | -$22 | $15/W | $1,463 | -$7,084 | -$2,298 | -$1,705 | -$1,355 | -$1,164 |
| | Medium | | | -$614 | -$405 | -$362 | -$343 | -$326 | -$314 | | $544 | $927 | $1,235 | $1,494 | $1,911 | $2,486 |
| | High | | | -$2,057 | -$750 | -$612 | -$560 | -$516 | -$486 | | $330 | $367 | $400 | $421 | $446 | $469 |
| Low | Low | $355 | $5/W | -$8 | -$8 | -$8 | -$7 | -$7 | -$7 | $10/W | $975 | -$4,723 | -$1,532 | -$1,137 | -$903 | -$776 |
| | Medium | | | -$205 | -$135 | -$121 | -$114 | -$109 | -$105 | | $363 | $618 | $823 | $996 | $1,274 | $1,657 |
| | High | | | -$686 | -$250 | -$204 | -$187 | -$172 | -$162 | | $220 | $245 | $266 | $281 | $297 | $312 |

***How to Interpret the Following Tables***

Table 148 through Table 152 provide the TDV benefits of mCHP systems of various efficiencies and capacities for the Home A configuration in each location. The analysis assumed performance and costs detailed in Appendix E.1. Our analysis first evaluated whether the mCHP system could provide a net TDV benefit for a specific mixed-fuel home in each location under the range of performance characteristics (e.g., capacity, thermal efficiency, electrical efficiency). We modeled each mCHP system at a range of capacities (0.5-5 kW) to understand how net TDV value changes once the mCHP system satisfies the home's thermal loads. mCHP efficiency and capacity combinations highlighted in each table denotes positive TDV energy benefit. In these cases, the annual electrical and thermal output of the mCHP system on a TDV energy basis is greater than the thermal energy input on a TDV basis.

**Table 148. TDV Benefit of mCHP Systems in Los Angeles – Home A**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -520 | -1073 | -1627 | -2181 | -3288 | -5502 |
| | Medium | 22% | 54% | -10 | -49 | -90 | -131 | -213 | -378 |
| | High | 25% | 68% | 4 | -21 | -48 | -75 | -130 | -238 |
| Fuel Cell | Low | 30% | 65% | 18 | 8 | -4 | -16 | -41 | -91 |
| | Medium | 38% | 39% | 29 | 36 | 41 | 45 | 52 | 65 |
| | High | 60% | 24% | 38 | 72 | 100 | 127 | 178 | 277 |

**Table 149. TDV Benefit of mCHP Systems in Pasadena – Home A**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -528 | -1082 | -1635 | -2189 | -3296 | -5510 |
| | Medium | 22% | 54% | -17 | -57 | -98 | -139 | -222 | -386 |
| | High | 25% | 68% | -2 | -29 | -56 | -84 | -138 | -247 |
| Fuel Cell | Low | 30% | 65% | 12 | 0 | -12 | -24 | -49 | -99 |
| | Medium | 38% | 39% | 24 | 30 | 34 | 38 | 44 | 56 |
| | High | 60% | 24% | 38 | 69 | 95 | 121 | 171 | 270 |

**Table 150. TDV Benefit of mCHP Systems in Riverside – Home A**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -530 | -1084 | -1637 | -2191 | -3298 | -5512 |
| | Medium | 22% | 54% | -19 | -59 | -100 | -141 | -224 | -388 |
| | High | 25% | 68% | -4 | -31 | -58 | -86 | -140 | -249 |
| Fuel Cell | Low | 30% | 65% | 10 | -2 | -14 | -27 | -51 | -101 |
| | Medium | 38% | 39% | 23 | 28 | 32 | 36 | 42 | 54 |
| | High | 60% | 24% | 38 | 68 | 94 | 119 | 169 | 268 |

**Table 151. TDV Benefit of mCHP Systems in Bakersfield – Home A**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -541 | -1095 | -1648 | -2202 | -3309 | -5523 |
| | Medium | 22% | 54% | -29 | -70 | -111 | -152 | -235 | -399 |
| | High | 25% | 68% | -15 | -42 | -69 | -97 | -151 | -260 |
| Fuel Cell | Low | 30% | 65% | -1 | -13 | -25 | -38 | -62 | -112 |
| | Medium | 38% | 39% | 13 | 18 | 21 | 25 | 31 | 43 |
| | High | 60% | 24% | 30 | 58 | 84 | 109 | 158 | 257 |

**Table 152. TDV Benefit of mCHP Systems in Palm Springs – Home A**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -528 | -1082 | -1635 | -2189 | -3296 | -5510 |
| | Medium | 22% | 54% | -17 | -57 | -98 | -139 | -221 | -386 |
| | High | 25% | 68% | -3 | -29 | -56 | -83 | -138 | -247 |
| Fuel Cell | Low | 30% | 65% | 11 | 0 | -12 | -24 | -49 | -99 |
| | Medium | 38% | 39% | 23 | 29 | 34 | 38 | 44 | 56 |
| | High | 60% | 24% | 37 | 68 | 94 | 120 | 170 | 270 |

***How to Interpret the Following Tables***

Table 153 through Table 157 provide the cost-effectiveness of mCHP systems of various efficiencies and capacities for the Home A configuration in each location. The analysis assumed mCHP performance and costs detailed in Appendix E.1 and solar PV system costs for each location. We then compared the mCHP system's benefits on a $/TDV basis to a solar PV system to understand whether the mCHP system may offer a lower cost to reach ZNE status. mCHP efficiency and capacity combinations highlighted denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase. To displace solar PV capacity for ZNE homes, mCHP systems must show lower $/TDV production for the 30 year life of the home. Because the lifetime for solar PV systems (25 years) is substantially longer than the useful life than mCHP systems (15 years), we compared the purchase costs of the two technologies on a net present value basis.[88]

**Table 153. Cost-Effectiveness of mCHP Systems in Los Angeles – Home A**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $310 | $20/W | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 | $20/W | $917 | $3,928 | -$13,307 | -$4,072 | -$2,401 | -$1,808 |
| | Medium | | | -$1,633 | -$673 | -$549 | -$502 | -$462 | -$435 | | $567 | $906 | $1,193 | $1,445 | $1,889 | $2,545 |
| | High | | | $3,863 | -$1,576 | -$1,027 | -$874 | -$760 | -$689 | | $429 | $455 | $491 | $519 | $555 | $592 |
| Medium | Low | $310 | $15/W | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $688 | $2,946 | -$9,981 | -$3,054 | -$1,801 | -$1,356 |
| | Medium | | | -$1,225 | -$505 | -$412 | -$376 | -$347 | -$326 | | $425 | $680 | $895 | $1,084 | $1,417 | $1,909 |
| | High | | | $2,897 | -$1,182 | -$770 | -$655 | -$570 | -$517 | | $322 | $342 | $368 | $389 | $416 | $444 |
| Low | Low | $310 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $459 | $1,964 | -$6,654 | -$2,036 | -$1,201 | -$904 |
| | Medium | | | -$408 | -$168 | -$137 | -$125 | -$116 | -$109 | | $283 | $453 | $597 | $722 | $945 | $1,272 |
| | High | | | $966 | -$394 | -$257 | -$218 | -$190 | -$172 | | $214 | $228 | $245 | $260 | $277 | $296 |

[88] Assumes only upfront purchase and subsequent replacement costs, and does not include any assumptions for reduced purchase costs in future, residual value, efficiency degradation, operating costs, maintenance costs, or component replacement (e.g., inverter).

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**Table 154. Cost-Effectiveness of mCHP Systems in Pasadena – Home A**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $310 | $20/W | -$31 | -$30 | -$30 | -$30 | -$30 | -$30 | $20/W | $1,412 | $88,533 | -$4,088 | -$2,681 | -$1,994 | -$1,655 |
| | Medium | | | -$989 | -$576 | -$502 | -$472 | -$445 | -$425 | | $678 | $1,093 | $1,437 | $1,747 | $2,249 | $2,924 |
| | High | | | -$6,710 | -$1,128 | -$875 | -$786 | -$714 | -$665 | | $435 | $478 | $518 | $544 | $576 | $609 |
| Medium | Low | $310 | $15/W | -$23 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $1,059 | $66,399 | -$3,066 | -$2,011 | -$1,496 | -$1,241 |
| | Medium | | | -$742 | -$432 | -$376 | -$354 | -$333 | -$319 | | $509 | $819 | $1,078 | $1,310 | $1,687 | $2,193 |
| | High | | | -$5,033 | -$846 | -$656 | -$590 | -$536 | -$499 | | $327 | $359 | $388 | $408 | $432 | $457 |
| Low | Low | $310 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $706 | $44,266 | -$2,044 | -$1,340 | -$997 | -$828 |
| | Medium | | | -$247 | -$144 | -$125 | -$118 | -$111 | -$106 | | $339 | $546 | $719 | $873 | $1,124 | $1,462 |
| | High | | | -$1,678 | -$282 | -$219 | -$197 | -$179 | -$166 | | $218 | $239 | $259 | $272 | $288 | $304 |

**Table 155. Cost-Effectiveness of mCHP Systems in Riverside – Home A**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $310 | $20/W | -$31 | -$30 | -$30 | -$30 | -$30 | -$30 | $20/W | $1,693 | -$19,579 | -$3,492 | -$2,473 | -$1,915 | -$1,622 |
| | Medium | | | -$883 | -$556 | -$492 | -$465 | -$441 | -$423 | | $718 | $1,166 | $1,529 | $1,848 | $2,359 | $3,035 |
| | High | | | -$3,667 | -$1,053 | -$844 | -$767 | -$704 | -$660 | | $437 | $485 | $526 | $552 | $583 | $613 |
| Medium | Low | $310 | $15/W | -$23 | -$23 | -$23 | -$22 | -$22 | -$22 | $15/W | $1,270 | -$14,684 | -$2,619 | -$1,855 | -$1,436 | -$1,216 |
| | Medium | | | -$662 | -$417 | -$369 | -$349 | -$330 | -$317 | | $539 | $875 | $1,147 | $1,386 | $1,770 | $2,276 |
| | High | | | -$2,750 | -$790 | -$633 | -$576 | -$528 | -$495 | | $327 | $364 | $395 | $414 | $437 | $460 |
| Low | Low | $310 | $5/W | -$8 | -$8 | -$8 | -$7 | -$7 | -$7 | $10/W | $846 | -$9,790 | -$1,746 | -$1,237 | -$957 | -$811 |
| | Medium | | | -$221 | -$139 | -$123 | -$116 | -$110 | -$106 | | $359 | $583 | $765 | $924 | $1,180 | $1,518 |
| | High | | | -$917 | -$263 | -$211 | -$192 | -$176 | -$165 | | $218 | $243 | $263 | $276 | $291 | $307 |

**Table 156. Cost-Effectiveness of mCHP Systems in Bakersfield – Home A**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $306 | $20/W | -$30 | -$30 | -$30 | -$30 | -$30 | -$30 | $20/W | -$18,298 | -$2,591 | -$1,962 | -$1,749 | -$1,577 | -$1,463 |
| | Medium | | | -$560 | -$469 | -$443 | -$431 | -$420 | -$411 | | $1,262 | $1,864 | $2,308 | $2,674 | $3,203 | $3,810 |
| | High | | | -$1,075 | -$779 | -$710 | -$680 | -$652 | -$632 | | $541 | $565 | $589 | $604 | $622 | $640 |
| Medium | Low | $306 | $15/W | -$23 | -$22 | -$22 | -$22 | -$22 | -$22 | $15/W | -$13,723 | -$1,943 | -$1,471 | -$1,312 | -$1,183 | -$1,097 |
| | Medium | | | -$420 | -$352 | -$332 | -$323 | -$315 | -$308 | | $946 | $1,398 | $1,731 | $2,006 | $2,403 | $2,857 |
| | High | | | -$806 | -$584 | -$532 | -$510 | -$489 | -$474 | | $406 | $424 | $442 | $453 | $466 | $480 |
| Low | Low | $306 | $5/W | -$8 | -$7 | -$7 | -$7 | -$7 | -$7 | $10/W | -$9,149 | -$1,295 | -$981 | -$874 | -$789 | -$731 |
| | Medium | | | -$140 | -$117 | -$111 | -$108 | -$105 | -$103 | | $631 | $932 | $1,154 | $1,337 | $1,602 | $1,905 |
| | High | | | -$269 | -$195 | -$177 | -$170 | -$163 | -$158 | | $271 | $283 | $295 | $302 | $311 | $320 |

**Table 157. Cost-Effectiveness of mCHP Systems in Palm Springs – Home A**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $319 | $20/W | -$31 | -$30 | -$30 | -$30 | -$30 | -$30 | $20/W | $1,496 | $69,997 | -$4,174 | -$2,708 | -$2,005 | -$1,660 |
| | Medium | | | -$958 | -$578 | -$503 | -$472 | -$445 | -$425 | | $707 | $1,118 | $1,452 | $1,745 | $2,236 | $2,911 |
| | High | | | -$5,626 | -$1,137 | -$878 | -$789 | -$715 | -$666 | | $438 | $484 | $523 | $548 | $578 | $609 |
| Medium | Low | $319 | $15/W | -$23 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $1,122 | $52,498 | -$3,130 | -$2,031 | -$1,503 | -$1,245 |
| | Medium | | | -$719 | -$434 | -$377 | -$354 | -$334 | -$319 | | $530 | $838 | $1,089 | $1,309 | $1,677 | $2,183 |
| | High | | | -$4,220 | -$852 | -$659 | -$591 | -$537 | -$500 | | $328 | $363 | $392 | $411 | $433 | $457 |
| Low | Low | $319 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $748 | $34,999 | -$2,087 | -$1,354 | -$1,002 | -$830 |
| | Medium | | | -$240 | -$145 | -$126 | -$118 | -$111 | -$106 | | $353 | $559 | $726 | $872 | $1,118 | $1,455 |
| | High | | | -$1,407 | -$284 | -$220 | -$197 | -$179 | -$167 | | $219 | $242 | $261 | $274 | $289 | $304 |

***How to Interpret the Following Tables***

Table 158 through Table 162 provide the TDV benefits of mCHP systems of various efficiencies and capacities for the Home C configuration in each location. The analysis assumed performance and costs detailed in Appendix E.1. Our analysis first evaluated whether the mCHP system could provide a net TDV benefit for a specific mixed-fuel home in each location under the range of performance characteristics (e.g., capacity, thermal efficiency, electrical efficiency). We modeled each mCHP system at a range of capacities (0.5-5 kW) to understand how net TDV value changes once the mCHP system satisfies the home's thermal loads. mCHP efficiency and capacity combinations highlighted in each table denotes positive TDV energy benefit. In these cases, the annual electrical and thermal output of the mCHP system on a TDV energy basis is greater than the thermal energy input on a TDV basis.

**Table 158. TDV Benefit of mCHP Systems in Los Angeles – Home C**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -519 | -1072 | -1626 | -2179 | -3286 | -5501 |
| | Medium | 22% | 54% | -12 | -48 | -89 | -130 | -212 | -377 |
| | High | 25% | 68% | 3 | -20 | -47 | -74 | -128 | -237 |
| Fuel Cell | Low | 30% | 65% | 16 | 9 | -2 | -15 | -40 | -90 |
| | Medium | 38% | 39% | 24 | 34 | 40 | 46 | 53 | 66 |
| | High | 60% | 24% | 37 | 68 | 96 | 123 | 176 | 278 |

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**Table 159. TDV Benefit of mCHP Systems in Pasadena – Home C**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -520 | -1073 | -1627 | -2181 | -3288 | -5502 |
| | Medium | 22% | 54% | -11 | -49 | -90 | -131 | -213 | -378 |
| | High | 25% | 68% | 4 | -21 | -48 | -75 | -130 | -238 |
| Fuel Cell | Low | 30% | 65% | 17 | 8 | -4 | -16 | -41 | -91 |
| | Medium | 38% | 39% | 28 | 36 | 41 | 45 | 52 | 65 |
| | High | 60% | 24% | 38 | 72 | 100 | 126 | 177 | 277 |

**Table 160. TDV Benefit of mCHP Systems in Riverside – Home C**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -521 | -1075 | -1628 | -2182 | -3289 | -5503 |
| | Medium | 22% | 54% | -12 | -50 | -91 | -132 | -214 | -379 |
| | High | 25% | 68% | 2 | -22 | -49 | -76 | -131 | -240 |
| Fuel Cell | Low | 30% | 65% | 16 | 7 | -5 | -17 | -42 | -92 |
| | Medium | 38% | 39% | 28 | 34 | 39 | 44 | 51 | 63 |
| | High | 60% | 24% | 38 | 71 | 99 | 125 | 176 | 276 |

**Table 161. TDV Benefit of mCHP Systems in Bakersfield – Home C**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -521 | -1075 | -1628 | -2182 | -3289 | -5503 |
| | Medium | 22% | 54% | -12 | -51 | -91 | -132 | -214 | -379 |
| | High | 25% | 68% | 2 | -23 | -49 | -76 | -131 | -240 |
| Fuel Cell | Low | 30% | 65% | 16 | 6 | -5 | -17 | -42 | -92 |
| | Medium | 38% | 39% | 28 | 34 | 39 | 43 | 51 | 63 |
| | High | 60% | 24% | 38 | 72 | 99 | 125 | 176 | 275 |

**Table 162. TDV Benefit of mCHP Systems in Palm Springs – Home C**

| mCHP Category | Efficiency Class | Technology Efficiency | | TDV Benefit per mCHP Capacity (kW Electric) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Electrical Efficiency | Thermal Efficiency | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Engine-Based | Low | 4% | 85% | -531 | -1084 | -1638 | -2191 | -3298 | -5512 |
| | Medium | 22% | 54% | -20 | -60 | -100 | -142 | -224 | -388 |
| | High | 25% | 68% | -5 | -32 | -59 | -86 | -140 | -249 |
| Fuel Cell | Low | 30% | 65% | 9 | -2 | -14 | -27 | -52 | -102 |
| | Medium | 38% | 39% | 23 | 27 | 31 | 35 | 41 | 54 |
| | High | 60% | 24% | 38 | 68 | 94 | 119 | 168 | 267 |

***How to Interpret the Following Tables***

Table 163 through Table 167 provide the cost-effectiveness of mCHP systems of various efficiencies and capacities for the Home C configuration in each location. The analysis assumed mCHP performance and costs detailed in Appendix E.1 and solar PV system costs for each location. We then compared the mCHP system's benefits on a $/TDV basis to a solar PV system to understand whether the mCHP system may offer a lower cost to reach ZNE status. mCHP efficiency and capacity combinations highlighted denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase. To displace solar PV capacity for ZNE homes, mCHP systems must show lower $/TDV production for the 30 year life of the home. Because the lifetime for solar PV systems (25 years) is substantially longer than the useful life than mCHP systems (15 years), we compared the purchase costs of the two technologies on a net present value basis.[89]

**Table 163. Cost-Effectiveness of mCHP Systems in Los Angeles – Home C**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $309 | $20/W | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 | $20/W | $1,053 | $3,790 | -$19,827 | -$4,415 | -$2,477 | -$1,833 |
| | Medium | | | -$1,407 | -$684 | -$556 | -$507 | -$465 | -$436 | | $686 | $975 | $1,217 | $1,440 | $1,848 | $2,496 |
| | High | | | $5,543 | -$1,652 | -$1,055 | -$889 | -$768 | -$692 | | $444 | $485 | $516 | $535 | $561 | $592 |
| Medium | Low | $309 | $15/W | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $790 | $2,843 | -$14,871 | -$3,311 | -$1,858 | -$1,375 |
| | Medium | | | -$1,055 | -$513 | -$417 | -$380 | -$349 | -$327 | | $515 | $731 | $913 | $1,080 | $1,386 | $1,872 |
| | High | | | $4,158 | -$1,239 | -$791 | -$666 | -$576 | -$519 | | $333 | $364 | $387 | $401 | $421 | $444 |
| Low | Low | $309 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $527 | $1,895 | -$9,914 | -$2,207 | -$1,238 | -$917 |
| | Medium | | | -$352 | -$171 | -$139 | -$127 | -$116 | -$109 | | $343 | $488 | $609 | $720 | $924 | $1,248 |
| | High | | | $1,386 | -$413 | -$264 | -$222 | -$192 | -$173 | | $222 | $243 | $258 | $267 | $280 | $296 |

[89] Assumes only upfront purchase and subsequent replacement costs, and does not include any assumptions for reduced purchase costs in future, residual value, efficiency degradation, operating costs, maintenance costs, or component replacement (e.g., inverter).

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**Table 164. Cost-Effectiveness of mCHP Systems in Pasadena – Home C**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $352 | $20/W | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 | $20/W | $952 | $4,159 | -$13,143 | -$4,072 | -$2,401 | -$1,808 |
| | Medium | | | -$1,536 | -$670 | -$549 | -$502 | -$462 | -$435 | | $578 | $922 | $1,211 | $1,461 | $1,892 | $2,545 |
| | High | | | $4,538 | -$1,563 | -$1,027 | -$874 | -$760 | -$689 | | $432 | $459 | $494 | $522 | $557 | $593 |
| Medium | Low | $352 | $15/W | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $714 | $3,120 | -$9,858 | -$3,054 | -$1,801 | -$1,356 |
| | Medium | | | -$1,152 | -$502 | -$411 | -$376 | -$347 | -$326 | | $434 | $692 | $909 | $1,096 | $1,419 | $1,909 |
| | High | | | $3,404 | -$1,172 | -$770 | -$655 | -$570 | -$517 | | $324 | $344 | $370 | $391 | $418 | $445 |
| Low | Low | $352 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $476 | $2,080 | -$6,572 | -$2,036 | -$1,201 | -$904 |
| | Medium | | | -$384 | -$167 | -$137 | -$125 | -$116 | -$109 | | $289 | $461 | $606 | $731 | $946 | $1,272 |
| | High | | | $1,135 | -$391 | -$257 | -$218 | -$190 | -$172 | | $216 | $229 | $247 | $261 | $278 | $296 |

**Table 165. Cost-Effectiveness of mCHP Systems in Riverside – Home C**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | $430 | $20/W | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 | $20/W | $1,031 | $5,016 | -$9,974 | -$3,802 | -$2,336 | -$1,785 |
| | Medium | | | -$1,364 | -$652 | -$542 | -$497 | -$460 | -$433 | | $592 | $958 | $1,253 | $1,507 | $1,937 | $2,590 |
| | High | | | $7,230 | -$1,473 | -$1,003 | -$861 | -$754 | -$685 | | $429 | $460 | $498 | $527 | $561 | $596 |
| Medium | Low | $430 | $15/W | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | $15/W | $773 | $3,762 | -$7,480 | -$2,852 | -$1,752 | -$1,339 |
| | Medium | | | -$1,023 | -$489 | -$406 | -$373 | -$345 | -$325 | | $444 | $718 | $940 | $1,130 | $1,453 | $1,943 |
| | High | | | $5,423 | -$1,105 | -$752 | -$646 | -$565 | -$514 | | $322 | $345 | $374 | $395 | $421 | $447 |
| Low | Low | $430 | $5/W | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | $10/W | $515 | $2,508 | -$4,987 | -$1,901 | -$1,168 | -$893 |
| | Medium | | | -$341 | -$163 | -$135 | -$124 | -$115 | -$108 | | $296 | $479 | $627 | $753 | $969 | $1,295 |
| | High | | | $1,808 | -$368 | -$251 | -$215 | -$188 | -$171 | | $215 | $230 | $249 | $263 | $281 | $298 |

**Table 166. Cost-Effectiveness of mCHP Systems in Bakersfield – Home C**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | | | -$32 | -$31 | -$30 | -$30 | -$30 | -$30 | | $1,023 | $5,180 | -9659 | -3796 | -2336 | -1785 |
| | Medium | $317 | $20/W | -$1,368 | -$649 | -$541 | -$497 | -$460 | -$433 | $20/W | $585 | $953 | 1256 | 1513 | 1944 | 2591 |
| | High | | | $7,274 | -$1,459 | -$1,002 | -$861 | -$754 | -$685 | | $428 | $458 | 496 | 526 | 561 | 596 |
| Medium | Low | | | -$24 | -$23 | -$23 | -$23 | -$22 | -$22 | | $767 | $3,885 | -7244 | -2847 | -1752 | -1339 |
| | Medium | $317 | $15/W | -$1,026 | -$487 | -$406 | -$373 | -$345 | -$325 | $15/W | $439 | $715 | 942 | 1135 | 1458 | 1943 |
| | High | | | $5,456 | -$1,094 | -$752 | -$646 | -$565 | -$514 | | $321 | $344 | 372 | 394 | 421 | 447 |
| Low | Low | | | -$8 | -$8 | -$8 | -$8 | -$7 | -$7 | | $511 | $2,590 | -4829 | -1898 | -1168 | -893 |
| | Medium | $317 | $5/W | -$342 | -$162 | -$135 | -$124 | -$115 | -$108 | $10/W | $292 | $477 | $628 | $757 | $972 | $1,295 |
| | High | | | $1,819 | -$365 | -$251 | -$215 | -$188 | -$171 | | $214 | $229 | $248 | $263 | $280 | $298 |

**Table 167. Cost-Effectiveness of mCHP Systems in Palm Springs – Home C**

| mCHP Costs Category | mCHP Efficiency Class | Solar PV Costs | Engine-Based Costs ($/W) | Engine-Based mCHP $/TDV Savings | | | | | | Fuel Cell Costs ($/W) | Fuel Cell mCHP $/TDV Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW | | 0.5 kW | 1 kW | 1.5 kW | 2 kW | 3 kW | 5 kW |
| Current/ High | Low | | | -$31 | -$30 | -$30 | -$30 | -$30 | -$30 | | $1,849 | -$13,799 | -$3,413 | -$2,449 | -$1,905 | -$1,618 |
| | Medium | $295 | $20/W | -$841 | -$551 | -$490 | -$464 | -$440 | -$423 | $20/W | $715 | $1,199 | $1,576 | $1,888 | $2,380 | $3,050 |
| | High | | | -$3,018 | -$1,038 | -$840 | -$765 | -$702 | -$659 | | $437 | $485 | $526 | $554 | $586 | $615 |
| Medium | Low | | | -$23 | -$23 | -$23 | -$22 | -$22 | -$22 | | $1,387 | -$10,350 | -$2,559 | -$1,837 | -$1,429 | -$1,213 |
| | Medium | $295 | $15/W | -$631 | -$413 | -$368 | -$348 | -$330 | -$317 | $15/W | $536 | $899 | $1,182 | $1,416 | $1,785 | $2,287 |
| | High | | | -$2,263 | -$779 | -$630 | -$574 | -$527 | -$494 | | $328 | $363 | $395 | $416 | $439 | $461 |
| Low | Low | | | -$8 | -$8 | -$8 | -$7 | -$7 | -$7 | | $925 | -$6,900 | -$1,706 | -$1,225 | -$953 | -$809 |
| | Medium | $295 | $5/W | -$210 | -$138 | -$123 | -$116 | -$110 | -$106 | $10/W | $357 | $599 | $788 | $944 | $1,190 | $1,525 |
| | High | | | -$754 | -$260 | -$210 | -$191 | -$176 | -$165 | | $218 | $242 | $263 | $277 | $293 | $308 |

***How to Interpret the Following Tables***

Table 168 provides the TDV benefits of different gas heat pump systems of various technologies and efficiencies for the Home B configuration in each location. The analysis assumed performance and costs detailed in Appendix E.2. Our analysis evaluated whether the gas heat pump could provide a net TDV energy savings for a specific mixed-fuel home in each location under a range of operating modes and efficiencies. The gas heat pump system replaced a baseline configuration of 80% AFUE furnace, 0.6 EF storage water heater, and SEER 14 air conditioner. Gas heat pump technology and efficiency combinations with positive values denotes TDV energy savings over the baseline configuration. On a TDV basis, gas heat pumps providing space heating offer an attractive proposition for homes with larger space and water heating loads.

**Table 168. TDV Benefit of Gas Heat Pumps – Home B**

| Gas Heat Pump Category | Location | Technology Efficiency | | TDV Savings | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Heating COP | Cooling COP | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| Engine-Based | Low | 1.2 | 1.1 | 14.3 | 13.7 | 15.0 | 20.0 | 14.9 |
| | Medium | 1.5 | 1.2 | 17.9 | 17.2 | 19.2 | 26.4 | 20.0 |
| | High | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Absorption (Reversible) | Low | 1.3 | 0.6 | 15.2 | 12.8 | 12.4 | 13.4 | -12.4 |
| | Medium | 1.6 | 0.8 | 18.8 | 17.1 | 18.1 | 23.4 | 5.3 |
| | High | 2.2 | 1.2 | 22.5 | 21.4 | 24.0 | 33.5 | 22.9 |
| Absorption (Heating Only) | Low | 1.2 | n/a | 14.4 | 16.1 | 20.3 | 31.6 | 10.0 |
| | Medium | 1.4 | n/a | 16.9 | 18.5 | 23.0 | 35.6 | 11.7 |
| | High | 1.6 | n/a | 18.9 | 20.3 | 25.0 | 38.6 | 12.9 |
| Absorption (Cooling Only) | Low | n/a | 0.6 | 0.0 | -1.4 | -3.0 | -6.3 | -22.9 |
| | Medium | n/a | 0.7 | 0.0 | -1.0 | -2.1 | -4.2 | -15.7 |
| | High | n/a | 0.8 | 0.0 | -0.7 | -1.4 | -2.8 | -10.7 |

***How to Interpret the Following Tables***

Table 169 through Table 173 provide the cost-effectiveness of gas heat pump systems of various technologies and efficiencies for the Home B configuration in each location. The analysis assumed performance and costs detailed in Appendix E.2. and the costs for an efficiency measure (i.e., condensing furnace) in each location. We compared the gas heat pump system's benefits on a $/TDV basis to the $/TDV savings of the condensing furnace to understand whether the gas heat pump technology and efficiency combination system may offer a lower cost to reach ZNE status. Because the lifetime for condensing furnaces (12-15 years) closely matches the useful life of gas heat pumps (12-15 years), we compared the original incremental costs of the technologies. To displace condensing furnaces or other efficiency options for ZNE homes, gas heat pumps must show lower $/TDV savings. Gas heat pump technology and efficiency combinations highlighted denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase.

On a TDV basis, gas heat pumps providing space heating offer an attractive proposition for homes with larger space and water heating loads. Under medium- and low-cost assumptions, heat-only or reversible gas heat pumps systems could become attractive relative to other efficiency options, such as condensing furnaces. Because ZNE homes have substantially smaller space heating loads, manufacturers must develop lower capacity gas heat pumps to serve Southern California.

**Table 169. Cost-Effectiveness of Gas Heat Pumps in Los Angeles – Home B**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $140 | n/a | $41 | n/a | $61 | $49 | n/a | $71 | $57 | n/a |
| Absorption (Reversible) | $140 | $48 | $39 | $32 | $57 | $46 | $39 | $67 | $54 | $45 |
| Absorption (Heating Only) | $140 | $51 | $43 | $39 | $61 | $51 | $46 | $71 | $60 | $54 |
| Absorption (Cooling Only) | $140 | -$20,983 | -$26,589 | -$32,706 | -$25,105 | -$31,812 | -$39,131 | -$29,227 | -$37,035 | -$45,555 |

Table 170. Cost-Effectiveness of Gas Heat Pumps Systems in Pasadena – Home B

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $167 | $58 | $46 | n/a | $69 | $55 | n/a | $80 | $64 | n/a |
| Absorption (Reversible) | $167 | $62 | $46 | $37 | $74 | $55 | $44 | $86 | $64 | $51 |
| Absorption (Heating Only) | $167 | $49 | $43 | $39 | $59 | $51 | $47 | $68 | $60 | $54 |
| Absorption (Cooling Only) | $167 | -$565 | -$812 | -$1,172 | -$676 | -$972 | -$1,402 | -$786 | -$1,131 | -$1,632 |

Table 171. Cost-Effectiveness of Gas Heat Pumps Systems in Riverside – Home B

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $130 | $64 | $50 | n/a | $76 | $60 | n/a | $89 | $70 | n/a |
| Absorption (Reversible) | $130 | $78 | $53 | $40 | $93 | $63 | $48 | $108 | $74 | $56 |
| Absorption (Heating Only) | $130 | $47 | $42 | $39 | $57 | $50 | $46 | $66 | $58 | $54 |
| Absorption (Cooling Only) | $130 | -$323 | -$469 | -$685 | -$387 | -$561 | -$819 | -$450 | -$653 | -$954 |

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**Table 172. Cost-Effectiveness of Gas Heat Pumps Systems in Bakersfield – Home B**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $43 | $56 | $42 | n/a | $67 | $51 | n/a | $78 | $59 | n/a |
| Absorption (Reversible) | $43 | $83 | $48 | $33 | $100 | $57 | $40 | $116 | $66 | $47 |
| Absorption (Heating Only) | $43 | $35 | $31 | $29 | $42 | $38 | $35 | $49 | $44 | $40 |
| Absorption (Cooling Only) | $43 | -$178 | -$264 | -$400 | -$213 | -$316 | -$478 | -$248 | -$368 | -$557 |

**Table 173. Cost-Effectiveness of Gas Heat Pumps Systems in Palm Springs – Home B**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $436 | $49 | $36 | n/a | $58 | $44 | n/a | $68 | $51 | n/a |
| Absorption (Reversible) | $436 | -$59 | $138 | $32 | -$70 | $165 | $38 | -$82 | $192 | $44 |
| Absorption (Heating Only) | $436 | $73 | $62 | $56 | $87 | $75 | $68 | $101 | $87 | $79 |
| Absorption (Cooling Only) | $436 | -$32 | -$46 | -$68 | -$38 | -$55 | -$82 | -$44 | -$65 | -$95 |

***How to Interpret the Following Tables***

Table 174 provides the TDV benefits of different gas heat pump systems of various technologies and efficiencies for the Home A configuration in each location. The analysis assumed performance and costs detailed in Appendix E.2. Our analysis evaluated whether the gas heat pump could provide a net TDV energy savings for a specific mixed-fuel home in each location under a range of operating modes and efficiencies. The gas heat pump system replaced a baseline configuration of 80% AFUE furnace, 0.6 EF storage water heater, and SEER 14 air conditioner. Gas heat pump technology and efficiency combinations with positive values denotes TDV energy savings over the baseline configuration. On a TDV basis, gas heat pumps providing space heating offer an attractive proposition for homes with larger space and water heating loads.

**Table 174. TDV Benefit of Gas Heat Pumps – Home A**

| Gas Heat Pump Category | Location | Technology Efficiency | | TDV Savings | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Heating COP | Cooling COP | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| Engine-Based | Low | 1.2 | 1.1 | 10.9 | 10.3 | 11.3 | 15.0 | 11.7 |
| | Medium | 1.5 | 1.2 | 13.5 | 12.9 | 14.3 | 19.6 | 15.4 |
| | High | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Absorption (Reversible) | Low | 1.3 | 0.6 | 11.5 | 9.8 | 9.2 | 9.9 | -9.2 |
| | Medium | 1.6 | 0.8 | 14.2 | 12.9 | 13.5 | 17.3 | 4.2 |
| | High | 2.2 | 1.2 | 17.0 | 16.0 | 17.8 | 24.7 | 17.5 |
| Absorption (Heating Only) | Low | 1.2 | n/a | 10.9 | 11.9 | 15.2 | 23.6 | 10.8 |
| | Medium | 1.4 | n/a | 12.8 | 13.7 | 17.1 | 26.4 | 12.7 |
| | High | 1.6 | n/a | 14.2 | 15.0 | 18.6 | 28.6 | 14.2 |
| Absorption (Cooling Only) | Low | n/a | 0.6 | 0.0 | -0.9 | -2.2 | -4.5 | -17.0 |
| | Medium | n/a | 0.7 | 0.0 | -0.6 | -1.5 | -3.0 | -11.5 |
| | High | n/a | 0.8 | 0.0 | -0.4 | -1.0 | -1.9 | -7.7 |

***How to Interpret the Following Tables***

Table 175 through Table 179 provide the cost-effectiveness of gas heat pump systems of various technologies and efficiencies for the Home A configuration in each location. The analysis assumed performance and costs detailed in Appendix E.2. and the costs for an efficiency measure (i.e., condensing furnace) in each location. We compared the gas heat pump system's benefits on a $/TDV basis to the $/TDV savings of the condensing furnace to understand whether the gas heat pump technology and efficiency combination system may offer a lower cost to reach ZNE status. Because the lifetime for condensing furnaces (12-15 years) closely matches the useful life of gas heat pumps (12-15 years), we compared the original incremental costs of the technologies. To displace condensing furnaces or other efficiency options for ZNE homes, gas heat pumps must show lower $/TDV savings. Gas heat pump technology and efficiency combinations highlighted denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase.

On a TDV basis, gas heat pumps providing space heating offer an attractive proposition for homes with larger space and water heating loads. Under medium- and low-cost assumptions, heat-only or reversible gas heat pumps systems could become attractive relative to other efficiency options, such as condensing furnaces. Because ZNE homes have substantially smaller space heating loads, manufacturers must develop lower capacity gas heat pumps to serve Southern California.

**Table 175. Cost-Effectiveness of Gas Heat Pumps in Los Angeles – Home A**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $201 | $49 | $39 | n/a | $58 | $47 | n/a | $68 | $54 | n/a |
| Absorption (Reversible) | $201 | $46 | $37 | $31 | $55 | $44 | $37 | $64 | $52 | $43 |
| Absorption (Heating Only) | $201 | $49 | $41 | $37 | $58 | $49 | $44 | $68 | $57 | $52 |
| Absorption (Cooling Only) | $201 | -$43,982 | -$55,891 | -$68,964 | -$52,621 | -$66,870 | -$82,510 | -$61,260 | -$77,849 | -$96,056 |

**Table 176. Cost-Effectiveness of Gas Heat Pumps Systems in Pasadena – Home A**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $260 | $54 | $43 | n/a | $65 | $52 | n/a | $75 | $60 | n/a |
| Absorption (Reversible) | $260 | $57 | $43 | $35 | $68 | $52 | $42 | $79 | $60 | $49 |
| Absorption (Heating Only) | $260 | $47 | $41 | $37 | $56 | $49 | $45 | $65 | $57 | $52 |
| Absorption (Cooling Only) | $260 | -$621 | -$913 | -$1,364 | -$743 | -$1,093 | -$1,631 | -$865 | -$1,272 | -$1,899 |

**Table 177. Cost-Effectiveness of Gas Heat Pumps Systems in Riverside – Home A**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $158 | $57 | $45 | n/a | $68 | $54 | n/a | $79 | $63 | n/a |
| Absorption (Reversible) | $158 | $70 | $48 | $36 | $83 | $57 | $43 | $97 | $66 | $50 |
| Absorption (Heating Only) | $158 | $42 | $37 | $34 | $51 | $45 | $41 | $59 | $52 | $48 |
| Absorption (Cooling Only) | $158 | -$291 | -$426 | -$631 | -$348 | -$510 | -$755 | -$405 | -$593 | -$879 |

**Table 178. Cost-Effectiveness of Gas Heat Pumps Systems in Bakersfield – Home A**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $63 | $51 | $39 | n/a | $61 | $47 | n/a | $71 | $54 | n/a |
| Absorption (Reversible) | $63 | $77 | $44 | $31 | $92 | $53 | $37 | $107 | $62 | $43 |
| Absorption (Heating Only) | $63 | $32 | $29 | $27 | $39 | $35 | $32 | $45 | $40 | $37 |
| Absorption (Cooling Only) | $63 | -$169 | -$258 | -$407 | -$203 | -$309 | -$486 | -$236 | -$359 | -$566 |

**Table 179. Cost-Effectiveness of Gas Heat Pumps Systems in Palm Springs – Home A**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $779 | $56 | $42 | n/a | $67 | $51 | n/a | $78 | $59 | n/a |
| Absorption (Reversible) | $779 | $83 | $48 | $33 | $100 | $57 | $40 | $116 | $66 | $47 |
| Absorption (Heating Only) | $779 | $84 | $73 | $66 | $101 | $87 | $78 | $118 | $101 | $91 |
| Absorption (Cooling Only) | $779 | -$178 | -$264 | -$400 | -$213 | -$316 | -$478 | -$248 | -$368 | -$557 |

***How to Interpret the Following Tables***

Table 180 provides the TDV benefits of different gas heat pump systems of various technologies and efficiencies for the Home C configuration in each location. The analysis assumed performance and costs detailed in Appendix E.2. Our analysis evaluated whether the gas heat pump could provide a net TDV energy savings for a specific mixed-fuel home in each location under a range of operating modes and efficiencies. The gas heat pump system replaced a baseline configuration of 80% AFUE furnace, 0.6 EF storage water heater, and SEER 14 air conditioner. Gas heat pump technology and efficiency combinations with positive values denotes TDV energy savings over the baseline configuration. On a TDV basis, gas heat pumps providing space heating offer an attractive proposition for homes with larger space and water heating loads.

**Table 180. TDV Benefit of Gas Heat Pumps – Home C**

| Gas Heat Pump Category | Location | Technology Efficiency | | TDV Savings | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Heating COP | Cooling COP | Los Angeles | Pasadena | Riverside | Bakersfield | Palm Springs |
| Engine-Based | Low | 1.2 | 1.1 | 13.2 | 14.1 | 8.2 | 21.7 | 16.6 |
| | Medium | 1.5 | 1.2 | 17.0 | 17.8 | 12.6 | 28.7 | 22.1 |
| | High | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Absorption (Reversible) | Low | 1.3 | 0.6 | 14.1 | 13.1 | 5.0 | 14.1 | -14.4 |
| | Medium | 1.6 | 0.8 | 18.0 | 17.7 | 11.3 | 25.3 | 5.4 |
| | High | 2.2 | 1.2 | 21.9 | 22.3 | 17.7 | 36.5 | 25.2 |
| Absorption (Heating Only) | Low | 1.2 | n/a | 13.3 | 16.8 | 14.1 | 34.6 | 10.2 |
| | Medium | 1.4 | n/a | 16.0 | 19.3 | 16.9 | 39.0 | 11.9 |
| | High | 1.6 | n/a | 18.0 | 21.2 | 19.1 | 42.3 | 13.2 |
| Absorption (Cooling Only) | Low | n/a | 0.6 | 0.0 | -1.5 | -7.0 | -6.8 | -25.1 |
| | Medium | n/a | 0.7 | 0.0 | -1.0 | -5.9 | -4.5 | -17.0 |
| | High | n/a | 0.8 | 0.0 | -0.7 | -5.2 | -2.8 | -11.3 |

***How to Interpret the Following Tables***

Table 181 through Table 185 provide the cost-effectiveness of gas heat pump systems of various technologies and efficiencies for the Home C configuration in each location. The analysis assumed performance and costs detailed in Appendix E.2. and the costs for an efficiency measure (i.e., condensing furnace) in each location. We compared the gas heat pump system's benefits on a $/TDV basis to the $/TDV savings of the condensing furnace to understand whether the gas heat pump technology and efficiency combination system may offer a lower cost to reach ZNE status. Because the lifetime for condensing furnaces (12-15 years) closely matches the useful life of gas heat pumps (12-15 years), we compared the original incremental costs of the technologies. To displace condensing furnaces or other efficiency options for ZNE homes, gas heat pumps must show lower $/TDV savings. Gas heat pump technology and efficiency combinations highlighted denotes positive economic attractiveness on $/TDV basis. Negative values show net TDV consumption increase.

On a TDV basis, gas heat pumps providing space heating offer an attractive proposition for homes with larger space and water heating loads. Under medium- and low-cost assumptions, heat-only or reversible gas heat pumps systems could become attractive relative to other efficiency options, such as condensing furnaces. Because ZNE homes have substantially smaller space heating loads, manufacturers must develop lower capacity gas heat pumps to serve Southern California.

**Table 181. Cost-Effectiveness of Gas Heat Pumps in Los Angeles – Home C**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $114 | $63 | $49 | n/a | $75 | $58 | n/a | $87 | $68 | n/a |
| Absorption (Reversible) | $114 | $59 | $46 | $38 | $70 | $55 | $45 | $82 | $64 | $53 |
| Absorption (Heating Only) | $114 | $62 | $52 | $46 | $75 | $62 | $55 | $87 | $72 | $64 |
| Absorption (Cooling Only) | $114 | -$29,876 | -$39,123 | -$49,945 | -$35,744 | -$46,808 | -$59,755 | -$41,613 | -$54,493 | -$69,566 |

**Table 182. Cost-Effectiveness of Gas Heat Pumps Systems in Pasadena – Home C**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $136 | $64 | $51 | n/a | $77 | $61 | n/a | $90 | $71 | n/a |
| Absorption (Reversible) | $136 | $70 | $52 | $41 | $83 | $62 | $49 | $97 | $72 | $57 |
| Absorption (Heating Only) | $136 | $54 | $47 | $43 | $65 | $57 | $52 | $76 | $66 | $60 |
| Absorption (Cooling Only) | $136 | -$601 | -$879 | -$1,300 | -$719 | -$1,051 | -$1,555 | -$837 | -$1,224 | -$1,810 |

**Table 183. Cost-Effectiveness of Gas Heat Pumps Systems in Riverside – Home C**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $89 | $136 | $88 | n/a | $163 | $106 | n/a | $190 | $123 | n/a |
| Absorption (Reversible) | $89 | $222 | $98 | $63 | $265 | $118 | $75 | $309 | $137 | $88 |
| Absorption (Heating Only) | $89 | $79 | $66 | $58 | $95 | $79 | $70 | $110 | $92 | $81 |
| Absorption (Cooling Only) | $89 | -$159 | -$187 | -$214 | -$190 | -$224 | -$256 | -$222 | -$261 | -$298 |

**Table 184. Cost-Effectiveness of Gas Heat Pumps Systems in Bakersfield – Home C**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $37 | $59 | $45 | n/a | $71 | $53 | n/a | $82 | $62 | n/a |
| Absorption (Reversible) | $37 | $91 | $51 | $35 | $109 | $61 | $42 | $126 | $71 | $49 |
| Absorption (Heating Only) | $37 | $37 | $33 | $30 | $44 | $39 | $36 | $52 | $46 | $42 |
| Absorption (Cooling Only) | $37 | -$188 | -$286 | -$451 | -$225 | -$343 | -$539 | -$262 | -$399 | -$628 |

**Table 185. Cost-Effectiveness of Gas Heat Pumps Systems in Palm Springs – Home C**

| Gas Heat Pump Category | Condensing Furnace $/TDV Savings | Gas Heat Pump $/TDV Savings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Cost ($56/kBtu-hr) | | | Medium Cost ($67/kBtu-hr) | | | High Cost ($78/kBtu-hr) | | |
| | | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency | Low Efficiency | Medium Efficiency | High Efficiency |
| Engine-Based | $341 | $52 | $39 | n/a | $62 | $47 | n/a | $72 | $54 | n/a |
| Absorption (Reversible) | $341 | -$60 | $161 | $34 | -$72 | $192 | $41 | -$83 | $224 | $48 |
| Absorption (Heating Only) | $341 | $60 | $50 | $45 | $71 | $60 | $54 | $83 | $70 | $63 |
| Absorption (Cooling Only) | $341 | -$34 | -$51 | -$77 | -$41 | -$61 | -$92 | -$48 | -$71 | -$107 |

***How to Interpret the Following Tables***

Table 186 through Table 188 provide the TDV benefit and cost-effectiveness of electric battery energy storage systems for each home design and location. The analysis assumed performance and costs detailed in Section 3.3.2.1 and the costs for a solar PV system in each location. When coupled with a solar PV system, the battery storage can time-shift the solar electricity to achieve a greater TDV offset than would normally occur. For example, a battery would charge using solar PV electricity generated at 1pm and discharge at 5pm when the TDV value is higher. As modeled for a 10 kWh, 5 kW electric battery storage system, on-site energy storage can provide meaningful TDV energy reductions by shifting the consumption of grid-supplied electricity to hours with lower TDV values. We compared the energy storage system's benefits on a $/TDV basis to the $/TDV savings of the solar PV system to understand whether the energy storage system at different cost assumptions could offer a lower cost to reach ZNE status. Under current cost projections, battery storage systems are not cost-effective compared to incrementally larger solar PV systems, but future cost reductions (e.g., $100/kWh) could improve their economic attractiveness for ZNE homes above other technologies.

**Table 186. TDV Benefit and Cost-Effectiveness of Energy Storage Systems – Home B**

| Location | TDV Energy Savings for 10kWh System (MMBtu) | $/TDV Savings at Various Cost Projections | | | | Solar PV $/TDV Savings |
|---|---|---|---|---|---|---|
| | | $750/kWh | $600/kWh | $300/kWh | $100/kWh | |
| Los Angeles | 4.9 | $1,525 | $1,220 | $610 | $203 | $254 |
| Pasadena | 6.0 | $1,250 | $1,000 | $500 | $168 | $217 |
| Riverside | 7.4 | $1,007 | $806 | $403 | $134 | $213 |
| Bakersfield | 10.2 | $734 | $587 | $294 | $98 | $203 |
| Palm Springs | 9.2 | $813 | $650 | $325 | $108 | $240 |

**Table 187. TDV Benefit and Cost-Effectiveness of Energy Storage Systems – Home A**

| Location | TDV Energy Savings for 10kWh System (MMBtu) | $/TDV Savings at Various Cost Projections | | | | Solar PV $/TDV Savings |
|---|---|---|---|---|---|---|
| | | $750/kWh | $600/kWh | $300/kWh | $100/kWh | |
| Los Angeles | 3.2 | $2,375 | $1,900 | $950 | $317 | $210 |
| Pasadena | 5.2 | $1,433 | $1,146 | $573 | $191 | $210 |
| Riverside | 6.3 | $1,200 | $960 | $480 | $160 | $210 |
| Bakersfield | 8.9 | $847 | $678 | $339 | $113 | $207 |
| Palm Springs | 8.7 | $865 | $692 | $346 | $115 | $216 |

**Table 188. TDV Benefit and Cost-Effectiveness of Energy Storage Systems – Home C**

| Location | TDV Energy Savings for 10kWh System (MMBtu) | $/TDV Savings at Various Cost Projections | | | | Solar PV $/TDV Savings |
|---|---|---|---|---|---|---|
| | | $750/kWh | $600/kWh | $300/kWh | $100/kWh | |
| Los Angeles | 4.7 | $1,598 | $1,278 | $639 | $213 | $209 |
| Pasadena | 7.0 | $1,070 | $856 | $428 | $143 | $238 |
| Riverside | 7.9 | $949 | $759 | $379 | $127 | $291 |
| Bakersfield | 10.6 | $704 | $563 | $282 | $94 | $214 |
| Palm Springs | 6.8 | $1,100 | $880 | $440 | $147 | $200 |

# Appendix H. Additional Technical Analyses

As discussed in Section 4.4, SCG staff requested further investigation on certain topics and the sensitivity of major assumptions on the technical results. This section provides the full results of these additional technical analyses:

- Comparison of 2016 vs. 2013 TDV Values
- List of Measures Proposed for Title 24-2019
- Sensitivity to Optimization by First Costs Only
- Cost-Effective "Near-ZNE" Building Technologies.

## *H.1 Comparison of 2016 vs. 2013 TDV Values*

Navigant performed a sensitivity study to understand the impacts of using 2016 TDV values[90] when optimizing energy efficiency and renewable building technologies, rather than 2013 values. The sensitivity analysis included mixed-fuel and electric-only home designs, in 3 locations (Los Angeles, Palm Springs, Bakersfield), with 2,500 sq.ft. home size (Home B) and South-facing PV orientation. We scaled the end-use consumption for each baseline and optimized home by the new 2016 TDV values to understand how our analysis would change with future assumptions. Table 189 provides a summary of the optimized TDV consumption values for mixed-fuel and electric-only ZNE homes and Table 190 outlines the changes in solar PV output between 2016 and 2013 TDV values.

**Table 189. Comparison of ZNE Home Consumption Using 2016 vs. 2014 TDV Values – Home B**

| Home Design | Location | 2013 Time Dependent Valuation (MMBtu/yr.) | | | 2016 Time Dependent Valuation (MMBtu/yr.) | | | Overall % Increase | Electricity % Increase | Natural Gas % Increase |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Electric | Natural Gas | Total | Electric | Natural Gas | Total | | | |
| Mixed-Fuel | Los Angeles | 57.4 | 35.3 | 92.7 | 58.7 | 36.5 | 95.2 | 2.7% | 2.2% | 3.5% |
| | Bakersfield | 71.1 | 44.7 | 115.8 | 72.7 | 46.3 | 119.0 | 2.7% | 2.3% | 3.4% |
| | Palm Springs | 92.9 | 25.8 | 118.7 | 96.4 | 26.7 | 123.0 | 3.6% | 3.7% | 3.4% |
| Electric-Only | Los Angeles | 104.0 | 0.0 | 104.0 | 105.9 | 0.0 | 105.9 | 1.8% | 1.8% | n/a |
| | Bakersfield | 108.3 | 0.0 | 108.3 | 109.9 | 0.0 | 109.9 | 1.4% | 1.4% | n/a |
| | Palm Springs | 136.7 | 0.0 | 136.7 | 141.1 | 0.0 | 141.1 | 3.2% | 3.2% | n/a |

[90] 2016 TDV values provided at http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-09_workshop/2017_TDV_Documents/.

**Table 190. Comparison of Solar PV Output Using 2016 vs. 2014 TDV Values – Home B**

| Location | Solar PV Output (TDV MMBtu/yr. per kW) | | Overall % Increase |
|---|---|---|---|
| | 2013 | 2016 | |
| Los Angeles | 27.6 | 27.4 | -0.95% |
| Bakersfield | 27.7 | 28.2 | 1.54% |
| Palm Springs | 27.6 | 27.7 | 0.34% |

Our analysis revealed the following findings:

- Electricity and natural gas TDV consumption increase by 1.5-3.5% using 2016 TDV values for both mixed-fuel and electric-only ZNE homes.
- Gas TDV values for Title 24 2016 increase (%) more than electricity TDV values (%).
- Mixed-fuel ZNE homes have < 1% larger increase (%) using 2016 TDV values compared to electric-only homes.
- Palm Springs has larger electricity TDV increases (%) compared to Los Angeles or Bakersfield, whereas each location has similar gas TDV increases (%).
- The value of a solar PV system (TDV/kW) changes by -1% to +1.5% using 2016 TDV values.

In general, the sensitivity study revealed that the Phase 1 results are generally consistent using the 2016 TDV values, with minor fluctuations based on home design, location, and other aspects. These findings suggest the Phase 1 results will be applicable under future TDV definitions.

## *H.2 List of Measures Proposed for Title 24-2019*

Navigant reviewed the proposed measures for Title 24-2019 provided by SCG staff and performed additional analyses to determine the impacts for Phase 1 results. Table 191 provides a summary of the 22 potential measures identified for potential Title 24-2019 inclusion, as well as whether each was included in Phase 1.

**Table 191. List of Potential Measures for Title 24-2019**

| Measure Name | Included in Phase 1 (Y/N) | Included in Follow-Up Analysis (Y/N) | Notes/Comments |
|---|---|---|---|
| High slope cool roofs | No | No | Unlikely to have large industry support due to aesthetic considerations |
| High performance windows | Yes | No | Included in Phase 1 |
| Coastal compressor-less comfort | No | No | Requires updates to the comfort model, and also included in "evaporative cooling baseline" below |
| High efficacy lighting | Yes | No | Included in Phase 1 |
| Controlled receptacles | No | Yes | Regulates plug loads during unoccupied/ sleeping hours |
| Evaporative cooling baseline | No | Yes | Specifies evaporative cooling as the standard of design for the energy budget in certain CZs |
| Infiltration testing | No | No | Infiltration testing is already included to stringent levels, further reductions pose ventilation issues in milder climates |
| VOCs and RH controlled supply mechanical ventilation | No | No | Unlikely to model energy impacts, although could be included as a prescriptive requirement |
| DHW Heat Recovery | Yes | No | Included in Phase 1 |
| Compact water distribution | Yes | No | Included in Phase 1 |
| Next generation lighting | Yes | No | Included in Phase 1 |
| Fault detection and diagnostics system and charge indicator display (FDD/CID) | No | Yes | Included for commercial, could be included for residential and modeled as "avoided energy degradation" |
| IAQ source generation and ventilation effectiveness | No | No | CalGreen measure |
| Heat recovery ventilation | Yes | No | Included in Phase 1 |
| Grey water reuse | No | No | CalGreen measure |
| Comfort modeling | No | No | Requires updates to the comfort model |
| Locational efficiency - infill vs. sprawl | No | No | CalGreen measure for building zoning |
| Residential integrated heat pump | Yes | No | Included in Phase 1 |
| Ceiling mounted radiant heating and/or cooling | No | No | Unlikely to be adopted by industry as a baseline standard |

| Measure Name | Included in Phase 1 (Y/N) | Included in Follow-Up Analysis (Y/N) | Notes/Comments |
|---|---|---|---|
| Smart and dynamic fenestration systems | Yes | No | Included in Phase 1 |
| Phase change thermal storage drywall | No | No | Unlikely to be widely accepted by industry in time for 2019 standard |
| High efficiency appliances | Yes | No | Included in Phase 1 |

Navigant and SCG determined that 3 additional technologies could be eligible for inclusion in Title 24-2019 due to current estimates for energy savings, upfront cost, market acceptance, and potential barriers:

- Controllable electrical receptacles
- Evaporative cooling as a baseline cooling system
- Fault detection and diagnostic system / charge indicator display (FDD/CID) for HVAC systems.

Table 192 provides summary information for each of these measures.

**Table 192. Summary of Selected Measures for Title 24-2019**

| Measure Name | Brief Description | Estimated Savings | Estimated Cost | Source |
|---|---|---|---|---|
| Controlled receptacles | Regulates plug loads during unoccupied/ sleeping hours (12-6am) | 100-200 kWh/yr. per home for 8 receptacles | $460 per home | 2013 CASE Document[91] and other studies |
| Evaporative cooling baseline | Specifies evaporative cooling as the standard design in the energy budget in certain CZs | Upgrade from SEER 14 to SEER 25-40 | Similar to standard air conditioners | Manufacturer literature |
| Fault detection and diagnostics system and charge indicator display (FDD/CID) | Included for commercial, could be included for residential and modeled as "avoided energy degradation" | 5-10% avoided efficiency degradation | $70-100 | Navigant Residential HVAC Report[92] |

[91] 2013 CASE Document – Residential Plug-load Controls. October 2011. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Lighting/2013_CASE_PowerDist2_ResPlugLoads_10.7.2011.pdf

[92] Goetzler et al. 2012. "Energy Savings Potential and Research, Development, & Demonstration Opportunities for Residential Building Heating, Ventilation, and Air Conditioning Systems." U.S. Department of Energy Building Technologies Office. October 2012.

Navigant conducted additional simulations to understand the potential impacts of these technologies. Table 193 summarizes the results of the simulations. While each provided at least some TDV energy savings for ZNE homes, only the FDD/CID technology has a clear regulatory and market pathway towards inclusion in Title 24-2019. If included, FDD/CID would have a similar impact for both mixed-fuel and electric-only homes since the majority of savings come occur from space cooling, which is common for both home designs.

**Table 193. TDV Savings and Findings for Selected Measures for Title 24-2019**

| Measure Name | Estimated TDV Savings | Findings | Result |
|---|---|---|---|
| Controlled receptacles | 0.8-2.2 | • Minimal energy savings overall, but does target plug-and-process loads<br>• Unclear how Title 24 would include this measure in energy budget, since homeowners program their schedule for each outlet, and could easily opt-out | Unlikely for Title 24-2019 |
| Evaporative cooling baseline | 0.1-37.2 | • Evaporative coolers show attractive savings in inland climates.<br>• Prospective homeowners may prefer conventional A/C systems to handle the hottest and most humid days.<br>• Additionally, an evaporative cooler for an electric-only home would replace the high efficient heating of an air-source heat pump. | |
| Fault detection and diagnostics system and charge indicator display (FDD/CID) | 0.2-11.7 | • Modest savings at low-cost for vapor-compression A/C and heat pump systems<br>• Similar savings for both mixed-fuel and electric-only homes in each location | Possible for Title 24-2019 |

## *H.3 Sensitivity to Optimization by First Costs Only*

In Phase 1, the optimization software selected building technologies based on full life-cycle costs, including original purchase, energy savings, and replacement costs. To model first costs only, we conducted additional simulations by raising the lifetime of each technology to 30 years from the original lifetimes outlined in Table 194.

**Table 194. Original Lifetime for Building Technologies**

| Measure Name | Original Lifespan (Years) |
|---|---|
| Mechanical Ventilation | 18 |
| Central Air Conditioner | 16 |
| Furnace | 20 |
| Air-Source Heat Pump | 15 |
| Water Heater | 12 (HPWH), 13 (gas), 20 (tankless) |
| Refrigerator | 17 |
| Cooking Range | 15 |
| Dishwasher | 11 |
| Clothes Washer | 12 |
| Clothes Dryer | 13 |
| Solar PV Panels | 25 |
| Solar PV Inverter | 10 |

In general, the software selected additional HVAC, water heating, and solar PV technologies in place of building envelope measures. When evaluated on first costs only, mixed-fuel ZNE homes still maintain advantages over electric-only designs, but the gap is narrowed. As shown in Table 195, the incremental first cost advantage changes from $2,000 to $500-$1,500 and the solar PV advantage changes from 0.5 kW to 0.0–0.2 kW. Similar to Phase 1, mixed-fuel ZNE homes still offer lower incremental cost to reach ZNE status and generally require smaller solar PV systems. Compared to the Phase 1 results, mixed-fuel homes had slightly increased costs while electric-only homes had slightly decreased costs. These findings support the Phase 1 conclusion that ZNE homes using natural gas appliance show similar or better results than those using electric-only designs, but echo the sensitivity of these advantages to external issues such as developer cost, consumer preference, etc.

**Table 195. Comparison of Mixed-Fuel ZNE Advantages**

| Location | TDV Advantage (MMBtu/yr) | | Incremental Cost Advantage ($) | | PV System Size Advantage (kW) | |
|---|---|---|---|---|---|---|
| | First Cost | Life-Cycle Cost | First Cost | Life-Cycle Cost | First Cost | Life-Cycle Cost |
| Los Angeles | 6.0 | 11.3 | $1731 | $2111 | 0.2 | 0.4 |
| Bakersfield | -6.9 | -7.5 | $678 | $8951 | -0.2 | -0.3 |
| Palm Springs | 0.6 | 18.0 | $462 | $2727 | 0.0 | 0.7 |

### H.4 Cost-Effective "Near-ZNE" Building Technologies

Single-family homes will require solar PV systems to meet ZNE building codes starting in 2020, but builders can provide homeowners energy and utility savings before ZNE building codes take effect by incorporating select packages of building technologies. Navigant conducted additional analysis to identify cost-effective building technologies for mixed-fuel homes in each location and evaluate their energy savings, incremental cost, payback, and TRC values. Table 196 provides a summary of the cost-effective near-ZNE technology packages for mixed-fuel homes. Depending on the location, the list of cost-effective measures includes: advanced windows, tankless water heaters, condensing furnaces, advanced thermostats, and higher efficiency cooling systems. Other technologies, such as improved insulation or ENERGY STAR appliances can provide additional energy savings, but decrease the overall cost-effectiveness of the technology packages and create paybacks longer than 4-6 years. Builders could also incorporate the technologies listed in Table 5 for additional savings before they become state or federal standard, such as high efficacy lighting.

**Table 196. Near-ZNE Technology Packages for Mixed-Fuel Homes – Home B**

| Near-ZNE Technology Packages for Mixed-Fuel Homes | | | | |
|---|---|---|---|---|
| **Los Angeles** | **Pasadena** | **Riverside** | **Bakersfield** | **Palm Springs** |
| Advanced Windows<br>90% Condensing Furnace<br>HW Distribution<br>Tankless WH | Adv. Thermostat (Cooling)<br>Advanced Windows<br>90% Condensing Furnace<br>HW Distribution<br>Tankless WH | Adv. Thermostat (Cooling)<br>Advanced Windows<br>90% Condensing Furnace<br>HW Distribution<br>Tankless WH | Adv. Thermostat (Heating/Cooling)<br>Advanced Windows<br>90% Condensing Furnace<br>HW Distribution<br>Tankless WH | Adv. Thermostat (Cooling)<br>Advanced Windows<br>SEER 18 AC<br>HW Distribution<br>Tankless WH |

Note – results for 2,500 sq.ft., two-story home, and will be similar for other home sizes.

In the next several years before 2020 codes take effect, builders could advertise these homes as "near-ZNE" or "ZNE-ready" since they will already incorporate the major efficiency measures applicable to a ZNE home. Even though they do not provide the full benefits of a ZNE home, these building packages provide meaningful energy savings with attractive payback and TRC values, as shown in Table 197. SCG already has programs for many of these technologies that offer rebates and support to builders and homeowners.

**Table 197. Near-ZNE Technology Package Economics – Home B**

| Location | TDV Savings (%) | Incremental Cost ($) | Payback (Yrs.) | TRC Value |
|---|---|---|---|---|
| Los Angeles | 7.9 | $286 | 5.7 | 2.9 |
| Pasadena | 7.7 | $342 | 5.9 | 2.4 |
| Riverside | 8.1 | $362 | 4.8 | 2.6 |
| Bakersfield | 10.5 | $487 | 4.1 | 3.0 |
| Palm Springs | 12.4 | $1,341 | 5.5 | 1.8 |

Note – Comparisons against baseline mixed-fuel homes meeting Title 24-2016. Results for 2,500 sq.ft., two-story home, and will be similar for other home sizes.