SILICON VALLEY
CLEAN ENERGY

Heat Pump Technology

Opportunities in Santa Clara County

A COST-EFFECTIVENESS STUDY

April 2019

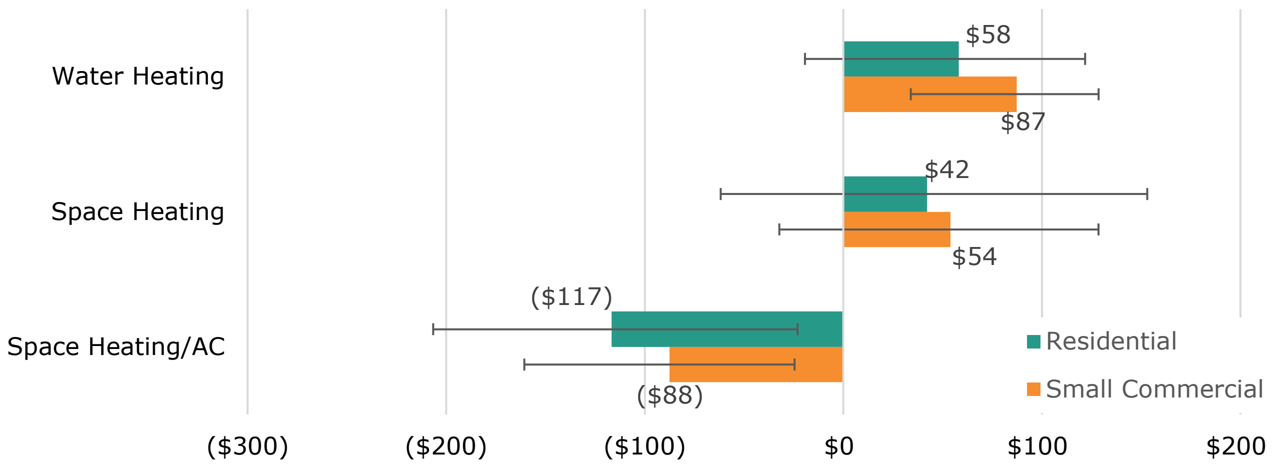
`

Executive Summary

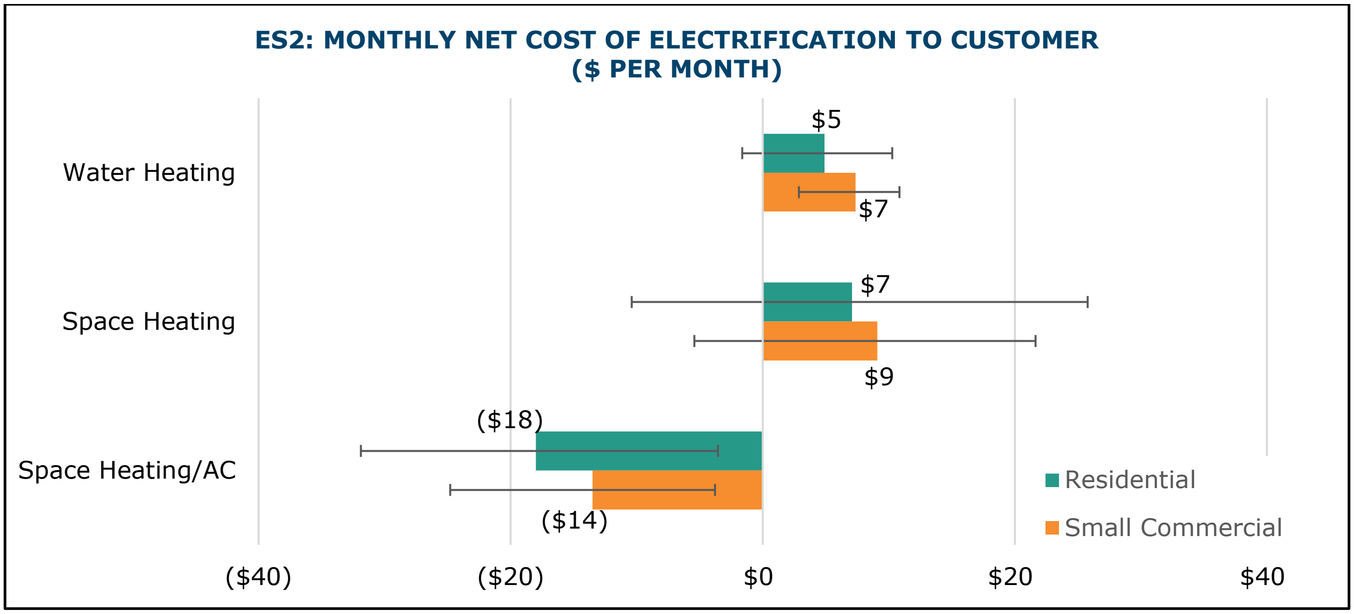
Nearly one third of Silicon Valley Clean Energy's (SVCE's) greenhouse gas (GHG) emissions are from the combustion of natural gas in building appliances, such as for space and water heating. Given SVCE's carbon-free electricity supply, a key strategy to reduce GHG emissions from the built environment is to replace natural gas appliances with efficient electric appliances that run on clean electricity. This fuel-switching activity is referred to as "electrification."

This report documents a cost-effectiveness analysis of space conditioning and water heating electrification opportunities in Santa Clara County, the two end uses which are responsible for the majority of natural gas consumption in buildings. The lifetime net cost of ownership was calculated and compared for natural gas and electric appliances, for water heating, space heating and combined space heating and cooling, for both single-family residential and small commercial buildings. The cost-effectiveness evaluation was carried out from the customer perspective, meaning all costs and revenues born by the customer were considered, including, for instance, installation costs, equipment costs, and ongoing fuel costs. Electrifying an end use is cost-effective if the lifetime net cost of ownership for the electric appliance is lower than that of the natural gas appliance. The costs were also expressed in terms of the incremental cost of GHG abatement, to facilitate comparisons to other GHG abatement measures. The sensitivity of the results to the various input assumptions was captured through a scenario analysis and represented as error bars in the figures of results.

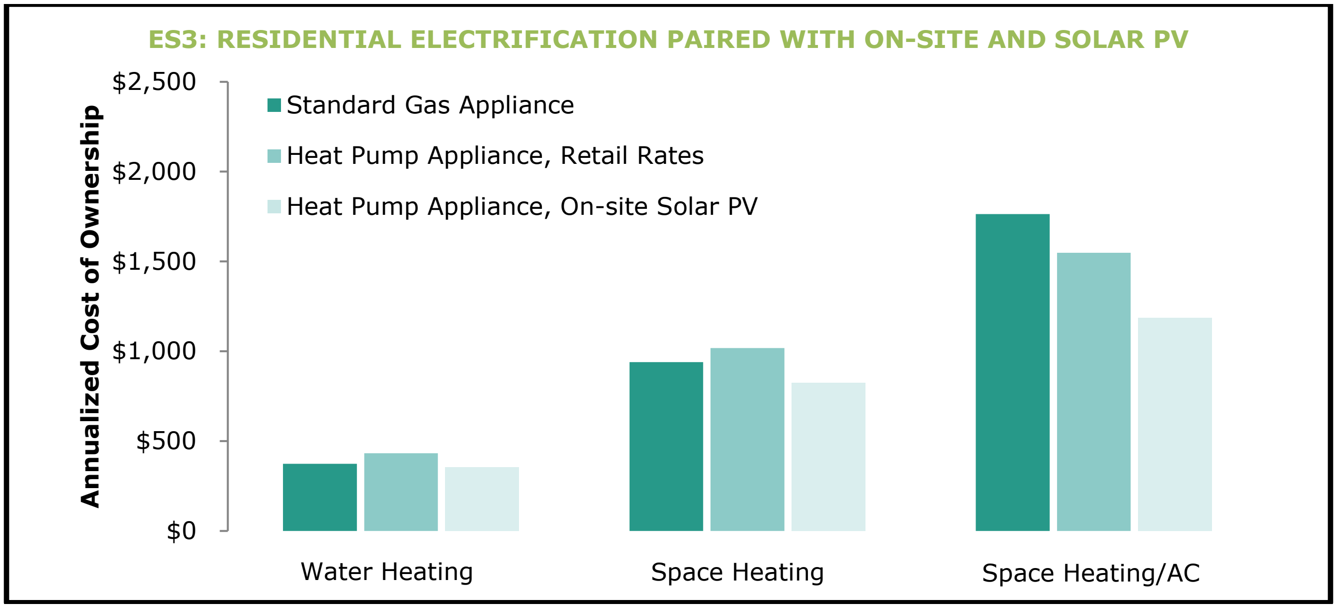
Figure ES1: Incremental Customer GHG Abatement Cost of Electrification ($ per MT CO2e)



The results from the baseline scenario are summarized in Figure ES1, along with error bars showing the results of the scenario analysis. The figure shows the incremental cost of GHG emissions abatement, which are the costs in addition to the price of carbon already embedded in the natural gas and electric retail rates from California's cap-and-trade program. As shown in the figure, from a customer perspective, electrification of water heating and space heating results in increased costs using base case assumptions. The wide range of potential outcomes resulting from the sensitivity analysis as indicated by the error bars in the figure – e.g. water heating could result in a $20 savings per MT CO2e to $120 in costs – demonstrate the sensitivity of the findings to key inputs, such as electricity and natural gas retail rates. Many scenarios evaluated result in cost-effective electrification of these two end uses. However, switching from the standard combination of electric air conditioning and natural gas space heating to an electric heat pump space conditioning system was found to be cost-effective for the baseline scenario and all other scenarios considered. For this case, the customer is both saving money and saving carbon by electrifying.


ES2: MONTHLY NET COST OF ELECTRIFICATION TO CUSTOMER ($ PER MONTH)

Monthly net costs of electrification are shown in Figure ES2, and are less than $10 per end use for water and space heating using base case assumptions. For buildings that have both heating and cooling needs, there is an observed monthly *savings* for the combined space heating and cooling system, which is $18 and $14 per month for residential and small commercial, respectively, using base case assumptions. Based on the sensitivity analysis for commercial customers, pursuing both space and water heating electrification (assuming no building cooling needs) would range from net savings of $2 per month to net costs of $33 per month. For residential customers, the range is from net savings of $12 per month to net costs of $36 per month.


ES3: RESIDENTIAL ELECTRIFICATION PAIRED WITH ON-SITE AND SOLAR PV

The outcome of the cost-effectiveness analysis is strongly dependent specifically on electric and natural gas retail rates. One option for those with sufficient solar irradiance on their property is to install an on-site solar PV system concurrently with pursuing electrification measures. Figure ES3 shows the annualized net cost of ownership for residential customers for the baseline natural gas technology and the electric heat pump replacement technology using two different electricity sources: retail rates and on-site solar PV. As shown in the results, the cost-effectiveness improves significantly for all end uses when electrification is combined with on-site solar adoption.

ES4: IMPACT OF GRID INTERACTIVITY PAYMENTS ON INCREMENTAL CARBON ABATEMENT COST FOR WATER HEATING

Heat pump electric appliances can incorporate technology to enable connectivity and control. So-called "smart" appliances can then be used for on-site load management (avoiding electricity demand during peak price periods) or for grid integration (aggregating and controlling a fleet of smart appliances to participate in wholesale power markets). Load management can serve to lower retail electricity costs, while grid integration can provide an additional value stream that would otherwise not be monetized. The value of load management was also probed and shown to benefit customer economics significantly. To further analyze the potential impact of grid integration of heat pump water heaters, the cost-effectiveness calculation was carried out incorporating an additional value stream resulting from the water heater providing grid services. As shown in Figure ES4, while there is still the significant uncertainty as indicated by the large range of the error bars, the customer economics improve substantially when grid services are monetized and passed on to the customer.

The above analysis focuses on "like-for-like" replacements of electric or natural gas appliances. Put another way, this analysis looks at the cost of replacing and operating the same kind of equipment that was already present in the building, whether natural gas or electric. The analysis is framed in this way to determine whether an electric technology will be cost-effective for the customer on an ongoing basis, across multiple appliance lifetimes. Nevertheless, there are significant costs and barriers surrounding the initial, transitional decision on electrification. For existing homes with natural gas appliances, costs associated with transitional activities such as rewiring and upgrading an electrical panel to convert from a natural gas appliance to an electric one can be substantial, exceeding $5,000 per household when rewiring and potential electrical panel upgrades are considered. These costs present a major barrier for electrifying existing buildings. Such transitional activities and their associated costs can be avoided when an all-electric building design is chosen at the time of new construction. Furthermore, multiple recent studies of all-electric versus dual-fuel buildings in the Bay Area have shown additional, substantial savings associated with avoided costs of a separate utility connection and piping for natural gas service.

In summary, building electrification using heat pump technologies for space and water heating is a key strategy for affordable and effective decarbonization of the built environment. The customer economics are most favorable when the building has both space cooling and heating needs; electrification is combined with on-site solar PV adoption; the appliance load is managed to use electricity during times of off-peak demand and leveraged to provide grid services; and, an all-electric building design is chosen at the time of new construction. SVCE will work with partners on behalf of its customers and community to launch targeted programs that can help overcome identified market barriers to continue to support decarbonization in the built environment.

About This Report

Silicon Valley Clean Energy's (SVCE) mission is to "reduce dependence on fossil fuels by providing carbon-free, affordable and reliable electricity and innovative programs for the SVCE community." Building on an estimated 21% reduction in community-wide greenhouse gas emissions from a 2015 baseline from adopting a carbon-free default electricity supply portfolio, SVCE is working with its member communities to extend these reductions to 30% by 2021, 40% by 2025 and 50% by 2030. Natural gas usage in buildings is a major source of the remaining community emissions, and the results described in this report are intended to help inform policy discussions among SVCE, member agencies, and the community.

As a part of SVCE's mission to promote transparency, the spreadsheet model underpinning this analysis has been made available on the SVCE website at the following link: https://www.svcleanenergy.org/researchandanalysis/.

About Silicon Valley Clean Energy

SVCE, a community choice energy agency, is redefining the local electricity market and providing our residents and businesses with new clean energy choices—renewable and carbon-free electricity at competitive rates. SVCE was formed as a Joint Powers Authority in 2016 and now serves approximately 270,000 residential and commercial electricity customers across a service area comprised of the following thirteen communities: Campbell, Cupertino, Gilroy, Los Altos, Los Altos Hills, Los Gatos, Milpitas, Monte Sereno, Morgan Hill, Mountain View, Saratoga, Sunnyvale and Unincorporated Santa Clara County.

Contact Information

Please direct any questions, comments, corrections, or requests to the SVCE Innovation email inbox (innovation@svcleanenergy.org) or to the call line 1-844-474-SVCE (7823).

Acknowledgments

SVCE would like to recognize and thank the City of Palo Alto Utilities for preparing and sharing the spreadsheet analysis and report on residential electrification in the Palo Alto community, which formed the foundation of SVCE's work.

SVCE would also like to recognize and thank the following Sunnyvale city staff for their input on the initial version of the analysis, which was presented at a Sunnyvale City Council Study Session on November 27, 2018: Kent Steffens, Ramana Chinnakotla, Trudi Ryan, Melody Tovar and Nupur Hiremath.

The following SVCE staff contributed to this study: Justin Zagunis, Karen Pauls, John Supp, Aimee Bailey

Table of Contents

Heat Pump Technology Opportunities in Santa Clara County

A COST-EFFECTIVENESS STUDY

SILICON VALLEY CLEAN ENERGY

Chapter 1: Introduction

SVCE's member cities have achieved an estimated 21% reduction in community-wide GHG emissions from a 2015 baseline by launching SVCE and adopting a carbon-free default electricity supply. Current efforts focus is extending these emissions reductions to 30% by 2021, 40% by 2025 and 50% by 2030[1]. Reaching these ambitious goals will require a broad set of policy and programmatic efforts. As SVCE's electricity supply is carbon-free, switching end uses that currently use from fossil fuels to those that use decarbonized electricity – known as "electrification" – is a key strategy to achieve deep decarbonization. Electrification can refer to the replacement of natural gas use in buildings and gasoline use in vehicles with electricity use. The broad scientific consensus is that substantial electrification of the building and transportation is required to achieve deep decarbonization[2]. This report focuses on the electrification of buildings by transitioning away from natural gas usage, which is a major source of the remaining GHG emissions in SVCE service territory.

The report focuses exclusively on space heating, space cooling and water heating appliances found in single-family households and small commercial buildings. Natural gas usage and associated GHG emissions are primarily from space- and water-heating end uses. This report analyzes the cost-effectiveness, from the customer perspective, of electrification options for these small commercial and residential customers. The options are compared on a "like-for-like" basis, meaning the appliances are replacing existing, old units of the same technology type. If the lifetime net cost of ownership of the natural gas technology is higher than the alternative electric technology, then electrifying the technology will be cost-effective for the customer on an ongoing basis. The results are also expressed in terms of the GHG emissions abatement cost, which consists of the incremental cost associated with an electric option per metric ton of carbon dioxide equivalent (CO_2e) no longer emitted. The results section also contains evaluations of grid-interactivity, retrofit costs, new construction savings, solar PV adoption and solar thermal water heating. The final chapters of the report discuss the limitations and conclusions of this study.

The assumptions included in this report are based on the information available to SVCE at the time of publishing and have significant implications for the results. Therefore, a sensitivity analysis was conducted using various combinations of input rate assumptions, the outcomes of which comprise the error bars displayed in the figures of results. To ensure applicable and accurate results for a given city or at a future time, these assumptions may need to be updated. For transparency, tables of assumptions are included as appendices to this report, and the spreadsheet model underpinning this analysis is available for download on SVCE's website[3].

---

[1] https://www.svcleanenergy.org/wp-content/uploads/2019/03/Decarbonization-Strategy-Programs-Roadmap_Dec-2018.pdf

[2] See, for instance, the 2012 landmark study "The Pivotal Role of Electricity", published in Science.

[3] https://www.svcleanenergy.org/researchandanalysis/

Chapter 2: Methodology

The lifetime net cost of ownership to the customer for each technology was computed by calculating the summation of the net present value of all costs and revenue streams. Given that some technologies, like water heaters, have different lifetimes, this lifetime net cost of ownership was divided by the expected lifetime to arrive at the annualized net cost of ownership, when needed.

Section 2.1: Cost-Effectiveness from Customer Perspective

The net cost of ownership calculation from the customer perspective incorporates all costs and revenues borne by the customer. For appliances in the standard Santa Clara County building, the costs include the up-front purchase, installation, permitting and any ongoing fuel, operation or maintenance. The costs are offset by any available rebates and financial incentives offered to the customer by any source. The customer perspective uses the projected retail cost of electricity and natural gas when looking at future-year impacts.

Table 1 shows a summary of the costs and incentives encompassed by the customer perspective.

TABLE 1: CUSTOMER PERSPECTIVE COMPONENTS

Category	Customer Perspective
Up-front	- Equipment, tax, permit & installation costs - Federal incentives - State incentives - Utility incentives
Fuel	- Retail electricity cost - Retail natural gas cost
O&M	- Equipment O&M costs

Section 2.2: Base Case Assumptions

The summaries of the Base Case assumptions that were incorporated in the analysis are provided below. Appendix A has an inclusive catalog of all costs and incentives incorporated in the analysis.

Section 2.2.1: General Assumptions

Table 2 summarizes the Base Case assumptions. The 4% discount rate is an estimated internal rate-of-return assumption and is used to find the net present value of future costs. Inflation, as measured by the Consumer Price Index (CPI), is estimated to be a constant 4.5% based on the most recent data for all urban consumers in this area and is used to escalate specified costs.

California has an economy-wide cap-and-trade program established by the California Air Resources Board (CARB) that covers both electricity and natural gas usage. Therefore, a cost of carbon associated is already embedded in the retail rates used as inputs to this analysis. Nonetheless, the allowance cost through the program remains arguably so low as to be ineffective. For this reason and to facilitate comparison between electrification and other GHG abatement measures, the figures of results are also expressed in terms of incremental abatement costs, meaning the costs above what is already embedded in the retail rates through the cap-and-trade program.

The analysis assumptions incorporate one residential rate and one commercial rate in this analysis. These rates are from standard Pacific Gas and Electric (PG&E) rate offerings. The electric rates were effective January 1, 2019: E-TOU-C3 for residential and A-1 for commercial. The electric rates are not adjusted to reflect SVCE's cheaper electricity offerings for simplicity and due to the level of uncertainty with ongoing rate-setting proceedings. This analysis can, therefore, be treated as underrepresenting the benefits of electrification for SVCE customers. The natural gas rates were from the December 2018 rate forecast for residential and small commercial. For the base case assumptions, the rates are averaged into single, annual values. The time-dependence of rates on electrification is captured in the sensitivity analysis.

TABLE 2: BASE CASE ASSUMPTIONS, GENERAL

Base Case Assumptions, General	
Description	**Value**
Discount rate	4.0%
Inflation/Consumer Price Index	4.5%
Electricity, residential retail cost	$0.31 per kWh: average of summer and winter, peak and off-peak E-TOU-C3 rates; escalated based on historical rate changes
Electricity, small commercial retail cost	$0.24 per kWh: average A-1 rates; escalated based on historical rate changes
Natural gas, residential retail cost	$1.60 per therm: average residential rate; escalated based on historical rate changes
Natural gas, small commercial retail cost	$1.09 per therm: average commercial rate; escalated based on historical rate changes

Section 2.2.2: Appliance Assumptions

Three end uses are considered for the appliance analysis: water heating, space heating, and combined space heating and cooling. For each of these end uses, a variety of technologies are included in the analysis, as outlined in Table 3.

TABLE 3: APPLIANCE TECHNOLOGIES INCLUDED IN THE ANALYSIS

Building Appliances Analysis	
Water Heating	
	Standard Efficiency Natural Gas (EF 0.58)
	High Efficiency Natural Gas (EF 0.72)
	Natural Gas Tankless (EF 0.93)
	Standard Efficiency Electric Resistance (EF 0.93)
	Electric Tankless (EF 0.99)
	Heat Pump Electric (COP 3.55)
	Solar Thermal with Electric Backup
Space Heating	
	Standard Efficiency Natural Gas (AFUE 80)
	High Efficiency Natural Gas (AFUE 95.5)

	Standard Efficiency Electric Resistance (AFUE 100)
	Air Source Duct Heat Pump (COP 3.8)
Space Heating and Cooling	
	Standard Efficiency Natural Gas Heater (AFUE 80) and Standard Efficiency Electric Air Conditioner (SEER 14)
	Air Source Duct Heat Pump (COP 3.8 and SEER 14)
	Air Source Mini-Split Heat Pump (COP 3.6 and SEER 21)

Incremental customer GHG emissions abatement cost calculations use the standard efficiency natural gas appliance as the baseline and the electric heat pump appliance technologies as the electrification alternatives for each end use. Note that the air source duct heat pump used for solely space heating is the same unit as the one used for combined space heating and cooling. The equipment and installation costs are therefore equivalent, but the electricity consumption differs as the solely space heating calculations assume that it is not used to provide any cooling. Complete results for the lifetime net cost of ownership calculations are calculated for each of the technologies listed in Table 3 and displayed in the results. The GHG emissions abatement costs for each end use comparison listed in Table 4 are also displayed in the results.

TABLE 4: NATURAL GAS APPLIANCES AND ELECTRIFICATION ALTERNATIVES

Building Appliances Analysis		
End Use	**Baseline Appliance**	**Electric Replacement Appliance**
Water Heating	Standard Efficiency Natural Gas	Heat Pump Electric
Space Heating	Standard Efficiency Natural Gas	Air Source Duct Heat Pump Electric (heating only)
Space Heating and Cooling	Standard Efficiency Natural Gas	Air Source Duct Heat Pump Electric (heating and cooling)

Table 5 lists the appliance Base Case assumptions. Equipment costs are taken primarily from the online Home Depot and Lowe’s websites, as collected in February 2019. The standard air conditioner (AC) unit and heat pump equipment costs were drawn from several product-specific webpages. The solar thermal water heater data was from the California Solar Initiative database. The water heater installation costs include estimated local permit costs and installer estimates through Amazon. Space heating and cooling installation costs came from several recent reports on building electrification in California. These costs are representative of the like-for-like ongoing replacement scenario, which is distinct from new construction and retrofit.

Retrofitting existing building stock to transition from a natural gas appliance to an electric one can add several thousand dollars to the overall costs. The additional retrofit costs are not included in the cost-effectiveness analysis, as the report focuses on replacements after the decision on a fuel source has been made. Retrofit costs and other considerations are addressed in Section 3.3.

Appendix A includes a detailed table of appliance-specific assumptions for the equipment and installation costs, annual fuel usage and available incentives.

TABLE 5: BASE CASE ASSUMPTIONS FOR BUILDING APPLIANCES ANALYSIS

Base Case Assumptions, Building Appliances Analysis	
Description	**Value**
Equipment and installation costs	- Solar thermal water heater: California Solar Initiative - Other water heaters: Home Depot or Lowe's online quotes, Feb 2019 - Space heating and cooling: product webpages - 9% sales tax: standard for most of SVCE territory - $500 - $7,000 installation costs: permits, online quotes, and reports - Electrical panel upgrade and other rewiring not included
Appliance lifetimes	- Water heater, with tank (natural gas and electric): 12 years - Water heater, no tank (natural gas and electric): 20 years - Solar thermal water heater with electric backup: 20 years - Space heating and cooling (natural gas and electric): 20 years
Operations and maintenance (O&M)	- $50 annual O&M for solar thermal and tankless water heaters, escalated annually by CPI - $100 annual O&M for space heating and cooling, escalated annually by CPI
Appliance fuel consumption	- Water heater: Federal trade commission energy guide label - Space heating and cooling: Rocky Mountain Institute report
Water heater capacity	- Tank: ~70 gallons first hour volume - Tankless: ~3.8 gallons per minute at 65 degrees Fahrenheit
Space heating and cooling capacity	- Heating: ~65,000 BTU or equivalent - Cooling: ~3 ton

Section 2.3: Sensitivity Analysis

The results of this analysis strongly depend on retail rate assumptions for electricity and natural gas that are used to calculate the net cost of ownership and emissions. A sensitivity analysis was carried out to probe the dependence of the results on the input assumptions. This analysis spans four scenarios for both residential and commercial customers. The scenarios use Base Case assumptions except where explicitly stated.

Scenario 1. Residential Base Case: The cost-effectiveness calculations use the residential Base Case assumptions described in Section 2.2.

Scenario 2. Residential Best Case: The electric rate was changed to be the average of the summer and winter off-peak energy rates on the residential E-TOU-C3 rate, with a 50% lower escalation rate than in the residential Base Case. The natural gas rate was changed to have a 50% higher escalation rate than in the residential Base Case.

Scenario 3. Residential Worst Case: The electric rate was changed to be the average of the summer and winter peak energy rates on the residential E-TOU-C3 rate, with a 50% higher escalation rate than in the residential Base Case. The natural gas rate was changed to have a 50% lower escalation rate than in the residential Base Case.

Scenario 4. Residential On-Site Solar PV: The electricity needed to supply the all-electric appliance was priced at the levelized cost of energy (LCOE) of a standard solar photovoltaic (PV) residential system.

Scenario 5. Commercial Base Case: The cost-effectiveness calculations use the commercial Base Case assumptions described in Section 2.2.

Scenario 6. Commercial Best Case: The electric rate was changed to be the average of the summer and winter off-peak energy rates on the commercial A-1 rate, with a 50% lower escalation rate than in the commercial Base Case. The natural gas rate was changed to have a 50% higher escalation rate than in the commercial Base Case.

Scenario 7. Commercial Worst Case: The electric rate was changed to be the average of the summer and winter peak energy rates on the commercial A-1 rate, with a 50% higher escalation rate than in the commercial Base Case. The natural gas rate was changed to have a 50% lower escalation rate than in the commercial Base Case.

Scenario 8. Commercial On-Site Solar PV: The electricity needed to supply the all-electric appliance was priced at the levelized cost of energy (LCOE) of a standard solar photovoltaic (PV) small commercial system.

A summary of these scenarios is shown in Table 6. Results from the sensitivity analysis are incorporated throughout the results, where the two ends of the error bars shown in the figures comes from the highest and lowest values found across all relevant scenarios.

TABLE 6: SCENARIOS CONSIDERED IN SENSITIVITY ANALYSIS

Scenario Description	Retail Electricity	Retail Natural Gas
Residential		
1. Residential Base Case:	Average retail rate	Average retail rate
2. Residential Best Case	Off-peak average retail rate, escalates at half Base Case rate	Average retail rate, escalates at 2X Base Case rate
3. Residential Worst Case	On-peak average retail rate, escalates at 2X Base Case rate	Average retail rate, escalates at half Base Case rate
4. Residential Onsite Solar PV	On-site solar LCOE and average retail rate	Average retail rate
Commercial		
5. Commercial Base Case	Average retail rate	Average retail rate
6. Commercial Best Case	Average retail rate, escalates at half Base Case rate	Average retail rate, escalates at 2X Base Case rate
7. Commercial Worst Case	Average retail rate, escalates at 2X Base Case rate	Average retail rate, escalates at half Base Case rate
8. Commercial On-Site Solar PV	On-site solar LCOE and average retail rate	Average retail rate

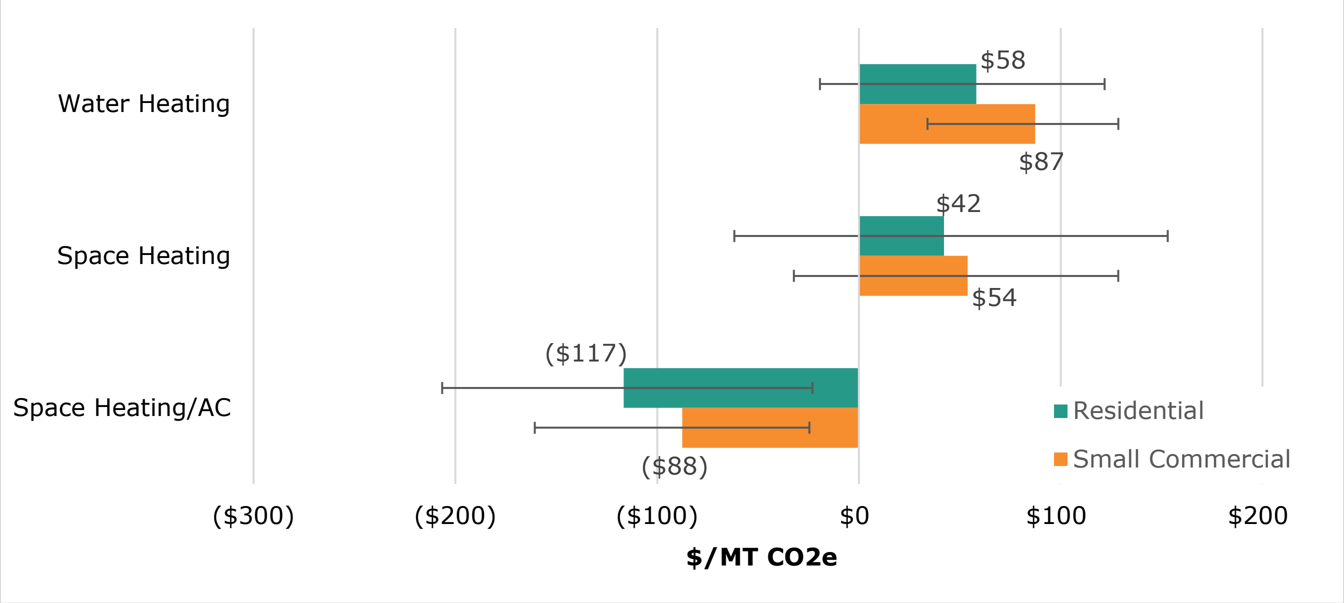
Chapter 3: Results

This chapter documents the major results from the analysis. Section 3.1 presents the overall results in the form of an incremental customer GHG emissions abatement cost range for each end use, along with the monthly cost of electrification. Section 3.2 presents the lifetime net cost of ownership comparing all technologies by end use. Section 3.3 briefly discusses how this analysis compares to installations in new construction and retrofit situations. Section 3.4 investigates the impact of combining electrification measures with on-site solar PV adoption. Section 3.5 evaluates the costs and benefits of solar water heating from traditional solar thermal systems versus installing a solar PV system and retrofitting to a heat pump water heater. Section 3.6 examines the possible cost-effectiveness impacts of a virtual power plant program paying customers for grid-interactive water heaters.

Section 3.1: GHG Emissions Abatement Costs

As discussed in Chapter 1, this section presents the GHG emissions abatement costs from the customer perspective. These values represent the additional cost (or savings) associated with using the electric option compared to the natural gas option, per metric ton of carbon dioxide equivalent abated.

FIGURE 1: INCREMENTAL CUSTOMER GHG EMISSIONS ABATEMENT COST OF ELECTRIFICATION BY END USE



The abatement cost shown in Figure 1 compares the difference in the net cost of ownership of the heat pump technology relative to the baseline natural gas technology, divided by the total amount of abated GHG emissions. The Base Case scenario values are plotted and labeled with numbers on the figure. The highest and lowest abatement cost values found in any of the scenarios described in Section 2.3 comprise the endpoints of the error bars for each electrification measure.

Both the water and space heating appliance Base Case options show that electrification has a positive net incremental abatement cost, meaning the customer would be paying that amount to reduce each metric ton of carbon dioxide equivalent. For commercial water heating, the range of costs remains positive, while for residential water heating there is a wide range of possible costs in the positive and negative that are observed. The space heating technologies show an extremely wide range of possible costs, both positive and negative. The space heating and air conditioning combined electrification Base Case shows a negative incremental abatement cost, meaning the customer will actually save money to reduce their emissions. The range for the space heating and air conditioning combined electrification remains negative for all scenarios.

FIGURE 2: INCREMENTAL CUSTOMER GHG EMISSIONS ABATEMENT COST OF ELECTRIFICATION BY END USE FOR ALL SCENARIOS

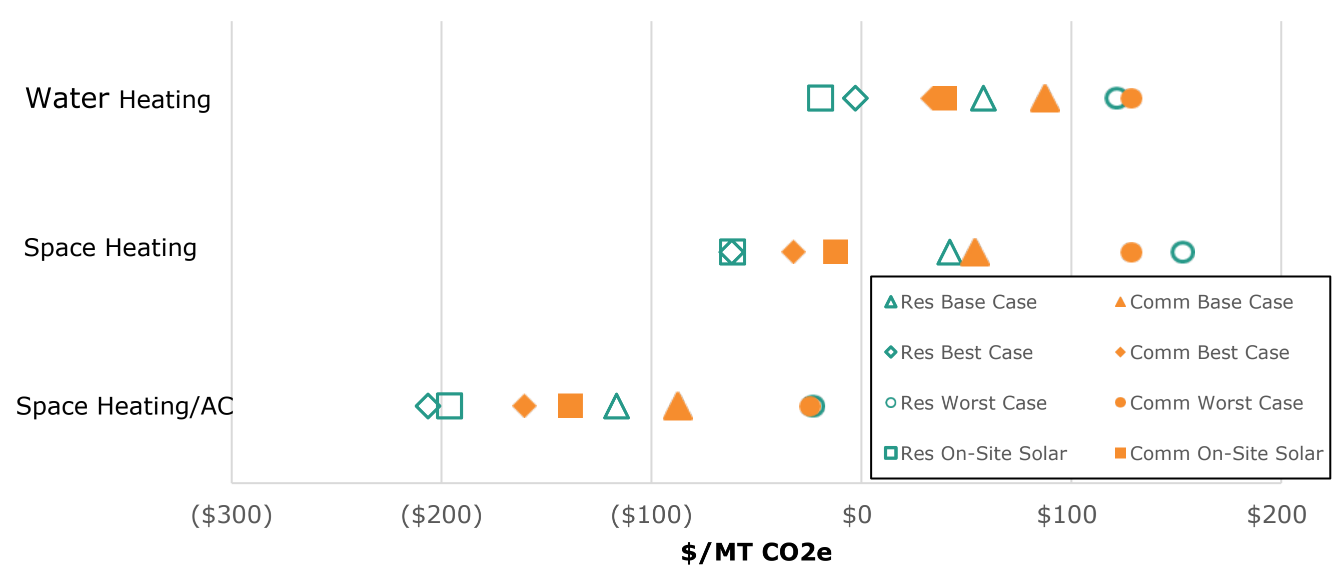


Figure 2 shows the resultant incremental customer GHG emissions abatement cost curve for all scenarios described in Section 2.3. This figure includes the maximum and minimum outcomes from the scenario analysis used as the endpoints of the error bars in Figure 1. This figure additionally provides a detailed breakdown of the results by scenario. The difference in outcomes for each end use are substantial and show different trends between the residential and commercial sectors. The spread of results reflects the sensitivity of the findings of this analysis to the many input assumptions.

The most notable trend for all measures and sectors is that installing on-site solar under a net metering offering provides a significant opportunity to reduce the costs of electrification to a customer. The impact of on-site solar option is greater for residential customers compared to commercial when compared with the associated Base Case, due to higher residential electric rates.

FIGURE 3: MONTHLY NET COST OF ELECTRIFICATION TO CUSTOMER

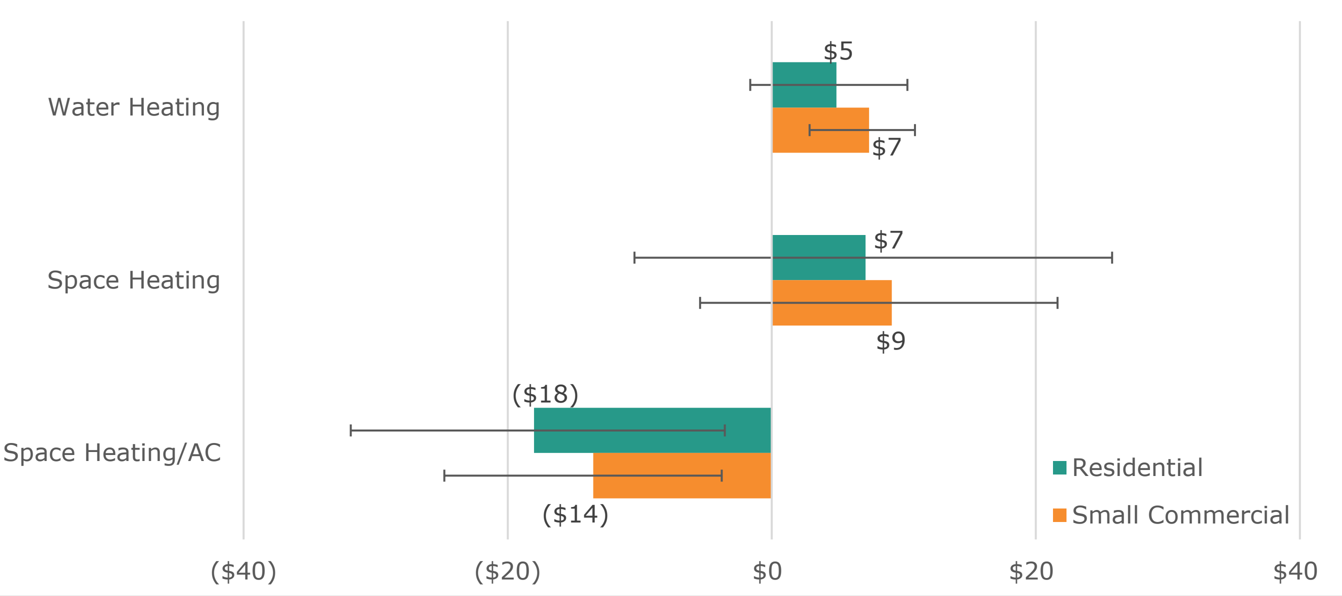
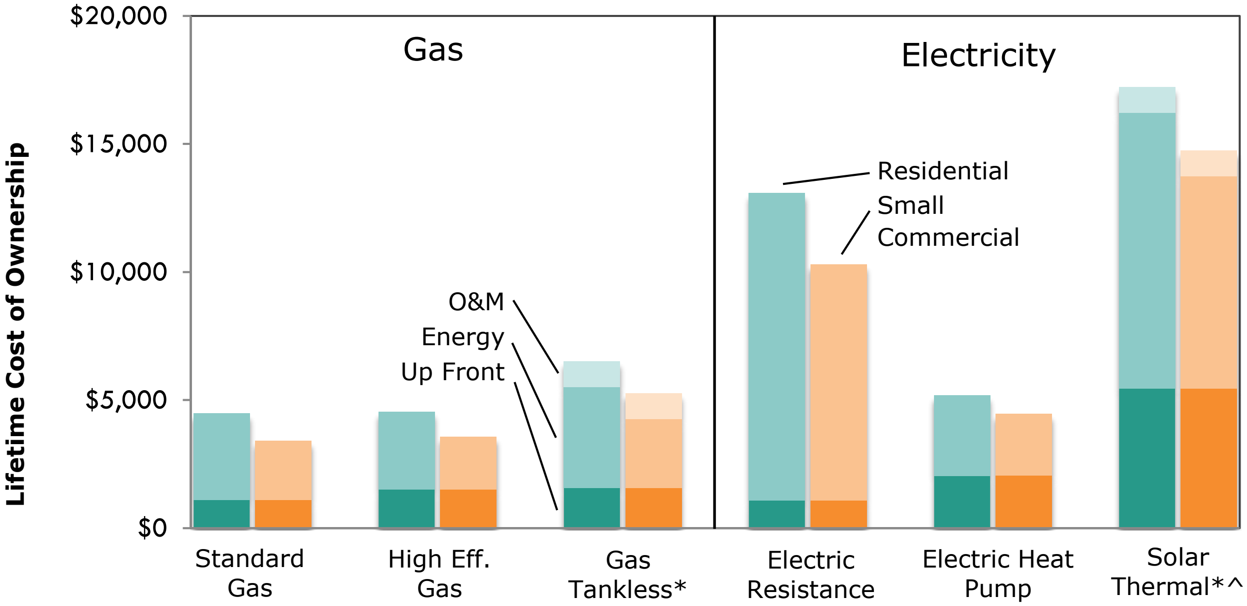


Figure 3 shows the monthly net cost to a customer for each electrification measure. Under the Base Case scenario, implementing both water and space heating electrification would have monthly net costs of $12 for residential and $16 for commercial. Implementing both water heating and combined space heating and cooling electrification would have monthly net savings of $13 for residential and $7 for commercial under the Base Case scenario. As indicated by the error bars in the figure, the actual costs or savings seen by a customer when pursuing two measures could vary by up to nearly $50 per month based on which scenario most closely mimics how the future will unfold.

Section 3.2: Lifetime Net Costs

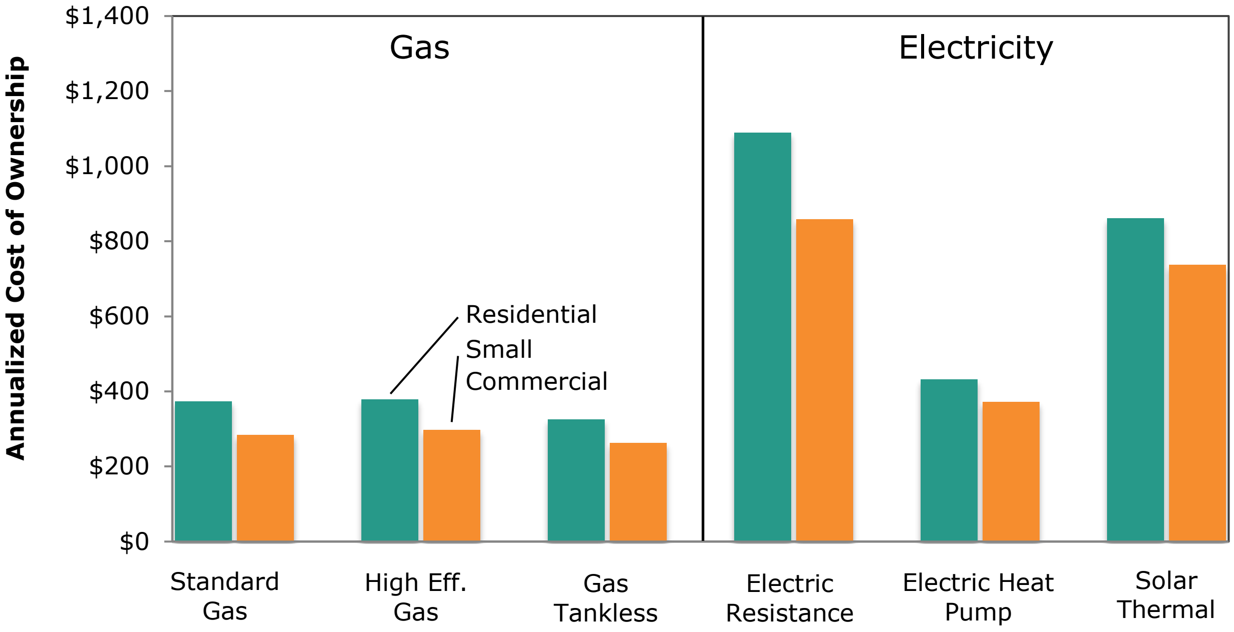
The lifetime net cost of ownership from the customer's perspective for all measures are shown in the following figures. As water heater technologies have different expected lifetimes by technology type, both the lifetime and annualized net costs of ownership are included for those measures to facilitate comparisons on an equivalent basis. The figures include costs for all equipment types analyzed for each measure.

FIGURE 4: LIFETIME NET COST OF OWNERSHIP OF WATER HEATING TECHNOLOGIES



*Gas tankless & solar thermal have longer estimated life; annualized costs shown on following figure.
^ Electric resistance backup. Includes federal tax incentive and PG&E rebate.

FIGURE 5: ANNUALIZED NET COST OF OWNERSHIP OF WATER HEATING TECHNOLOGIES



Figures 4 and 5 tell a similar story, showing that the standard and high efficiency gas water heaters have a slight cost advantage over the electric heat pump. When considering the longer lifetime of the gas tankless water heater, it becomes the most cost-effective option from the customer's perspective. Solar thermal has the highest lifetime cost but lasts longer than most of the other technologies, leaving the electric resistance water heater as the least cost-effective on an annualized basis. The analysis supports that electrification is only cost-competitive when considering the newer, high-efficiency electric technologies like heat pumps and not conventional electric resistance.

FIGURE 6: LIFETIME NET COST OF OWNERSHIP OF SPACE HEATING TECHNOLOGIES

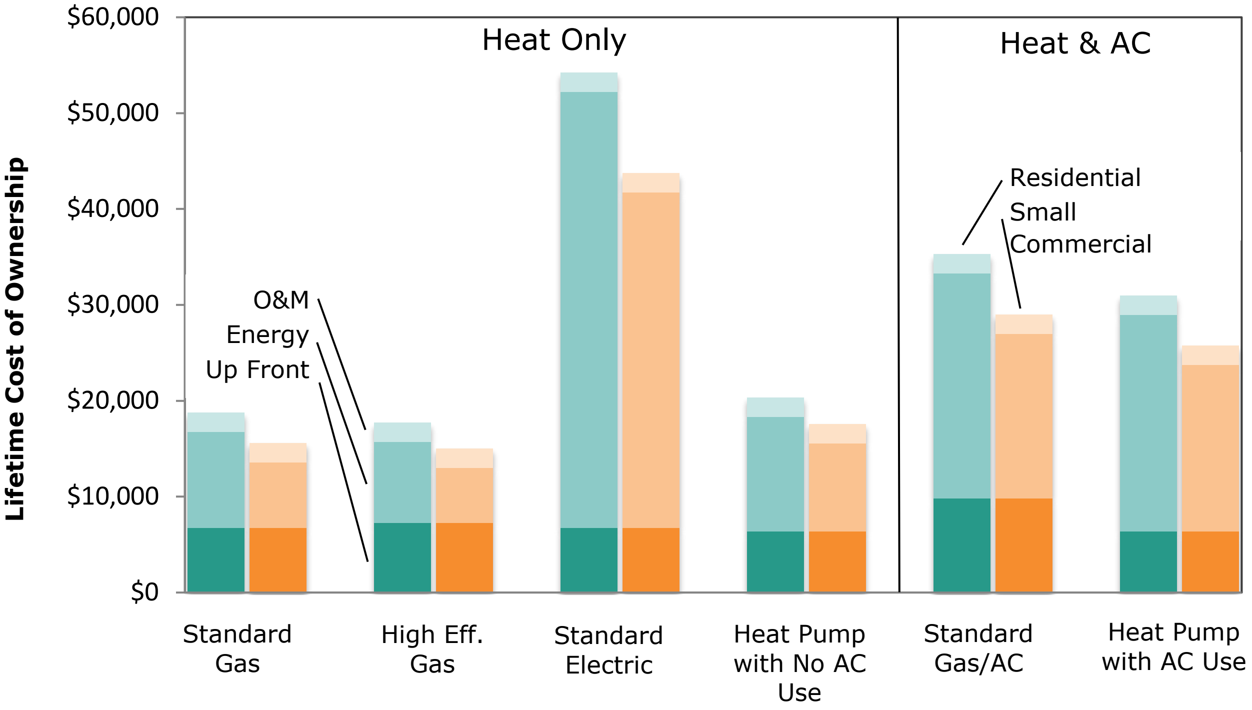


Figure 6 presents two separate analyses – one for the space heating only and one for the space heating and cooling (AC) combined. As heat pumps can operate in both heating and cooling operations, the equipment, installation and maintenance costs are equivalent when looking at a unit operating in heating only mode or as combined heating and cooling. For all other technologies, there are additional up-front costs when adding the space cooling component. This discrepancy leads the heat pump to be slightly more expensive when looking at space heating only, while being the cheaper option when looking at combined space heating and cooling. As with the water heater analysis, the standard electric resistance space heater is the least cost-effective technology.

Section 3.3: New Construction versus Retrofit Costs

Results displayed in the prior sections of this report for building appliance electrification incorporate all costs for a like-for-like replacement. The analysis is intended to compare the ongoing costs between technologies for a given end use, without consideration as to what infrastructure is in place in the building. However, there are additional costs and savings associated with the electrification of an end use via the new construction or retrofit pathways. Retrofits have substantially higher up-front costs than what is included in the cost-effectiveness calculations for like-for-like replacements.

Retrofitting an existing building from a natural gas appliance to an electric one can incur $1,000-$2,000 per appliance with wiring and running conduit from the electrical panel to the appliance location[4]. Retrofit costs can even exceed this range if the appliance must be relocated or additional venting installed due to new sizing or ambient air constraints. The electrical panel may also need to be upgraded to accommodate one or more new electric appliances. Costs of upgrading a 100 Amp to a 200 Amp service can range from $2,500 to $5,000[5], depending on the building and permitting jurisdiction and local market. When considering a retrofit, electrifying multiple appliances at one time could lead to significant cost savings as compared to sequential retrofits.

Choosing an all-electric building at the time of construction can instead lead to significant cost savings, even though additional wiring and larger electric panels are still needed. The building owner avoids the cost of natural gas assets (appliances, piping, supporting network infrastructure, etc.), which can range from approximately $6,000 for residential to $12,000 for small commercial[6]. Furthermore, there are also savings from the simpler design and single-fuel permitting process.

Section 3.4: Combining Electrification with On-Site Solar PV Adoption

The outcome of these cost-effectiveness calculations is strongly dependent on the electric and natural gas rate forecasts used in the analysis. One option for customers who have enough solar irradiance on their property could be to install a solar PV system under the available net energy metering (NEM) incentive rates. Solar under a NEM rate gives value for excess electricity generated and sent to the grid, while also offsetting some or all of the need to draw electricity from the grid during times when solar electricity is being generated. PG&E's initial NEM 1 program offered the full value of the retail rate for excess electricity exported to the grid. This analysis assumed that a customer would be on the NEM 1 rate, or equivalently that all load would occur simultaneously with on-site generation. PG&E's solar rate offerings are transitioning away from NEM 1 to NEM 2[7] and, eventually, to an as-yet-to-be-determined NEM 3 rate. Any customer considering installation of a new solar PV system must consider the less-beneficial economics of these new rates. The spreadsheet used for the analysis includes the ability to change how much benefit the solar PV system conveys by allowing for mixed sourcing: some electricity purchased from the grid and some provided by the solar PV system. In the on-site solar analysis presented throughout this report, the value used is 50%, indicating that half the electricity is generated from on-site solar PV and half is purchased at retail rates. This assumption may roughly reflect a future NEM 3 scenario, or can be treated as a conservative estimate of the NEM 1 and 2 rate offerings.

---

[4] https://www.cityofpaloalto.org/civicax/filebank/documents/56134

[5] Ibid.

[6] Ibid.

[7] https://www.cpuc.ca.gov/General.aspx?id=3800

FIGURE 7: ANNUALIZED NET COST OF OWNERSHIP COMPARING THREE DIFFERENT RESIDENTIAL CUSTOMER FUEL COST ASSUMPTIONS: GAS RATE, ELECTRICITY RATE, AND ON-SITE SOLAR PV

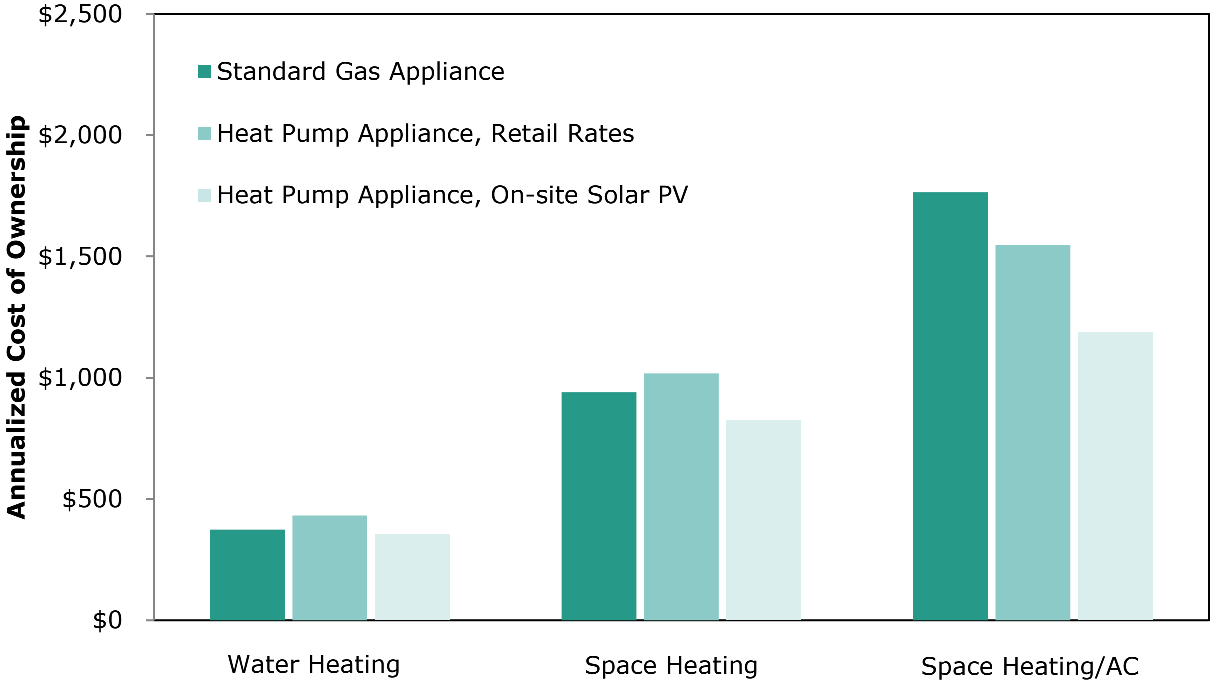


Figure 7 shows the annualized net cost of ownership between the baseline natural gas technology and the electric heat pump replacement technology for two different electricity sources: 1) retail rate base case assumption, and 2) on-site solar PV. Figure 7 shows the results for residential customers for three different appliance types, while commercial findings follow a similar trend. Electrification combined with on-site solar adoption is more cost-effective to the customer than the other options considered, as shown previously in Figure 2.

If the percent of electricity provided by the on-site solar PV system is increased, the economics of the heat pump appliance improve even further. Looking at a 90% sourcing of electricity from the on-site solar PV – an approximation of the NEM 2 rate – decreases the annualized net costs shown in Figure 7 by $63 for water heating, $153 for space heating, and $289 for space heating and cooling. Looking at a 100% sourcing of electricity from the solar PV – in line with the NEM 1 rate – instead decreases the annualized net costs shown in Figure 7 by $78 for water heating, $192 for space heating, and $362 for space heating and cooling. While on-site solar paired with a heat pump always remains more cost-effective than the electric and natural gas base cases for all three benefit levels considered (50%, 90%, and 100%), the sensitivity of cost to the available NEM rates is clear. Results for commercial customers follow similar trends, although the impact of changing to different NEM rates is muted due to the comparatively lower commercial retail electricity rates.

Section 3.5: Impact of Grid-Interactive Water Heaters

Newly electrified loads could incorporate the capability to be connected and controlled in order to enhance grid reliability and to help integrate high penetrations of renewables. Grid-interactive, demand-response-capable heat pump water heaters, for instance, could offer a sizeable amount of dispatchable load once deployed at scale. This dispatchable load could help the local load-serving entity (i.e. SVCE) achieve cost savings by reducing energy demand during periods when wholesale market prices are spiking, savings which would then be passed on to customers. To analyze the impact on customer economics of grid integration of heat pump water heaters, the cost-effectiveness calculation was re-calculated while incorporating an additional value stream resulting from the water heater providing grid services. The value stream was estimated to be $66 dollars scaled annually by CPI, which was estimated from a recent study[8].

FIGURE 8: COMPARISON OF HEAT PUMP WATER HEATER ANNUALIZED COST OF OWNERSHIP WITH AND WITHOUT PAYMENTS FOR GRID INTERACTIVITY

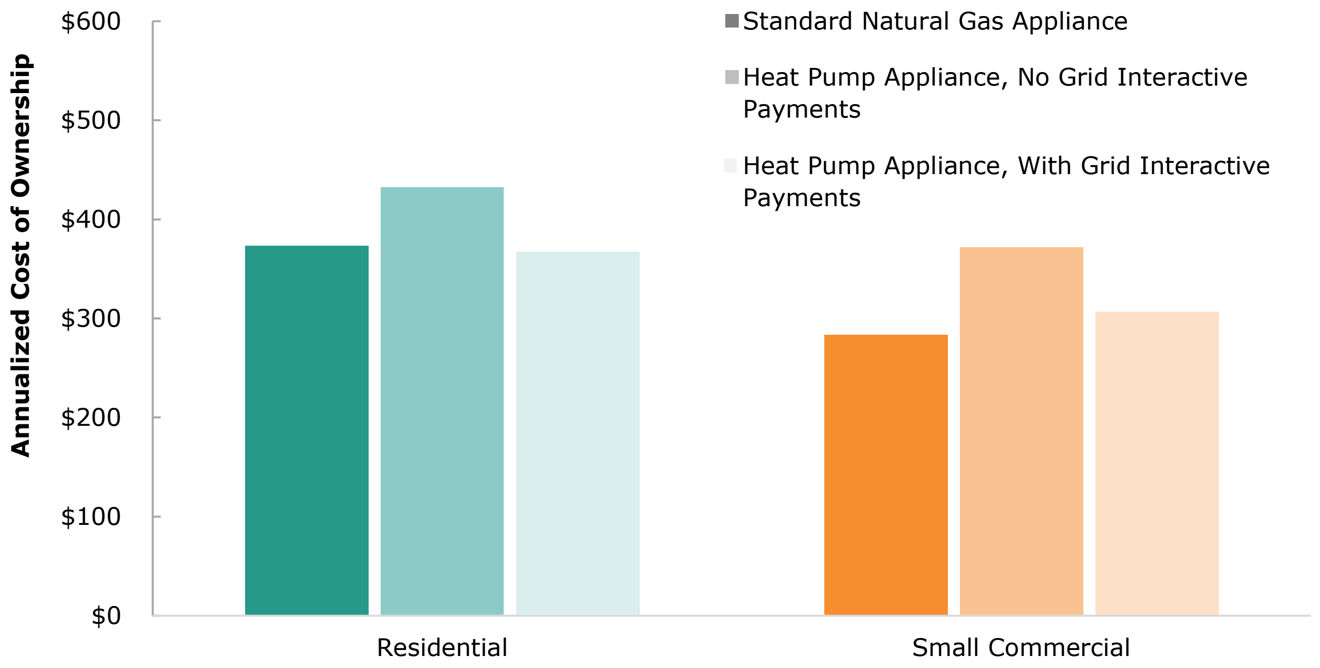


Figure 8 shows the impact of potential payments for grid interactivity to the customer. The annualized cost of ownership of decreases substantially for the customer when this additional value stream is monetized. For residential customers, the heat pump base case scenario changes from an annualized cost of $433 to $367. Commercial customers see a similarly significant drop in costs.

These results support SVCE's plan to pursue grid integration activities to support the monetization of demand-side flexibility to make electrification more cost-effective to customers. Heat pump

---

[8] http://www.electric.coop/wp-content/uploads/2016/07/The-Hidden-Battery-01-25-2016.pdf

water heaters are one measure that could benefit among many others, such as smart thermostats, smart electric vehicle chargers, storage systems, and building energy management systems.

Chapter 4: Discussion

This study has a number of limitations worth noting. For instance, viable technologies were excluded that could impact the cost-effectiveness results, such as ground source heat pumps, distributed storage, and non-solar distributed generation. Also, variability between buildings results in a wide range of installation and retrofit requirements and costs (layout of the building, age, location of electrical panel, and available ambient space), and this variability is not reflected in the scenario analysis. The scenario analysis attempts to capture the uncertainty in the input assumptions such as the retail rates, yet the actual rates over the twenty-year horizon under consideration in this study may deviate significantly from the assumptions. For this reason, the range of outcomes presented in the results charts should be given greater consideration than any specific scenario.

There are also significant benefits not considered within the analysis, such as the positive public health and safety impacts resulting from reduced natural gas usage. On-site natural gas combustion generates emissions that must be properly ventilated or risk health impacts[9]. Combustion equipment that is not properly maintained can produce increased levels of these chemical byproducts, including carbon monoxide[10]. There are also safety considerations with the distribution of natural gas to buildings, as these systems can suffer catastrophic accidents[11]. By removing the presence of natural gas and on-site combustion, electrifying a building can improve indoor air quality and safety.

Emissions abatement from electrification was also likely significantly underestimated based on the methodology in the report. The analysis assumes complete combustion of natural gas (i.e. no methane released, only carbon dioxide) and no methane leakage from the distribution system. Recent studies reference that methane leakage is a source of substantial GHG emissions[12], so this assumption particularly underestimates the impact of electrification on reducing GHG emissions.

A possible barrier not addressed in this analysis is the perceived or actual differences in customer experience between conventional and heat pump space and water heating technologies. While this analysis has shown that heat pumps can be cost-effective and eliminate carbon emissions, the underlying assumption is that there is an equivalent customer experience between natural gas and electric appliances as it relates to comfort and convenience. Comprehensive studies on customer experience with heat pump appliances in the California market were not found by the time of writing. Nonetheless, worthwhile to note, heat pump appliances dominate other U.S. regional and international markets and are typically offered as “hybrid” technologies, where there is an electric

---

[9] https://newscenter.lbl.gov/2012/10/17/elevated-indoor-carbon-dioxide-impairs-decision-making-performance/

[10] https://www.cpsc.gov/Safety-Education/Safety-Guides/Home/The-Inside-Story-A-Guide-to-Indoor-Air-Quality

[11] http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Safety/Natural_Gas_Pipeline/News/AgendaStaffReportreOIIPGESanBrunoExplosion.pdf

[12] https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf

resistance backup to maintain consistency of service during periods of peak heating demand. Furthermore, air source heat pumps cool the surrounding air when operating in heating mode, which in a retrofit scenario may result in a difference in comfort and convenience (often improved) to the building occupant.

Another consideration in the development of potential building decarbonization policies and programs is market readiness. Potential market barriers include limited availability and familiarity of heat pump technologies within the supply chain by suppliers and contractors[13]. To accelerate building electrification using heat pump technology, SVCE and other entities must pursue strategies to address these barriers. One such strategy, for instance, could be to support local and regional workforce education and training on heat pump technologies.

Chapter 5: Conclusions

The results from this analysis support electrification of space and water heating, along with space cooling, as affordable and effective methods for decarbonization. Both space and water heating using heat pump technologies have nearly achieved cost parity with conventional natural gas appliances. Heat pump space heating combined with cooling has already become more cost-effective than the conventional alternative. Scenario analysis presented throughout this report shows that these conclusions exist within a spectrum of possibilities, nonetheless are generally supported. Heat pump technologies will likely continue to become more affordable as the market matures.

As discussed in the report, the cost-effectiveness calculations focused on like-for-like replacement of appliance technologies. That is, only the costs associated with replacing an existing, similar unit using the same fuel source were included in the calculation, to simulate the costs incurred on an ongoing basis across multiple appliance lifetimes. However, as most homes and businesses currently have natural gas appliances, retrofitting the existing building stock will incur thousands of dollars of additional costs for rewiring and panel upgrades. These additional retrofit costs can be avoided by choosing all-electric at the time of new construction. New buildings, meanwhile, represent an even more cost-effective opportunity to electrify than existing buildings, as there are savings associated with eliminating the natural gas utility connection and piping to serve the building. SVCE is supporting building electrification reach codes to assist its member agencies target this new construction market as the most cost-effective and prudent intervention point for building electrification.

The results of this analysis support a sustained investment in heat pump water and space heating technologies in buildings as a pathway for decarbonization. While outside of the scope of this report, existing literature supports similar conclusions for the variety of other electrification opportunities in the building and transportation sectors. SVCE will continue to explore these opportunities on behalf of its customers and community, and work to launch targeted programs that can help overcome market barriers to support decarbonization in the built environment.

---

[13] Ibid.

APPENDIX A: Catalog of Assumptions

Section A.1: General

Description	Value
Sales tax (%)	9.0%
Discount rate	4.0%
CO_2 emissions from natural gas usage (MT/therm)	0.0053
CPI	4.5%
Annual O&M cost escalation (%)	4.5%

Section A.2: Fuel Forecasts

A.2.1: Residential Retail Electricity Cost

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Low	$0.291	$0.295	$0.300	$0.305	$0.309	$0.314	$0.319	$0.324	$0.330	$0.335	$0.340	$0.346	$0.351	$0.357	$0.362	$0.368	$0.374	$0.380	$0.386	$0.392
Base Case	$0.311	$0.321	$0.331	$0.341	$0.352	$0.363	$0.375	$0.387	$0.399	$0.412	$0.425	$0.439	$0.453	$0.467	$0.482	$0.497	$0.513	$0.530	$0.546	$0.564
High	$0.331	$0.347	$0.363	$0.381	$0.399	$0.418	$0.438	$0.459	$0.481	$0.504	$0.528	$0.553	$0.579	$0.607	$0.636	$0.667	$0.698	$0.732	$0.767	$0.803

A.2.2: Commercial Retail Electricity Cost

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Low	$0.212	$0.216	$0.219	$0.222	$0.226	$0.230	$0.233	$0.237	$0.241	$0.245	$0.249	$0.252	$0.256	$0.261	$0.265	$0.269	$0.273	$0.278	$0.282	$0.286
Base Case	$0.239	$0.247	$0.254	$0.262	$0.271	$0.279	$0.288	$0.298	$0.307	$0.317	$0.327	$0.337	$0.348	$0.359	$0.371	$0.382	$0.395	$0.407	$0.420	$0.434
High	$0.248	$0.260	$0.272	$0.285	$0.299	$0.313	$0.328	$0.344	$0.360	$0.378	$0.396	$0.415	$0.435	$0.455	$0.477	$0.500	$0.524	$0.549	$0.575	$0.602

A.2.3: On-Site Solar Electricity Cost – NEM 1 Equivalent

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Residential	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147
Commercial	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147	$0.147

A.2.4: On-Site Solar Electricity Cost – NEM 2 Equivalent

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Residential	$0.163	$0.164	$0.165	$0.166	$0.167	$0.168	$0.170	$0.171	$0.172	$0.173
Commercial	$0.156	$0.157	$0.158	$0.158	$0.159	$0.160	$0.161	$0.162	$0.163	$0.164

2029	2030	2031	2032	2033	2034	2035	2036	2037	2038

$0.175	$0.176	$0.177	$0.179	$0.180	$0.182	$0.183	$0.185	$0.187	$0.188
$0.165	$0.166	$0.167	$0.168	$0.169	$0.170	$0.172	$0.173	$0.174	$0.175

A.2.5: On-Site Solar Electricity Cost – NEM 3 Equivalent

	2019	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**
Residential	$0.229	$0.234	$0.239	$0.244	$0.250	$0.255	$0.261	$0.267	$0.273	$0.279	$0.286	$0.293	$0.300	$0.307	$0.314	$0.322	$0.330	$0.338	$0.347	$0.355
Commercial	$0.193	$0.197	$0.201	$0.205	$0.209	$0.213	$0.218	$0.222	$0.227	$0.232	$0.237	$0.242	$0.247	$0.253	$0.259	$0.265	$0.271	$0.277	$0.283	$0.290

A.2.6: Residential Retail Natural Gas Cost

	2019	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**
Low	$1.60	$1.63	$1.65	$1.68	$1.71	$1.73	$1.76	$1.79	$1.82	$1.85	$1.88	$1.91	$1.94	$1.97	$2.01	$2.04	$2.07	$2.10	$2.14	$2.17
Base Case	$1.60	$1.65	$1.71	$1.76	$1.82	$1.88	$1.94	$2.00	$2.07	$2.13	$2.20	$2.27	$2.35	$2.43	$2.50	$2.59	$2.67	$2.76	$2.85	$2.94
High	$1.60	$1.68	$1.76	$1.85	$1.94	$2.03	$2.13	$2.23	$2.34	$2.46	$2.58	$2.70	$2.83	$2.97	$3.12	$3.27	$3.43	$3.59	$3.77	$3.95

A.2.7: Commercial Retail Natural Gas Cost

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Low	$1.09	$1.11	$1.13	$1.14	$1.16	$1.18	$1.20	$1.22	$1.24	$1.26	$1.28	$1.30	$1.32	$1.34	$1.37	$1.39	$1.41	$1.43	$1.46	$1.48
Base Case	$1.09	$1.13	$1.16	$1.20	$1.24	$1.28	$1.32	$1.36	$1.41	$1.45	$1.50	$1.55	$1.60	$1.65	$1.71	$1.76	$1.82	$1.88	$1.94	$2.00
High	$1.09	$1.14	$1.20	$1.26	$1.32	$1.38	$1.45	$1.52	$1.60	$1.67	$1.75	$1.84	$1.93	$2.02	$2.12	$2.23	$2.33	$2.45	$2.57	$2.69

A.2.8: Grid-Interactivity Revenue

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Payments	$66	$69	$72	$75	$79	$82	$86	$90	$94	$98	$102	$107	$112	$117	$122	$128	$133	$139	$146	$152

Section A.3: Building Appliances

Description	Annual gas usage (therm)	Annual electricity usage (kWh)	Lifetime (yr)	Price	Installation Cost	Incentives and Rebates	Annual O&M
Water Heater							
Standard Efficiency Gas (EF 0.58)	191	0	12	$424	$632	$0	$0
High Efficiency Gas (EF 0.72)	171	0	12	$804	$632	$0	$0
Gas Tankless (EF 0.93)	137	0	20	$865	$632	$0	$50
Standard Efficiency Electric Resistance (EF 0.93)	0	3,493	12	$410	$632	$0	$0
Electric Tankless (EF 0.998)	0	3,744	20	$549	$632	$0	$50
Electric Heat Pump (COP 3.55)	0	915	12	$1,299	$632	$0	$0
Solar Thermal and Electric Backup	0	1,940	20	$9,150	Incl. in Price	$4,521	$50
Space Heater Only							
Standard Efficiency Gas (AFUE 80)	350	0	20	$1,085	$5,543	$0	$100
High Efficiency Gas (AFUE 95.5)	293	0	20	$1,593	$5,543	$0	$100
Standard Efficiency Electric Resistance (AFUE 100)	0	8,193	20	$1,108	$5,543	$0	$100

Air Source Heat Pump (COP 3.8)	0	2,156	20	$4,540	$1,420	$0	$100
Space Heater and Air Conditioner							
Standard Efficiency Gas Heater (AFUE 80) and Standard Efficiency Electric Air Conditioner (14 SEER)	350	2,412	20	$2,336	$7,292	$0	$100
Air Source Ducted Heat Pump (COP 3.8 and 18 SEER)	0	4,069	20	$4,540	$1,420	$0	$100
Air Source Mini-Split Heat Pump (COP 3.6 and 21 SEER)	0	4,295	20	$4,497	$1,420	$0	$100