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Assessment of Residential Natural Gas & Electric Decarbonization in Washington State

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Executive Summary

There is active dialogue on policy considerations pertaining to future pathways for reducing greenhouse gas (GHG) emissions. This report focuses on energy use and future residential GHG reduction pathways for the State of Washington. This information encompasses quantitative and qualitative analytical results on consumer costs and environmental benefits as well as a review of real-world challenges and potential unintended or unanticipated consequences of residential electrification.

Key results:

- **The ratio of residential electricity and natural gas prices has grown over the past 15 years.** In 2020, Washington homeowner electricity prices were over 2.7 times higher than natural gas on an energy equivalent basis.
- Consumer surveys across the US provide evidence that most homeowners prefer natural gas over electricity, particularly for space heating, water heating, and cooking.
- **Residential electrification results in significant increases in annual energy bills for Washington homeowners.** Mid-case electric heat pump (HSPF 9) results in a 41% increase in annual consumer energy costs, about $338 million annual increase, for all homes now using natural gas in Washington.
- Figure 43 shows annual energy costs and capital cost comparisons for a typical 1,476 ft^2 home in Washington between gas and electric. With electrification, energy bills would go up over 72% for a typical single-family home.

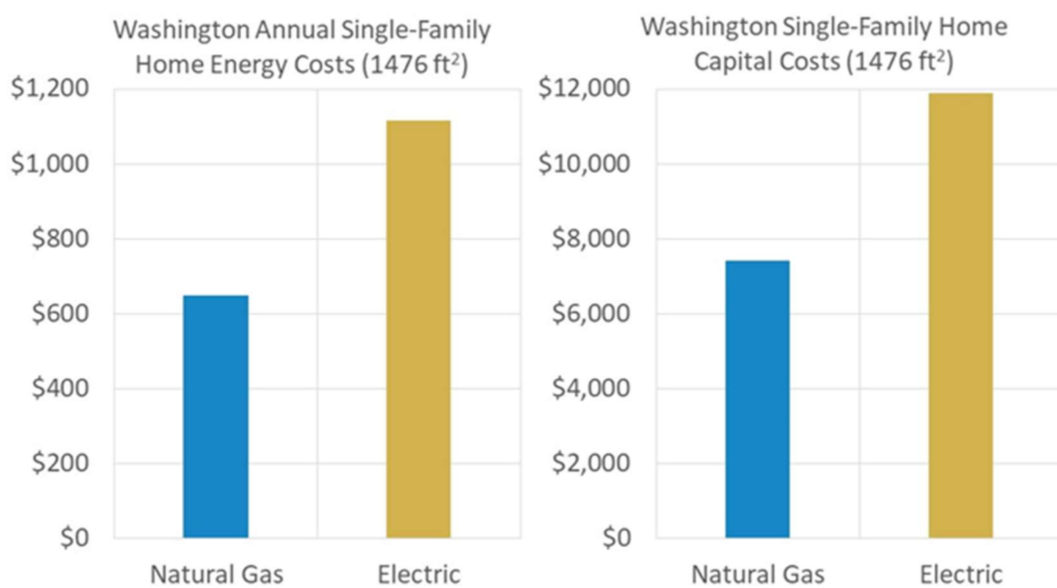

Figure 1: Annual Energy Costs and Lifecycle Costs for Typical 1,476 ft^2 Single-Family Home in Washington

- **Natural gas pathways for GHG reductions have lower consumer and societal costs when measured in $/metric ton of CO_2 reduced (**Figure 44**).** Using currently available high-efficiency gas equipment results in very cost-effective GHG reductions (-$37/metric ton of CO_2). High-efficiency furnaces with renewable natural gas further reduce GHG emissions at a cost of $62/metric ton of CO_2. Higher levels of GHG reduction are possible using gas heat pumps with RNG (64% reduction). Residential electrification with typical electric heat pumps (HSPF 9) and potential future power generation improvements have CO_2 abatement costs of $160 to $170/metric ton; however, when electric space heating is powered in part by seasonal natural gas generation, GHG abatement costs are in the range of $213 to $226/metric ton.

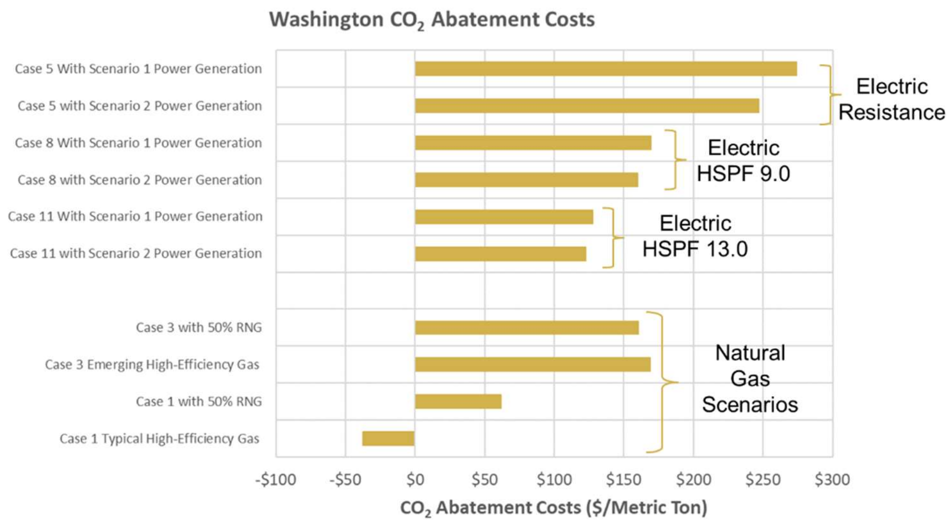

Figure 2: Comparison of CO_2 Abatement Costs ($/metric ton)

- **The most significant issue with residential electrification scenarios is the intense seasonal energy demand for space heating**. Report data highlight the increase in peak winter electricity use that would occur in the Washington residential sector with widespread electrification. The challenges with cold-weather space heating are often oversimplified or underestimated in public policy electrification discussions. The potential power generation and electric infrastructure cost and reliability implications for consumers and society are significant.
- Using the matching principle and reasonable options at this time, **most new winter peak electricity demand that arises from electric space heating will be met with dispatchable natural gas generation**. Without GHG mitigation for this scenario, potential GHG reductions from electric space heating will be much less than anticipated.
- **There is no evidence wind or solar resources can address prospective seasonal energy-intensive space heating electricity peaks during Washington winters**. Solar PV systems have a significant drop in winter output.
- There is no evidence battery energy storage can play a value-added role in meeting high winter electricity demands and pumped hydro is not a practicable option for Washington.
- Hybrid space heating systems that optimize the use of electric heat pumps at milder temperatures and natural gas heating systems at cold temperatures can avoid a host of issues associated with cold climate electric heat pump operation.
- Natural gas distribution systems have quantifiably higher service reliability and lower outage rates than electric distribution systems, leading more homes to install natural gas generators to avoid the cost and issues associated with grid power interruptions.

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Introduction

There is active international, national, state, and local dialogue on policy considerations pertaining to future pathways for reducing greenhouse gas (GHG) emissions. This report focuses on energy use and future residential GHG reduction pathways for the State of Washington. Natural gas and electricity, the two main residential energy choices, are reviewed in this analysis in terms of the current market situation and potential future pathways for GHG reductions using natural gas or electricity or hybrid approaches employing both energy options. The report encompasses a quantitative assessment of residential consumer economic impacts (e.g., capital costs and annual energy costs) and societal benefits and costs (e.g., GHG reduction and $/metric CO_2 reduction) stemming from the use of gas and electric appliances for Washington homes.

There are energy delivery system challenges with seasonal residential space heating, including: (1) high winter peak-day/peak-month energy demand, (2) expanded need for electric power generation, transmission, distribution, and energy storage assets on a limited seasonal basis, and (3) the type of generation resources typically employed for seasonal, dispatchable service. These issues may result in higher than anticipated consumer and societal costs along with lower-than-expected GHG reduction benefits being captured in the real world.

In some extreme cases, there are public policy discussions on eliminating natural gas service to homes. Beyond the consumer economic impacts quantified in this report, such measures would override consumer choice principles and negatively impact the growing number of homeowners using natural gas emergency generators to improve home energy system reliability and resilience.

The report reviews trends in Washington residential natural gas and electricity prices and discusses – at a high level – potential issues in future electric system asset investment that may arise from higher home electricity use. While relevant to policy discussions, the potential impact future electric system infrastructure investments may have on residential electricity prices is not considered in this report.

Recommendations are made for pursuing immediate common sense and cost-effective measures for reducing GHG emissions from Washington homes using natural gas. Gaseous resources – conventional natural gas and renewable gases – and their delivery infrastructure can play a positive long-term role in realizing GHG reductions along with energy resilience. These recommendations emphasize consumer choice, cost-effective investments (including leveraging existing infrastructure and improving building envelope thermal efficiency), the potential role for hybrid natural gas and electric systems for home space heating, an expanded role for low-carbon gaseous energy resources, and the value of future innovation and optionality. The report places an emphasis on quantified GHG reduction pathways using a common metric (i.e., $/metric ton of CO_2).

Residential Energy Use, Prices, and Preferences

Table 1 is a breakdown of the approximately 3.2 million homes in Washington. Most residential units are single-family detached or attached (duplex) homes (67.2%), with the balance comprising a mix of large and smaller apartment/condo buildings and mobile homes. From these data, GTI estimated the number of natural gas homes for each category (right column).

Table 1: Washington Residential Building Characteristics (US Census, 2019; GTI estimates)

Total Homes	3,195,100	% of Market	Estimated Natural Gas Homes
Single-Family Detached	2,019,300	63.2%	807,700
Single-Family Attached	127,800	4.0%	46,000
Multi-Family 2-4 units	191,700	6.0%	49,800
Multi-Family (over 4 units)	655,000	20.5%	157,200
Mobile Homes	195,000	6.1%	29,300

Natural gas and electricity are the main space heating energy choices for Washington homes (Figure 3). Electricity has a 56% share of the residential space heating market, followed by natural gas at 34%.

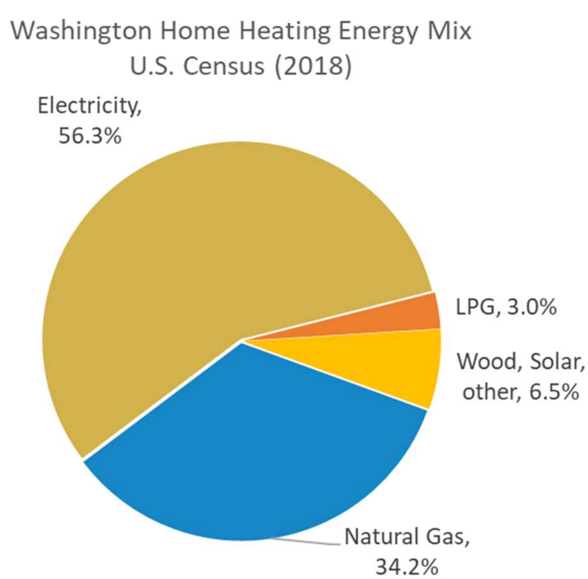


Figure 3: Washington Residential Space Heating Home Share (US Census)

In most areas of the US, substantially more energy is used for space heating than cooling – especially in colder-weather regions (Figure 4). As a first-order approximation, the energy required for home space conditioning depends on temperature differences inside and outside the dwelling. For example, cooling a home from 90ºF to 74ºF is a temperature difference of 16ºF, while heating a home from 30ºF to 70ºF is a temperature difference of 40ºF and requires a proportionally larger amount of energy. In addition, across much of the US, the duration of the heating season and runtime (hours) for space heating equipment is longer than equipment runtime needed for cooling homes.

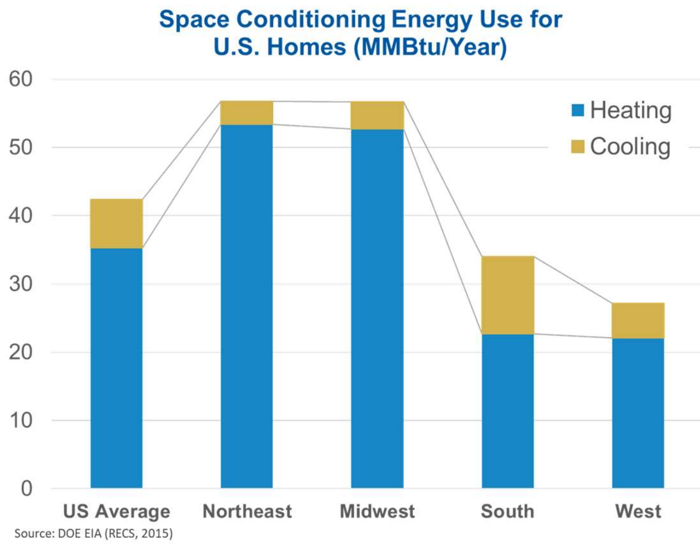


Figure 4: Annual Average Space Conditioning Energy Use for US Homes

Heating and Cooling Degree Days (HDD and CDD, respectively) are metrics that account for: (1) space conditioning temperature differences (that is, between the outdoor and indoor temperatures) and (2) the number of days needed for heating and cooling. Figure 5 shows HDD and CDD values since 2000 for the US Average and the Pacific Region (which includes Washington) in addition to the nominal range for two cities in Washington. A key consideration is the higher HDD requirements for interior locations such as Spokane, which are 50% greater than Seattle. This demonstrates how the energy needed for heating is considerably greater than cooling energy loads in Washington, with space heating energy consumption about 50% greater in the interior, eastern portion of the state.

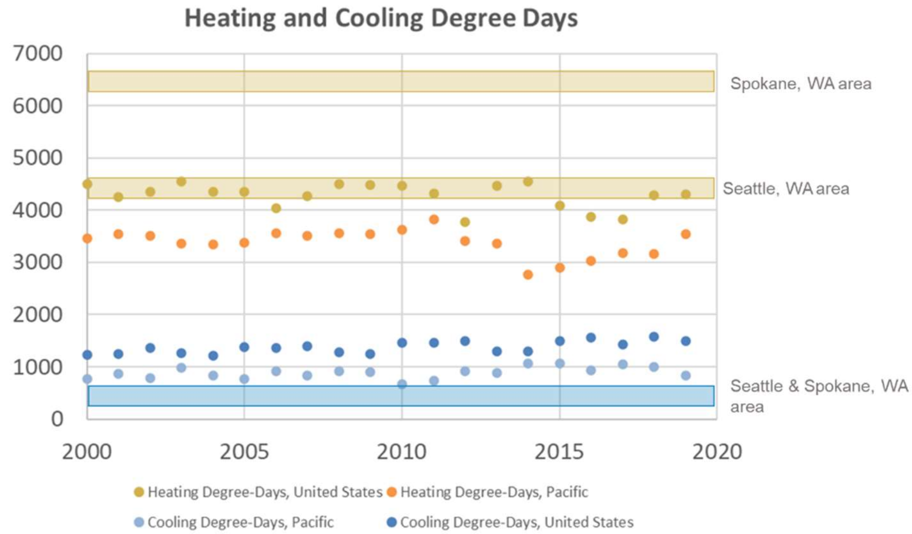


Figure 5: US and Washington Region Heating and Cooling Degree Days (DOE-EIA)

HDD and CDD can serve as a proxy for space conditioning energy requirements. Illustrating this, Figure 6 shows monthly electricity and natural gas energy use in Washington homes over a seven-year period (2013 to 2020). Each sparkline graph is on the same monthly energy use scale, enabling direct comparisons. This highlights the significant seasonal natural gas energy required to heat Washington homes during the winter relative to other year-round gas loads for water heating, cooking, and clothes drying.

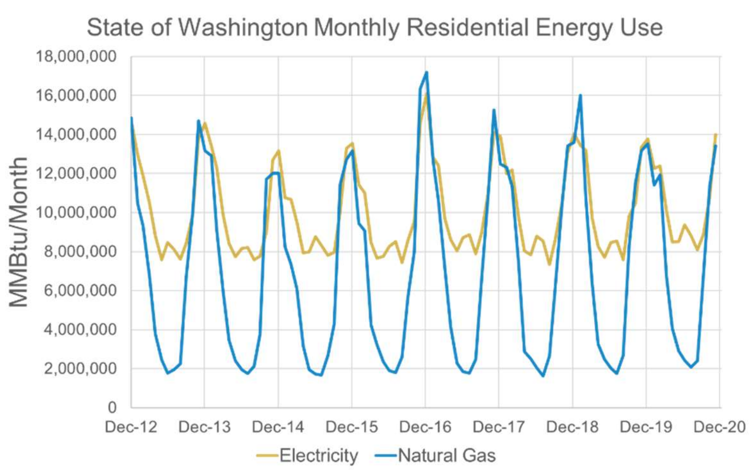


Figure 6: Monthly Residential Energy Use in Washington Over Seven Years (DOE-EIA)

Nationally, homeowner surveys show consumers prefer natural gas over electricity in four primary thermal energy applications: space heating, water heating, cooking, and clothes drying.

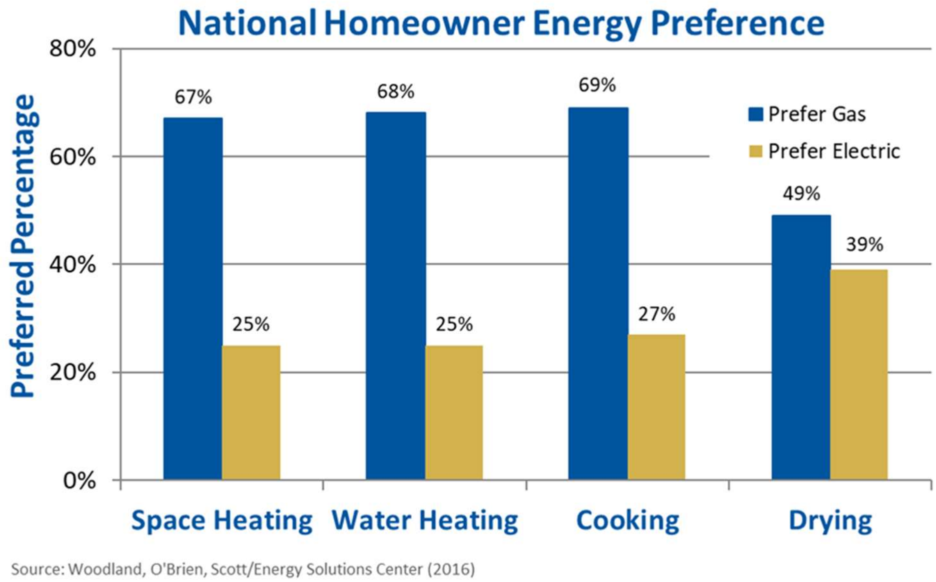


Figure 7: National Residential Homeowner Energy Preferences

People prefer natural gas mainly for its cost-effectiveness. Figure 8 shows trends for average annual Washington residential electricity and natural gas prices since 2005. In this period, residential electricity prices grew over 49% while natural gas prices dropped 7%. With these price changes, Washington residential electricity prices are currently over 2.7 times greater than natural gas on an energy equivalent basis. According to DOE-EIA, the average 2020 Washington residential electric price was 9.74 cents/kWh. In similar energy units, the average 2020 Washington residential natural gas price was about 3.7 cents/kWh (or about $10.75/MMBtu). Natural gas is a cost-effective energy option for Washington energy consumers.

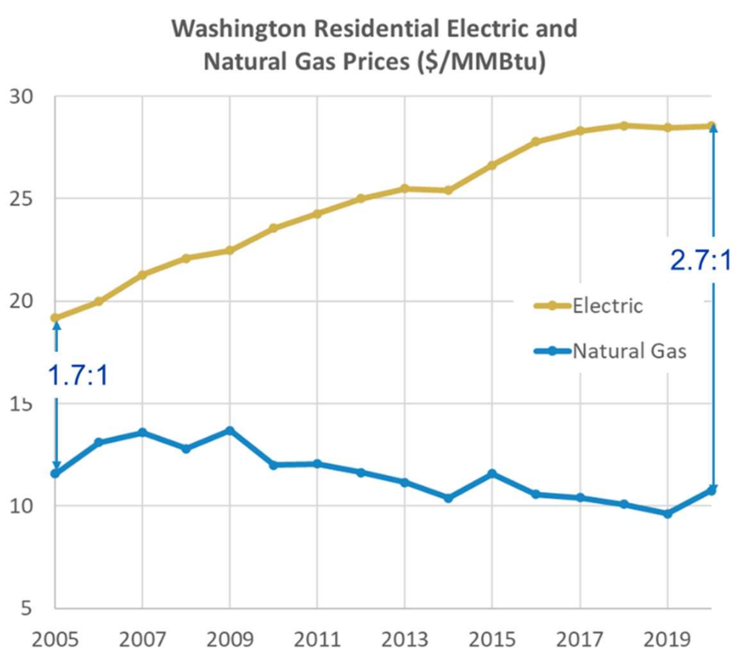


Figure 8: Washington Residential Electric and Natural Gas Price Trends (DOE-EIA)

Estimating potential future electricity price impacts from large-scale residential electrification is outside the scope of this study; however, the unavoidable challenges of scaling up electric energy systems to provide the capacity and performance required for the large task of seasonal heating will likely negatively impact electric prices.

Beyond the economic value natural gas provides, consumers prefer natural gas because of its performance advantages over equivalent electric options:

- Homes heated with natural gas have greater indoor comfort due to higher delivered air temperatures compared to electric heat pumps
- Natural gas furnaces and boilers often provide 2-4 times greater energy delivery rates than electric heat pumps, allowing rapid heat up. This is particularly valuable when using energy saving setback thermostats or smart thermostats that allow indoor temperatures to drop when the home is not occupied or overnight
- Natural gas water heaters provide rapid water heating and faster recovery times (e.g., with conventional storage water heaters) or continuous hot water supply rates (e.g., with more efficient gas tankless water heaters)
- Natural gas cooking provides more rapid stovetop heating of water or food products – with greater control – than conventional electric resistance stoves

Beyond traditional natural gas uses, more homeowners are using natural gas for fireplaces, outdoor grills, and home emergency generators. Natural gas fireplaces are a clean-burning alternative to wood, while virtually eliminating carbon monoxide and particulate emissions.

Residential generators are increasingly popular as a means of improving home energy security, reliability, and resilience. According to the US Census American Housing Survey, over 23% of single-family homes (nearly 15 million in total) in the US have some form of home power generation – typically a stationary or portable generator fueled by natural gas, propane, or gasoline. Over the past 15 years, natural gas home generators have grown substantially in popularity (Figure 9), due to growing reliance on electricity to provide space conditioning and refrigerated food storage as well as home internet, sump pumps, and other important services.

Figure 9: Typical Natural Gas Home Emergency Generator (Spectrum Electric Ltd)

In regions with intermittent electric service or potential for extended weather-driven power outages, residential generators provide homeowner security and value – including stress reduction over potential property losses and personal safety. The topic of energy delivery systems and home energy reliability is discussed later in this report. The uniquely high reliability of natural gas distribution service (and ability to avoid needing to periodically refill propane or gasoline tanks) is an important driving force for homeowners choosing natural gas emergency generators for their homes and businesses.

Residential Energy Codes

This section highlights information on residential building energy codes. Topics include:

- Model Energy Codes
- Application in State and Local Codes
- Washington State and Seattle Energy Codes
- Policy Implications

Model Energy Codes

The U.S. does not have a federal energy code. States governments can choose to adopt a version of a model energy code such as the International Energy Conservation Code® (IECC®), adopt a model energy code with amendments (e.g., Washington State Energy Code), develop their own energy code, or have no state-level energy code. Ultimately, model energy codes or state energy codes are adopted or amended in ordinances by local governments (e.g., Seattle Energy Code), with legally enforceable compliance requirements developed to meet local objectives.

The IECC® establishes minimum requirements for energy-efficient buildings using prescriptive and performance options. It contains separate provisions for residential and commercial buildings, including new buildings and renovations or additions to existing buildings. Read-only versions of the IECC® in their entirety are available on the International Code Council website https://codes.iccsafe.org/content/IECC2021P1.

States are required under the 1992 Energy Policy Act to demonstrate that their state energy codes meet or exceed the minimum energy efficiency requirements of the most recent version of ASHRAE Standard 90.1 for commercial buildings. Each State is also required to review the provisions of its residential building code regarding energy efficiency and make a determination as to whether it is appropriate for such State to revise such residential building code provisions to meet or exceed the minimum energy efficiency requirements of most recent version of the IECC® (the successor to the 1992 CABO Model Energy Code) https://www.congress.gov/102/statute/STATUTE-106/STATUTE-106-Pg2776.pdf.

Application in State and Local Codes

Figure 10 provides a US Department of Energy (DOE) snapshot status of state residential energy code adoption of model energy codes on its website https://www.energycodes.gov/status/residential.

The model energy code adoption status is continuously evolving – more quickly today than in the past. It is important to cross-check with individual state energy codes to verify the current application and amendments to the model energy code and its version, as well as alternative compliance options in addition to the amended model energy code. For example, the State of Illinois adopts "the most recent version of the IECC®" in its state energy code, which is the 2018 version, not the 2012 version shown in the figure. In Ohio, the 2018 version of IECC is one of three options for compliance. According to the Midwest Energy Efficiency Alliance, "Code compliance in Ohio can be met through three methods for residential buildings: compliance with the IECC, compliance with sections 1101-1104 of the Residential Code, or through an alternative

compliance option agreed to with the Ohio Home Builders Association found in section 1105 of the Residential Code. Codes are enforced by the jurisdiction having authority over the buildings. If no local jurisdiction has authority, then the Ohio Department of Commerce Division of Industrial Compliance reviews commercial building plans and construction. Residential buildings are enforced only at the local level."
https://www.mwalliance.org/initiatives/policy/ohio/ohio-building-energy-codes

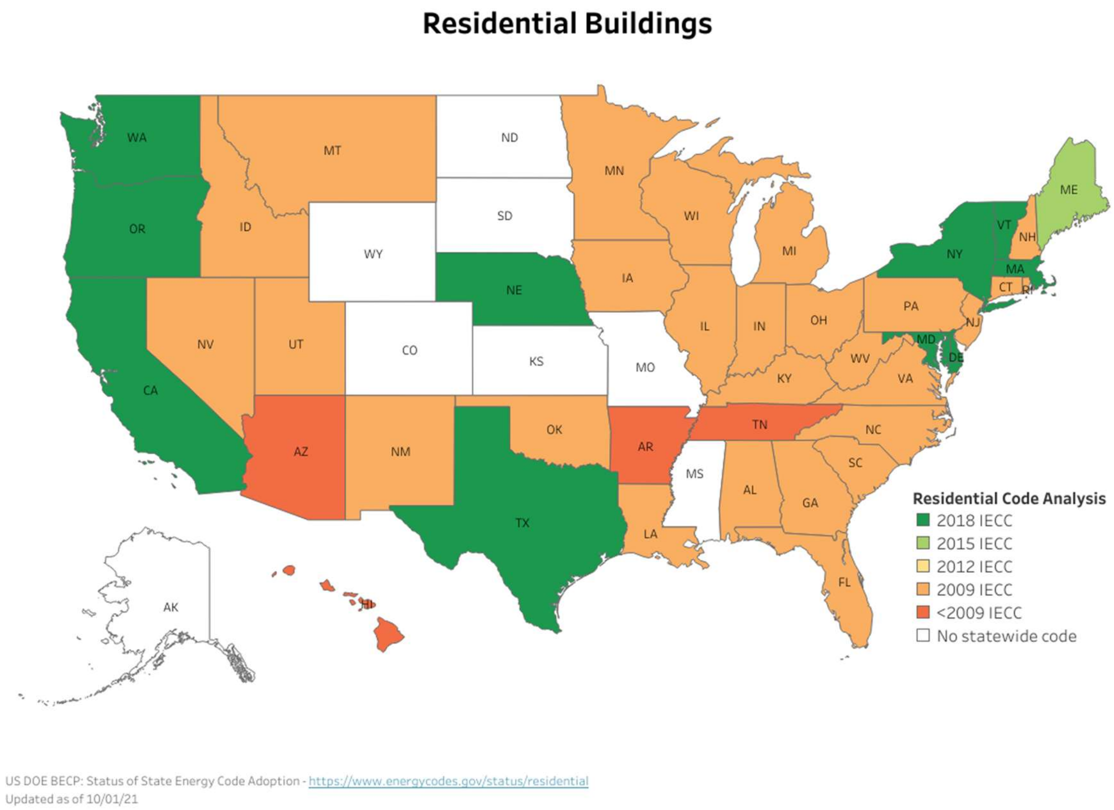


Figure 10: Status of State Residential Energy Code Adoption

Washington State and Seattle Energy Codes

The 2018 Washington State Energy Code, effective February 1, 2021, covers both residential and commercial buildings https://sbcc.wa.gov/state-codes-regulations-guidelines/state-building-code/energy-code. It adopted the 2018 IECC®, with significant amendments from the 2021 version of IECC® as well as other critical amendments that change the metric and methodology compared to the previous version of the code. "Residential" includes One- and Two-family dwellings, Townhouses and Group R-2 and R-3 buildings three stories or less; "Commercial" includes all buildings not covered under "Residential"

According to ACEEE, the State of Washington requires all local jurisdictions to comply with the state residential building energy code but permits local jurisdictions to have more stringent commercial energy codes https://database.aceee.org/city/energy-code-stringency.

In Washington, the most significant amendments to the IECC® are the substitution of carbon emissions for energy costs in the performance path, and the "jurisdictional option" of an outcome path based on site Energy Use Intensity (EUI) targets in the commercial building code. It also added a section requiring additional energy efficiency measures using a point system for each qualifying option, and criteria for passive houses. The residential section excluded the Energy Rating Index compliance path (Section R406 in the IECC®).

The commercial performance path shifts from the IECC® "same as proposed" multiple standard reference design methodology contained in Section C407 of the IECC® to the "deemed to comply" single standard reference design methodology used in ASHRAE Standard 90.1 Appendix G. The single reference design methodology is unique to the commercial section of the Washington State Energy Code. The residential section uses the same multiple standard reference design methodology as the IECC® residential section R405.

A multiple standard reference design methodology differs from a single baseline methodology in a couple significant ways. The multiple standard reference design methodology results in a different reference level of performance depending on the fuel choices for heating or service water heating, considering all reference systems to be equivalent to each other for compliance with the performance path. While this "deemed equivalent" approach has its own equity issues, it avoids a direct comparison of gas space heating and water heating with electric space heating and water heating when determining compliance.

A single standard reference design methodology can be used for a direct comparison across energy forms under consideration. While the single standard reference design methodology can be applied more fairly than a multiple standard reference design methodology, the selection of the baseline, the metric, and the values for compliance calculations can dramatically change the result against a "deemed to qualify" single standard reference design. By shifting from energy cost to carbon emissions, and by selecting carbon emission factors that may align with policy objectives, the Washington State Energy Code commercial provisions provide more incentive to use electric options compared to the ASHRAE Standard 90.1 calculations that are based on state energy prices.

The Seattle Energy Code http://www.seattle.gov/sdci/codes/codes-we-enforce-(a-z)/energy-code#2018seattleenergycode also substituted carbon emissions for energy cost in its performance path calculations, but differs from the Washington State Energy Code by prohibiting both electric resistance heat or fossil fuel heat in its commercial building performance path and target performance path. It also contains more stringent commercial efficiency requirements than the state code. By law, its residential provisions are the same as the state energy code.

Policy Implications

Washington State Energy Code provisions have been shifting from a focus on energy efficiency and energy cost to an increased focus on deep decarbonization pathways, especially electrification and on-site renewable energy. The Washington State Energy Code and local code revisions have shifted to annual greenhouse gas emissions as the decision metric, and local energy codes such as the Seattle Energy Code have started to include provisions that ban fossil fuel use. The implication of the shift to annual greenhouse gas emissions as the basis for comparisons depends on the standard reference design methodology. If the standard reference design is electric, the commercial code performance path will make it more difficult (and costly) for a fossil fuel option to qualify when compared, for example, to historical practices of using energy cost as the metric. If the standard reference design is fossil fuel, the commercial code performance path will make it easier (and less costly) to shift to an electric option. On the other hand, in the residential code, the standard reference design changes based on the fuel used in the proposed design. This avoids comparisons between fossil fuel options and electric options entirely and creates no advantage or disadvantage in the code for fuel switching to electricity.

The relative performance of natural gas options compared to electric options depends on the ratio of electricity to natural gas performance (E/G ratio) using the metric of interest. Table 2 shows the energy cost, source energy factors, and greenhouse gas emission factors and E/G ratios for the U.S. and the State of Washington in 2019 and in the Washington State Energy Code

Table 2: Performance Metrics and E/G Ratios

Application	Energy Cost ($/MMBtu)	Source Energy Factor	CO_2e Emissions (lb/MMBtu)
U.S 2019 Electric / Gas Factors	38.13/12.50	2.68/1.09	310/146
U.S 2019 E/G Ratio	3.05	2.46	2.12
Washington State 2019 Electric / Gas Factors	28.46/8.90	1.65/1.09	105/146
Washington State 2019 E/G Ratio	3.19	1.51	0.72
WA State Energy Code Electric / Gas Factors	NA	NA	234/117
WA State Energy Code E/G Ratio	NA	NA	2.00

As illustrated in Table 2, the choice of metric and basis of factors has a dramatic effect on comparative results. E/G ratios range from 3.19 to 0.72 depending on metric and basis, changing the relative performance results for electric and gas options by a factor of 4.4. This example shows the importance of continuous involvement in development of model energy codes, state energy codes, and local energy codes, as well as federal, state, and local energy legislation.

Residential Greenhouse Gas Reduction Pathways

This section reviews natural gas, electric, and hybrid natural gas/electric GHG reduction pathways for homes, providing context for the following GHG reduction benefit/cost analysis section. In crafting GHG reduction scenarios, it is essential to understand the complex dynamics that can influence the design and operation of natural gas and electric energy delivery systems along with real-world factors impacting end use equipment performance. This presents an informed framework for differentiating between reasonable future pathways versus idealized or potentially risky scenarios with unintended or unanticipated impacts.

Residential Greenhouse Gas Emission Reduction Pathways

Experts recognize a need to pursue multiple GHG reduction solutions based on available and emerging technology pathways to cost-effectively reduce climate change risks. Prominent potential measures and pathways for reducing residential-sector GHG emissions include:

(1) Natural gas appliance efficiency improvements
(2) Electric appliance efficiency improvements
(3) Building envelope enhancements
(4) Hybrid natural gas and electric appliance improvements
(5) Use of renewable energy (e.g., renewable natural gas, renewable hydrogen, rooftop solar PV or solar thermal systems).

Figure 11 shows a natural gas consumer-oriented depiction of near-term (commercially available) and mid-term emerging home appliances, efficiency measures, and renewable energy options for reducing GHG emissions. As highlighted in the benefit/cost analyses, these are practical near-term and mid-term options that offer more feasible, less costly, and/or less risky solutions than wholesale residential electrification.

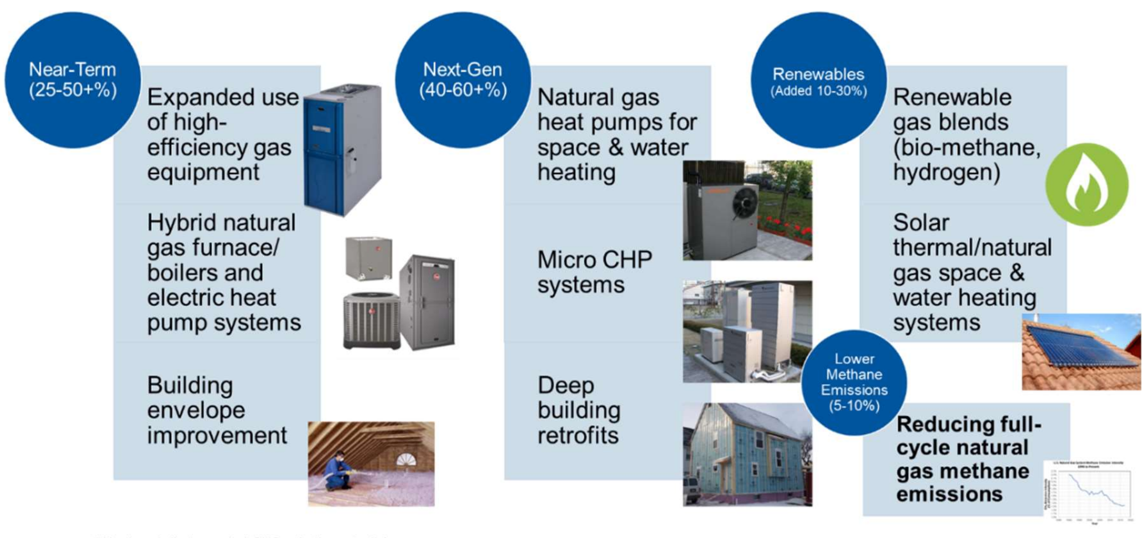


Figure 11: Natural Gas Home GHG Emission Reduction Pathways

Near-term options include high-efficiency gas equipment coupled with home weatherization. In addition, hybrid approaches with a high-efficiency natural gas furnace or boiler coupled with an electric heat pump (e.g., as an upgrade to a traditional home air conditioning system) can be implemented immediately. With hybrid space conditioning, electric heat pumps are used for heating at milder outdoor temperatures (e.g., 40ºF and above) while natural gas space heating is used at colder temperatures when electric heat pump heating output and efficiency decline. For next-generation solutions, options include: (1) natural gas heat pumps and (2) renewable gas. The following sections explore these home efficiency measures as well as a discussion on electric heat pumps and electric power generation in the State of Washington.

Space Heating and Heat Pumps

Space heating is the largest and most important natural gas application in homes as well as the most challenging and costliest to replace with electricity. Homes with natural gas heating use a forced-air furnace or a boiler that circulates hot water in a hydronic loop. These can be either mid-efficiency (e.g., 80% efficient) or high-efficiency systems (e.g., efficiencies of 92-98%). In addition, gas-fired tankless water heaters and boilers can be used as combination devices (also called combi systems) providing both hot water and space heating in a single unit, with rated efficiencies ranging from 80% up to 98%.

Natural gas heat pumps, an emerging efficiency measure, are like electric heat pumps but use natural gas as the primary energy input. There are several gas heat pump technologies with varying levels of efficiency (Figure 12). Like electric heat pumps, gas heat pump performance and efficiency vary with outdoor temperatures, though cold outdoor temperatures have lesser impact on gas heat pumps than electric heat pumps. There are several gas heat pump technology and product development efforts underway – documented in a GTI report: The Gas Heat Pump Technology and Market Roadmap (released in 2019).

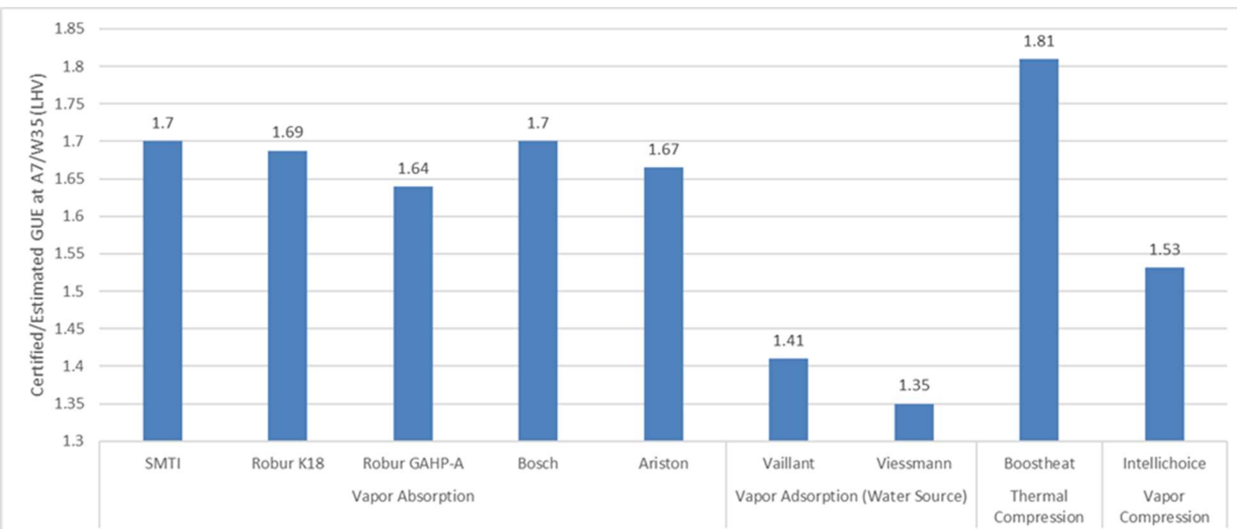


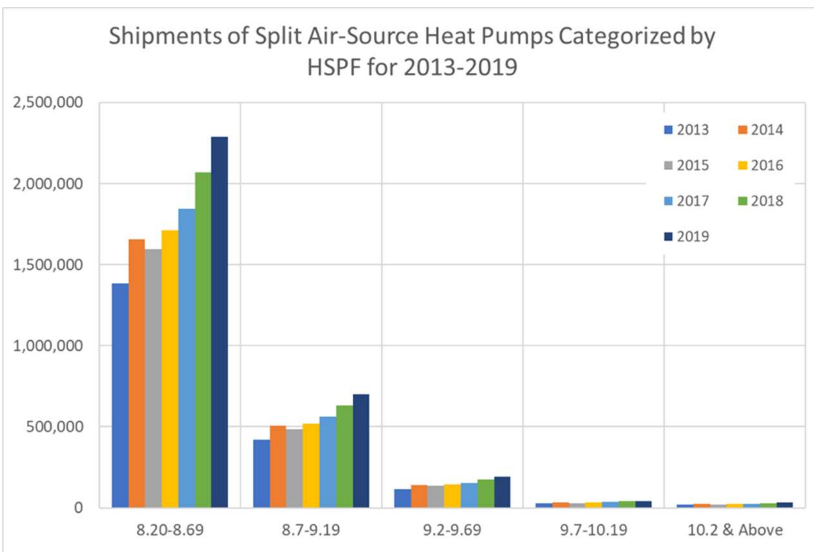
Figure 12: Example Natural Gas Heat Pumps and Efficiency

Table 3, based on DOE-EIA Residential Energy Consumption Survey (RECS) data, shows multi-year trends for US residential electric heating systems. The number of electrically heated homes has grown over the last 25 years (along with the total building stock), but the relative market share of electric heat pumps in electrically heated homes is largely unchanged at about 30% (about 40% for single-family homes). As the table reveals, most homes today with electric space heating use inexpensive but less efficient electric resistance heating rather than more efficient electric heat pumps with higher installed costs. From an energy efficiency program and GHG reduction perspective, policies should aim to upgrade homes from inefficient electric resistance home heating systems to electric heat pumps. This is a simpler and cost-effective strategy in comparison to wholesale energy system changes associated with switching from natural gas to electric space heating.

Table 3: Trends for US Electric Residential Heating Systems (DOE-EIA RECS)

DOE-EIA RECS Main Heat Source (millions of homes)	**1993**	**2005**	**2015**
All Homes	96.6	111.1	118.2
Electric Heating – All Types (% of homes)	25.3 (26.2%)	33.7 (30.3%)	42.9 (36.3%)
Electric Heat Pumps (% of Electric Homes)	7.5 (29.6%)	9.2 (27.3%)	12.1 (28.2%)

There is growing discussion of higher-efficiency cold-climate electric heat pumps. While new products offer efficiency improvements, data show most electric heat pump sales are units close to the minimum Federal efficiency standards (Figure 13). A very small percentage of the electric heat pump market have a Heating Seasonal Performance Factor (HSPF) greater than 10 with no current signs of sales ramping up.



Vast majority of electric heat pumps sold meet minimum Federal efficiency standards.

In 2019, 92% of electric heat pumps had an HSPF rating of 9.2 or lower.

Sales of higher efficiency electric heat pumps (e.g., HSPF 9.7 or higher) show no signs of higher growth rates.

Source: DOE; based on AHRI data

Figure 13: Residential Electric Air-Source Heat Pumps Sales Estimates

Beyond first cost, a key challenge and limitation of electric air-source heat pumps (EHP or ASHP) are their real-world performance and efficiency at cold outdoor temperatures. Below about 40ºF, most electric heat pumps start exhibiting system tradeoffs that include: (1) reduced heating capacity and lower supply air temperatures, (2) reduced system efficiency (or Coefficient of Performance, COP), (3) higher energy use for defrosting outside coils, and (4) increasing use of supplemental heating energy. At colder temperatures, electric heat pumps may use electric resistance devices for supplemental heating, thereby increasing electricity consumption and peak power that result with an overall decline in electric heating system efficiency. In other instances, homes with a hybrid heating system may switch to supplemental heating from a natural gas furnace during cold periods to avoid costly electric resistance heating.

Manufacturer electric heat pump ratings do not satisfactorily account for total, real-world energy use. Several factors can reduce electric heat pump efficiency, including: capacity reduction from frost, snow, or dust accumulation on outdoor coils; electric energy used to defrost outdoor coils; standby parasitic power and cycling losses; efficiency and performance degradation from improper refrigerant charge; and energy required for supplemental heating at cold temperatures. These factors lead to real-world electric heat pump system efficiencies that are less than rated values obtained from testing under controlled conditions.

Figure 14 shows recent independent large-scale cold-weather field testing of residential electric heat pumps. System performance notably declined as outdoor temperatures dropped; impacts of snow and ice accumulation on outdoor electric heat pumps were also documented.

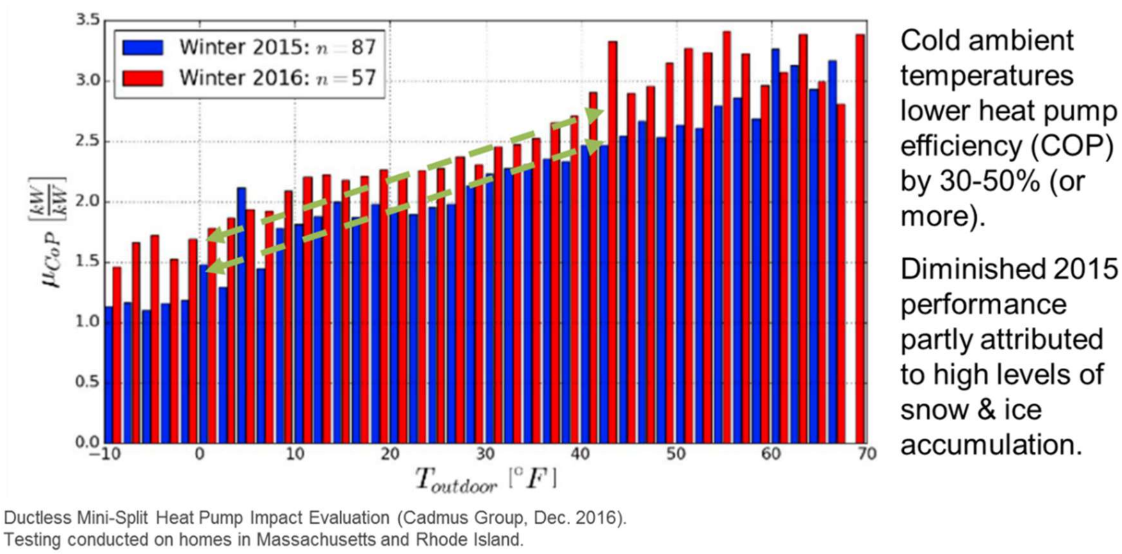


Figure 14: Cadmus Group Field Testing of Electric Heat Pumps in Northeastern US

GTI has conducted extensive lab and field testing as well as computer modeling of electric heat pump performance and efficiency, including conventional units and newer equipment characterized as cold climate air-source heat pump (ccEHP or ccASHP) systems. Figure 15 shows representative performance data for electric heat pumps at colder temperatures (below 40°F). These data account for real-world conditions like defrosting outside air coils and standby power consumption. Conventional electric heat pumps with nominal HSPF values around 9 (over 90% of current sales) show decreasing COP values at colder temperatures and fall below 1.5 around 10°F. Higher-efficiency (HSPF 10 and above) cold-climate electric heat pumps have improved efficiency compared to conventional systems, but still show a decline in efficiency from 40°F down to 10°F and lower. Cold-climate heat pumps are an improvement but have higher first costs and are not yet representative of consumer choices.

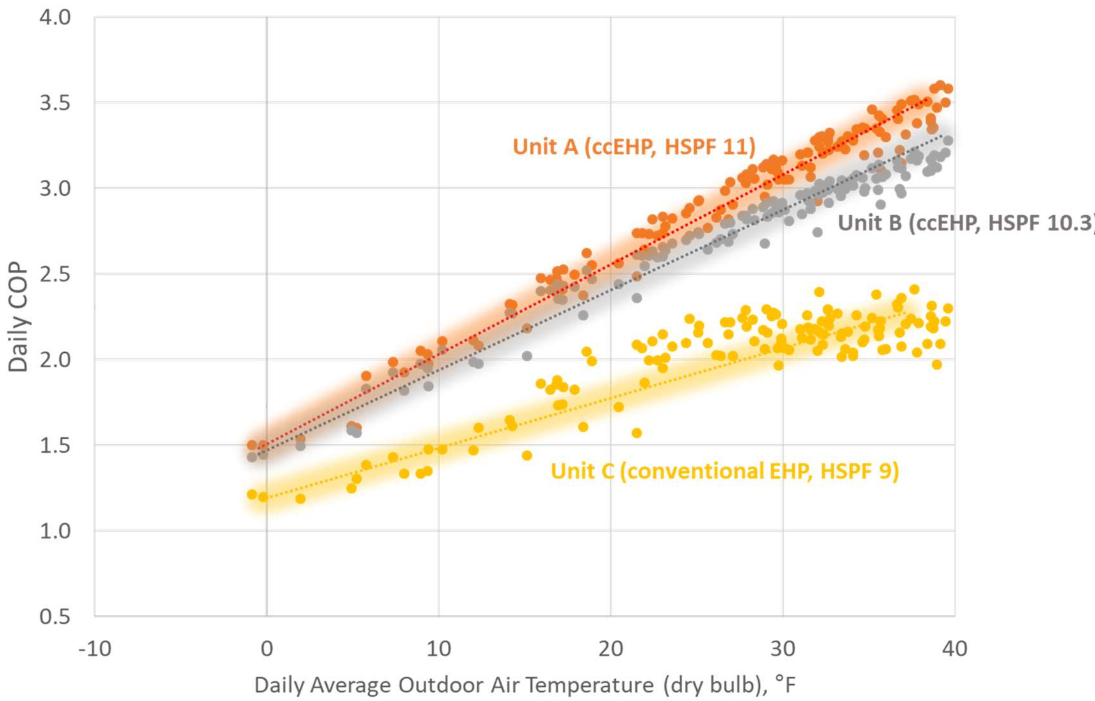


Figure 15: Electric Heat Pump Performance Below 40ºF (Source: GTI)

Figure 16 provides insights into the critical issue of non-linear increase in electricity use for space heating as outdoor temperatures drop. In this example, the building space heating load (shown in dark blue in left graph) increases by a factor of 2.7 at 20ºF and by a factor of 3.9 at 0ºF. These are the changes of heating needed to maintain indoor temperatures independent of the heating source. Since electric heat pump efficiency (or COP) drops with temperature, there is a compounded non-linear growth in hourly electricity consumption at colder outdoor temperatures. For example, a conventional electric heat pump (HSPF 9, shown in light blue) will use 7.8 times more electricity at 0ºF than it would at 40ºF. The right figure shows an example of the absolute electricity consumed in an hour as ambient temperatures change – with the more efficient heat pump using 9.3 times more electricity than its reference baseline at 40ºF. On an absolute basis, the more efficient cold-climate electric heat pumps, shown in gold, use about 20% less electricity than a conventional electric heat pump at 0ºF. These graphs would continue a non-linear increase at sub-zero temperatures. Note that these data are based on a nominal 1,660 ft^2 home built to 2010 International Energy Conservation Code (IECC) building standards. Older homes and/or larger homes will have proportionately larger hourly electricity demands and a further compounding effect on peak hourly electricity use at cold ambient temperatures.

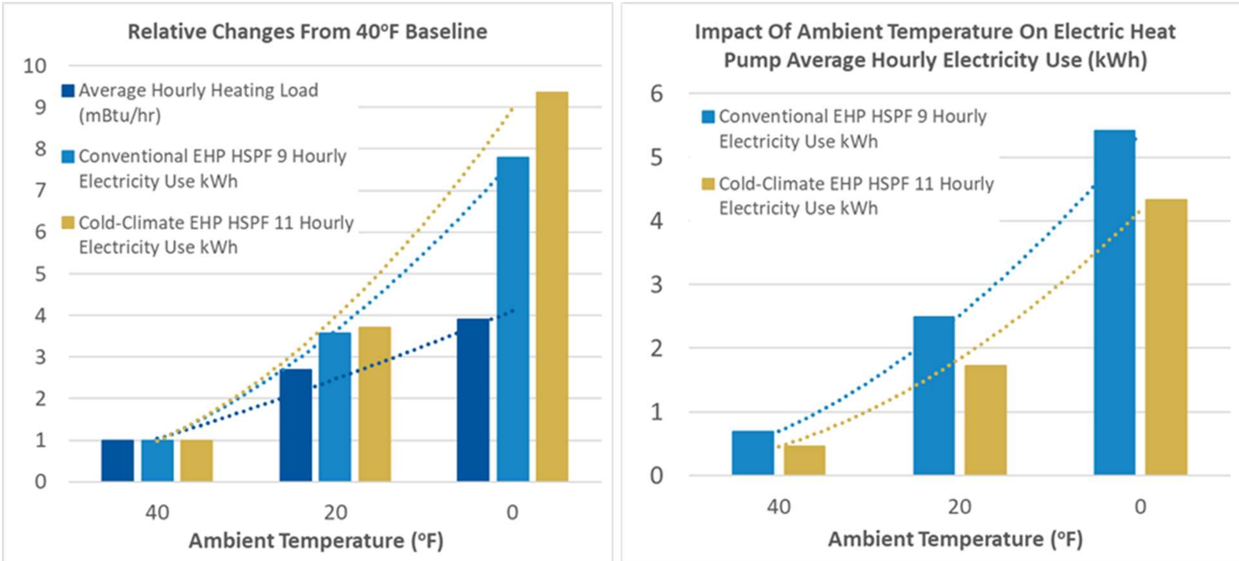


Figure 16: Impact of Ambient Temperature on Electric Heat Pump Electricity Use

Cold-climate electric heat pumps improve cold weather performance and efficiency compared with conventional EHP units by increasing refrigeration compressor speeds at colder temperatures and by incorporating more heat exchanger surface area (which results in higher capital costs). At this juncture, tit is uncertain whether a higher compressor speed operating strategy may impact cold-climate electric heat pump equipment durability and life.

In nearly all cases, operating electric heat pumps at very cold temperatures (e.g., below 10°F) results in a notable drop-off in heating capacity and efficiency. This has serious implications for consumer energy costs and for power generation and infrastructure sizing. Some manufacturers indicate that electric heat pumps may shut off during extreme cold weather events (e.g., <-15°F) such as a polar vortex event.

Electric heat pumps limitations at colder ambient temperatures raise several consumer and energy supplier concerns:

- Is a back-up home heating source available to ensure consumer comfort and safety?
- Will supplemental electric resistance heating substantially raise consumer heating bills?
- Will widespread simultaneous use of electric resistance heating at cold temperatures result in significantly higher peak-day electric power (generation, transmission, and distribution) asset requirements?

From a consumer perspective, there are three primary economic considerations for space heating equipment: (1) equipment installed cost, (2) annual operating cost, and (3) equipment life. Table 4 shows DOE data on space heating equipment cost and lifetime. The capital and installed cost of a conventional electric heat pump is estimated at 85% or greater than a natural gas furnace; higher-efficiency cold-climate heat pumps are even greater. While not directly addressed in this report, the retrofit installed cost for replacing gas heating with an electric heat pump(s) may be even higher than these estimates – especially for homes using hydronic heating. In addition, the expected life of an electric heat pump is around 15.5 years – about 28% shorter than a natural gas furnace equipment lifetime of about 21.5 years.

Table 4: Space Heating System Installed Cost and Lifetime (Source: DOE/NREL)

Space Heating Systems	Installed Cost	Equipment Lifetime Range, (Midpoint)
Natural Gas Furnace	$2,760 - 3,040	16 – 27 Years (21.5 Years; ~40% longer)
Electric Heat Pump	$5,100 – 6,100 (~85+% higher)	9 – 22 Years (15.5 Years)

There are unanswered questions on newer cold-climate electric heat pump operating life. Using electric heat pumps in non-traditional cold climates will result in higher annual heating run hours. Figure 17 shows GTI modeling data on annual operating hours using conventional and cold-climate electric heat pumps in different regions. Cold-climate EHP equipment have annual heating-mode runtime values 2-3 times higher than heat pumps operated in milder climates.

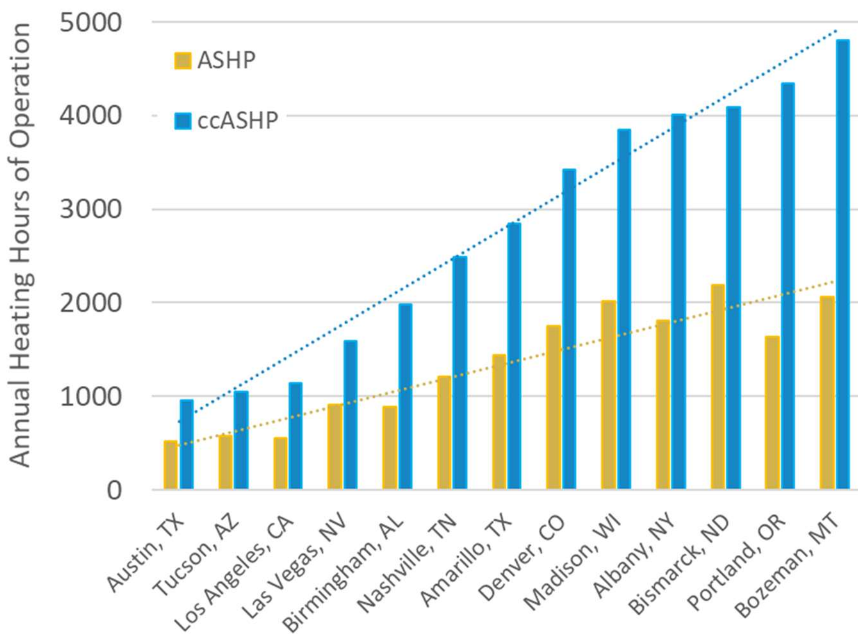


Figure 17: Electric Heat Pump Annual Heating Operating Hours in Different Climates (Source: GTI)

While long-term empirical evidence is pending, cold-climate electric heat pumps operating in cold-weather regions should see higher annual runtime. If run hours are a primary determinant of equipment life, these systems could see lower lifetime when measured in years of service.

Taken together, over the long term, consumers will pay more in capital costs for an electric heat pump compared to a gas furnace. This is due to the higher first cost of electric heat pumps as well as shorter equipment lifetime. The full lifecycle cost impact is somewhat lessened when factoring in consumer use of air conditioning systems – since an electric heat pump provides heating and cooling in one unit.

Complementing electric heat pumps with natural gas heating equipment (i.e., hybrid gas/electric systems) and using natural gas to satisfy heating loads at colder temperatures helps ameliorate consumer and societal cost impacts (Figure 18 and Figure 19) and empowers consumers and utilities with choices. In this scenario, gas heating is a cost-effective peak avoidance approach to avoiding significant electricity demand during very cold periods when electric heat pump efficiency drops and electricity use goes up. This is especially important for electric grid-constrained regions. Supplemental gas heating will also reduce an electric heat pump's annual runtime which may extend equipment years of service. A hybrid heating strategy also avoids running electric heating equipment mainly on dispatchable power generating systems (e.g., natural gas combined-cycle plants) that are likely to have higher GHG emission rates.

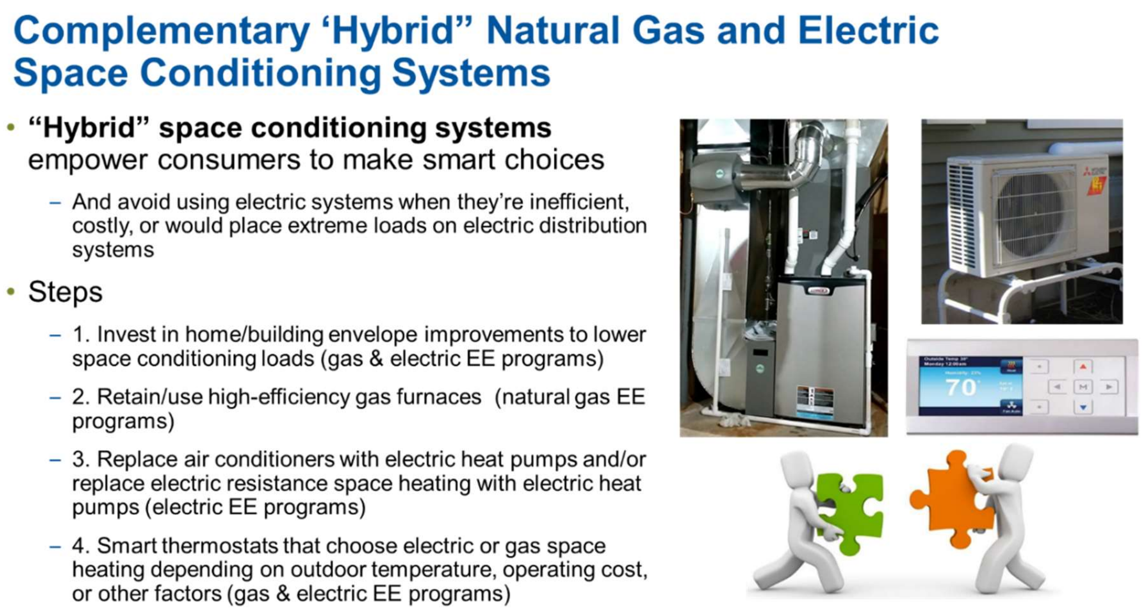


Figure 18: Natural Gas and Electric Hybrid Heating Systems

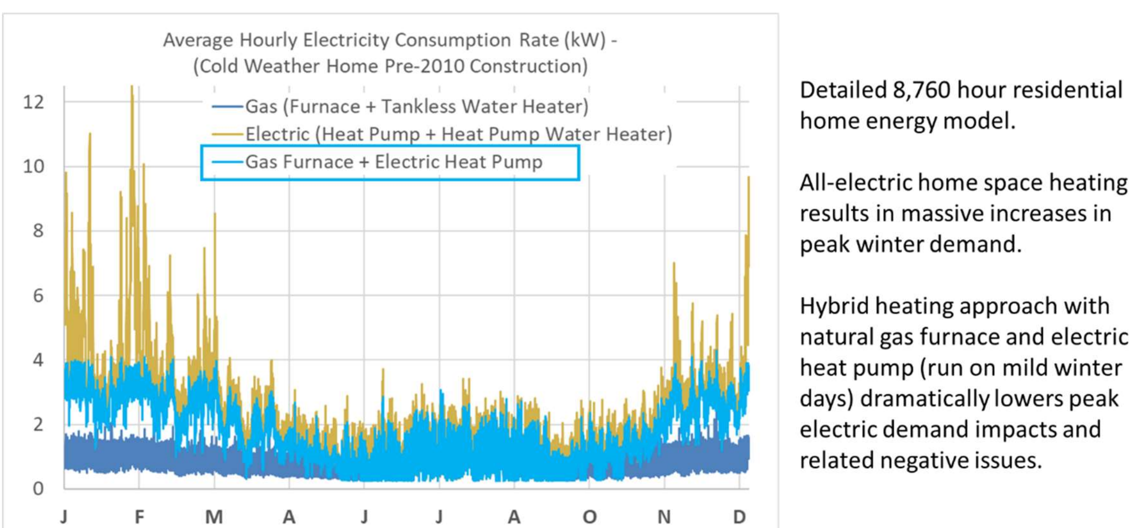


Figure 19: Hybrid Natural Gas and Electric Space Heating System (GTI)

Figure 20 shows results of GTI modeling of a 1,660 ft^2 home built to the 2010 IECC standard (example home located in Colorado). Electricity use with only electric heat pumps and electric resistance supplemental heating results in large increases in electricity consumption. Hybrid gas and electric systems provide a potential middle-ground solution that avoid many deleterious effects with dedicated electric heating systems in cold-weather regions.

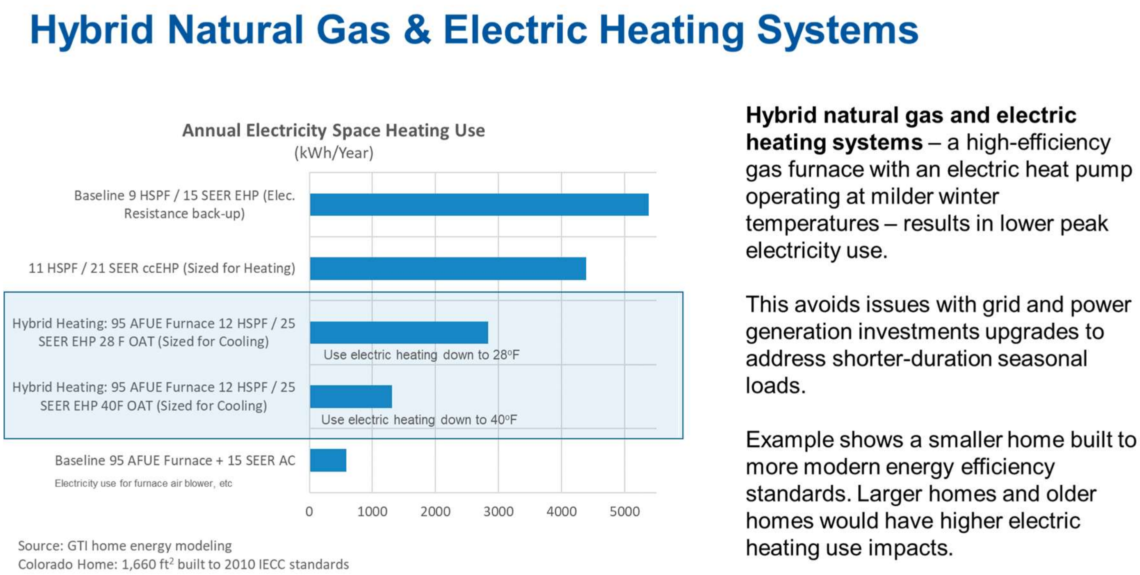


Figure 20: Hybrid Natural Gas and Electric Heating System Comparisons (GTI)

Electricity Generation in the US and Washington

This section reviews the current and potential future power generation mix in the US and Washington. Power generation is intimately connected to understanding the impact of residential electrification and potential GHG reduction pathways. Factoring in power generation emissions enables a comprehensive full-fuel-cycle review of primary energy and emissions associated with different scenarios.

US electric power generation sector (Figure 21) has undergone significant change, driven by the growth of natural gas, wind, and solar power generation sources along with a precipitous decline in coal generation (made possible by a large fleet of aging coal power plants).

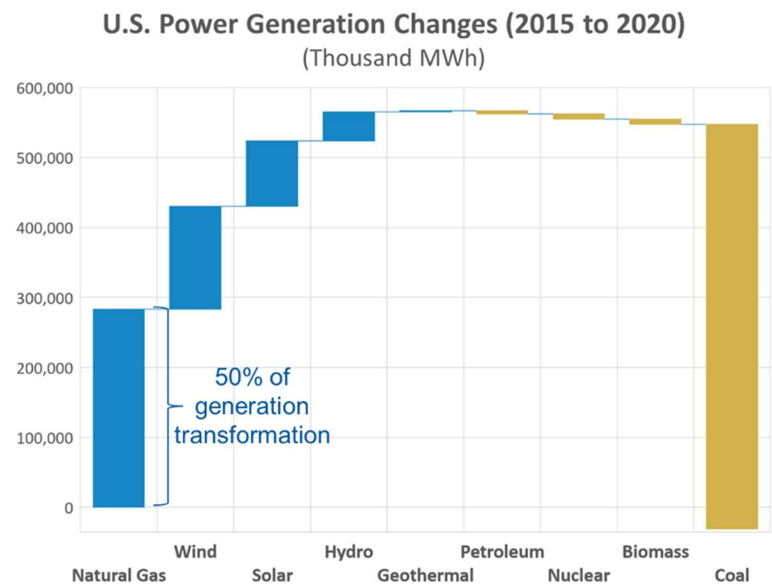


Figure 21: Changes in US Power Generation Output (2015–2020, DOE-EIA)

Figure 22 shows the primary power generation changes that have occurred in Washington since 2015, with a portfolio of additions including hydro, nuclear, wind, natural gas, and solar generation. Unlike other regions of the US, coal generation (which has a 4.5% market share) has not declined in Washington over this timeframe.

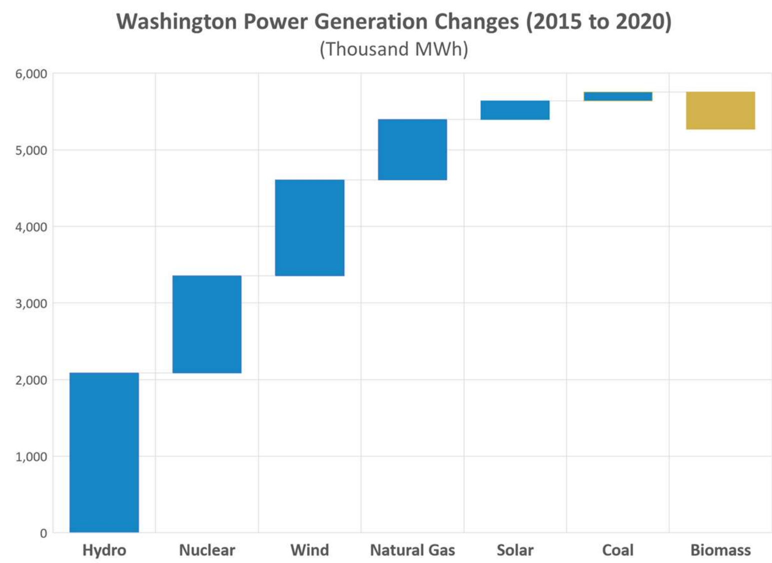


Figure 22: Washington Power Generation Changes (2015–2020, DOE-EIA)

Figure 23 shows trends in the US and Washington power generation average CO_2 emission rate since 2005. Washington is a leader in low CO_2 power generation emissions due in large part to the high reliance on hydro, with smaller contributions from natural gas, nuclear, and wind (Table 5).

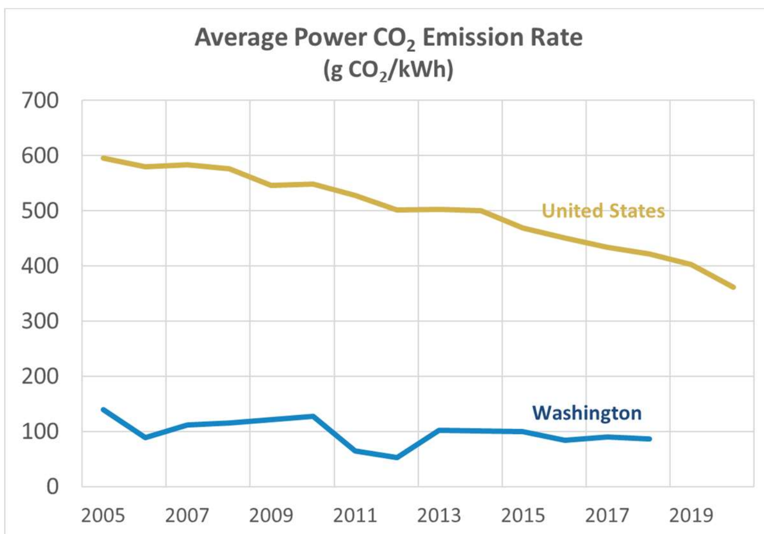


Figure 23: US Power Generation Average CO_2 Emission Rate (DOE-EIA)

Table 5: US and Washington 2020 Power Generation Mix (DOE-EIA)

2020 Power Generation Mix	United States	Washington
Natural Gas	40.3%	12.1%
Coal	19.3%	4.5%
Oil	0.2%	0%
Nuclear	19.7%	8.3%
Hydro	7.3%	66.1%
Wind	8.4%	7.3%
Solar	3.3%	0.3%
Biomass	1.4%	1.3%

For planning purposes, one can formulate hypotheses – a set of scenarios – for the future Washington power generation mix (e.g., 2030-2050). In advance of developing scenarios, it is pertinent to review the considerations and constraints with residential electrification in cold-weather regions:

- High seasonality of space heating energy use
- Seasonal/non-baseload power generation resources and their emission rates
- Mismatch of solar PV generation output (and to a lesser extent wind) with winter peak heating loads
- Electrical energy storage limitations and energy losses

Each of these issues will be more fully reviewed in the following sections. The challenge is overlaying demand-side impacts from electrification (e.g., very high winter peak demand) with a changing supply-side mix for power generation. A future with large-scale residential electrification is demonstrably different than today's market situation. Likewise, a future with large penetration of intermittent renewables such as wind and solar is also much different than today's market situation and likely to pose new challenges.

Seasonal and Non-Baseload Power Generation

There is an important consideration pertaining to generating power for building space conditioning: seasonality. The implications of seasonality are often glossed over in policy discussions of building electrification.

As shown previously in Figure 6, seasonal natural gas space heating loads are large. The importance of seasonality goes beyond the ability to deliver intense amounts of energy for short periods (e.g., multiple days or even 2-4 months for space heating loads in cold climates). This alone is significant and will be explored. What is also relevant is the type of power generation plants used to meet seasonal electricity use.

Seasonal or dispatchable, non-baseload power plants are often different than the average or baseload power generation mix. From a GHG reduction policy perspective, seasonal power generation resources often have appreciably different CO_2 emission rates than baseload plants (e.g., hydro or nuclear). Given the substantial energy used for building space heating, it is critical to take into account the seasonal power generation emission rates when assessing the potential GHG benefits of residential electrification.

Table 6 shows an overview of Washington state-level and area-wide power generation resources, including average as well as non-baseload or seasonal power generation resources. Washington is unique in its ability to tap into large hydro resources. It is uncertain whether future seasonal demand increases (e.g., greater electric space heating) could be partially matched to hydro resources. To the extent that Washington relies on dispatchable generation (e.g., natural gas generation) or the broader NWPP for seasonal non-baseload generation, the GHG emission rates from electric space heating are likely to be considerably higher than anticipated if one assumes the average baseload generation mix in Washington.

Table 6: Washington Area Power Generation Mix (DOE-EIA, EPA eGRID)

	Average Power Generation Mix		**Seasonal/Marginal Power Generation Mix**		
Washington Power Mix	DOE-EIA Washington Average (2020)	EPA eGRID NWPP Region All Plants (2019)	DOE-EIA 2020 Washington Summer Seasonal	DOE-EIA 2020 Washington Winter Seasonal	EPA eGRID NWPP Region Non-Baseload (2019)
CO_2 Emission Rate (g/kWh)	111	356	239	219	786
Natural Gas	12.1%	19.9%	67%	46.0%	46.6%
Coal	4.5%	23.1%	17.1%	16.3%	50.2%
Oil	0%	0.2%	0.0%	0.0%	0.2%
Nuclear	8.3%	3.1%	0%	1.0%	0.0%
Hydro*	66.1%	42.3%	0%	34.7%*	0.0%
Wind	7.3%	8.0%	13.4%	0%	0.0%
Solar	0.3%	1.4%	0.8%	0%	0.0%
Biomass, other	1.4%	1.3%	1.7%	2.0%	3.1%

* The ability of hydro to “flex up” generation output to match seasonal demand is a nuanced subject, particularly under a future scenario with considerably greater winter peak electricity use for space heating. Empirically in Washington, hydro output often peaks in the spring, typically 2-4 months after winter space heating peaks occur.

Future Power Generation Scenarios in Washington

The future Washington power generation outlook can be gauged based on the current generation mix coupled with insights on market experience and recent trends. In a business-as-usual scenario, this can be feasibly done. However, there are limitations when considering a longer-term framework which includes widespread residential electrification, since this will change load profiles in a meaningful way.

Figure 24 shows the current and projected electricity use in Washington with widespread residential electrification. This includes an 18% increase in annual electricity use, 44% increase in residential electricity use, and a 26.5% increase in peak month use. Broader electrification of the commercial, industrial, and transportation sectors would further expand this graph. The figure shows the current monthly hydro generation levels, with a peak in spring and gradual declines in remaining months. The large increase in winter seasonal demand (e.g., January and February) is the most prominent issue to address. This information will be used to craft future scenarios using a mix of baseload and seasonal, non-baseload power generation sources.

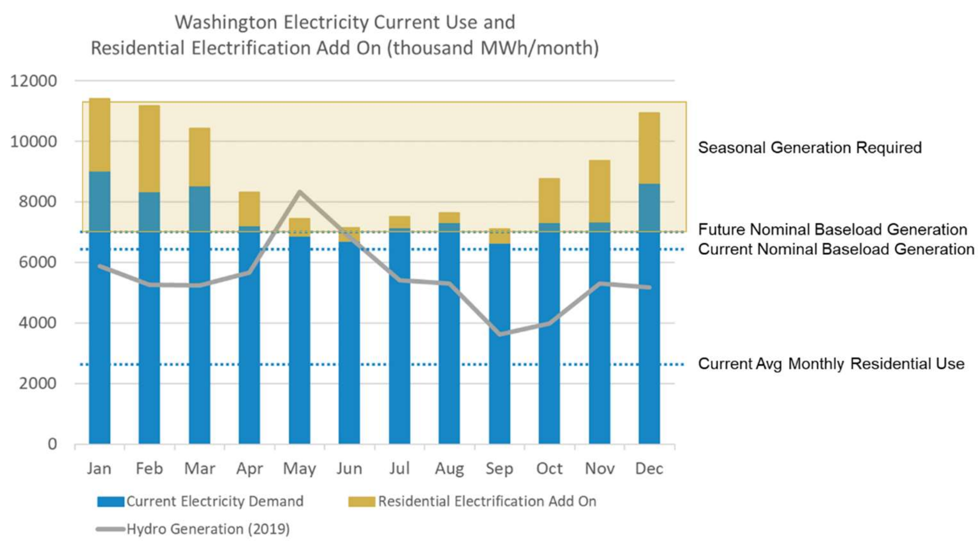


Figure 24: Washington Current Monthly Electricity Use and Projected Impact of Full Residential Electrification

There are three major factors to address the type of demand profile change shown in Figure 24:

- Step 1: Replace the coal generation in Washington with a mix of wind, solar, and natural gas.
- Step 2: Add baseload generation to address future elevated year-round baseload electricity demand (mainly hydro, wind, and solar).
- Step 3: Add low GHG dispatchable generation to meet increased seasonal peak electricity demand driven by electric space heating use (e.g., natural gas combined-cycle generation)

Generally hydro and pumped hydro storage can provide seasonal energy storage and generation, depending on the extent of future hydro expansion (or transmission access to Canadian resources) that may occur in Washington. The limitations of battery energy storage, discussed in a separate section, make it an unlikely or infeasible option for sustained seasonal energy use.

Based on current and reasonable technology options, the practical power generation option for meeting about four months of peak winter seasonal demand is likely to be a mix of dispatchable natural gas generation and hydro power (if available) along with wind and solar. The GHG reduction implications of replacing natural gas space heating with natural gas combined-cycle power generation will be explored in the next section – but the benefits are limited and would detract from residential electrification space heating as a GHG reduction strategy. However, dispatchable natural gas combined-cycle plants could result in a lower GHG footprint through measures such as:

- Using renewable gas blends (e.g., bio-methane and renewable hydrogen) to fuel turbines
- Using CO_2 capture with sequestration or reuse

A factor to consider when postulating future power generation scenarios is the comparably small year-over-year improvements seen in advanced low GHG power generation states such as Washington and California. As illustrated earlier in Figure 23, the pace of change in the US power generation mix since 2005 is considerably more than the pace of change seen in Washington over this timeframe (about 40% and 14%, respectively). This is akin to the economic principle of diminishing marginal returns, whereby additional improvements (i.e., GHG reductions) becoming increasingly more difficult or expensive to realize.

Table 7 shows the current 2020 Washington power generation mix along with two future 2030-2040 timeframe power generation scenarios. This assumes a portion of dispatchable resources is necessary to enable stable grid operation in the face of high wind and solar intermittency. These two scenarios represent sizeable reductions in CO_2 emission rates, 53% and 61% reductions lower than the current Washington power generation mix. This level of GHG emission rate is beyond what is now realized in leading states such as California and New York GHG; these are highly ambitious market changes. Along with the current generation mix, these future scenarios will be used in the benefit/cost analysis section of this report.

Table 7: Current and Two Future Washington Power Generation Scenarios

Future Washington Power Generation Mix Circa 2030-2040	Nominal Current Power Generation Mix (2020)	Scenario 1: Base Case Future Washington Generation Mix	Scenario 2: Higher Renewables Future Washington Generation Mix
Natural Gas	12.1%	15%	10%
Coal	4.5%	0%	0%
Wind	7.3%	9%	12%
Solar	0.3%	1.7%	3.7%
Nuclear	8.3%	8.3%	8.3%
Hydro	66.1%	66%	66%
Biomass, other	1.4%		
CO_2 Emission Rate (g/kWh)	111	70 (-37%)	50 (-55%)

Renewable Gas

The following is a brief renewable gas overview. There are several pathways to generate methane (CH_4) and other gases (e.g., hydrogen or H_2) from renewable resources, including:

- Conventional anaerobic digestion pathways that can produce bio-methane from landfills, wastewater treatment plants, farm digesters, and other sources; these are mature pathways with established and growing commercial use today
- Thermochemical conversion (e.g., gasification) pathways that produce renewable methane or hydrogen from biomass materials (e.g., wood waste and agricultural waste)
- Power-to-gas concepts using renewable or zero-carbon power generation sources (e.g., wind, solar, nuclear) to produce hydrogen via water electrolysis (which can subsequently be combined with recycled CO_2 to produce methane – a process called methanation – if desired)

Figure 25, from the American Gas Foundation (AGF), provides a visual description of these renewable gas pathways and the energy sources that can be used to produce renewable gases.

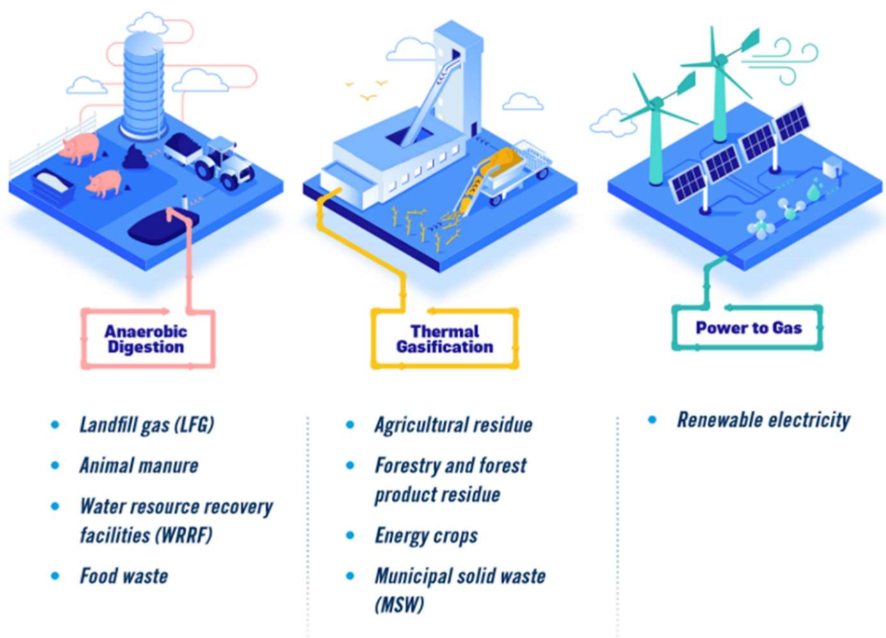


Figure 25: Renewable Gas Generation Pathways (Source: American Gas Foundation)

Renewable gas is an energy form – that is, chemical energy – which is important for several reasons:

(1) Intrinsically high energy density
(2) Readily and efficiently stored as a compressed gas
(3) Potentially compatible with existing gas pipeline infrastructure and end-use equipment
(4) Efficiently delivered to customers with minimal energy losses

Renewable gases can be injected into gas pipelines or used onsite to generate power, fuel vehicles, or fuel other process heating needs.

The AGF report, produced by ICF, indicates substantial US potential for three renewable gas pathways (Figure 26). The 2040 potential for renewable gas is equivalent to about 4,512 Trillion Btu/year. This is comparable to the total amount of natural gas consumed in the US residential sector – indicating a possibility for a total renewable gas displacement of conventional gas sources for this segment. For Washington, the AGF report indicates a technical resource potential for conventional biogas plus thermochemically produced gases of about 130 Trillion Btu/year; this amount exceeds the roughly 85 Trillion Btu/year of natural gas consumed in Washington homes. In theory, all Washington residential natural gas use could be displaced with bio-methane, a renewable low-carbon energy supply.

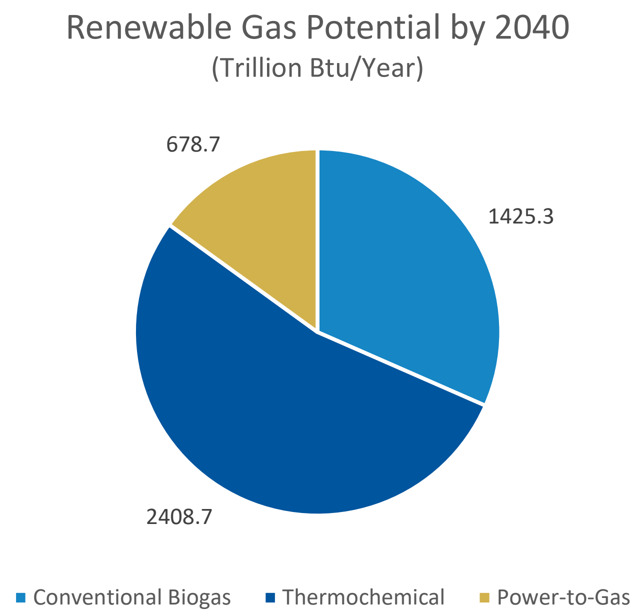


Figure 26: American Gas Foundation/ICF Renewable Gas Potential

Next-generation renewable gas options are possible through (1) thermochemical conversion of biomass and (2) power-to-gas systems. These are not yet widely reduced to commercial practice but have long-term potential to expand the portfolio of renewable and sustainable forms of methane or hydrogen.

Thermochemical conversion of biomass to methane or hydrogen has several favorable attributes, including feedstock flexibility and greater capability to produce large volumes of renewable gas. These processes can convert agricultural wastes, forestry wastes, organic municipal wastes, and byproducts from a variety of industries. These facilities are typically 2-10 times larger than conventional biogas facilities. The sustainable availability of biomass materials in Washington opens the potential for these processes to be a significant long-term source of renewable gas.

Power-to-gas is a pathway that produces hydrogen through the electrolysis of water. The power can come from any electrical source but is often viewed in the context of wind and solar power (as a means of storing excess power generation) or from nuclear power plants. This hydrogen can be used directly, stored as a compressed gas, or injected into a pipeline. Through a process called methanation, it can also be combined with captured and recycled CO_2 to produce methane, which can be used directly with existing natural gas infrastructure. This pathway offers feasible large-scale storage of renewable energy with the capability to meet long-duration seasonal demand (e.g., space heating) which cannot be met by other energy storage systems such as batteries.

Washington Residential GHG Reduction Analysis

This section highlights information on the benefits and costs of various natural gas, electric, and hybrid natural gas/electric greenhouse gas reduction pathways for Washington homes. This analysis is based on a free, publicly accessible online tool developed by GTI: Energy Planning Analysis Tool (EPAT; http://epat.gastechnology.org/).

Energy Planning Analysis Tool (EPAT) and Benefit/Cost Scenario Analysis

EPAT is a free publicly accessible analytical tool for conducting an energy and environmental analysis of various home energy uses. EPAT relies on government published and publicly available data sources to estimate source energy (i.e., full-fuel-cycle) and emissions for energy sources like natural gas and electricity consumed at a site. EPAT accounts for upstream energy use and emissions in the production and delivery of energy, including features such as methane emissions from the full natural gas production and delivery chain as well as full-fuel-cycle energy losses and emissions from electric power generation, transmission, and distribution. The EPAT electric generation component relies on EPA eGRID data, with granular information on power generation plant efficiency and emissions on a city, state, or regional level. For each scenario, the user can select the default power generation fuel mix based on the latest eGrid state or regional data or enter a custom power generation mix.

In this analysis, we use the population of natural gas homes shown previously in Table 1. EPAT involves a pair-wise comparison of a baseline and alternative scenario. The baseline for this analysis is a home using an 80% efficient natural gas furnace, 62% efficient gas water heater, and conventional natural gas cooking and dryer equipment. From this, a series of pair-wise comparisons are made for the baseline and alternative scenarios or cases. Table 8 shows a summary matrix of the 13 comparable cases in this analysis. These will be referred to as Case 1, Case 2, etc., in the analysis discussion. Detailed summary reports of each case are included in an appendix. There are also three additional space heating-only cases: two special cases with electric heat pumps exclusively on seasonal, dispatchable natural gas generation and one case of replacing an existing electric resistance heating system with an electric heat pump.

Building envelope improvements are shown in this table for completeness but are not part of the quantitative analysis. Improved home weatherization of homes is a critically important component of a resident building GHG reduction program. These measures provide value to consumers in the form of lower annual energy bills and improved indoor comfort while also reducing natural gas and electricity use for home space conditioning. Building envelope improvements are an important GHG reduction measure that is highly complementary and additive to the other natural gas and electric equipment-based efficiency measures assessed in this section but is not specifically assessed as a variable in this analysis.

Table 8: Washington Residential GHG Reduction Scenario Cases

Natural Gas	**No RNG**	**50% RNG**	
Baseline (80% efficient furnace, 62% efficient water heater, standard cooking and dryer appliances)	Baseline	--	
Existing High-Efficiency (98% efficient furnace, 95% efficient water heater, high-efficiency dryer)	1	2	
Emerging High-Efficiency (140% efficient natural gas heat pump, 130% efficient gas heat pump water heater, high-efficiency dryer)	3	4	
Electricity	**Current Power Mix**	**Scenario 1 Power Mix**	**Scenario 2 Power Mix**
Baseline Electric (all electric-resistance heating equipment)	5	6	7
Typical High-Efficiency Electric (HSPF 9.0 electric heat pump, water heater/EF = 0.95, standard cooking/dryer)	8	9	10
Emerging High-Efficiency Electric (HSPF 13.0 electric heat pump, electric heat pump water heater EF 2.0, induction cooking, high-efficiency dryer)	11	12	13
Single Family Home Comparison			
1476 ft^2 single-family home using Case 1 (gas) and Case 9 (electric) input		14	
Space heating only with 100% natural gas power generation for peak winter heating with electric heat pumps (HSPF = 9) compared to a 98% efficient natural gas furnace		15	

The main analytical thrust is energy used for space heating, water heating, cooking, and clothes drying applications. To properly account for capital costs, the gas cases include cost for central air conditioning systems in 60% of the homes (the percentage in Washington is below many other US states). This allows for equitable capital cost treatment of electric heat pumps which also provide cooling. The cases with 50% renewable natural gas (RNG) assume an RNG price of $15/MMBtu.

The current Washington power generation and future Scenario 1 and 2 power generation mixes, shown previously in Table 7, are used for the electric residential pathways. Note that the natural gas cases also use the Scenario 1 power generation mix, reflecting possible future GHG emission reductions for electricity used in gas equipment (e.g., furnace blower fans).

The EPAT analytical tool captures consumer costs in two main categories: annual energy costs (natural gas and electric) and capital costs. Equipment capital costs are annualized by a simple amortization achieved by dividing the capital cost by expected equipment life of the space heating systems. As noted, for gas furnaces this is 21.5 years and for heat pumps (electric or gas) this is 15.5 years. The annual energy costs and annualized capital costs are added together to provide a nominal annualized cost for each scenario – and used to calculate the GHG abatement costs in terms of $/metric ton of GHG reduced.

A brief comment about capital costs. The EPAT tool relies on the NREL National Residential Efficiency Measures (NREM) Database for equipment costs. Since equipment markup, distribution, and installation costs vary widely across the US, the NREM information resource may not accurately reflect installed equipment costs but does permit consistent cost comparisons. Further, there are likely additional upfront consumer costs in switching a home from natural gas to all-electric systems such as costs to upgrade the service panel and for additional home circuits. There also may be added costs to upgrade home space-conditioned air distribution systems, particularly for homes now using hydronic heat distribution (e.g., adding a SpacePak or similar small duct high-velocity system). There is no attempt to estimate or account for these potential added electrification capital costs or the challenges of evenly heating and cooling a home.

EPAT results also include information on the annual site and source (or full-fuel-cycle) energy use as well as a suite of annual conventional emissions (e.g., NO_x, SO_x) and GHG emissions (e.g., CO_2, methane, CO_2e).

This analysis is aimed at existing homes in Washington using natural gas. A component of the economic costs for electrification is the need to upgrade electrical distribution service to and within a home (along with additional possible site-specific HVAC upgrade needs). For this analysis, we included added initial one-time costs of $2,650 per home to upgrade the electric service facets of these homes. A National Association of Home Builders – Home Innovation Research Lab report provides more background on this topic (see References). These costs are amortized over 25 years, making the annualized per home cost impact relatively small ($106/year).

Figure 27: Home Electrical Service Panel and Circuit Upgrades

Annualized costs are divided by the annualized emission reductions for the individual cases relative to the baseline natural gas case. This results in a GHG cost/benefit ratio – also referred to as a carbon, CO_2, or GHG abatement cost. These are reported as $/metric ton of CO_2 or CO_2e reduced. In most cases, the GHG abatement cost is a positive number when consumers (and society) pay a cost premium to lower GHG emissions. In some instances, the GHG abatement cost is negative; in these highly favorable instances, consumers are saving money and reducing GHG emissions. GHG abatement costs values can be considered in the context of a carbon tax or the notion of the societal cost of carbon.

Washington Home GHG Reduction Pathways Cost and Benefit Results

Table 11 (end of this report section) provides data on Cases 1 through 13 described previously. Detailed reports on each case are in a report appendix.

> **Main Finding**: All three electric scenarios result in increases in annual energy bills for Washington homeowners (Table 9 and Figure 28). Mid-case electric heat pump (HSPF 9) results in a 41% increase in annual consumer energy costs (about $338 million increase).

Table 9: Annual Energy Cost Increases with Electric Systems

Electrification Case	Annual Energy Bills
Electric Resistance (Case 5)	124% higher ($1,023 million increase)
HSPF 9.0 Heat Pump (Case 8)	41% higher ($338 million increase)
HSPF 13.0 Heat Pump (Case 11)	4% lower ($33 million decrease)

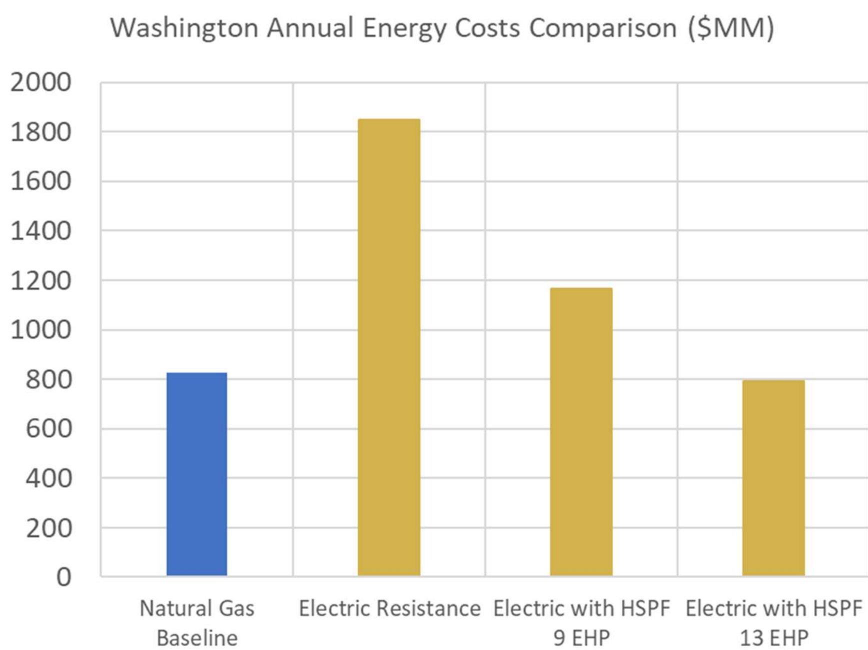


Figure 28: Washington Annual Energy Cost Comparison

Figure 29 shows a comparison of natural gas and electric GHG reduction options. Case 1 is the most cost-effective option (-$37/metric ton) using available high-efficiency gas equipment (e.g., high-efficiency furnaces), followed by using renewable gas with high-efficiency furnaces ($62/metric ton). Electrification cases are higher cost, with conventional electric pumps (HSPF 9) and possible future power generation mixes having CO_2 abatement costs ranging around $160-$170/metric ton. Higher-efficiency electric heat pumps (HSPF 13) and possible future power generation mix are in the range of $123-$128/metric ton; however, electric heat pumps come with greater initial costs that can impede market adoption.

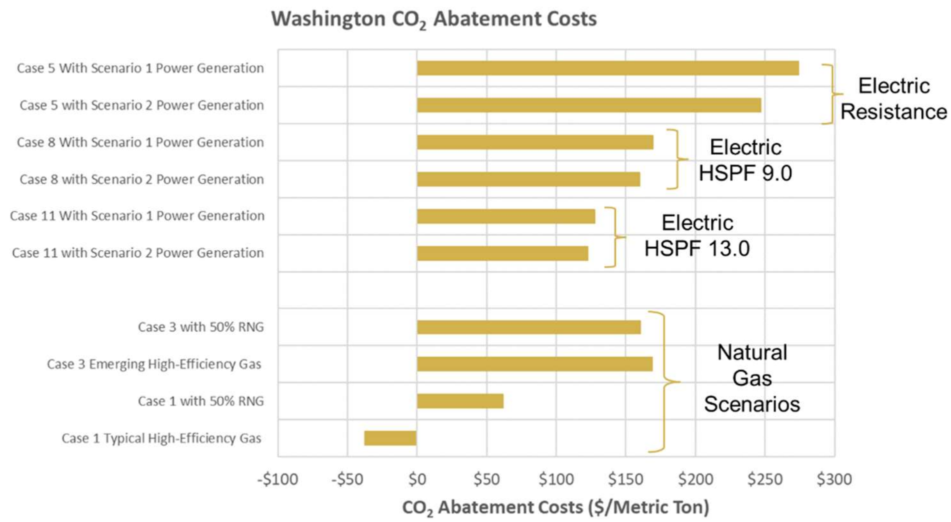


Figure 29: Comparison of CO_2 Abatement Costs ($/metric ton)[1]

There are cautionary factors for the electrification scenarios that are not included in this analysis: (1) the potential for future electricity price increases and (2) the likelihood much of the increased electric space heating will come from dispatchable natural gas power generation, resulting in lower real-world CO_2 reductions and elevated abatement costs. It is also worth remembering that building envelope improvements can yield additional percent reductions for gas and electric cases with attendant costs (not included in this analysis).

Figure 30 captures Washington natural gas and electric residential GHG reduction options. Natural gas offers lower-cost options with the ability to reduce CO_2 emissions by 20% to 63%. Electrification entails higher CO_2 abatement costs than the two most attractive natural gas cases, but is able to realize over 80% GHG emission reductions with assumed future grid power mixes.

1 Actual CO_2 abatement costs for electrification will likely be higher when factoring in emissions from dispatchable generators used to meet seasonal winter demand for electric space heating.

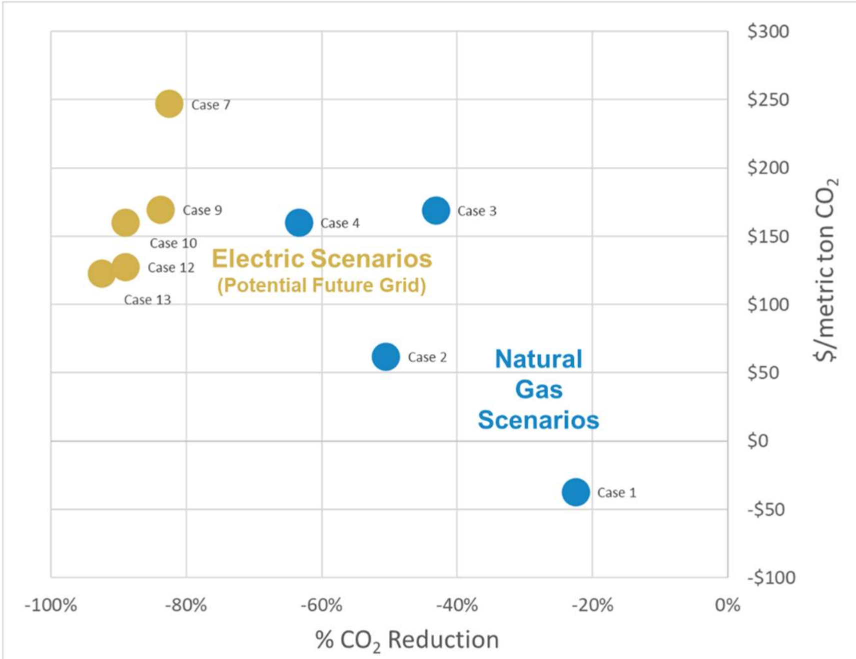


Figure 30: Washington Residential GHG Reduction Scenarios

While EPAT is a suitable screening tool, it does not dynamically match electric supply sources (and emissions) with year-round real-time demand. A subsequent report section discusses the case of space heating with dispatchable natural gas generation to meet peak winter demand and its implications. These data highlight that a sizeable portion of the electrification CO_2 reduction potential in Figure 30 could be illusory and not likely realized in practice without specific solutions such as natural gas combined-cycle plants using RNG or carbon capture.

Individual Single-Family Homes Cases

This section highlights a representative 1,476 ft^2 single-family Washington home that now uses available and efficient gas appliances and is required to move to all-electric equipment as highlighted in Case 9 (e.g., HSPF 9 electric heat pump).As shown in Figure 31, annual energy costs for all-electric homes are 72% higher compared to a home now using natural gas for four energy uses (i.e., space heating, water heating, cooking, and drying). Homeowners would also face significantly higher first costs for outfitting their home with all-electric appliances and upgrading their electrical panel and circuits. The total cost would be nearly $12,000 (an incremental cost of about $4,500 if the homes natural gas appliances already needed to be replaced).

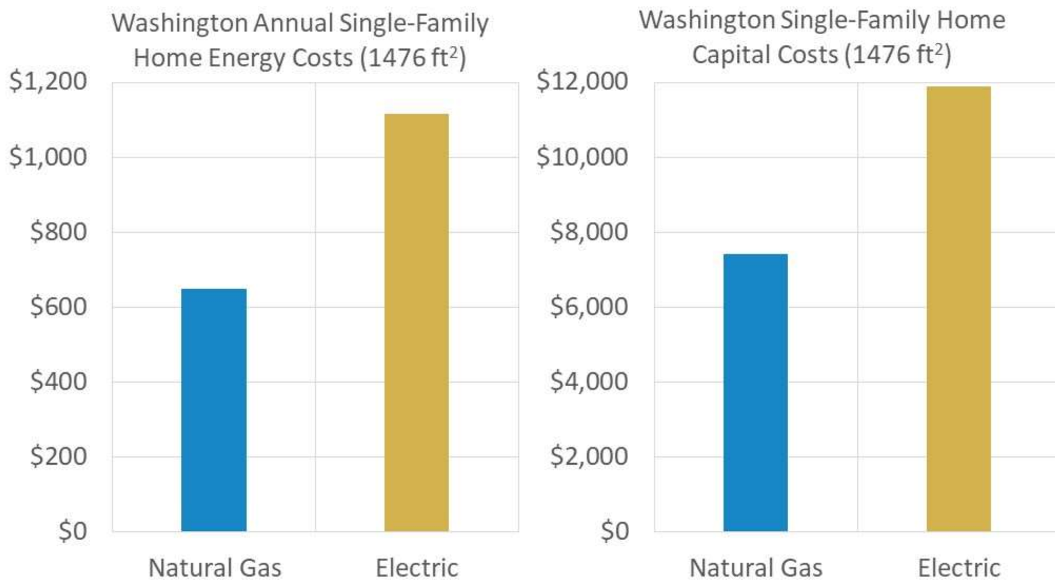


Figure 31: Annual Energy Costs and Capital Costs for Typical 1,476 ft^2 Single-Family Home in Washington

Special Space Heating Only Case

This report highlights the real-world challenges with seasonal home space heating. In particular, earlier graphs – e.g., Figure 6 and Figure 24 – help illustrate the challenges. There is also a high likelihood that a significant portion of electric space heating will be met by running dispatchable natural gas generators – rather than average or idealized future grid scenarios.

To illustrate the implications, Case 15 (HSPF 9.0 electric heat pump) and Case 16 (HSPF 13.0 electric heat pump) show the potential impact on GHG emissions of electric space heating equipment operating on 100% natural gas power generation mix (i.e., winter dispatchable generation). Table 10 compares these cases for a typical 1,476 ft^2 single-family home using a 98% efficient gas furnace. Under these assumptions, both electric heat pumps cases have significantly lower GHG savings relative to the more idealized Scenario 1 or 2 future power generation mixes.

Table 10: Comparison of Single-Family Home Using Gas and Electric Heating Supplied By 100% Natural Gas Power Generation (Case 15, 16)

Case	CO_2 Emissions kg/year
Natural Gas 98% Furnace	2,885
HSPF 9.0 Heat Pump (Case 15)	2,590
HSPF 13.0 Heat Pump (Case 16)	2,096

When considering the results in Table 10 with electric space heating operating with dispatchable natural gas power generation – and assuming 50% of winter electric heating will come from natural gas generation – the real-world electrification emission reductions will be less than anticipated and the costs higher. This impact is depicted in Figure 32.

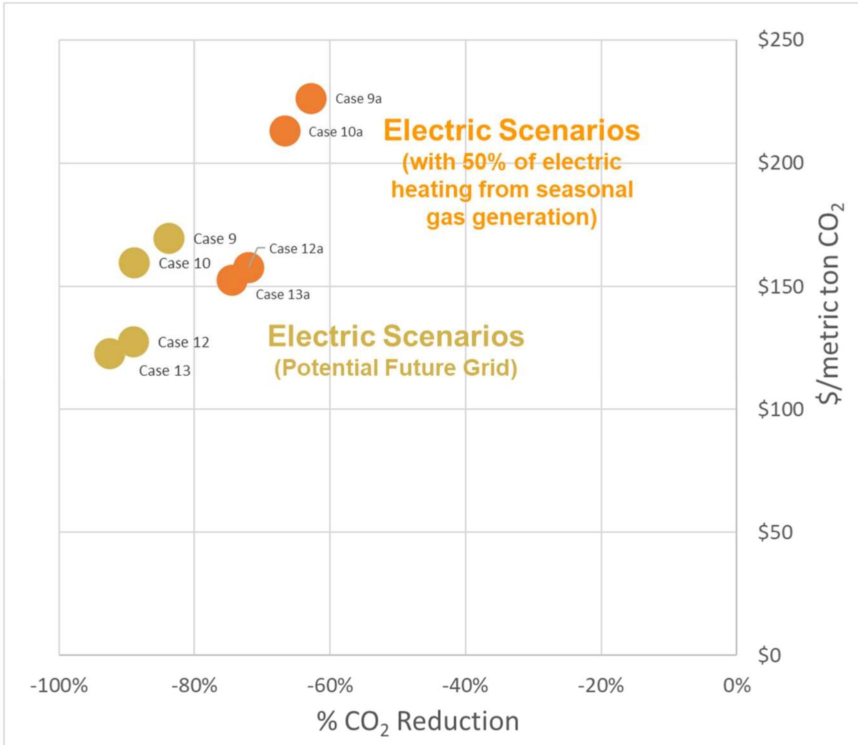


Figure 32: Directional Impact of Winter Peak Electricity Use on CO_2 Reduction and Cost/Benefit Ratio

Table 11: Energy and Environmental Cost and Benefit Data

Case	Description	Annual Energy Costs ($MM/yr)	Annualized Capital Costs ($MM/yr)	Total Annualized Costs ($MM/yr)	Annual CO_2 Emissions (MMT/yr)	Annual CO_2e Emissions (MMT/yr)	$/Metric Ton CO_2 Reduced	% CO_2 Reduction
--	Baseline: Natural Gas Systems	$826	$363	$1,189	5.20	5.90	--	--
1	Typical High-Efficiency Gas Equipment	$658	$488	$1,146	4.03	4.58	-$37	22.5%
2	Case 1 with 50% RNG	$864	$488	$1,352	2.58	3.08	$62	50.5%
3	Emerging High-Efficiency Gas Equipment	$544	$1,025	$1,569	2.96	3.35	$169	43.2%
4	Case 3 with 50% RNG	$693	$1,025	$1,718	1.91	2.28	$160	63.4%
5	Baseline All Electric Resistance Equipment / Current Power Generation	$1,849	$400	$2,249	2.11	2.26	$343	59.4%
6	Case 5 with Scenario 1 Power Generation	$1,849	$400	$2,249	1.34	1.47	$274	74.3%
7	Case 5 with Scenario 2 Power Generation	$1,849	$400	$2,249	0.91	1.00	$247	82.5%
8	Typical High-Efficiency Electric Equipment/Current Power Generation	$1,164	$764	$1,928	1.33	1.42	$191	74.5%
9	Case 8 with Scenario 1 Power Generation	$1,164	$764	$1,928	0.84	0.92	$170	83.8%
10	Case 8 with Scenario 2 Power Generation	$1,164	$764	$1,928	0.58	0.63	$160	88.9%
11	Emerging High-Efficiency Electric Equipment/Current Power Generation	$793	$987	$1,780	0.91	0.97	$138	82.6%
12	Case 11 with Scenario 1 Power Generation	$793	$987	$1,780	0.57	0.63	$128	89.0%
13	Case 11 with Scenario 2 Power Generation	$793	$987	$1,780	0.39	0.43	$123	92.5%

Additional Home Electrification Considerations and Challenges

This section discusses additional challenges or issues with the expanded use of electricity as a natural gas replacement in Washington homes. These center around energy transmission, distribution, and storage systems as well as the growing consumer importance placed on home energy service reliability and resilience.

Natural Gas and Electric Energy Delivery Systems

Figure 33 shows results of a prior GTI analysis of space heating electrification impact on peak winter demand in 17 different states. This data highlights the substantial scale-up and investment in electric transmission and delivery capacity required to support switching residential gas heating to electricity. Some electrification advocates point to distributed PV systems as an answer; however, decreased solar PV output during the winter largely negates their ability to offset this challenge.

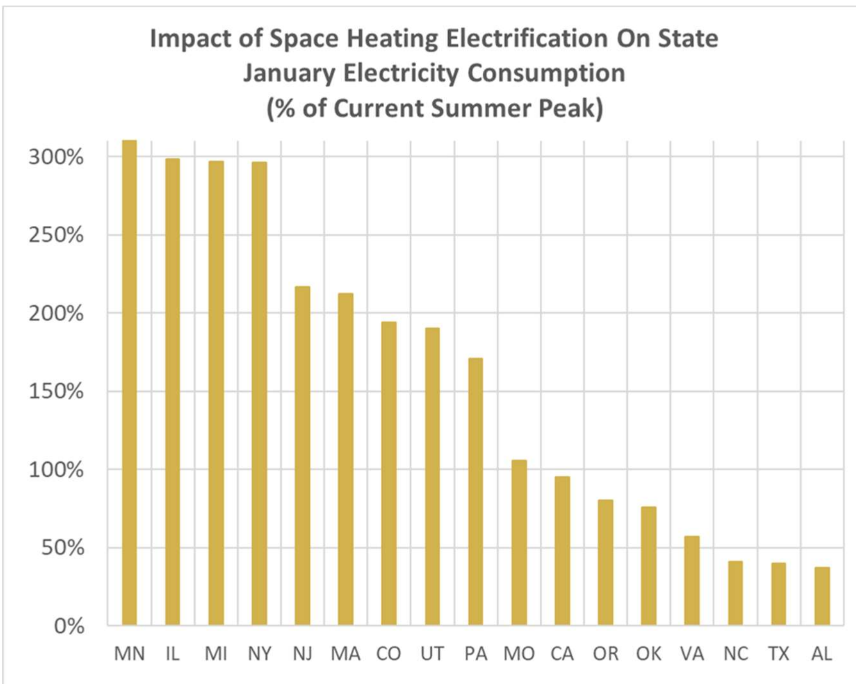


Figure 33: Impact of Electrification on Peak Winter Demand (Source: GTI)

The current ability of gaseous energy delivery systems to successfully meet severe peak winter demand is due to the combination of the major energy-carrying capacity of gas pipelines and natural gas storage. Figure 34 and Table 12 illustrate the typical rated energy delivery capacity of an interstate natural gas pipeline relative to electric transmission lines. Gas transmission pipelines have 10-50 times the energy delivery capacity of electric transmission lines.

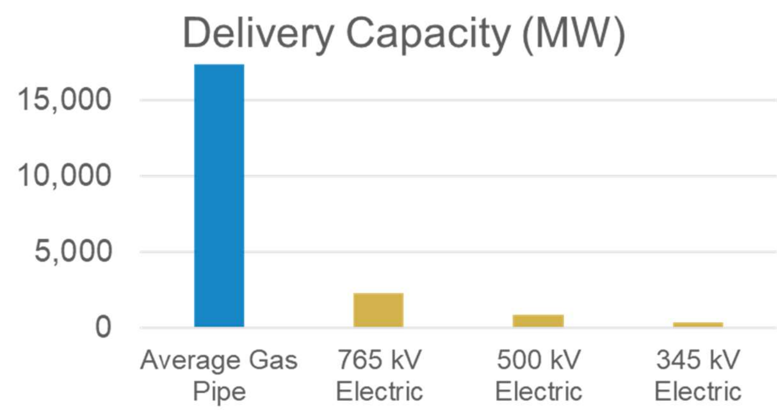


Figure 34: Major Natural Gas and Electric Transmission System Capacity (DOE, AEP)

Table 12: Major Natural Gas and Electric Transmission System Capacity (DOE, AEP)

350 US Gas Transmission Pipelines	Delivery Capacity, MW
Average Pipeline	17,386
90^{th} Percentile	~32,000
Electric Transmission Lines	**Capacity, MW**
765 kV	2,300
500 kV	900
345 kV	400

In addition to peak power generation challenges – and the lack of suitable dispatchable power generation other than natural gas combined cycle plants – substantial electric transmission and distribution system upgrades will likely be required to reliably meet high peak day/peak month electricity demand. This makes widespread full electrification of homes very problematic.

Natural Gas and Electric Energy Storage Systems

Energy storage systems are used in natural gas and electric energy delivery systems to manage peak demand periods as well as for other services. Table 13 summarizes key metrics for three main US energy storage systems: underground natural gas storage, pumped hydro energy storage, and battery energy storage (BES); the latter two are used for electric energy storage.

Natural gas underground storage systems are much larger than electric storage systems based on delivery capacity (over 20X larger) and demonstrated peak monthly energy delivery (over 100X larger). Gas underground storage and pumped hydro can provide seasonal energy storage capability (e.g., helping with winter or summer space conditioning loads); however, battery energy systems lack this capability. In terms of cycle efficiency and energy losses, natural gas underground storage systems are substantially more efficient (97-99%) than both battery electric (70-90%) or pumped hydro (60-88%) energy storage systems.

Table 13: Representative Gas and Electric Energy Storage Size and Performance Metrics (DOE-EIA, GTI)

Energy Storage System	Underground Gas Storage	Pumped Hydro	Battery Energy Storage
Nominal Capacity (GW)| (Gas: Electric Ratio)	495 (20.6:1)	23	1
Peak Monthly Energy Delivered, GWh (G:E Ratio)	331,800 (112:1)	2900	52
Peak Month Capacity Factor	23%	17%	7%
Peak Month Storage % of Monthly Total Energy Use	36%	1%	0.1%
Cycle Efficiency (Losses) (%)	98.8% (1.2%)	79% (21%)	82% (18%)

Figure 35 shows the much larger energy delivery capacity that is possible with natural gas underground storage compared to pumped hydro or BES systems. Gas storage has evolved to satisfy the sizeable winter heating loads discussed earlier. Replicating this capacity with electric energy storage systems – particularly considering the high seasonality of space heating loads – would be extraordinarily expensive and may only be technically feasible with pumped hydro systems or using gas turbines backed up with gas storage (which would negate the potential GHG benefits of electric space heating). Battery energy storage lacks the ability to seasonally store energy.

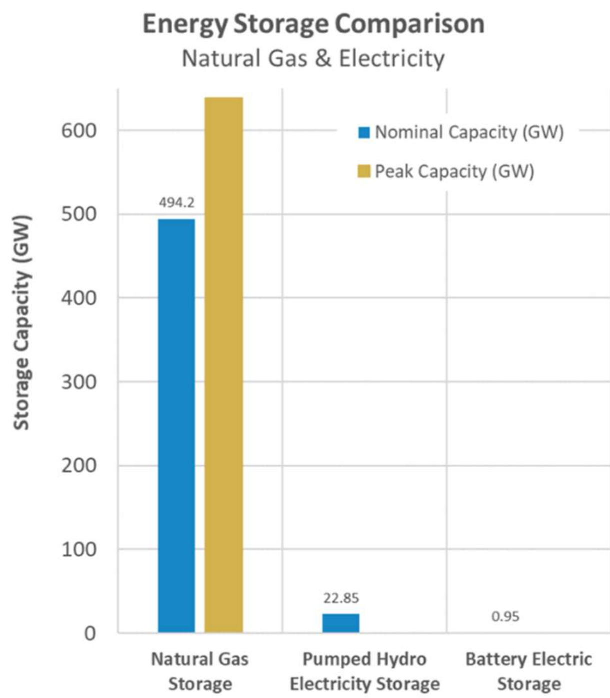


Figure 35: Nominal Energy Storage Capacity (DOE-EIA)

Figure 36 provides insights on annual energy storage system operations in the US. Large quantities of natural gas are efficiently drawn from storage as cold temperatures descend across the US. The amount of energy delivered is significantly larger than pumped hydro storage which, in turn, is currently about ten times larger than battery energy storage in the US.

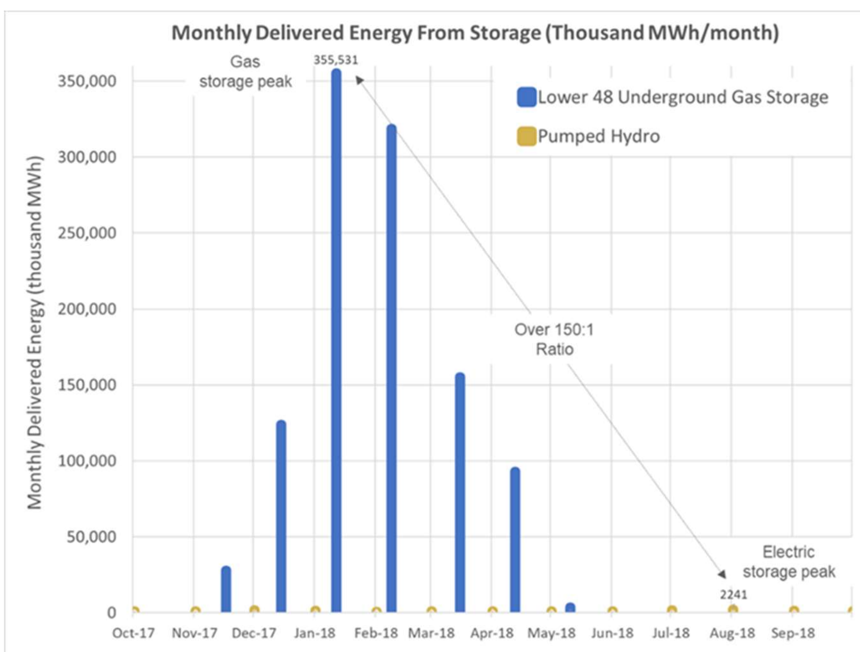


Figure 36: Example Monthly Energy Delivery for Storage (DOE-EIA)

Figure 37 shows the differences in energy storage cycle losses. Underground gas storage is very efficient, with only 1-3% round-trip cycle losses. In comparison, real-world DOE-EIA data show battery energy storage systems have losses of about 18% and pumped hydro cycle losses are slightly higher (20%). In other words, only about 80% of the energy stored in a battery can be recovered and only about 80% of the energy stored in pumped hydro. Energy losses from electric storage systems raise electricity costs and necessitate even larger investments in generating capacity to compensate for storage losses.

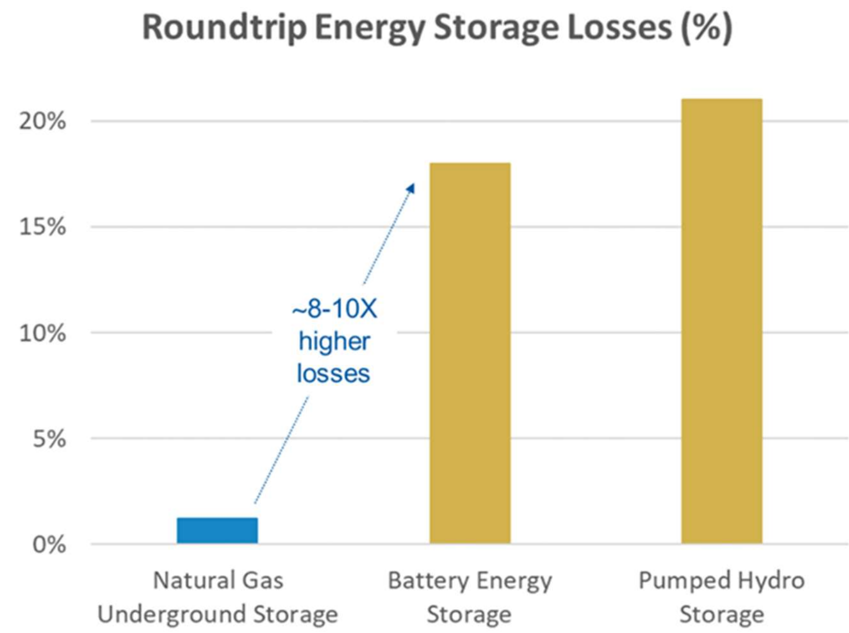


Figure 37: Energy Storage Cycle Energy Losses (DOE-EIA, GTI)

Battery energy storage lacks the seasonal storage capability needed for winter electric space heating. Figure 38 supports this, showing monthly capacity factors for these three forms of energy storage. Natural gas storage has demonstrated high seasonal storage capabilities as does pumped hydro to a lesser extent (typically used for summer space cooling loads). Battery energy storage however has no demonstrated seasonal differences in capacity factor. In addition, battery energy storage has much lower capacity factors – which has cost-effectiveness implications.

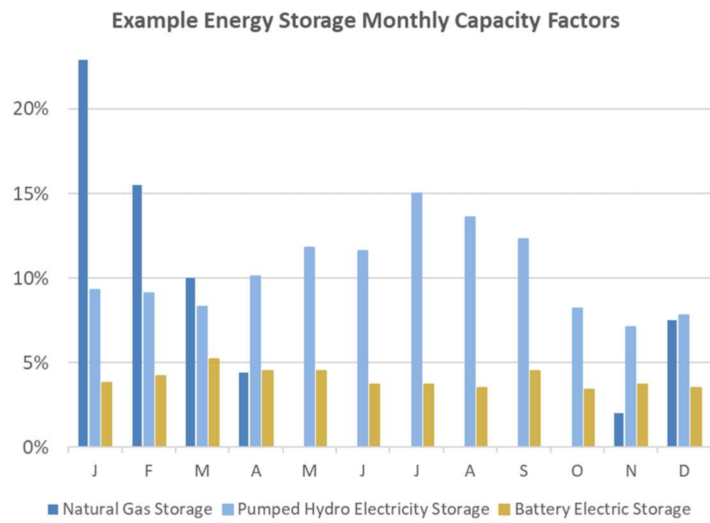


Figure 38: Example Energy Storage System Capacity Factors (DOE-EIA)

Figure 39 provides an additional technical basis for the challenges with electric energy storage in meeting long-duration winter space heating peak electricity demands. Only pumped hydro systems come close to having the system scale and operating attributes (e.g., discharge time) that are congruent with space heating loads. While larger battery energy storage systems are being deployed, they remain relatively small compared to pumped hydro and completely lack the fundamental capability of extended duration (e.g., weeks, months) discharge times.

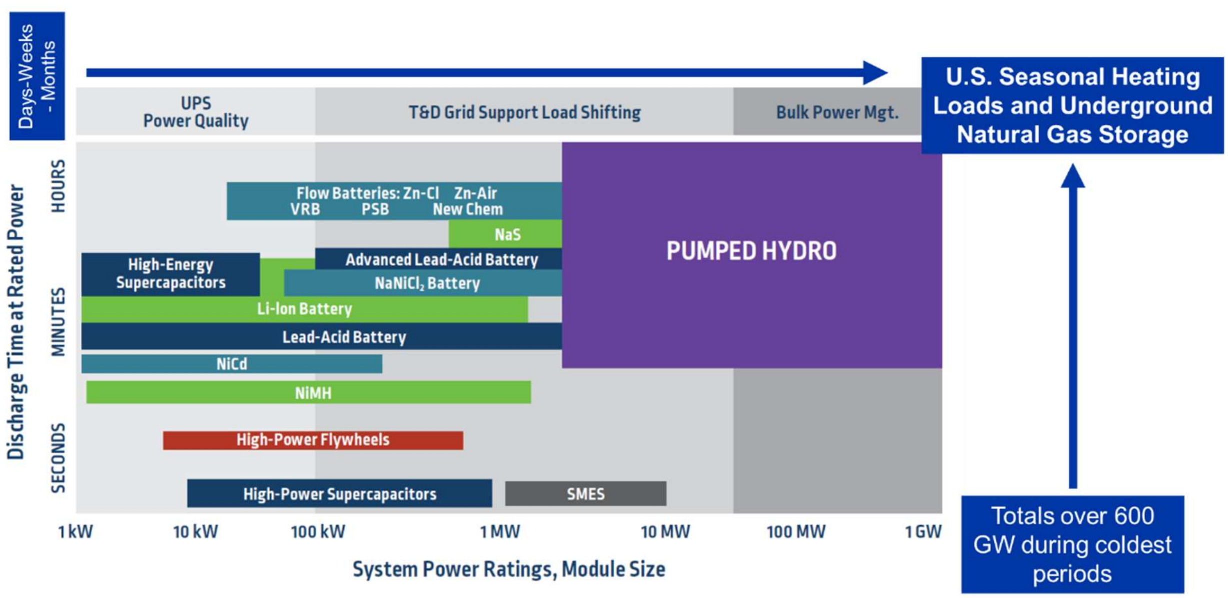


Figure 39: Size and Duration of Energy Storage Systems
(adapted from National Hydropower Association report)

Main Finding: Electric energy storage options have higher cycle losses than natural gas systems and battery energy storage systems lack the seasonal capability needed to meet the prospective winter electric peaks stemming from large-scale residential electrification. Pumped hydro storage has some seasonal capabilities but at a much smaller scale than seen with natural gas storage and with higher cycle losses; however, pumped hydro is likely not topographically practical for Washington.

Home Energy Supply Reliability and Resilience

Home energy system reliability and resilience have become increasingly important to residential homeowners, causing more consumers to install home emergency generators to ensure electricity is always available (Figure 40).

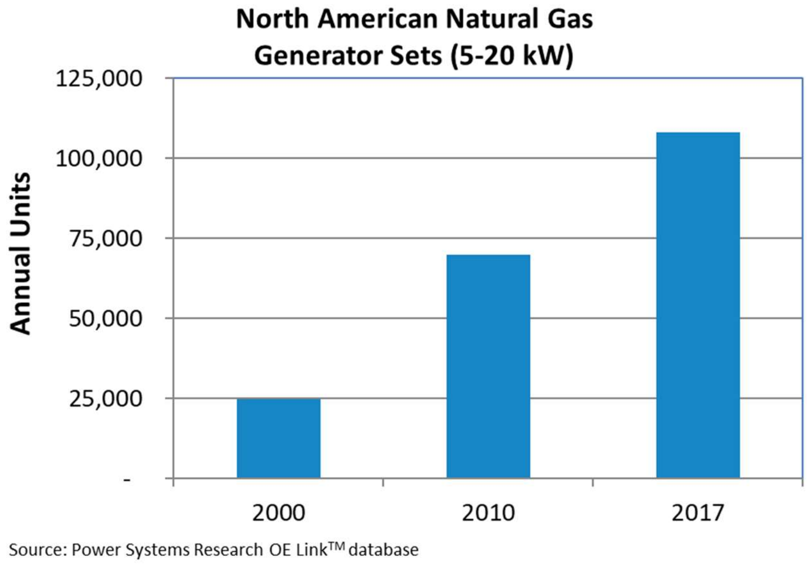


Figure 40: Trends in North American Residential Natural Gas Generators Units

Figure 41 highlights the main reasons consumers look to install equipment like natural gas home generators: (1) high electricity outage rates and (2) concomitant lower levels of reliability (when compared to natural gas distribution service). Installing a natural gas generator in homes and businesses provides energy security since natural gas distribution service is highly robust even during extreme weather events (e.g., tornados, flooding, etc). The extreme notion of removing natural gas service to homes and businesses not only substantially increases their annual energy bills, it also would remove a key solution consumers use to ensure their home's energy supply reliability and resilience (Figure 42). These data are comparable to the following IEEE 1366 Guide for Electric Power Distribution Reliability metrics: (1) System Average Interruption Frequency Index (SAIFI, left) and (2) Average Service Availability Index (ASAI, right).

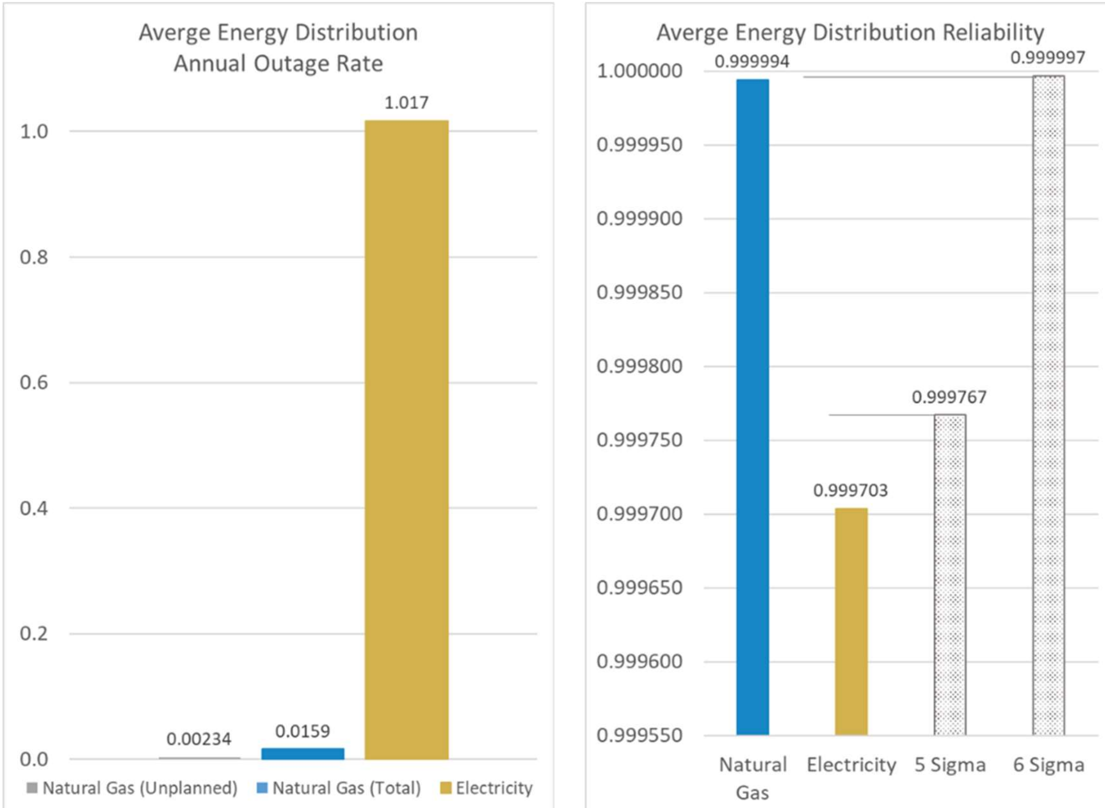


Figure 41: Natural Gas and Electric Distribution Outage Rates and Service Reliability

Figure 42: Example Residential and Commercial/Industrial Natural Gas Generator Sets

Washington Home GHG Reduction Recommendations

The following is a strategic framework for achieving feasible and cost-effective GHG reductions in Washington natural gas homes over the next two decades, predicated on the perspective that:

- Natural gas is an important, cost-effective, reliable, and abundant natural resource that provides tremendous value to consumers and the nation as a whole
- Two energy delivery systems – natural gas and electricity – provide an optimized approach to energy delivery and reliability
- Home gas and electric equipment can be complementary – within a smart energy system – to allow energy consumers, energy utility operators, and other stakeholders the option to choose gas or electricity to optimize cost, energy system reliability, and GHG reductions
- Pipeline energy delivery systems are important to society as reliable and resilient supply sources capable of delivering large quantities of energy to homes and businesses – especially during cold weather
- Long-term renewable gas (e.g., methane or hydrogen) can support a transition to lower GHG emissions by leveraging society's cumulative investment in gaseous pipeline and energy storage assets
- GHG reductions are appropriate to reduce the potential future threats of climate change. Selecting the most feasible and cost-effective approaches should be based on objective economic analyses and metrics such as $/metric ton of GHG reduction
- More information and progress in energy and environmental innovation will evolve over the next 10 to 20 years that help inform and guide GHG reduction policy dialogue and direction

Recommended steps and measures for Washington natural gas home GHG reductions:

1. Create a core focus on energy efficiency improvements
2. Emphasize building envelope efficiency improvements that help consumers – particularly for those people with older homes and lower incomes – reduce their annual energy costs, improve indoor comfort, reduce natural gas and electric energy consumption (including peak energy demand), and minimize GHG emissions
3. Support incentives for high-efficiency natural gas equipment (e.g., 95-98% efficient gas furnaces and water heaters) in addition to support for RD&D and market transformation resources for next-generation natural gas heat pumps (130%+ efficiency) for space and water heating
4. Support the expanded use of renewable natural gas (RNG) and related pathways for producing and using low-carbon sources of methane or hydrogen (including power-to-gas) to lower the carbon intensity of gaseous energy
5. Expand the use of hybrid space conditioning systems integrating a natural gas furnace (or boiler) with an electric heat pump (i.e., an upgrade to a conventional air conditioning system) in combination with smart controls at the home and utility level to optimize cost, capacity, energy delivery system investment and asset utilization, and GHG reductions. This approach provides high optionality value and avoids a series of pernicious issues with operating electric heat pumps at colder temperatures (e.g., reduced efficiency, high electricity peak demand, high marginal peak power GHG emission rates for seasonal demand)

Summary and Conclusions

There is an active dialogue on policy considerations pertaining to future pathways for reducing GHG emissions. This report focuses on energy use and future GHG reduction pathways for the Washington residential sector, with quantitative and qualitative information on consumer costs and environmental benefits. The study also presents information on real-world challenges as well as potential unintended or unanticipated consequences of residential electrification.

The following is a summary of key findings, conclusions, and recommendations:

- **The ratio of residential electricity and natural gas prices has grown over the past 15 years.** In 2020, Washington homeowner electricity prices were over 2.7 times higher than natural gas on an energy-equivalent basis.
- Consumer surveys across the US provide evidence that most homeowners prefer natural gas over electricity, particularly for space heating, water heating, and cooking.
- **Residential electrification results in significant increases in annual energy bills for Washington homeowners.** Mid-case electric heat pump (HSPF 9) results in a 41% increase in annual consumer energy costs, about $338 million annual increase, for all homes now using natural gas in Washington.
- Figure 43 shows annual energy costs and capital cost comparisons for a typical 1,476 ft^2 home in Washington between gas and electric. With electrification, energy bills would go up over 72% for a typical single-family home.

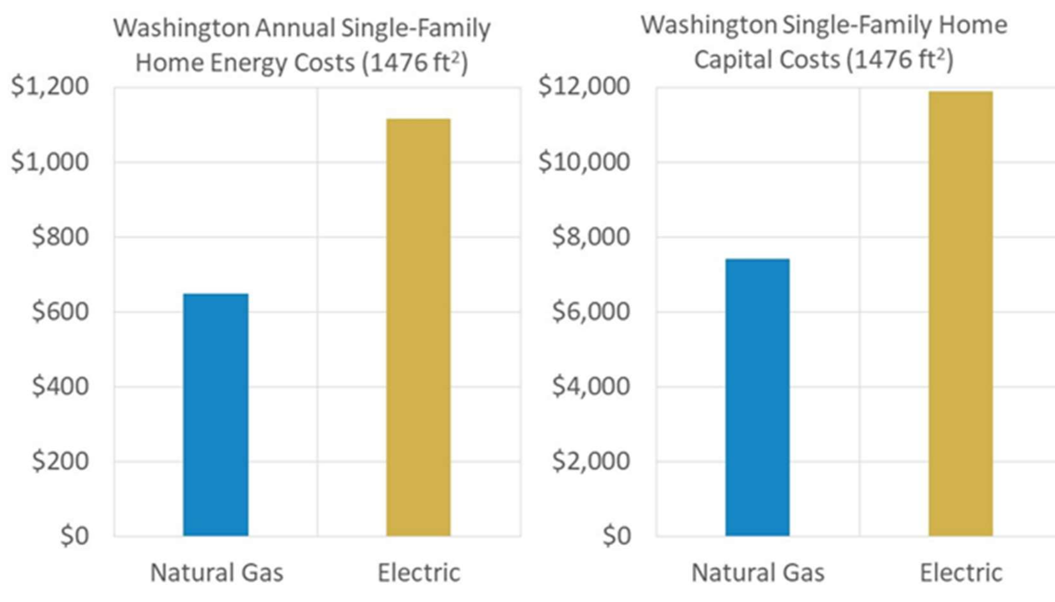


Figure 43: Annual Energy Costs and Lifecycle Costs for Typical 1,476 ft^2 Single-Family Home in Washington

- **Natural gas pathways for GHG reductions have lower consumer and societal costs when measured in $/metric ton of CO_2 reduced (**Figure 44**).** Using currently available high-efficiency gas equipment results in very cost-effective GHG reductions (-$37/metric ton of CO_2). High-efficiency furnaces with renewable natural gas can further reduce GHG emissions at a cost of $62/metric ton of CO2. Higher levels of GHG reduction are possible using gas heat pumps with RNG (64% reduction). Residential electrification with typical electric heat pumps (HSPF 9) and potential future power generation improvements have CO_2 abatement costs of \$160 to \$170/metric ton; however, when electric space heating is powered by seasonal natural gas generation the GHG abatement costs are more likely to be in the range of \$213 to \$226/metric ton.

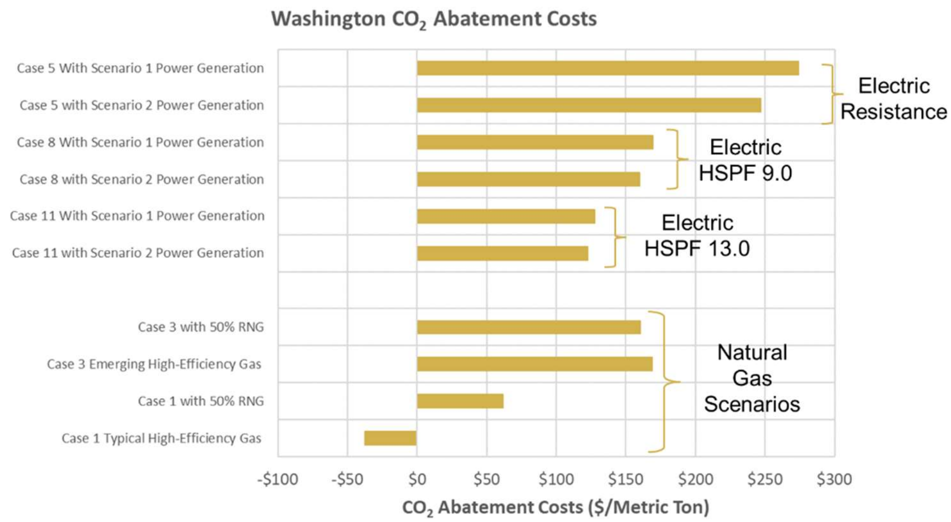


Figure 44: Comparison of CO_2 Abatement Costs (\$/metric ton)

- **The most significant issue with residential electrification scenarios is the intense seasonal energy demand for space heating**. Report data highlight the increase in peak winter electricity use that would occur in the Washington residential sector with widespread electrification. The challenges with cold-weather space heating are often oversimplified or underestimated in public policy electrification discussions. The potential power generation and electric infrastructure cost and reliability implications for consumers and society are significant.
- Using the matching principle and reasonable options at this time, **most new winter peak electricity demand that arises from electric space heating will be met with dispatchable natural gas generation**. Without GHG mitigation for this scenario, potential GHG reductions from electric space heating will be much less than anticipated.
- **There is no evidence wind or solar resources can address prospective seasonal energy-intensive space heating electricity peaks during Washington winters**. Solar PV systems have a significant drop in winter output.
- There is no evidence battery energy storage can play a value-added role in meeting high winter electricity demands and pumped hydro is not a practicable option for Washington.
- Hybrid space heating systems that optimize the use electric heat pumps at milder temperatures and natural gas heating systems at cold temperatures avoids a host of issues associated with cold climate electric heat pump operation.
- Natural gas distribution systems have quantifiably higher service reliability and lower outage rates than electric distribution systems, leading more homes to install natural gas generators to avoid the cost and issues associated with grid power interruptions.

Analytical Research Team and Contributors

Gas Technology Institute (GTI) is an independent, non-profit research & development organization with an 80-year history focused on developing new energy and environmental technologies and providing education and training services for the energy industry and its customers. The following biographies include GTI personnel that contributed directly and indirectly to this report and the underlying tools, data, and analysis used in compiling this publication. This includes a team of engineers, data analysts, and programmers which developed and refined GTI's publicly accessible Energy Planning and Analysis Tool (EPAT) over multiple years. These personnel are part of GTI's 40-person Building Energy Efficiency Group that is developing and validating a range of technologies and building envelope solutions aimed at reducing the energy and environmental impact of energy use in buildings.

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Mr. Liss has an over 34-year career at GTI spanning a wide-spectrum of challenges related to end-use markets (residential, commercial, industrial, onsite power, and transportation) and natural gas pipeline issues. He leads a broad-based group of over 100 energy professionals – engineers, scientists, data analysts, and technicians – focused on technology development and market adoption of new energy solutions that address important energy and environmental challenges. His career began with development of detailed benefit/cost analytical studies to support annual research & development plan submissions to the Federal Energy Regulatory Commission. He received a B.S. in Chemical Engineering from the University of Illinois at Chicago and an MBA from Keller Graduate School of Management.

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Ms. Rowley is an R&D Manager with the building energy efficiency group at GTI with over 25 years of hands-on and management experience in analytical, laboratory, and field work. Ms. Rowley's research and development experience includes expertise on technologies for commercial buildings, transportation, and distributed energy resources. Her most current work is focused on demonstration and validation of emerging technologies to improve energy efficiency, reduce costs, or enhance energy resilience for commercial facilities. Ms. Rowley has extensive experience in field demonstrations and laboratory evaluations with expertise in instrumentation, test design, and data acquisition. Ms. Rowley has developed technical and market analyses of technologies for commercial buildings and industrial applications based on analytical models and experimental data with a focus on technologies for space conditioning, water heating, and distributed power generation. She has developed modeling and spreadsheet tools to conduct technical and market assessment of natural gas and electric technologies based on full-fuel-cycle energy use, greenhouse gas emissions and life cycle costs for all sectors of the U.S. market. Ms. Rowley received a B.S. in Mechanical Engineering from Purdue University and an M.S. in Mechanical Engineering from the University of Illinois-Chicago.

Neil Leslie, P.E., Senior Institute Engineer – GTI

Mr. Leslie is the program manager and principal investigator for GTI's Carbon Management Information Center (CMIC), which provides clearinghouse information and analyses, energy and environmental analysis tools (http://seeatcalc.gastechnology.org/ and epat.gastechnology.org), and technical input to voluntary standards and regulatory initiatives developed and promulgated by other stakeholders. Mr. Leslie previously managed the residential and commercial program area at GTI that includes building energy efficiency analysis, carbon management, space conditioning, water heating, commercial food service, indoor environmental quality, combined heat and power systems, and emerging technology programs in support of industry energy efficiency programs. He has over 40 years of experience in the global energy, consulting, and manufacturing industries. In addition to his management experience, he has published technical reports, peer-reviewed papers, articles, and a book on source energy and greenhouse gas emissions measurement methods and societal benefits of direct use of natural gas and propane in buildings. He has a B.S. in Mechanical Engineering from Northwestern University and an MBA from the University of Chicago. He is a registered professional engineer in the State of Illinois and an ASHRAE life member.

Erin Bonetti, Principal Engineer – GTI

Ms. Bonetti is a Principal Engineer at GTI and focuses mainly on residential energy modeling, studying methane emissions in the commercial and residential sectors, understanding the changing energy landscape and its impact on emissions, and evaluation of emerging natural gas technologies. Prior to joining GTI, she supported technology investigations as part of Chevron's Energy Technology Company. Erin Bonetti is a licensed professional chemical engineer and received her B.S. degree at the University of California, Davis.

Jennifer Yang, Principal Engineer – GTI

Jennifer Yang is a principal engineer with the Energy Delivery & Utilization Group at Gas Technology Institute (GTI). She has focused on design and development of web tools for energy analysis: Source Energy and Emission Analysis Tool (SEATT), Energy Planning Analysis Tool (EPAT), Commercial Food Service Equipment Calculator, Total Cost of Ownership (TCO) Calculator for Natural Gas Standby Power Generation, and Pipe Insulation Energy Savings Calculator. She has been also programming on data acquisition and process controls for the research projects, and developing and maintenance of engineering analysis software. She has a M.S. degree in Chemical Engineering from Lamar University, TX, a M.S. degree in Environmental Engineering from Tsinghua University, China, and a B.S. degree in Environmental Engineering from Tsinghua University, China.

Alejandro Baez Guada, Principal Engineer – GTI

Alejandro Baez Guada is a principal engineer with the building energy efficiency group at GTI with over eight years of hands-on and modeling experience in analytical, laboratory and field work. Mr. Guada's research and development work has been focused on HVAC, water heating, micro-CHP and micro-grid equipment development and integration for space heating/cooling, water heating and on-site power management in the residential and light commercial sectors. Mr. Guada received a B.S. in Mechanical Engineering from Texas A&M University-Kingsville and a M.S. in Aerospace and Mechanical Engineering from the Illinois Institute of Technology.

References

American Electric Power, "Transmission Facts," http://web.ecs.baylor.edu/faculty/grady/_13_EE392J_2_Spring11_AEP_Transmission_Facts.pdf

American Gas Foundation/ICF, "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment," Dec. 2019, https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf

Cadmus Group, "Ductless Mini-Split Heat Pump Impact Evaluation, Dec. 2016, http://www.ripuc.ri.gov/eventsactions/docket/4755-TRM-DMSHP%20Evaluation%20Report%2012-30-2016.pdf

Department of Energy, Energy Information Administration (DOE-EIA). Residential Energy Consumption Survey, 2015 edition.

DOE-EIA, "Annual Energy Outlook 2020," https://www.eia.gov/outlooks/aeo/

DOE-EIA, Electricity Data,
https://www.eia.gov/electricity/data.php
https://www.eia.gov/electricity/data/eia860/

DOE-EIA, Natural Gas Data, https://www.eia.gov/naturalgas/data.php

DOE-EIA, Updated Buildings Sector Appliance and Equipment Costs and Efficiency, https://www.eia.gov/analysis/studies/buildings/equipcosts/

DOE, Supplemental Notice of Proposed Rulemaking (SNOPR) 2016. "Technical Support Document: Residential Furnaces," prepared for DOE by Navigant Consulting, Inc. and Lawrence Berkeley National Laboratory.

Energy Solutions Center, "Woodland, O'Brien & Scott: New Homeowner Energy Preference Survey," 2016.

Gas Technology Institute (GTI), Brio, "The Gas Heat Pump Technology and Market Roadmap*,"* October, 2019.

GTI, "Assessment of Natural Gas and Electric Distribution Service Reliability," July 2018. https://www.gti.energy/wp-content/uploads/2018/11/Assessment-of-Natural-Gas-Electric-Distribution-Service-Reliability-TopicalReport-Jul2018.pdf

GTI, "Gas and Electricity Energy Storage Systems," Nov. 2021.

GTI, Energy Planning Analysis Tool, http://epat.gastechnology.org/

GTI, "Right-Sizing Electric Heat Pump and Auxiliary Heating for Residential Heating Systems Based on Actual Performance Associated with Climate Zone," ASHRAE 2020 Winter Conference.

IEEE Standard 1316 – 2012 – IEEE Guide for Electric Power Distribution Reliability Indices, https://standards.ieee.org/findstds/standard/1366-2012.html

National Association of Home Builders/Home Innovation Research Labs, "Cost and Other Implications of Electrification Policies on Residential Construction," February, 2021 https://www.nahb.org/-/media/NAHB/nahb-community/docs/committees/construction-codes-and-standards-committee/home-innovation-electrification-report-2021.pdf?_ga=2.68390225.136981430.1620310119-27139123.1620310119

National Hydropower Association, "2018 Pumped Hydro Storage Report," https://www.hydro.org/wp-content/uploads/2018/04/2018-NHA-Pumped-Storage-Report.pdf

National Renewable Energy Laboratory (NREL), National Residential Efficiency Measures Database, https://remdb.nrel.gov/

NREL, "California Power-to-Gas and Power-to-Hydrogen Near-Term Business Case Evaluation," Dec. 2016, https://www.nrel.gov/docs/fy17osti/67384.pdf

Power Systems Research, OE Link™ Database, https://www.powersys.com/products-services/powertrain-databases/oe-link

United States Census Bureau, American Housing Survey, https://www.census.gov/programs-surveys/ahs.html

Appendix A: Energy Planning Analysis Tool (EPAT) Detailed Results

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	3.50	2.17	3.50

*Note: EIA 2019 state annual prices

Select Building Configurations

All Houses Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	Natural Gas, AFUE 98% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 459 (10^6 Therm) Installed Cost: 2,807 $/Unit + 3.86 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,588 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 400 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 56 (10^6 kWh) Gas Consumption: 156 (10^6 Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Gas Standard EF 3.84 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 27 (10^6 Therm) Installed Cost: 1,100 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

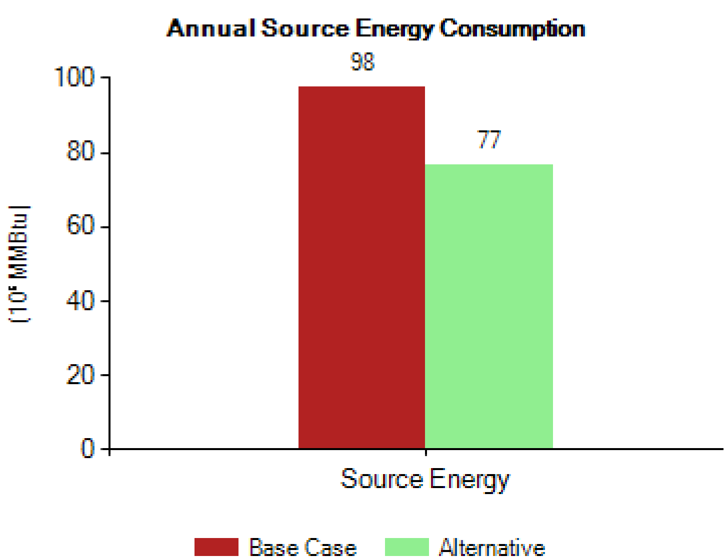
Electricity (lb/MWh)	154.9	0.050	0.380	0.514	0.0000	169.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

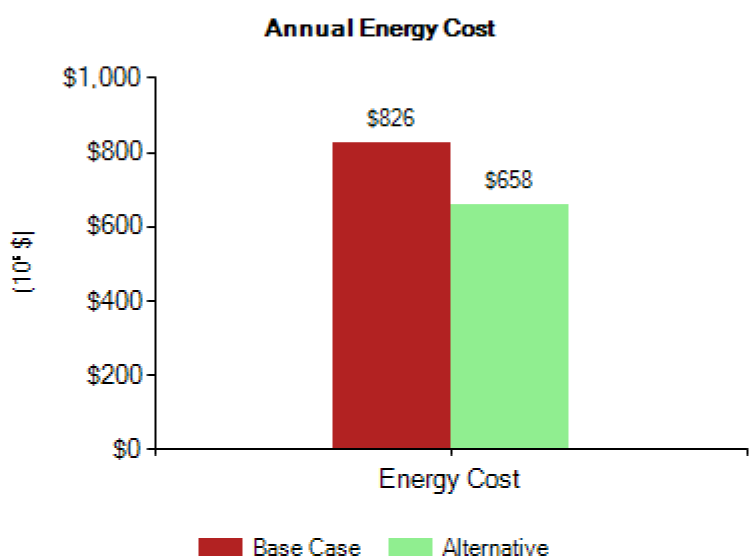
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.38 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.75	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	573 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 676 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.96 0.00 0.00 73.68 0.00 0.00 0.00 0.00 69.56	2.83 0.00 0.00 73.68 0.00 0.00 0.00 0.00 76.52	56 0 0 602 0 0 0 0 658	8,149

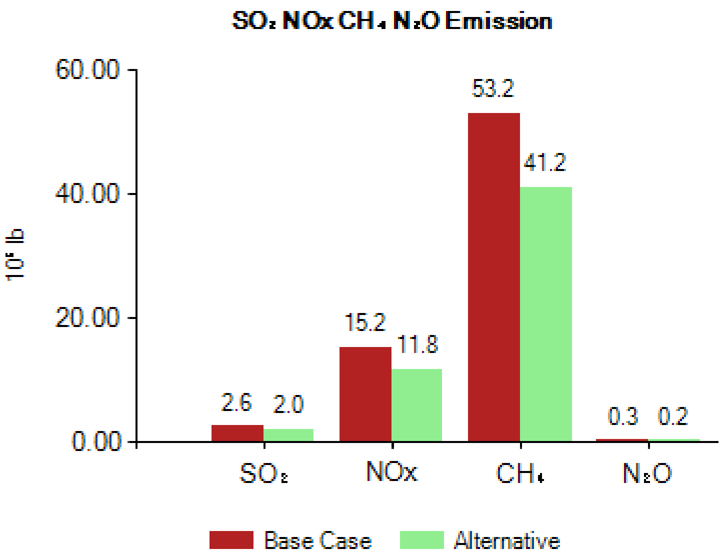
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	168	2,677	15.9

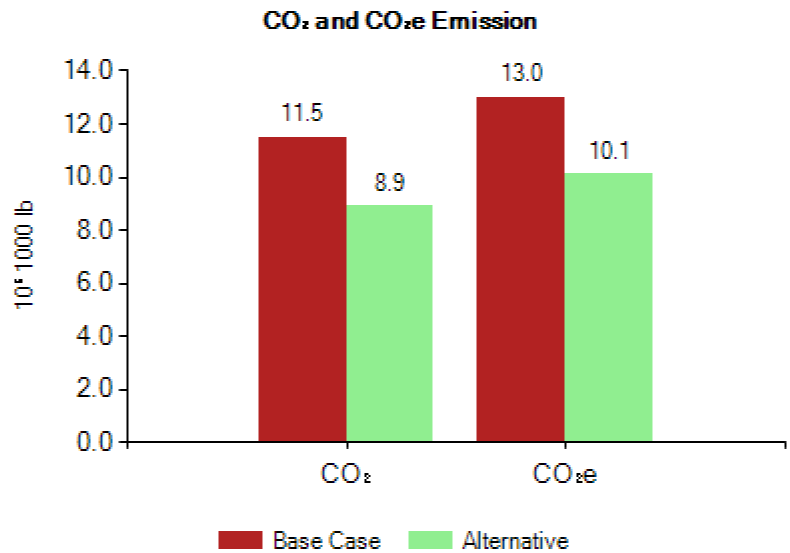




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.23	11.47	53.18	0.26	13.01
Alternative	1.99	11.84	8.89	41.19	0.20	10.09





Scenario 2

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses

Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	Natural Gas, AFUE 98% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 459 (10^6 Therm) Installed Cost: 2,807 $/Unit +3.86 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,588 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 400 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 56 (10^6 kWh) Gas Consumption: 156 (10^6 Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Gas Standard EF 3.84 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 27 (10^6 Therm) Installed Cost: 1,100 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

Electricity (lb/MWh)	154.9	0.050	0.380	0.514	0.0000	169.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
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Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

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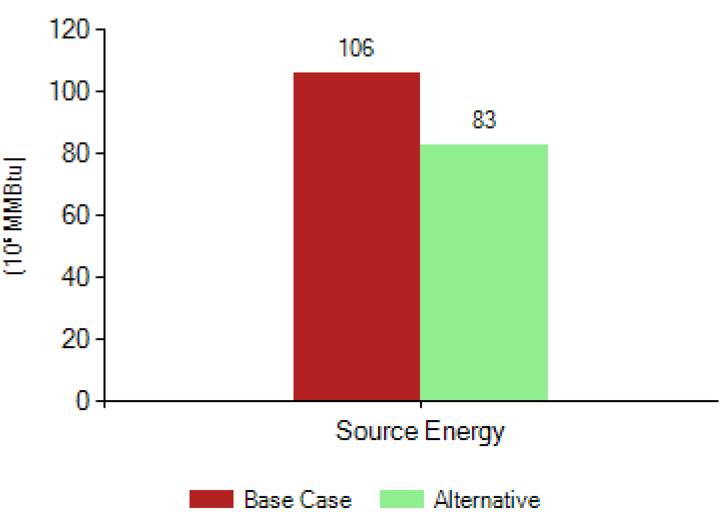
Energy Consumption and Cost

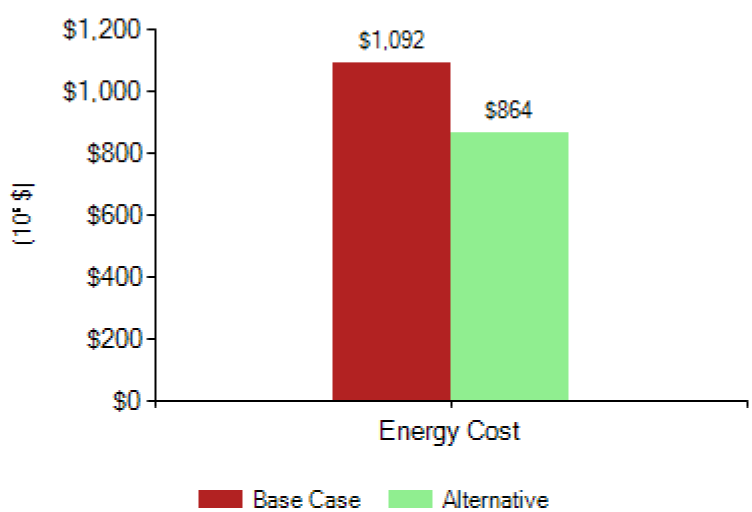
	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 438 (10^6 Therm) 0 (10^6 Therm) 438 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 43.75 0.00 43.75 0.00 0.00 89.14	2.38 0.00 0.00 47.69 0.00 56.00 0.00 0.00 106.07	47 0 0 389 0 656 0 0 1,092	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	573 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 338 (10^6 Therm) 0 (10^6 Therm) 338 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.96 0.00 0.00 36.84 0.00 36.84 0.00 0.00 69.56	2.83 0.00 0.00 36.84 0.00 36.84 0.00 0.00 82.94	56 0 0 301 0 507 0 0 864	8,149

	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	228	2,677	11.7

Annual Source Energy Consumption

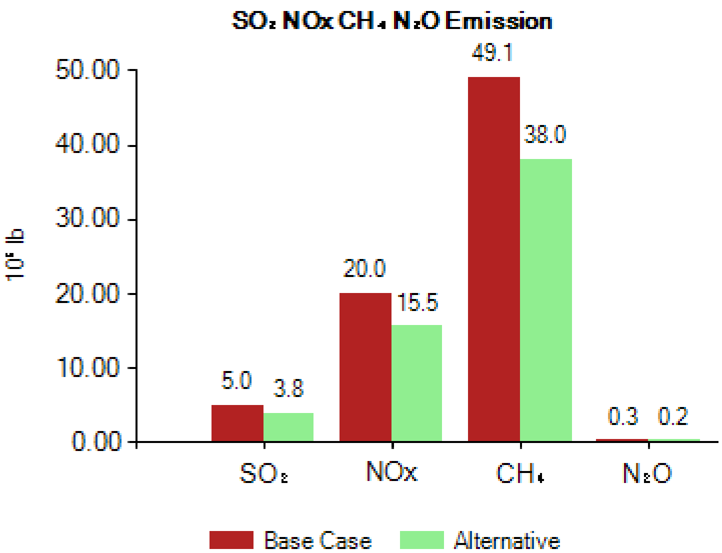


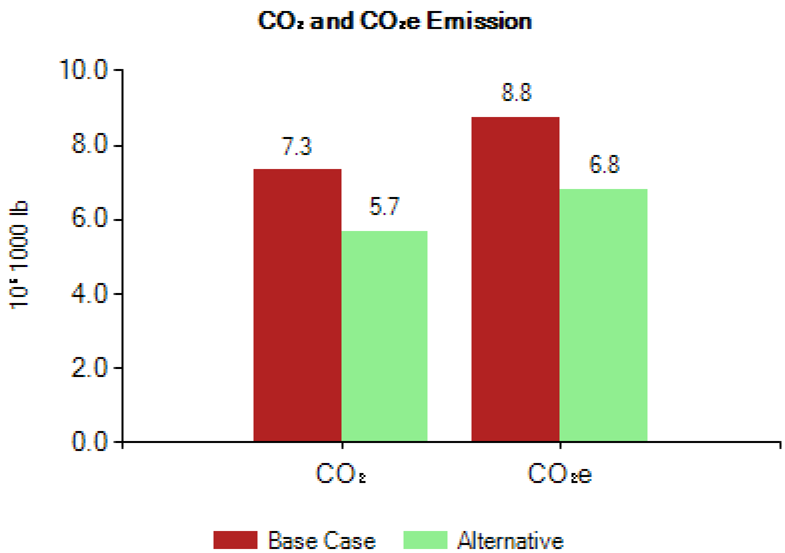
Annual Energy Cost



Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	4.97	20.00	7.31	49.07	0.26	8.75
Alternative	3.85	15.53	5.68	38.02	0.20	6.79





Scenario 3

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
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	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	3.50	2.17	3.50

*Note: EIA 2019 state annual prices

Select Building Configurations

All Houses   Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	1.4 AFUE Natural Gas Absorption Heat Pump (Prototype) Electric Consumption: 240 (10^6 kWh) Gas Consumption: 300 (10^6 Therm) Installed Cost: 5,500 $/Unit + 2,750 $/Unit Unit Capacity: 80 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,588 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal	Natural Gas EF 1.30 - Absorption Heat Pump Electric Consumption: 422 (10^6 kWh) Gas Consumption: 126 (10^6 Therm) Installed Cost: 2,250 $/Unit

		Unit Capacity: 40 Gal	Unit Capacity: 60 Gal
	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Gas Standard EF 3.84 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 27 (10^6 Therm) Installed Cost: 1,100 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

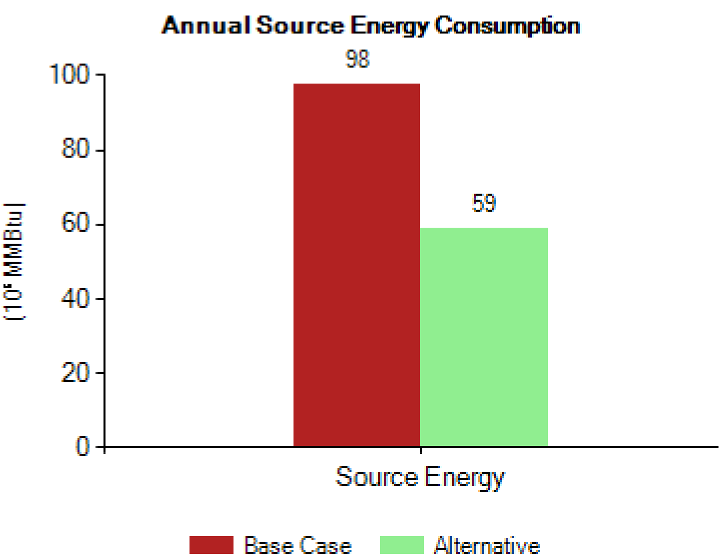
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	154.9	0.050	0.380	0.514	0.0000	169.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

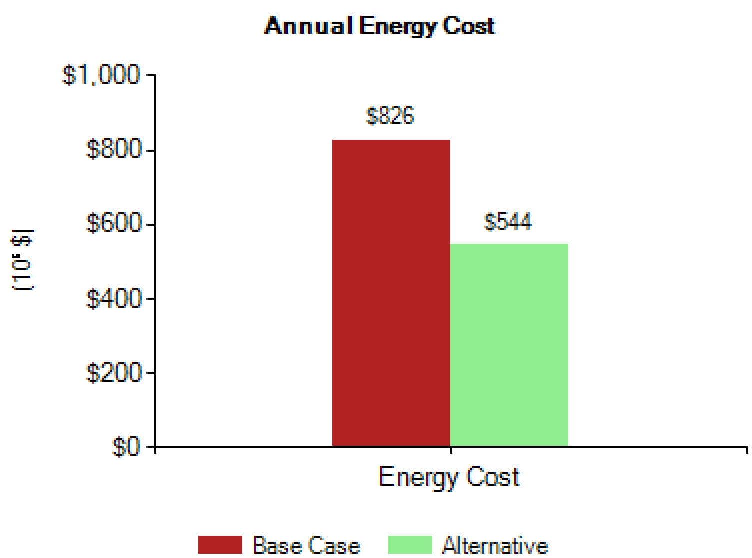
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.38 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.75	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	1,143 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 487 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	3.90 0.00 0.00 53.08 0.00 0.00 0.00 0.00 52.60	5.65 0.00 0.00 53.08 0.00 0.00 0.00 0.00 58.74	111 0 0 433 0 0 0 0 544	13,541

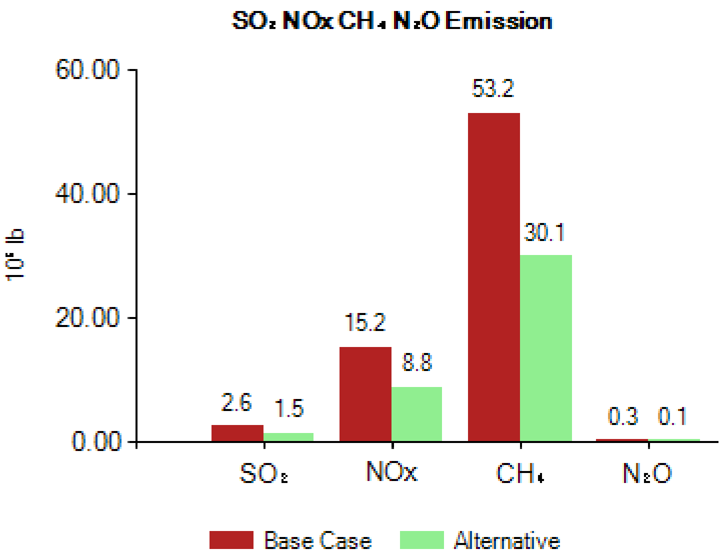
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	282	8,068	28.6

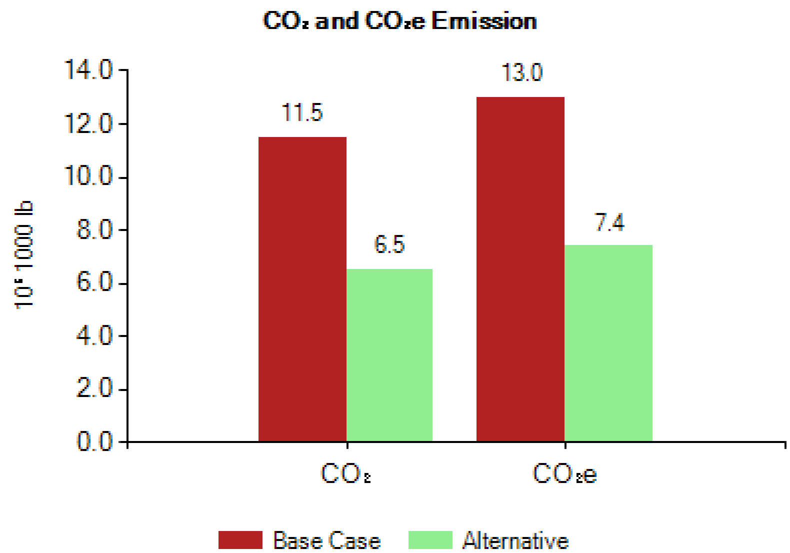




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.23	11.47	53.18	0.26	13.01
Alternative	1.47	8.81	6.52	30.05	0.15	7.39





Scenario 4

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	1.4 AFUE Natural Gas Absorption Heat Pump (Prototype) Electric Consumption: 240 (10^6 kWh) Gas Consumption: 300 (10^6 Therm) Installed Cost: 5,500 $/Unit +2,750 $/Unit Unit Capacity: 80 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,588 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal	Natural Gas EF 1.30 - Absorption Heat Pump Electric Consumption: 422 (10^6 kWh) Gas Consumption: 126 (10^6 Therm) Installed Cost: 2,250 $/Unit

		Unit Capacity: 40 Gal	Unit Capacity: 60 Gal
	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Gas Standard EF 3.84 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 27 (10^6 Therm) Installed Cost: 1,100 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

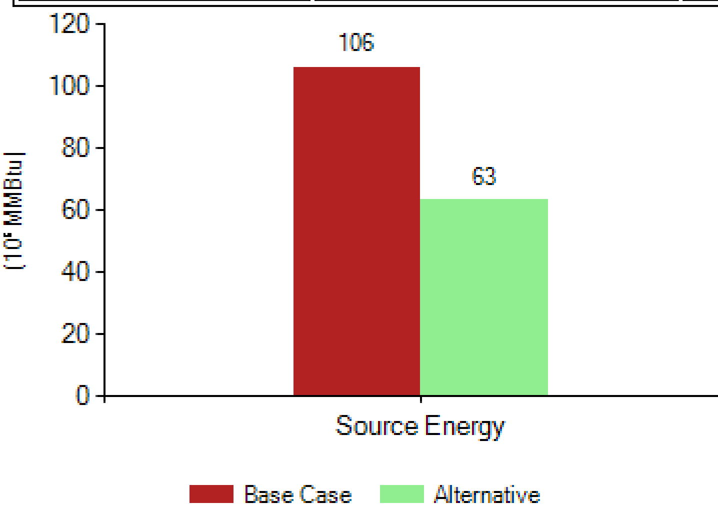
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	154.9	0.050	0.380	0.514	0.0000	169.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

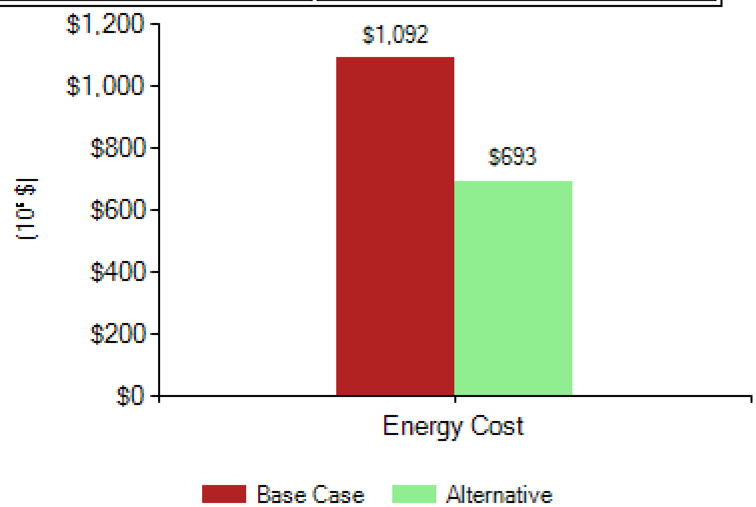
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 438 (10^6 Therm) 0 (10^6 Therm) 438 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 43.75 0.00 43.75 0.00 0.00 89.14	2.38 0.00 0.00 47.69 0.00 56.00 0.00 0.00 106.07	47 0 0 389 0 656 0 0 1,092	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	1,143 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 244 (10^6 Therm) 0 (10^6 Therm) 244 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	3.90 0.00 0.00 26.54 0.00 26.54 0.00 0.00 52.60	5.65 0.00 0.00 26.54 0.00 26.54 0.00 0.00 63.36	111 0 0 217 0 365 0 0 693	13,541

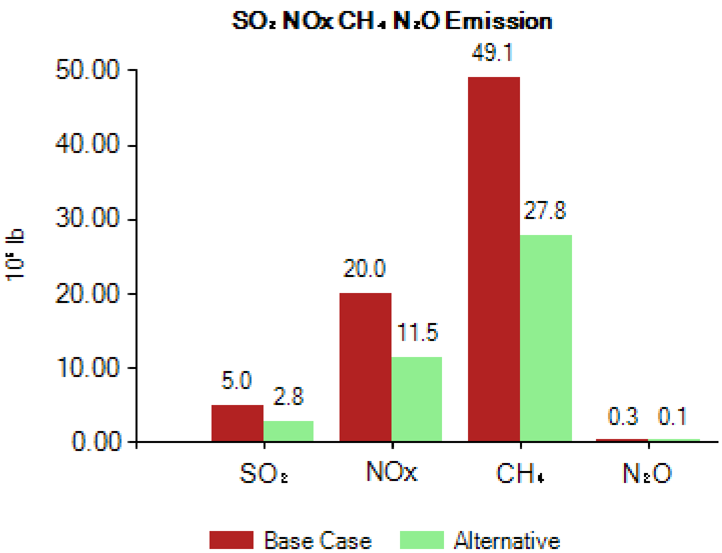
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	399	8,068	20.2

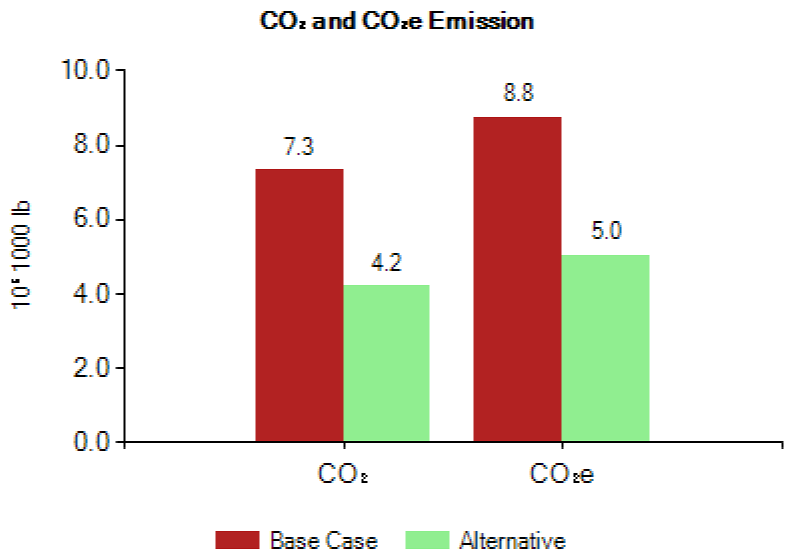




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	4.97	20.00	7.31	49.07	0.26	8.75
Alternative	2.81	11.46	4.20	27.76	0.15	5.02





CASE 5

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses

Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	Electric, Efficiency 100% Electric Consumption: 12,500 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 450 $/Unit +10.00 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,588 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 4,634 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 488 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 1,058 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 760 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.54	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO_2	SO_2	NO_x	CH_4	N_2O	CO_2e

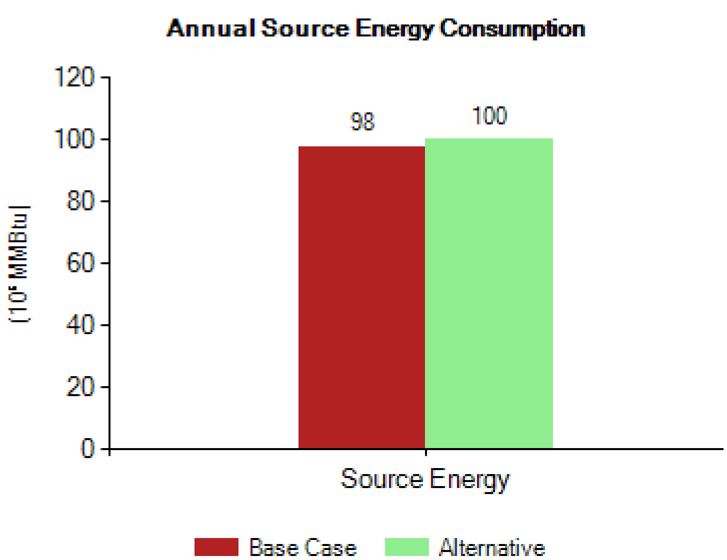
Electricity (lb/MWh)	244.6	0.400	1.590	0.605	0.0020	262.1
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

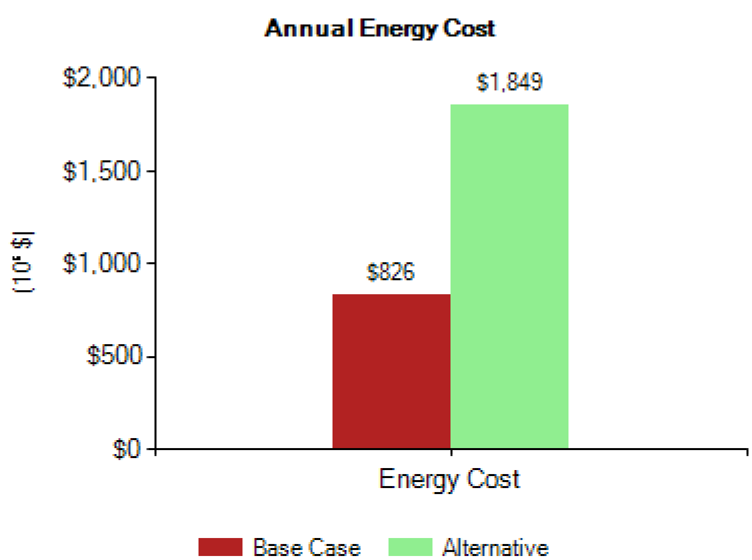
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.53 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.90	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	19,044 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	64.98 0.00 0.00 0.00 0.00 0.00 0.00 0.00 64.98	100.07 0.00 0.00 0.00 0.00 0.00 0.00 0.00 100.07	1,849 0 0 0 0 0 0 0 1,849	3,776

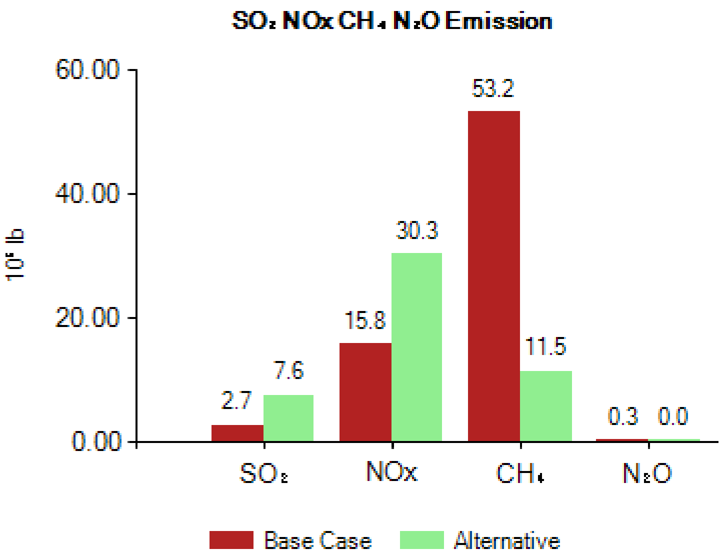
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	-1,023	-1,697	Never

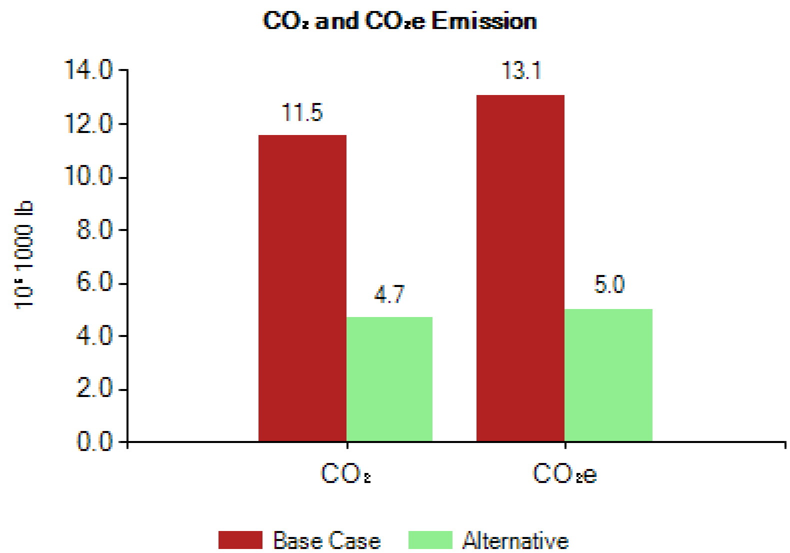




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.73	15.81	11.51	53.23	0.26	13.06
Alternative	7.62	30.28	4.66	11.52	0.04	4.99





Scenario 6

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses

Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	Electric, Efficiency 100% Electric Consumption: 12,500 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 450 $/Unit +10.00 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,588 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 4,634 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 488 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 1,058 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 760 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
x	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

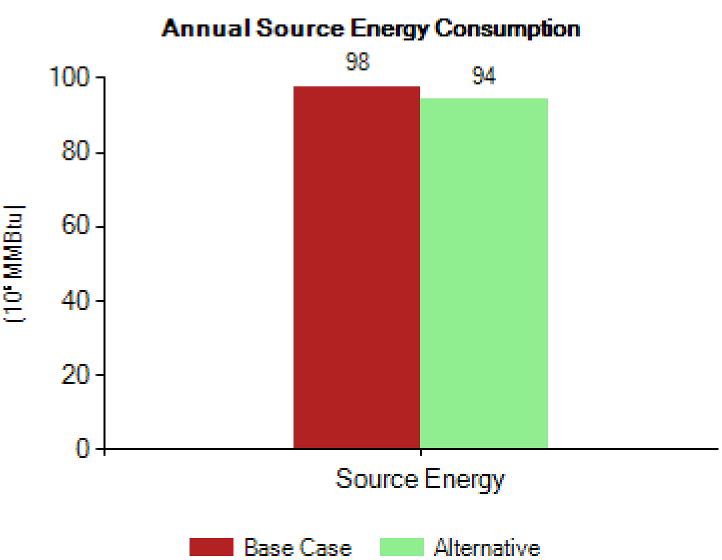
Electricity (lb/MWh)	154.9	0.050	0.380	0.514	0.0000	169.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

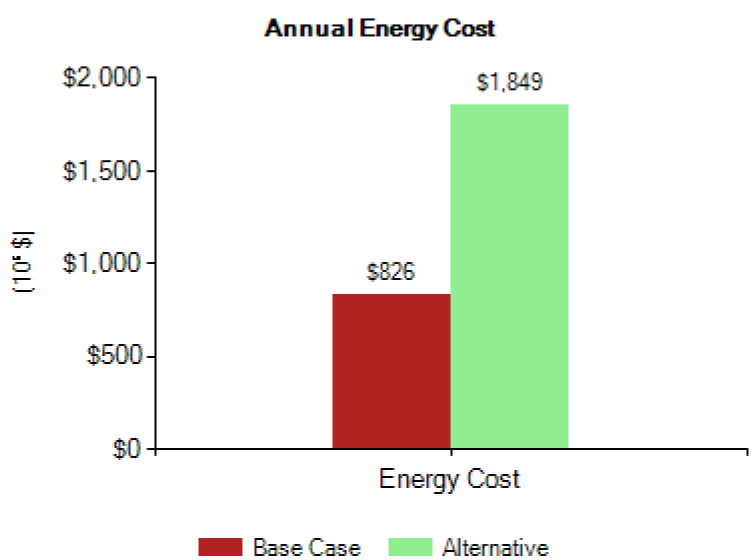
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.38 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.75	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	19,044 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	64.98 0.00 0.00 0.00 0.00 0.00 0.00 0.00 64.98	94.22 0.00 0.00 0.00 0.00 0.00 0.00 0.00 94.22	1,849 0 0 0 0 0 0 0 1,849	3,776

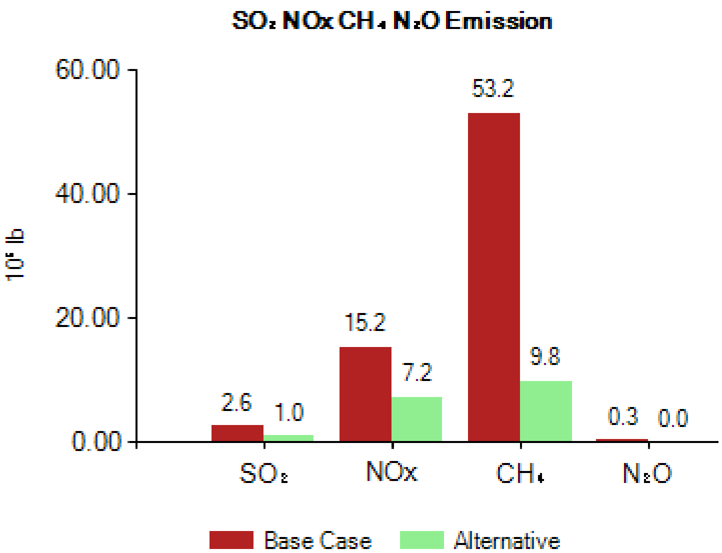
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	-1,023	-1,697	Never

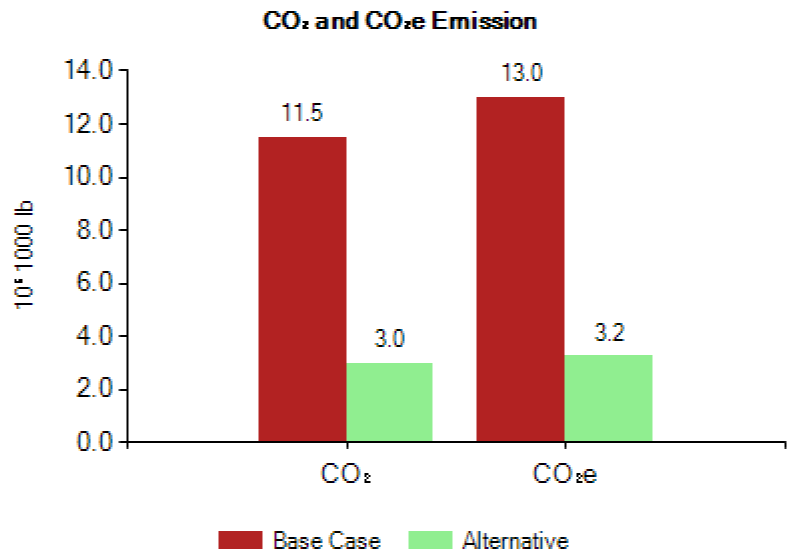




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.23	11.47	53.18	0.26	13.01
Alternative	0.95	7.24	2.95	9.79	0.00	3.23





CASE 7

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	Electric, Efficiency 100% Electric Consumption: 12,500 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 450 $/Unit +10.00 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,588 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 4,634 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 488 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 1,058 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 760 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.38	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

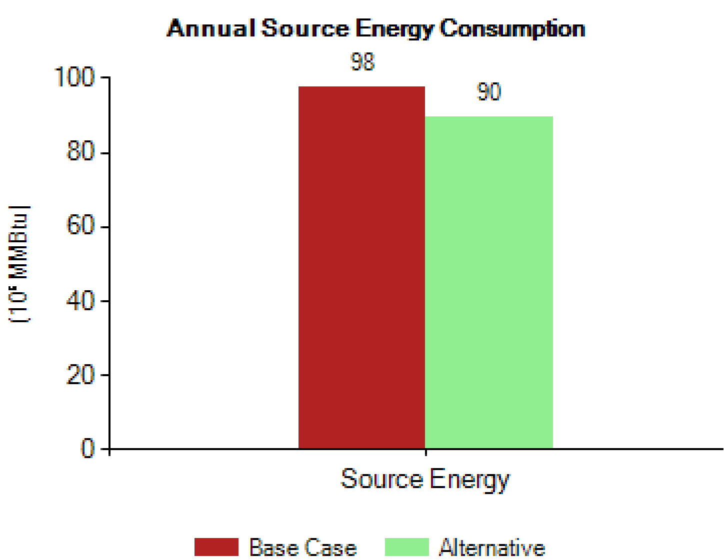
Electricity (lb/MWh)	105.7	0.040	0.260	0.349	0.0000	115.5
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

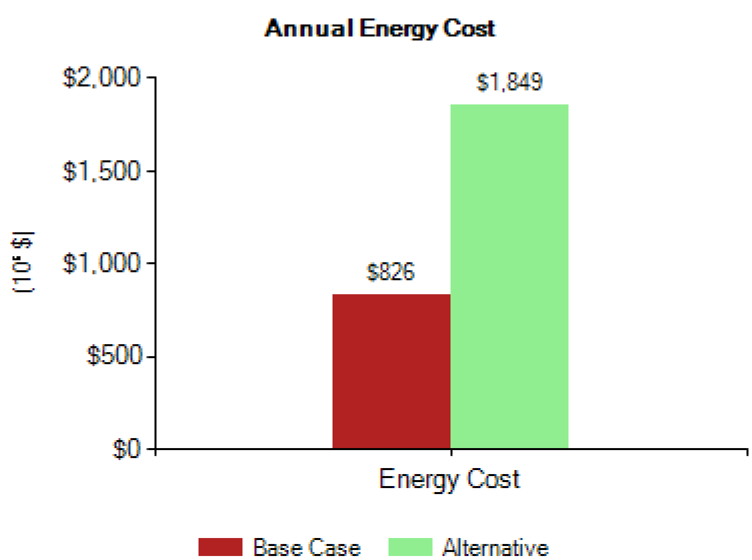
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.26 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.64	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	19,044 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	64.98 0.00 0.00 0.00 0.00 0.00 0.00 0.00 64.98	89.67 0.00 0.00 0.00 0.00 0.00 0.00 0.00 89.67	1,849 0 0 0 0 0 0 0 1,849	3,776

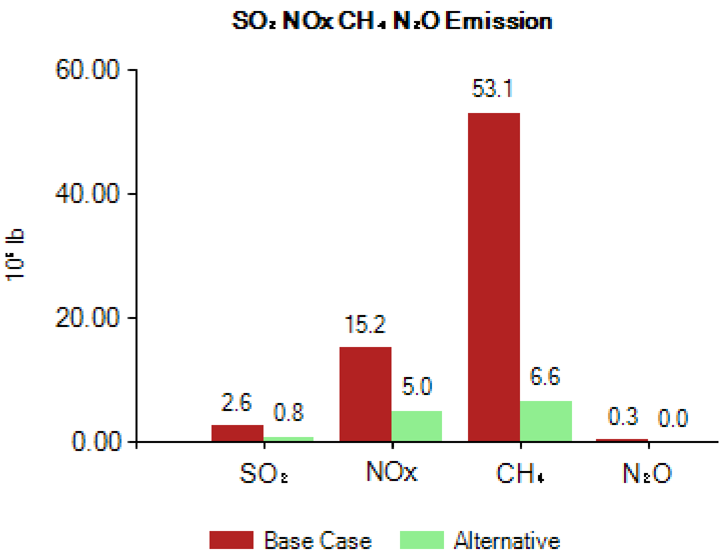
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	-1,023	-1,697	Never

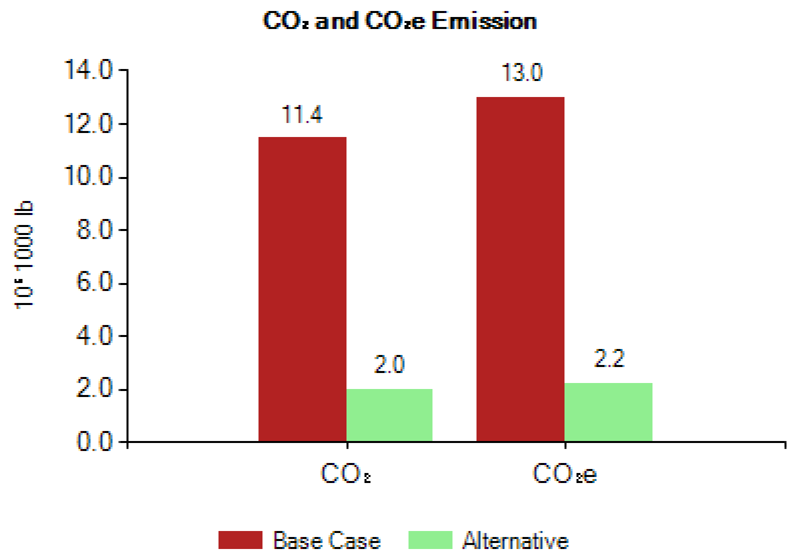




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.18	11.44	53.11	0.26	12.99
Alternative	0.76	4.95	2.01	6.65	0.00	2.20





CASE 8

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses — Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 5,445 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 3,873 $/Unit + 42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 134 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 4,634 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 488 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 1,058 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 760 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.54	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

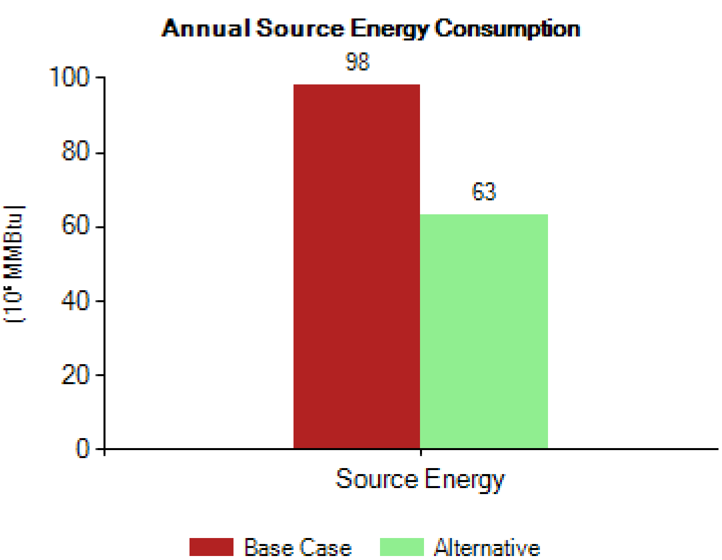
Electricity (lb/MWh)	244.6	0.400	1.590	0.605	0.0020	262.1
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

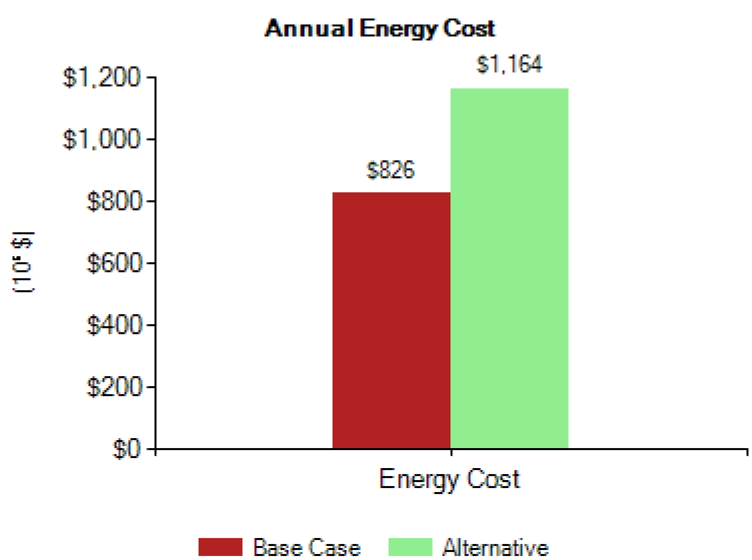
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.53 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.90	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	11,989 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	40.91 0.00 0.00 0.00 0.00 0.00 0.00 0.00 40.91	63.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 63.00	1,164 0 0 0 0 0 0 0 1,164	10,057

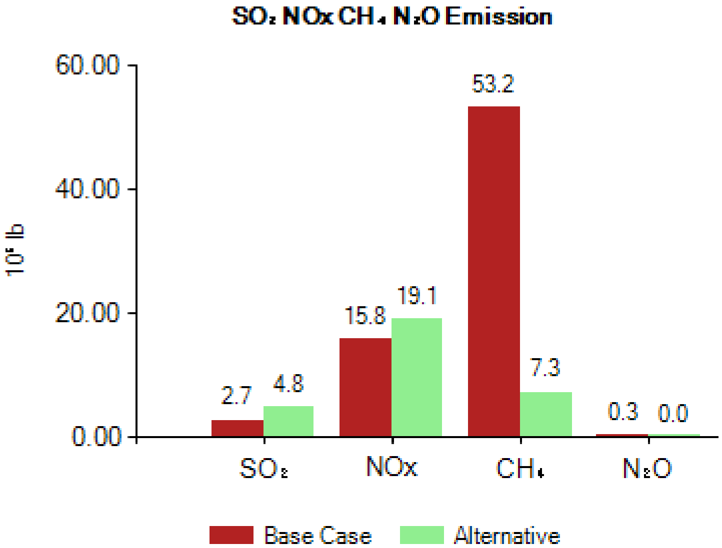
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	-338	4,585	Never

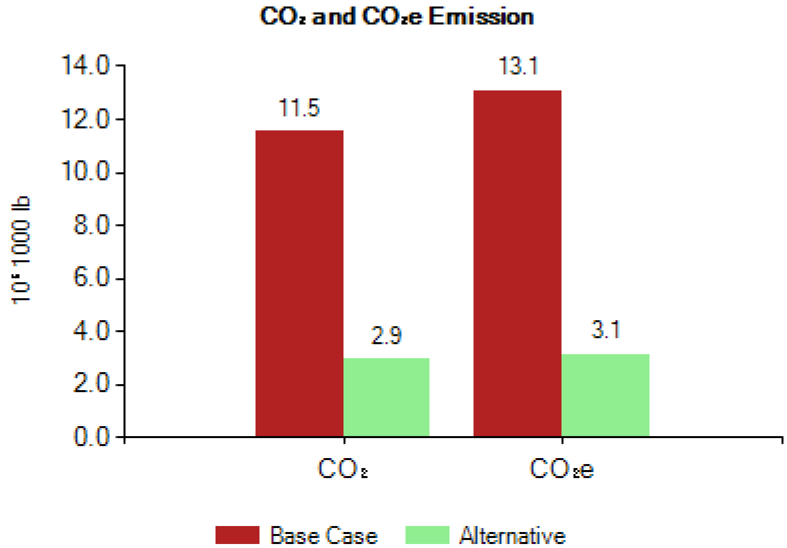




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.73	15.81	11.51	53.23	0.26	13.06
Alternative	4.80	19.06	2.93	7.25	0.02	3.14





Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 5,445 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 3,873 $/Unit +42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 134 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 0 $/Unit +0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 4,634 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 488 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 1,058 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 760 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
x	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

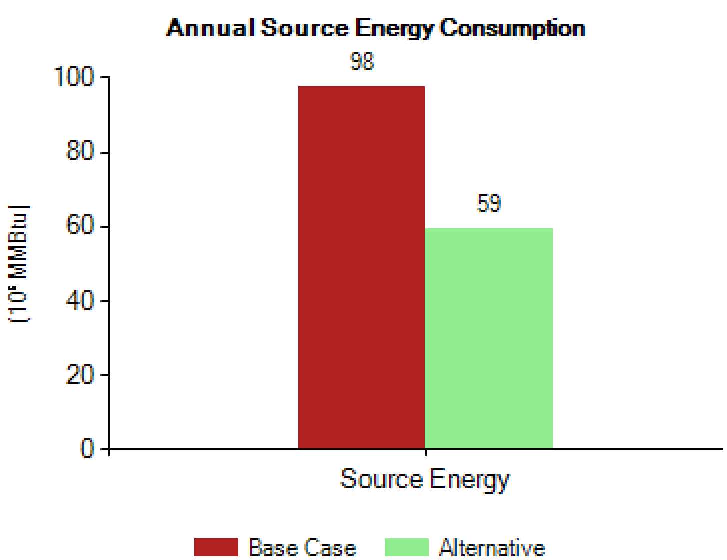
Electricity (lb/MWh)	154.9	0.050	0.380	0.514	0.0000	169.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

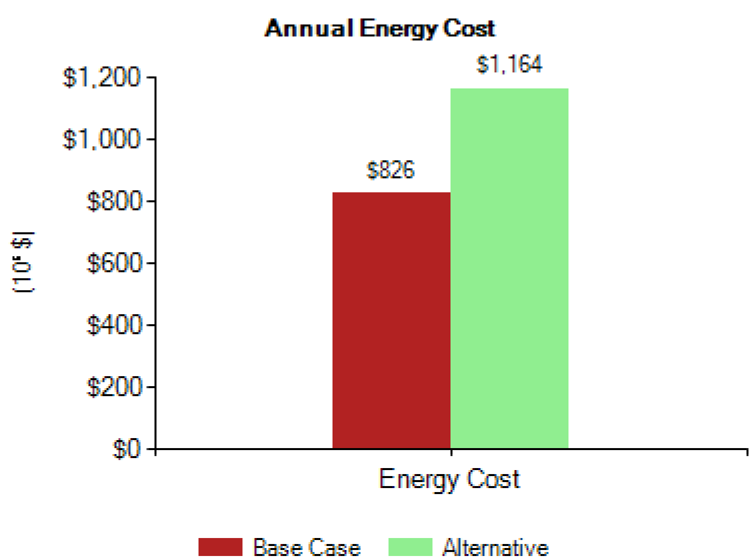
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.38 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.75	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	11,989 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	40.91 0.00 0.00 0.00 0.00 0.00 0.00 0.00 40.91	59.31 0.00 0.00 0.00 0.00 0.00 0.00 0.00 59.31	1,164 0 0 0 0 0 0 0 1,164	10,057

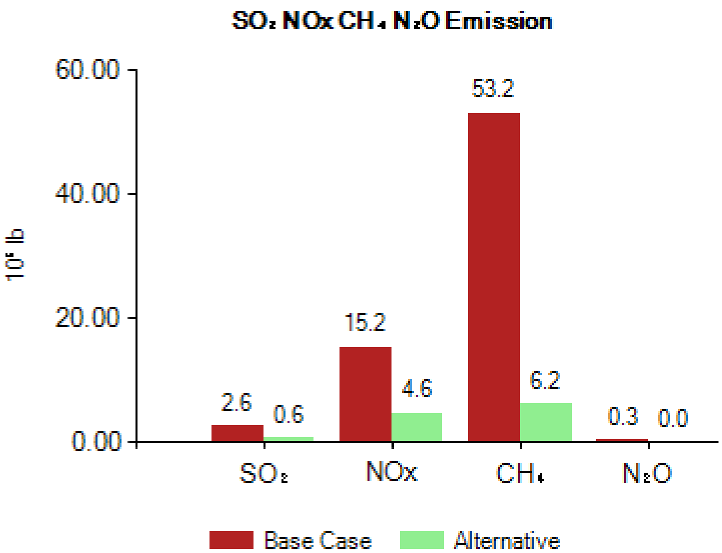
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	-338	4,585	Never

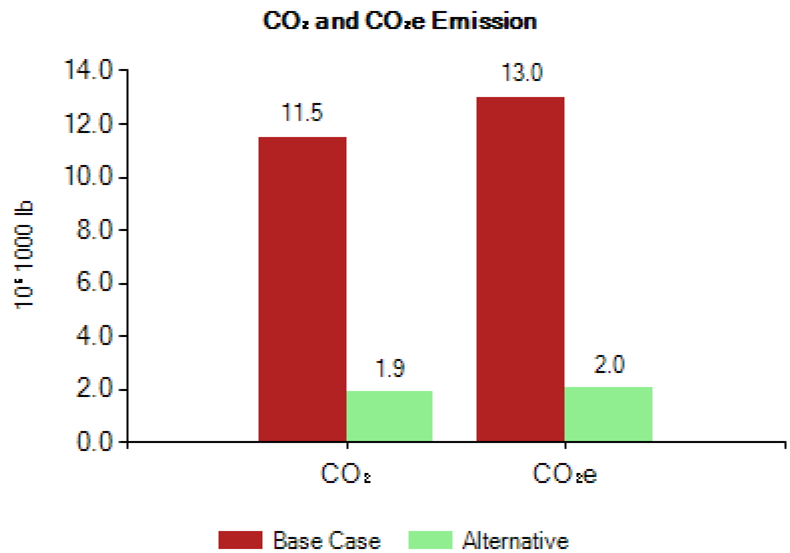




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.23	11.47	53.18	0.26	13.01
Alternative	0.60	4.56	1.86	6.16	0.00	2.03





CASE 10

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 5,445 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 3,873 $/Unit +42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 134 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 0 $/Unit +0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 4,634 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 488 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 1,058 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 760 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.38	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

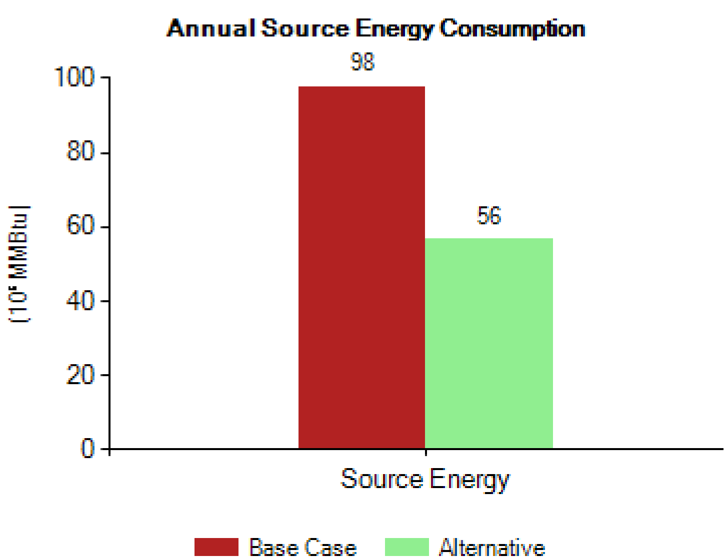
Electricity (lb/MWh)	105.7	0.040	0.260	0.349	0.0000	115.5
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

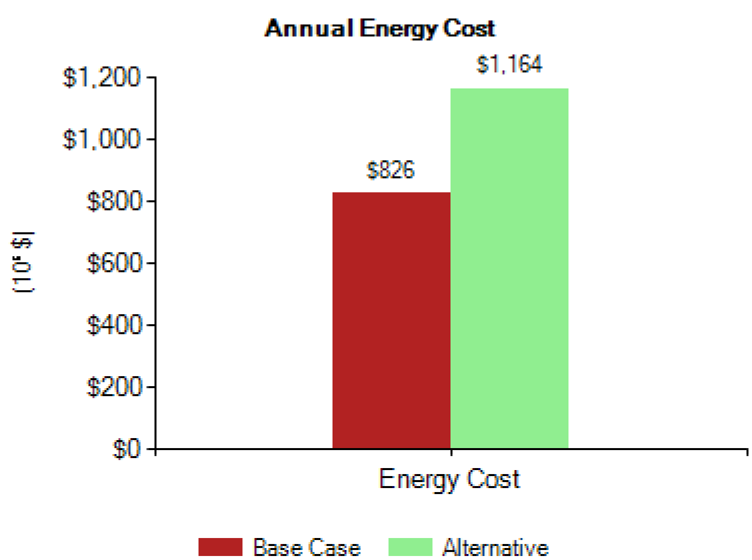
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.26 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.64	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	11,989 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	40.91 0.00 0.00 0.00 0.00 0.00 0.00 0.00 40.91	56.45 0.00 0.00 0.00 0.00 0.00 0.00 0.00 56.45	1,164 0 0 0 0 0 0 0 1,164	10,057

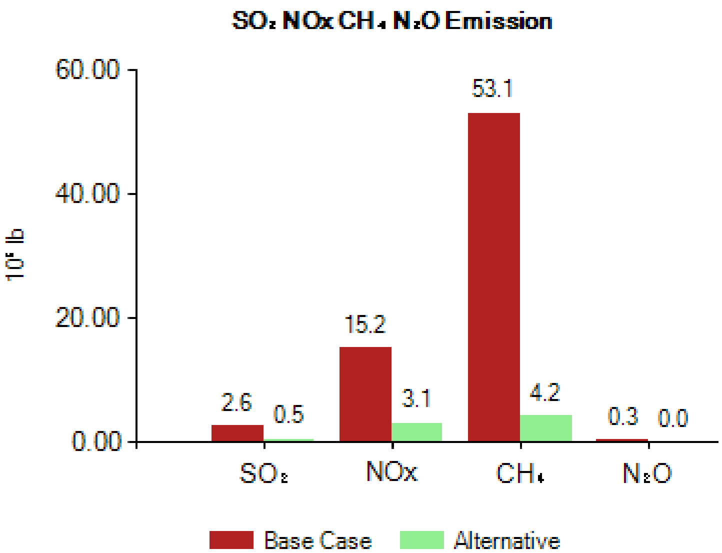
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	-338	4,585	Never

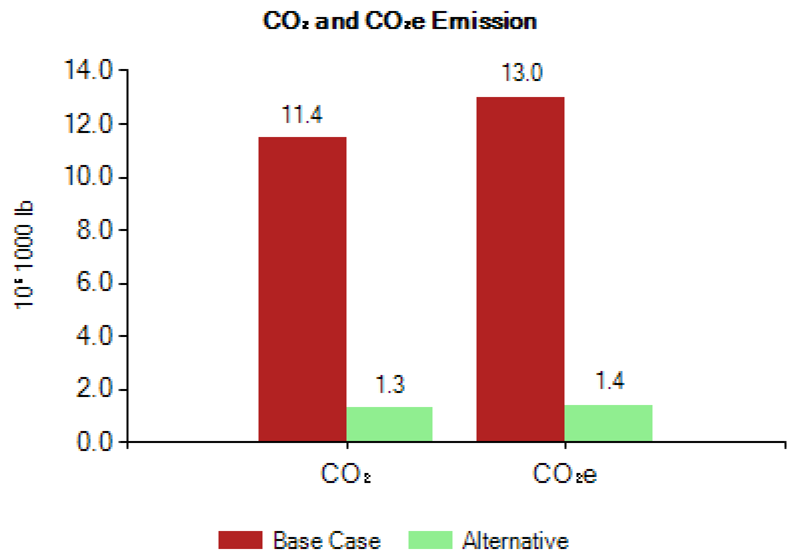




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.18	11.44	53.11	0.26	12.99
Alternative	0.48	3.12	1.27	4.18	0.00	1.38





CASE 11

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses — Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 4,331 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 4,745 $/Unit + 42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 102 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Heat Pump EF, 2.00 Electric Consumption: 2,201 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 1,900 $/Unit Unit Capacity: 50 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Induction EF 0.84 Electric Consumption: 431 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 1,879 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.93 Electric Consumption: 835 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 930 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.54	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

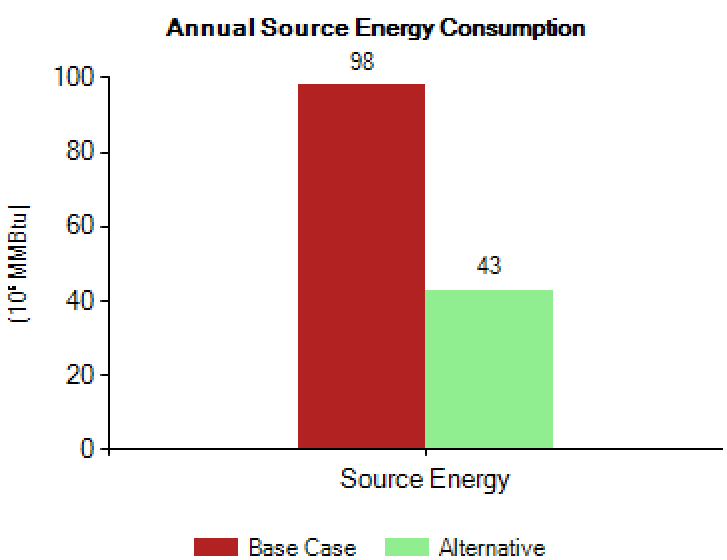
Electricity (lb/MWh)	244.6	0.400	1.590	0.605	0.0020	262.1
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

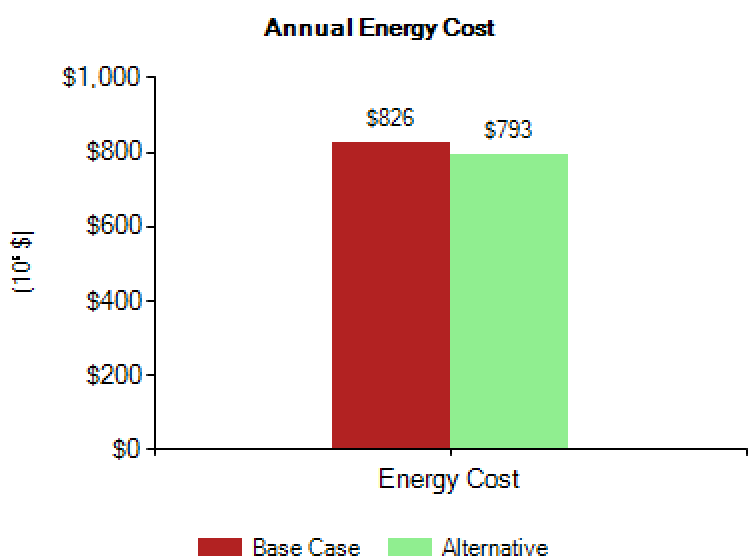
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.53 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.90	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	8,162 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	27.85 0.00 0.00 0.00 0.00 0.00 0.00 0.00 27.85	42.89 0.00 0.00 0.00 0.00 0.00 0.00 0.00 42.89	793 0 0 0 0 0 0 0 793	13,509

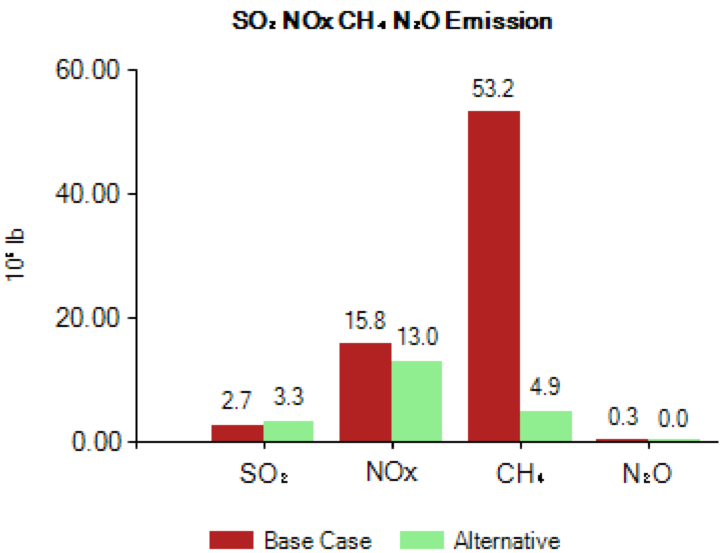
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	33	8,037	243.5

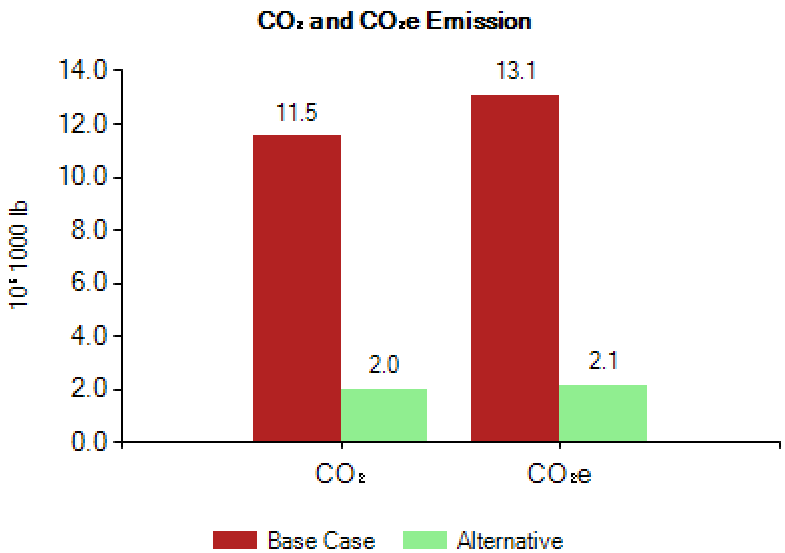




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.73	15.81	11.51	53.23	0.26	13.06
Alternative	3.26	12.98	2.00	4.94	0.02	2.14





CASE 12

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses   Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 4,331 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 4,745 $/Unit + 42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 102 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Heat Pump EF, 2.00 Electric Consumption: 2,201 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 1,900 $/Unit Unit Capacity: 50 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Induction EF 0.84 Electric Consumption: 431 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 1,879 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.93 Electric Consumption: 835 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 930 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

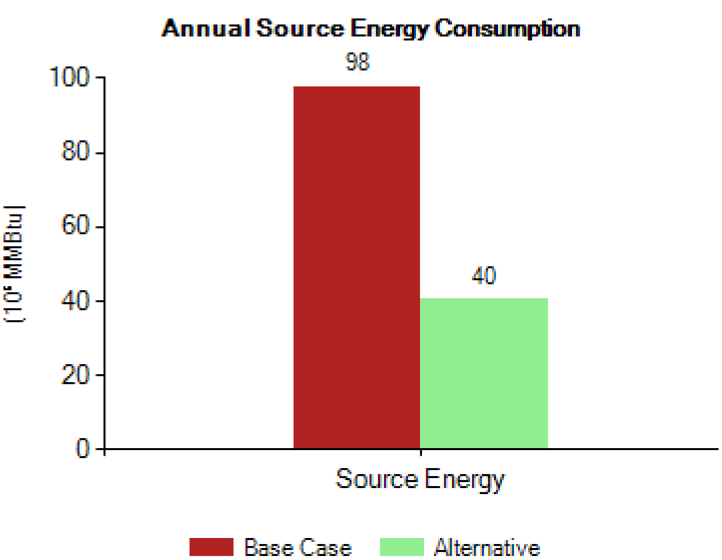
Electricity (lb/MWh)	154.9	0.050	0.380	0.514	0.0000	169.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

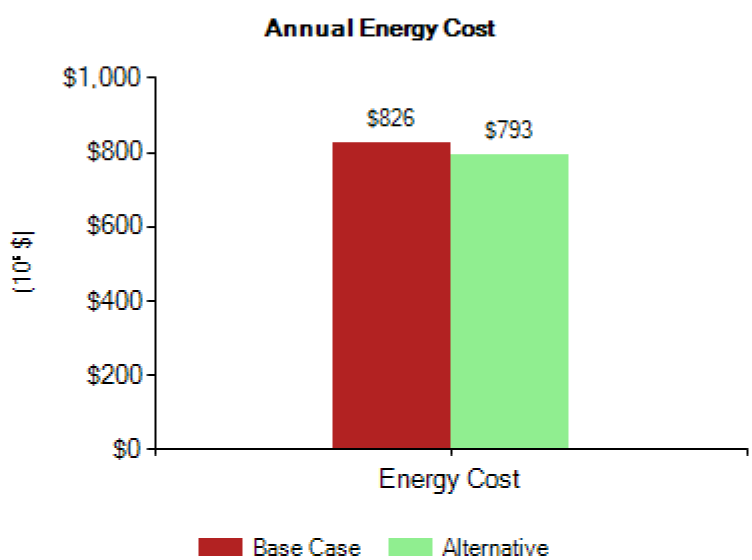
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.38 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.75	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	8,162 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	27.85 0.00 0.00 0.00 0.00 0.00 0.00 0.00 27.85	40.38 0.00 0.00 0.00 0.00 0.00 0.00 0.00 40.38	793 0 0 0 0 0 0 0 793	13,509

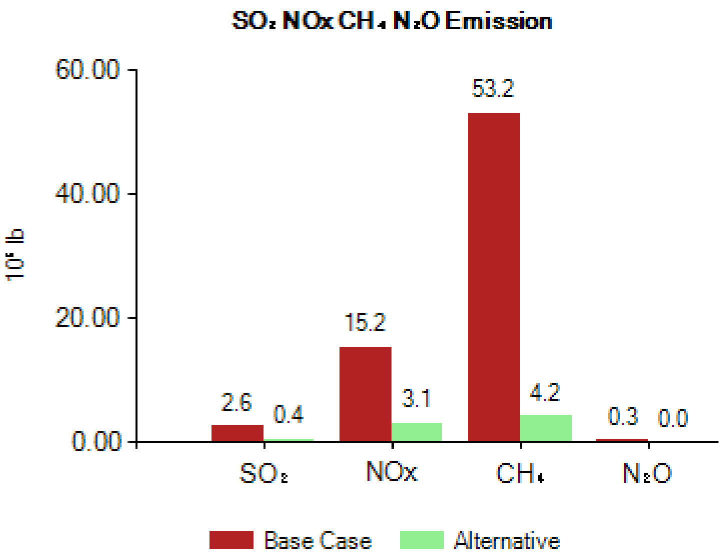
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	33	8,037	243.5

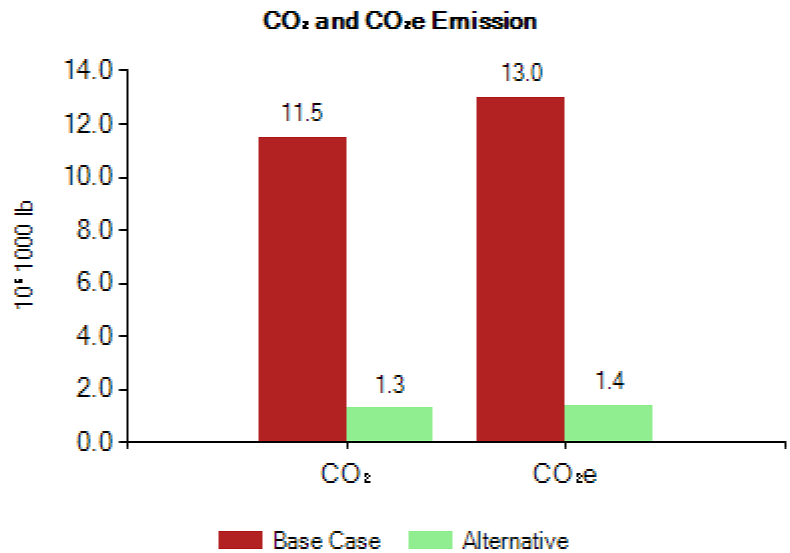




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.23	11.47	53.18	0.26	13.01
Alternative	0.41	3.10	1.26	4.20	0.00	1.38





CASE 13

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
x	Single Fam. Attached	46,000	982	3
x	Apt. Building 2 to 4 units	49,800	779	3
x	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	1,090,000	1,293	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	1.50	2.17	3.50

*Note: User-Specified prices

Select Building Configurations

All Houses

Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^6 kWh) Gas Consumption: 561 (10^6 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 4,331 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 4,745 $/Unit +42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 171 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 102 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 0 $/Unit +0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 364 (10^6 kWh)	Electric Consumption: 364 (10^6 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^6 kWh) Gas Consumption: 242 (10^6 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Electric Heat Pump EF, 2.00 Electric Consumption: 2,201 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 1,900 $/Unit Unit Capacity: 50 Gal

	Lighting & Plug-in Loads	Electric Consumption: 2,044 (10^6 kWh)	Electric Consumption: 2,044 (10^6 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 34 (10^6 kWh) Gas Consumption: 34 (10^6 Therm) Installed Cost: 823 $/Unit	Electric Induction EF 0.84 Electric Consumption: 431 (10^6 kWh) Gas Consumption: 0 (10^6 therm) Installed Cost: 1,879 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
	Dishwasher	How many: 1 Electric Consumption: 187 (10^6 kWh)	How many: 1 Electric Consumption: 187 (10^6 kWh)
	Washer	How many: 1 Electric Consumption: 96 (10^6 kWh)	How many: 1 Electric Consumption: 0 (10^6 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 83 (10^6 kWh) Gas Consumption: 38 (10^6 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.93 Electric Consumption: 835 (10^6 kWh) Gas Consumption: 0 (10^6 Therm) Installed Cost: 930 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (10^6 kWh) Battery Offsets: 0 (10^6 kWh) Electricity Exported to Grid: 0 (10^6 kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW	None Electric Reduced: 0 (10^6 kWh) Electric Export to Grid: 0 (10^6 kWh) NG Building Used Reduction: 0 (10^6 therm) mCHP NG Consumption: 0 (10^6 therm) Installed Cost: 0 $/Unit + 0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.38	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

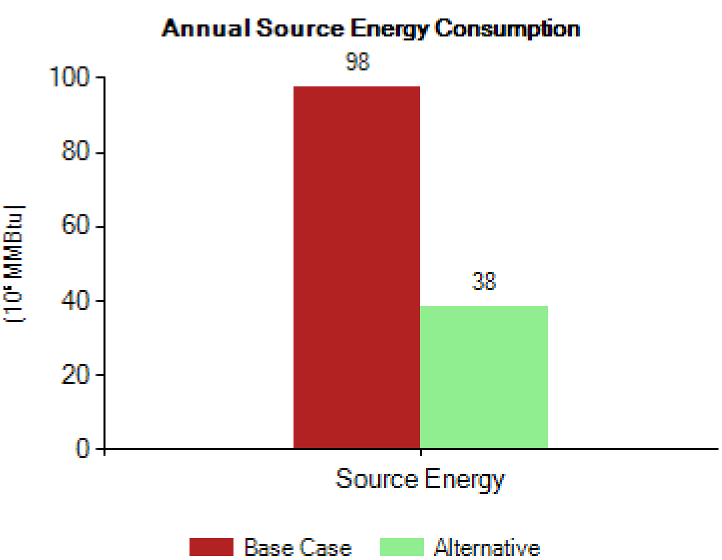
Electricity (lb/MWh)	105.7	0.040	0.260	0.349	0.0000	115.5
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

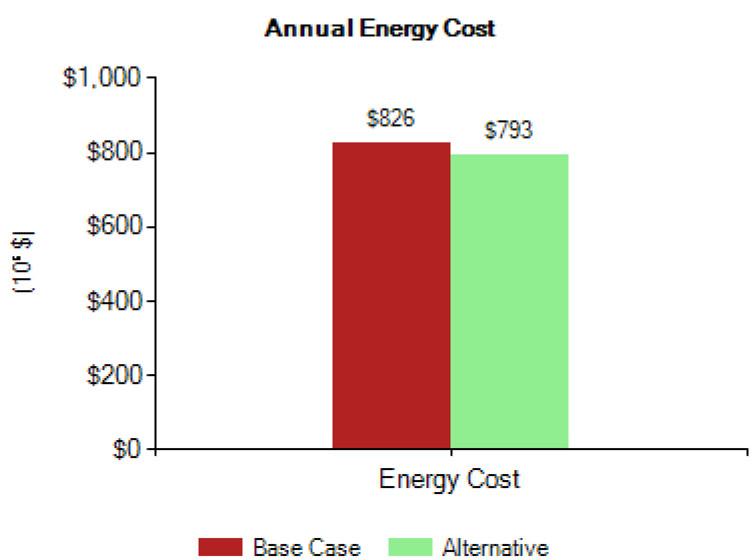
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(10^6 MMBtu)	(10^6 MMBtu)	(10^6 $)	(10^6 $)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	481 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 875 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	1.64 0.00 0.00 87.50 0.00 0.00 0.00 0.00 89.14	2.26 0.00 0.00 95.38 0.00 0.00 0.00 0.00 97.64	47 0 0 779 0 0 0 0 826	5,473
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	8,162 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 kWh) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Therm) 0 (10^6 Gal) 0 (10^6 Gal)	27.85 0.00 0.00 0.00 0.00 0.00 0.00 0.00 27.85	38.43 0.00 0.00 0.00 0.00 0.00 0.00 0.00 38.43	793 0 0 0 0 0 0 0 793	13,509

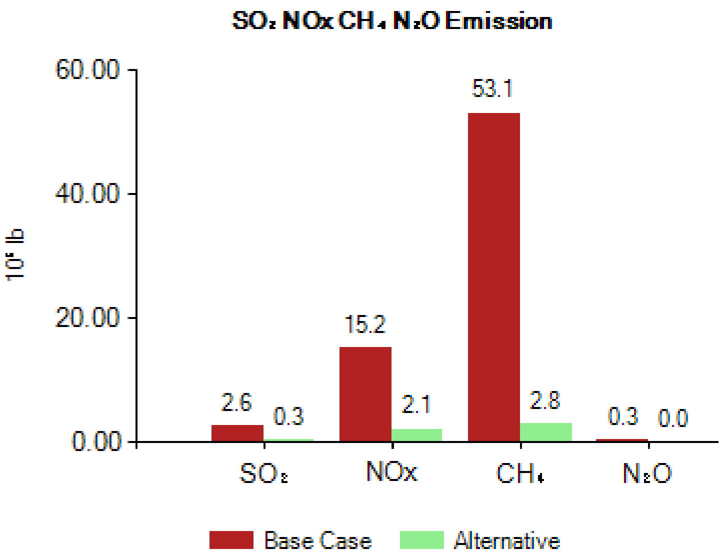
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^6 $)	(10^6 $)	(Year)
Comparison	33	8,037	243.5

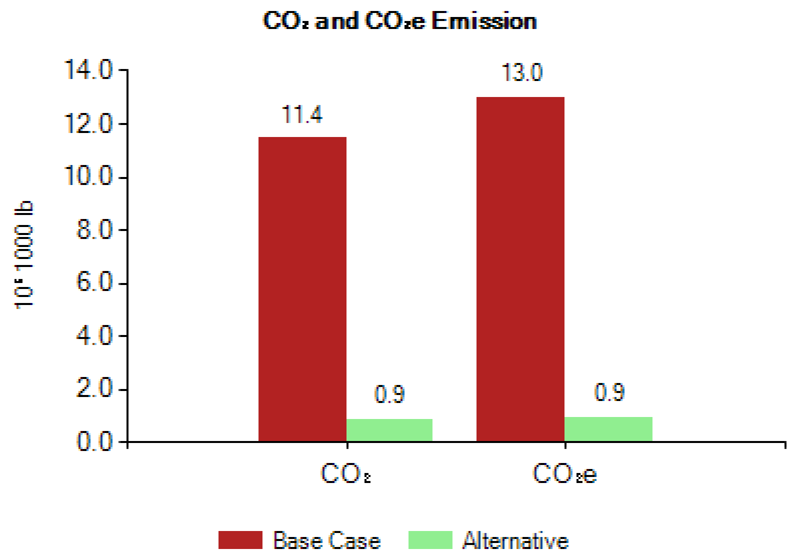




Annual Source Emissions

	SO2 (10^6 lb)	NOx (10^6 lb)	CO2 (10^9 lb)	CH4 (10^6 lb)	N2O (10^6 lb)	CO2e (10^9 lb)
Baseline	2.56	15.18	11.44	53.11	0.26	12.99
Alternative	0.33	2.12	0.86	2.85	0.00	0.94





CASE 14

Energy Planning Analysis Tool

Building Location and Configuration

State:	Washington	Population:	6,724,540	Total State Home:	2,518,046

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
	Moblile	29,300	871	3
x	Single Fam. Detached	807,700	1,476	3
	Single Fam. Attached	46,000	982	3
	Apt. Building 2 to 4 units	49,800	779	3
	Apt. Building 5+ units	157,200	688	3
	All Residential Electric Houses	807,700	1,476	3

State Energy Price *

Electric Price (Cents/kWh)	Natural Gas Price ($/Therm)	Renewable Natural Gas Price ($/Therm)	Propane Price ($/Gal)	Renewable Propane Price ($/Gal)
9.71	0.89	3.50	2.17	3.50

*Note: EIA 2019 state annual prices

Select Building Configurations

Single House — Equipment Cost Basis: Retrofit

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 5,443 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 3,873 $/Unit + 42.00 $/kBtuh Unit Capacity: 70 kBtuh	Natural Gas, AFUE 98% Electric Consumption: 0 (kWh) Gas Consumption: 459 (Therm) Installed Cost: 2,807 $/Unit + 3.86 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 124 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 30 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 158 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 2,588 $/Unit + 42.00 $/kBtu Unit Capacity: 30 kBtuh
x	HVAC Blower	Electric Consumption: 356 (kWh)	Electric Consumption: 392 (kWh)
x	Water Heating	Electric Resistance EF, 0.95 Electric Consumption: 4,251 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 40 Gal	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 51 (kWh) Gas Consumption: 143 (Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h
	Lighting &	Electric Consumption: 2,140 (kWh)	Electric Consumption: 2,140 (kWh)

	Plug-in Loads		
x	Cooking Range	Electric Standard EF 0.74 Electric Consumption: 448 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 923 $/Unit	Gas Standard Electric Consumption: 31 (kWh) Gas Consumption: 31 (therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (kWh)	How many: 1 Electric Consumption: 0 (kWh)
	Dishwasher	How many: 1 Electric Consumption: 172 (kWh)	How many: 1 Electric Consumption: 172 (kWh)
	Washer	How many: 1 Electric Consumption: 88 (kWh)	How many: 1 Electric Consumption: 0 (kWh)
x	Clothes Dryer	Electric Standard EF 3.1 Electric Consumption: 971 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 760 $/Unit	Gas Standard EF 2.75 Electric Consumption: 76 (kWh) Gas Consumption: 35 (Therm) Installed Cost: 1,000 $/Unit
	Electrical Service Upgrade	No Electrical Upgrade 0 $/house	No Electrical Upgrade 0 $/house
	Photovoltaic	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (kWh) Battery Offsets: 0 (kWh) Electricity Exported to Grid: 0 (kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System	PV Installed : No PV Array Size : 0 (kW) Battery Installed: No Battery Size: 0 (kWh) Economics: Net Metering Electricity Retail Rate Multiplier : 0 Direct Solar Offsets: 0 (kWh) Battery Offsets: 0 (kWh) Electricity Exported to Grid: 0 (kWh) PV Cost: 0 $/kW Battery Cost: 0 $/kWh Total Cost: 0 $/System
	Micro CHP	None Electric Reduced: 0 (kWh) Electric Export to Grid: 0 (kWh) NG Building Used Reduction: 0 (therm) mCHP NG Consumption: 0 (therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (kWh) Electric Export to Grid: 0 (kWh) NG Building Used Reduction: 0 (therm) mCHP NG Consumption: 0 (therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Washington

eGrid Database: eGRID State database

Source Energy Factors

	Electric	Natural Gas	Renewable Natural Gas	Propane	Renewable Propane
Btu/Btu	1.45	1.09	1.28	1.15	1.27

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e

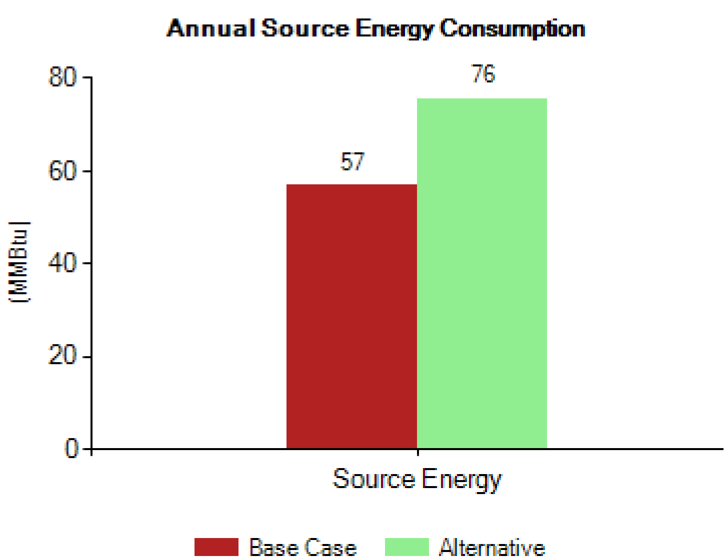
Electricity (lb/MWh)	155.6	0.050	0.390	0.516	0.0000	170.2
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Renewable Natural Gas (Building Used, lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Propane (lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Renewable Propane (Building Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	137.2	0.029	1.892	1.468	0.0000	178.4
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	128.9	0.028	0.055	0.603	0.0000	145.8

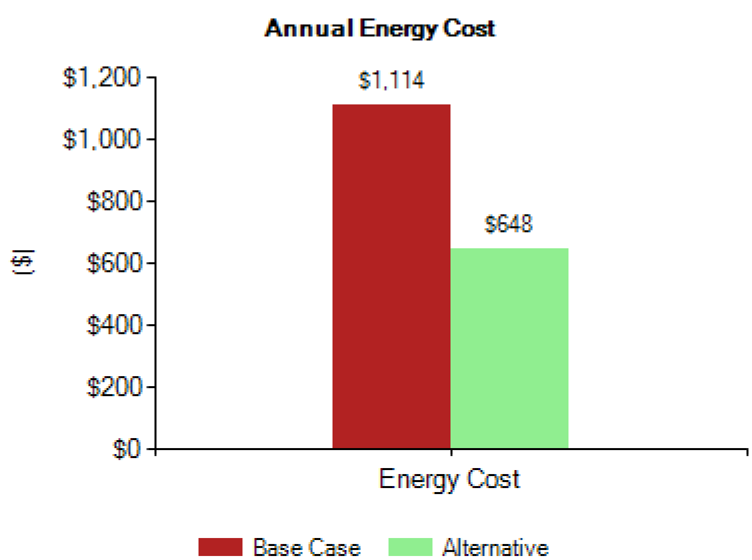
Source Energy and Emission Factors are calculated for WA: Energy conversion efficiency and specific emission data for electricity generated using fossil fuels and biomass are based on eGRID State database. Electric distribution efficiency data are based on eGRID State database. Electricity generation fuel mix distribution data are based on user custom data All other default data are based on EIA, NREL, and ANL (GREET 1 2012) data sources.

Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(MMBtu)	(MMBtu)	($)	($)
Baseline	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	11,469 (kWh) 0 (kWh) 0 (kWh) 0 (Therm) 0 (Therm) 0 (Therm) 0 (Gal) 0 (Gal)	39.13 0.00 0.00 0.00 0.00 0.00 0.00 0.00 39.13	56.74 0.00 0.00 0.00 0.00 0.00 0.00 0.00 56.74	1,114 0 0 0 0 0 0 0 1,114	9,227
Alternative	Electricity (Total Building Used) Electricity Offset (Distributed Generation) Electricity (Distributed Generation) Natural Gas (Building Used) Natural Gas (mCHP Used) Renewable Natural Gas (Building Used) Propane (Building Used) Renewable Propane (Building Used) Total	550 (kWh) 0 (kWh) 0 (kWh) 668 (Therm) 0 (Therm) 0 (Therm) 0 (Gal) 0 (Gal)	1.88 0.00 0.00 72.81 0.00 0.00 0.00 0.00 68.68	2.72 0.00 0.00 72.81 0.00 0.00 0.00 0.00 75.53	53 0 0 595 0 0 0 0 648	7,415

	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	($)	($)	(Year)
Comparison	466	-1,812	Immediately





Annual Source Emissions

	SO2 (lb)	NOx (lb)	CO2 (1000 lb)	CH4 (lb)	N2O (lb)	CO2e (1000 lb)
Baseline	0.57	4.47	1.78	5.92	0.00	1.95
Alternative	1.96	11.70	8.78	40.70	0.20	9.97