TOPICAL REPORT

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Assessment of Residential Natural Gas & Electric Decarbonization in Lawrence, KS

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Black Hills Energy

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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 Lawrence, KS. 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, particularly with space heating in a climate region like Kansas.

Key results:

- **The ratio of the residential cost of electricity and natural gas has grown over the past 15 years.** In 2019, Kansas homeowner electricity prices were over four 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 Lawrence, KS homeowners.** A mid-efficiency case using electric heat pumps (HSPF 9) results in a 95% increase in consumer energy costs, about $20.5 million annual increase, for all homes now using natural gas in Lawrence.
- Figure 1 compares annual energy costs and lifecycle net present cost comparisons (2020-2050) for a typical 1,800 ft^2 home in Lawrence with natural gas appliances vs an all-electric home. With electrification, energy bills would nearly double today for a typical single-family home.

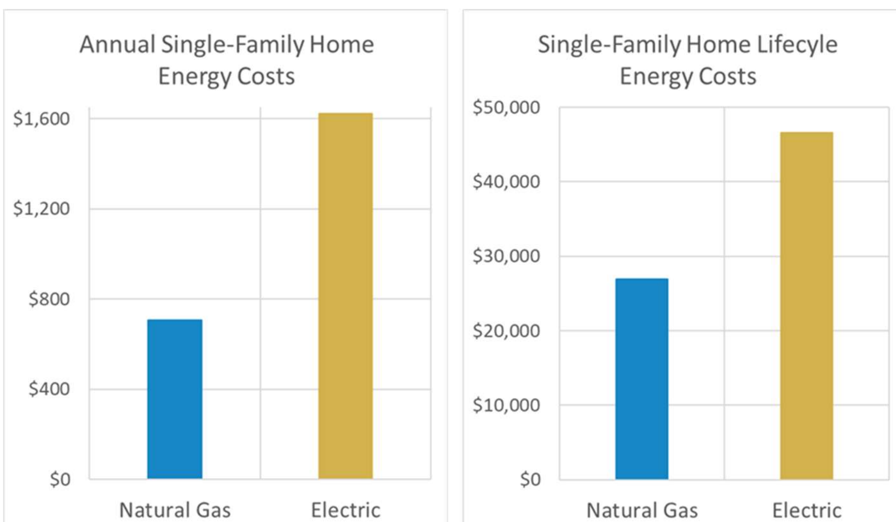

Figure 1: Annual Energy Costs and Lifecycle Costs for Typical 1,800 ft^2 Single-Family Home in Lawrence, KS

- **All-electric homes today in Kansas using the current average power generation mix in the state result in higher CO_2 emission rates** than a baseline natural gas home in most instances.
- **Natural gas pathways for GHG reductions have lower consumer and societal costs when measured in $/metric ton of CO_2 reduced (Figure 2).** Using currently available high-efficiency gas equipment results in cost-effective GHG reductions (-$28/metric ton of CO_2).

Combining renewable natural gas with existing high-efficiency equipment and next-generation natural gas heat pumps raises total GHG reduction potential at higher costs ($55 to $220/metric ton of CO_2). Electrification scenarios all have higher CO_2 abatement costs.

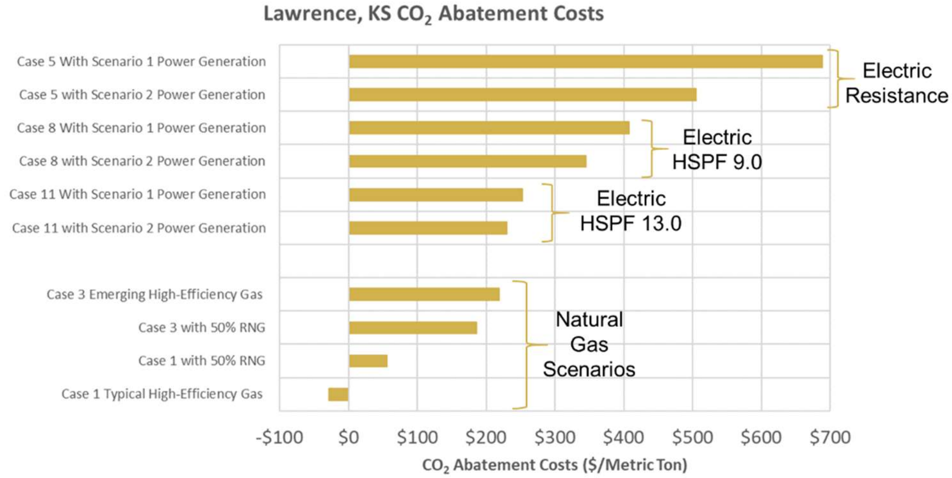

Figure 2: Comparison of CO_2 Abatement Costs ($/metric ton)

- **All-electric homes today in Kansas using the current average power generation mix in the state result in higher CO_2 emission rates** than a baseline natural gas home in most instances.
- A three-step process is outlined for the evolution of Kansas power generation over the next 10-20 years (from 2030 to 2040): (1) replacement of coal generation, (2) additional capacity for expanded baseload generation under an electrification scenario, and (3) strategies to address high seasonal winter electricity demand. Step 3 is the most challenging market development need and worthy of more concentrated RD&D to identify reasonable solutions.
- **A significant issue with residential electrification scenarios is the seasonal energy required for space heating when cold temperatures prevail**. The potential power generation and electric infrastructure cost and reliability implications for consumers and society are significant.
- There is no evidence wind or solar resources can address prospective energy-intensive space heating electricity peaks during Kansas winters. Solar PV systems have a significant drop in winter output.
- Using the matching principle and reasonable options at this juncture, **most new winter peak electricity demand for electric space heating will be met with dispatchable natural gas generation**. Without GHG mitigation for this scenario, GHG reductions from electric space heating will be much less than anticipated.
- 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 Kansas.
- Using hybrid space heating systems whereby electric heat pumps provide heating at milder outdoor temperatures and natural gas heating systems operate at cold temperatures is an option that avoids a host of issues associated with cold weather electric heat pump operation.
- Energy reliability and resilience is critical, especially the risk of electric grid outages at cold temperatures. 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 Lawrence, KS. 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 various future gas and electric appliances for Lawrence, KS homes.

There are unique and substantive energy delivery system challenges with seasonal residential space heating in cold-weather regions like Kansas, including: (1) high winter peak-day/peak-month energy demand, (2) expanded need for electric 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 cost impacts quantified in this report, such measures would override consumer choice principles and negatively impact the growing number of residential homeowners using natural gas emergency generators to improve home energy system reliability and resilience.

The report reviews trends in Kansas 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 impact possible future electric system infrastructure asset investments may have on residential electricity prices is outside the report scope.

Recommendations are made for pursuing immediate, no regrets, common sense, and cost-effective measures for reducing GHG emissions from Lawrence, KS homes now 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. 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 41,000 homes in Lawrence, KS. Most residential units are single-family detached or attached (duplex) homes (about 59%), 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 type (right column).

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

Total Occupied Homes	41,341	% of Market	Estimated Natural Gas Homes
Single-Family Detached	20,002	48.4%	16,100
Single-Family Attached	4,280	10.4%	3,250
Multi-Family 2-4 units	4,944	12%	3,400
Multi-Family (over 4 units)	11,407	27.6%	6,800
Mobile Homes	708	1.7%	140

Natural gas and electricity are the main space heating energy choices for Lawrence, KS homes (Figure 3). Natural gas has a dominant share (about 72%) of the residential space heating market, followed by electricity at 26%.

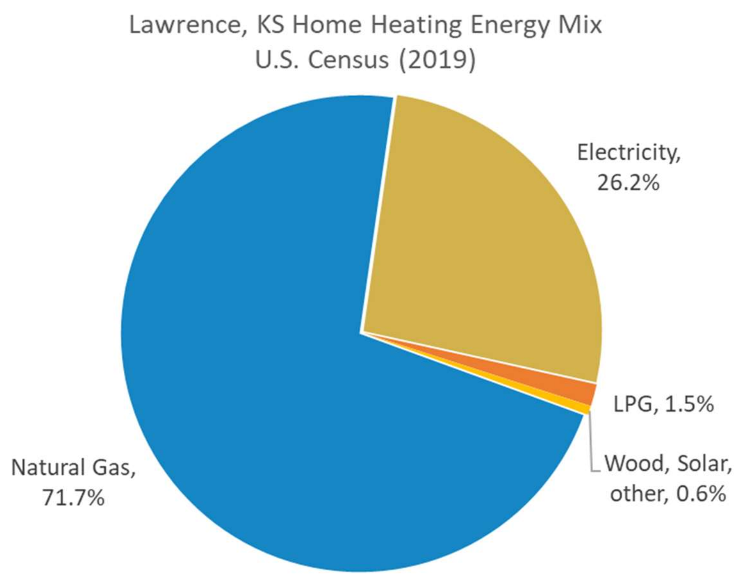


Figure 3: Lawrence, KS Residential Space Heating Home Share (US Census)

Across the US residential sector, 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 20ºF to 70ºF is a temperature difference of 50ºF. In addition, across much of the US, the duration of the heating season and runtime (hours) for space heating equipment is considerably higher than equipment runtime needed for cooling homes.

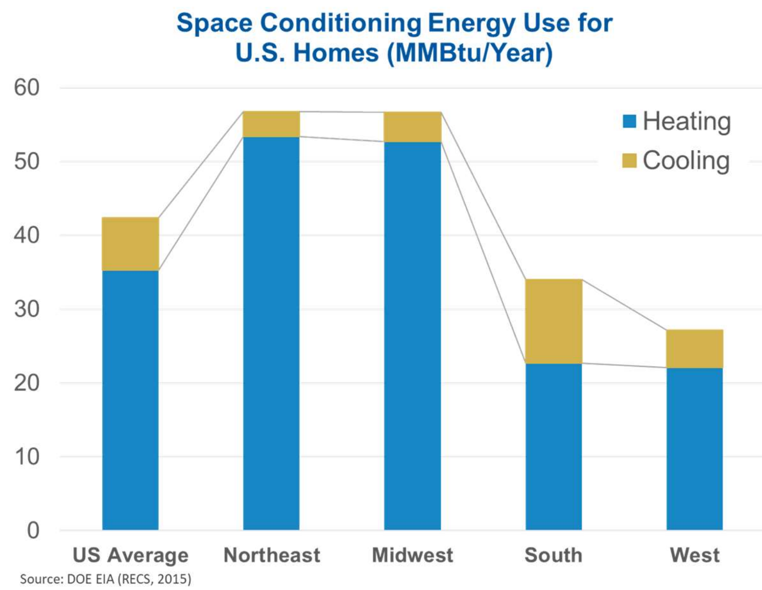


Figure 4: Annual Average Space Conditioning Energy Use for U.S. Homes

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 U.S. and Western Central Region (which includes Kansas) and the nominal range for Lawrence, KS. CDD are close to the U.S. average, while HDD are higher. HDD requirements are about 3.1 times more than CDD requirements in Lawrence, KS.

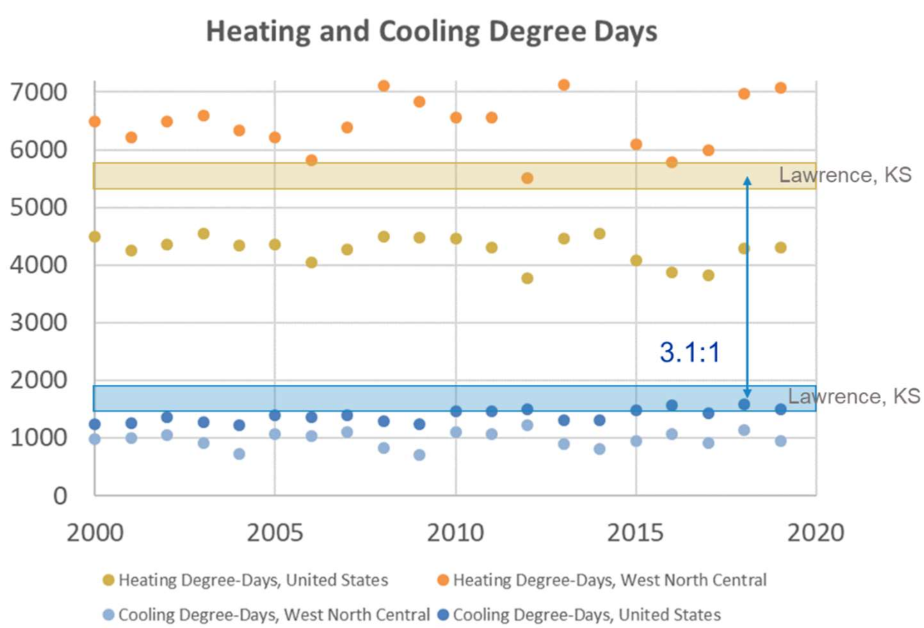


Figure 5: U.S. and Kansas Region Heating and Cooling Degree Days (DOE-EIA)

HDD and CDD serve as a proxy for space conditioning energy requirements. Illustrating this, Figure 6 shows monthly electricity and natural gas energy use in Kansas homes over a seven-year period (2013 to 2019). Each sparkline graph is on the same monthly energy use scale, enabling direct comparisons. This highlights the exceptionally larger seasonal natural gas energy required to heat Kansas homes compared to the electricity needed for cooling. This pattern of high natural gas winter peaks is seen across much of the U.S.

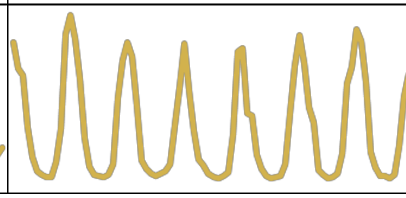
2013-2019	Residential Electric	Residential Natural Gas	Peak Natural Gas: Peak Electric Ratio
KS			2.7

Figure 6: Sparkline Graphs of Monthly Residential Energy Use in Kansas Over Seven Years (DOE-EIA)

Lawrence, KS residential energy preferences (e.g., 72% gas use for space heating) reflect results from published home energy surveys (Figure 7). Nationally, homeowner surveys show a consumer preference for natural gas over electricity in four primary thermal energy applications: space heating, water heating, cooking, and clothes drying.

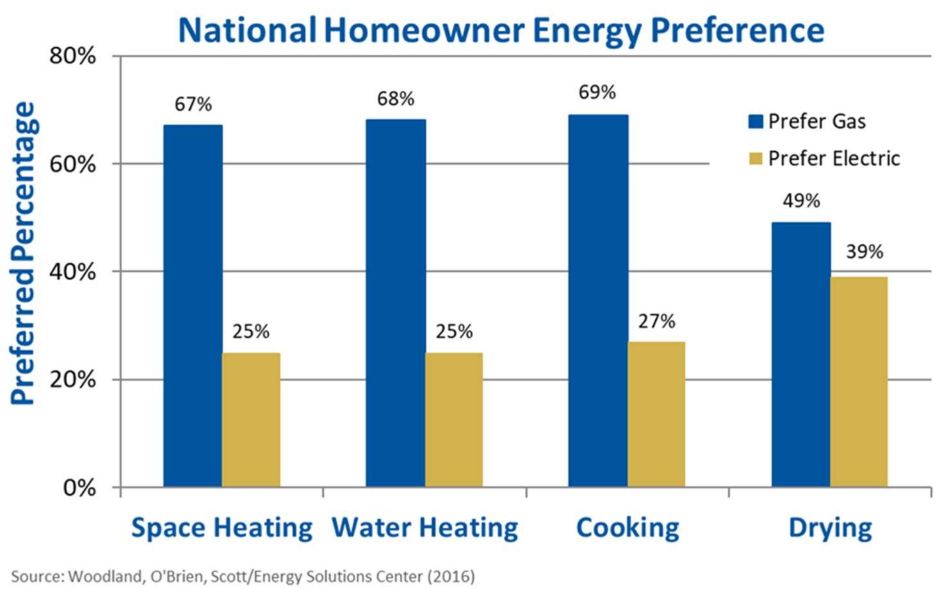


Figure 7: National Residential Homeowner Energy Preferences

People prefer natural gas mainly for is its cost-effectiveness. Figure 8 shows trends for average annual Kansas residential electricity and natural gas prices since 2005. During this period, residential electricity prices grew over 60% while natural gas prices dropped 23%. With these price movements, Kansas residential electricity prices are over 4 times greater than natural gas on an energy equivalent basis. According to DOE-EIA, the average 2019 Kansas residential electric price was 12.71 cents/kWh. In similar energy units, average KS residential natural gas price was about 3.1 cents/kWh (or about $9.06/MMBtu) in 2019. Natural gas is a cost-effective energy option for Lawrence, KS consumers.

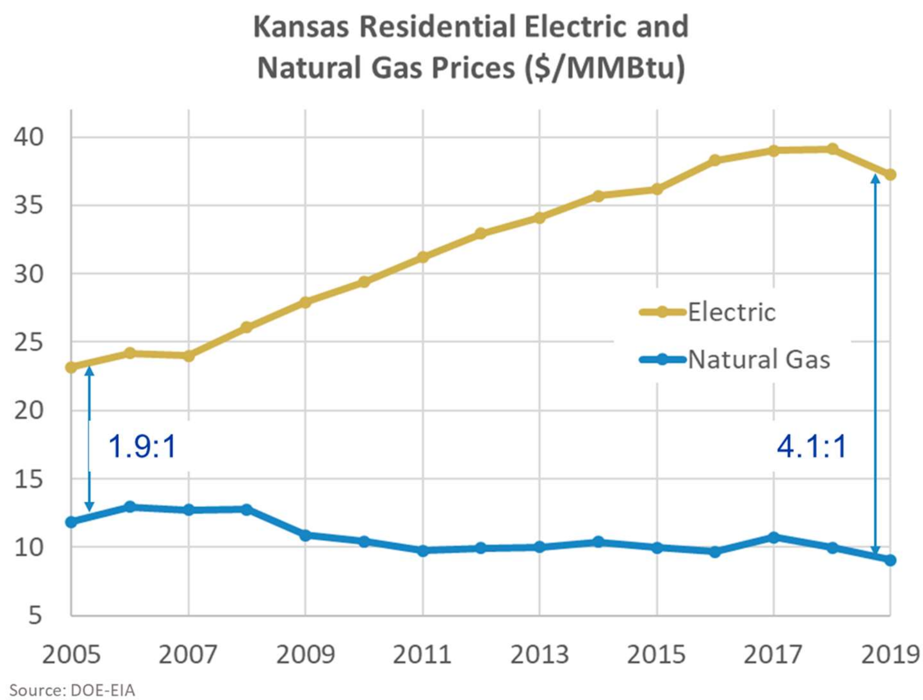


Figure 8: Kansas Residential Electric and Natural Gas Price Trends (DOE-EIA)

Estimating potential future electricity price impacts from large-scale residential electrification is outside the scope of this study. However, the report does discuss the challenge of scaling up electric energy systems to provide the capacity and performance required for the large task of heating cold-region homes on a seasonal basis – which could 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 high continuous hot water rates (e.g., with more efficient tankless water heaters)
- Natural gas cooking equipment provides more rapid stovetop heating of water or food products – with greater control – than conventional electric resistance stoves

In addition to 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 fireplaces while virtually eliminating carbon monoxide and particulate emissions compared to wood-burning units.

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 typically 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; Conifer, CO)

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 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 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 section on GHG reduction benefit/cost analysis. 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 that impact end-use equipment performance. This presents an informed framework for differentiating between reasonable future pathways versus idealized or potentially risky scenarios that may have unintended or unanticipated consequences or 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 threats and 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 10 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.

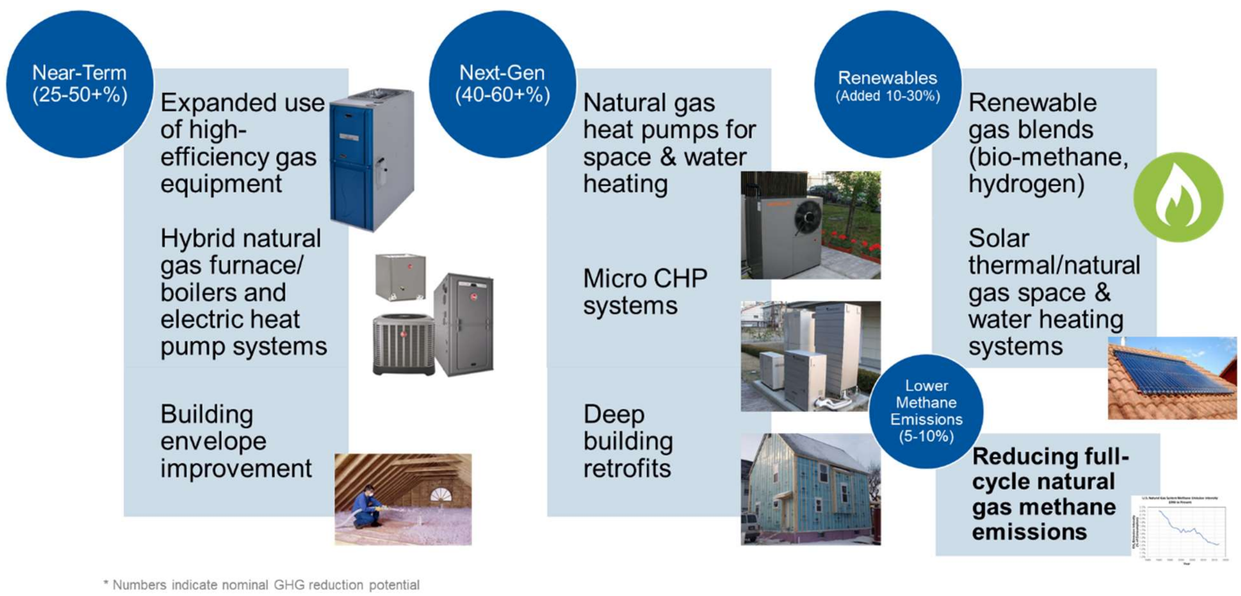


Figure 10: Natural Gas Home Greenhouse Gas Emission Reduction Pathways

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) are immediately implementable. 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 Kansas.

Space Heating and Heat Pumps

Space heating is the largest and most important natural gas application in homes and typically the most challenging and costliest to replace with electricity. Homes with natural gas heating often 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 condensing 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 of 80% to around 98%.

Natural gas heat pumps, an emerging efficiency measure, are analogous to electric heat pumps but use natural gas as the primary energy input. There are several types of gas heat pump technologies with varying levels of efficiency (Figure 11). 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).

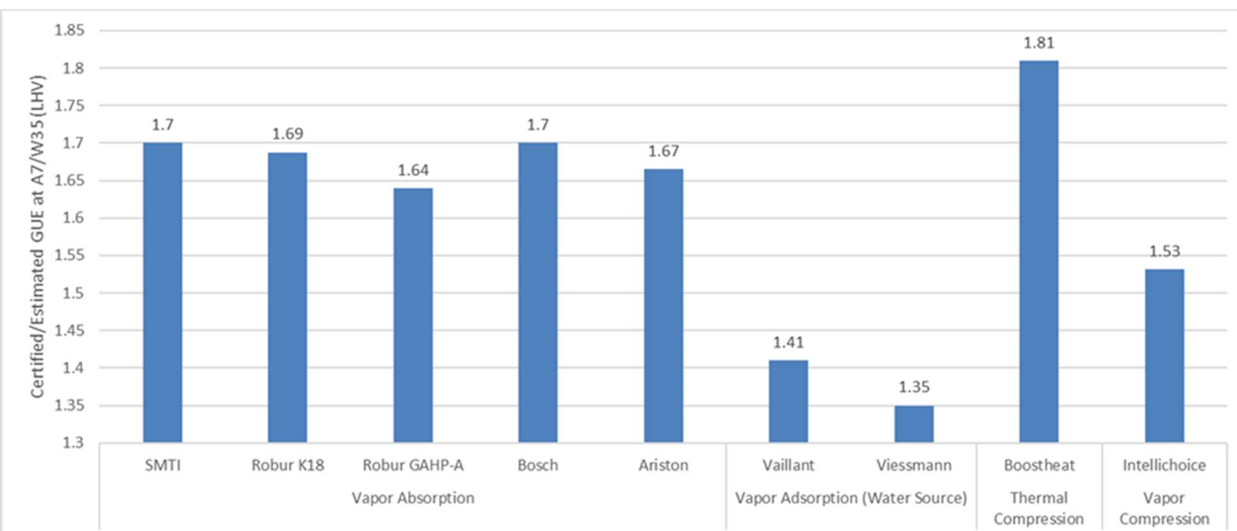


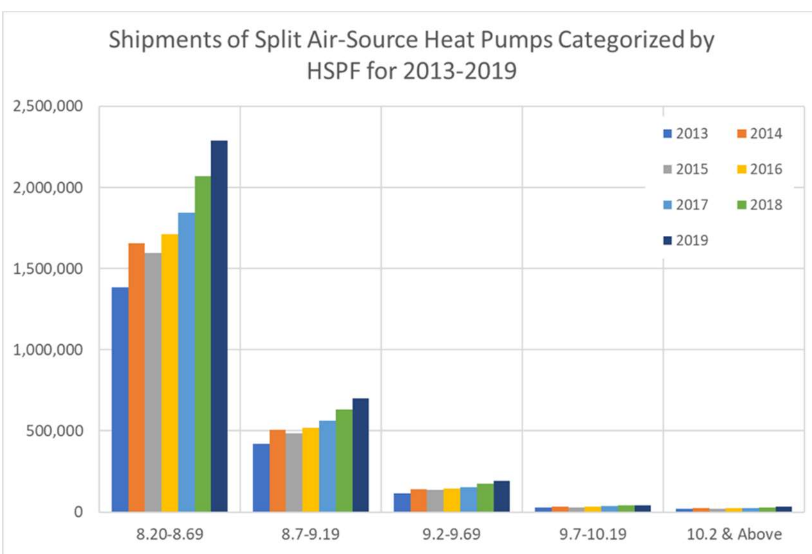
Figure 11: Example Natural Gas Heat Pumps and Efficiency

Table 2, 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% (for single-family homes this figure is closer to 40%). As shown in this table, most homes today with electric space heat use less expensive and less efficient electric resistance heating rather than more expensive and more efficient electric heat pumps. From an energy efficiency program and GHG reduction perspective, public policies should emphasize low-cost GHG improvements by upgrading inefficient electric resistance home heating systems to electric heat pumps. This is a simpler and more cost-effective strategy in comparison to wholesale energy system changes associated with switching from natural gas to electric space heating.

Table 2: Trends for U.S. 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 minimum Federal efficiency standards (Figure 12). 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 12: 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 may 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 heating for supplemental heat – which increases electricity consumption and peak power that lead to a decline in electric heating system efficiency. In other instances, homes may switch to supplemental heating from a natural gas furnace during cold periods to avoid costly electric resistance heating (i.e., a hybrid heating system).

Manufacturer electric heat pump ratings do not satisfactorily account for total, real-world energy use. Several factors can reduce electric heat pump efficiency, including: efficiency and 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.

Figure 13 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.

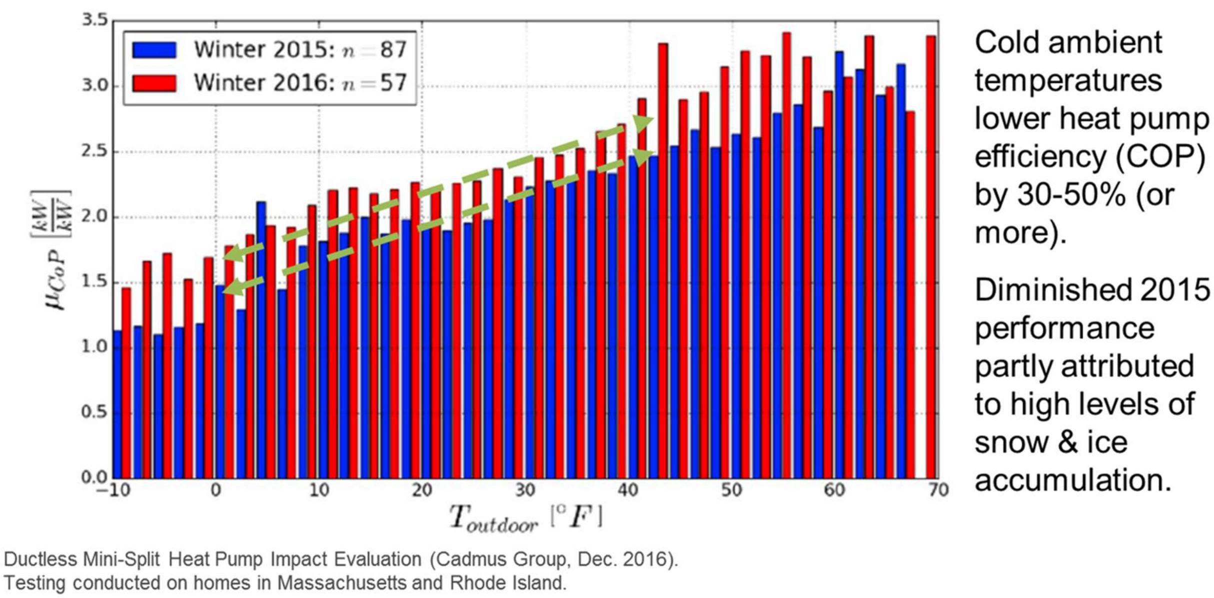


Figure 13: Cadmus Group Field Testing of Electric Heat Pumps in Northeastern U.S.

GTI has conducted extensive lab and field testing as well as computer modeling of electric heat pump performance and efficiency, including conventional units as well as newer options characterized as cold climate (ccEHP) systems. Figure 14 shows representative performance data on electric heat pumps at colder temperatures (below 40ºF). 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 10ºF. Higher-efficiency (HSPF 10 and above) cold-climate electric heat pumps have improved efficiency but show a decline in efficiency from 40ºF down to 10ºF and lower. Cold-climate heat pumps are an improvement, yet these high-efficiency electric heat pumps have higher first costs and are still a small portion of market sales – about 1% of 2019 electric heat pump sales.

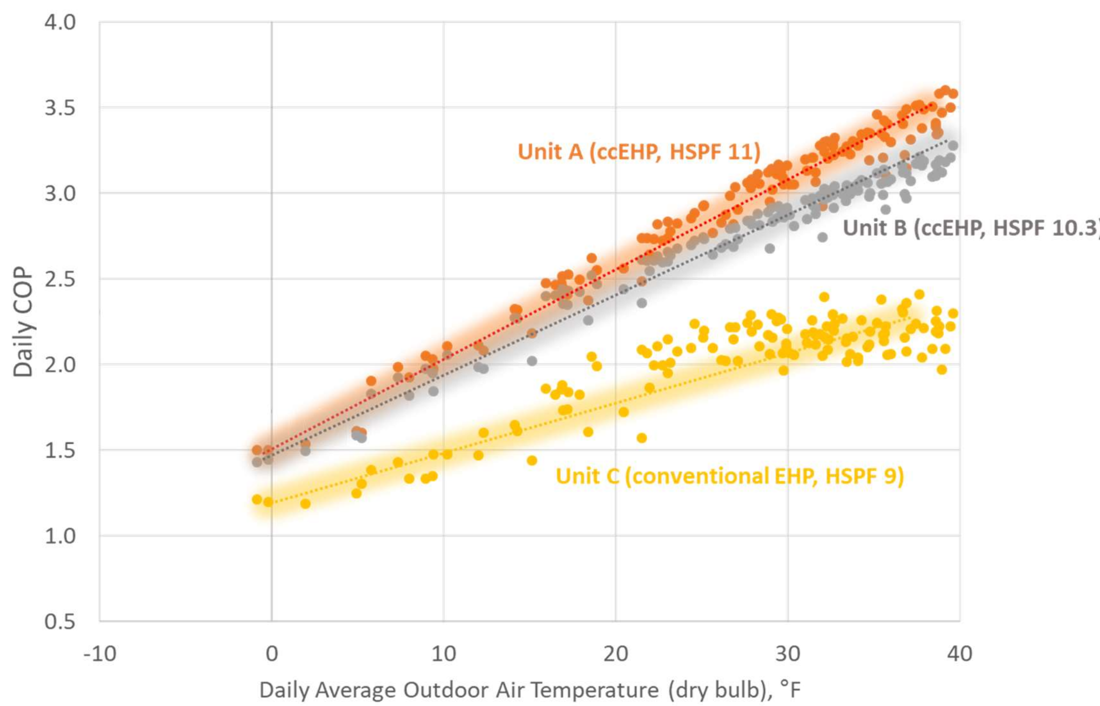


Figure 14: Electric Heat Pump Performance Below 40ºF (Source: GTI)

Figure 15 provides further 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 internal heating needed to maintain indoor temperatures independent of the heating source. Since electric heat pump efficiency (or COP) goes down with temperature, there is a compounded non-linear growth in average 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 the baseline conditions of 40ºF. The right figure shows example absolute electricity consumed in an average 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, uses 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 IECC building standards. Older homes and/or larger homes will have proportionately larger hourly electricity demands and will have a further compounding effect on peak hourly electricity use at cold ambient temperatures.

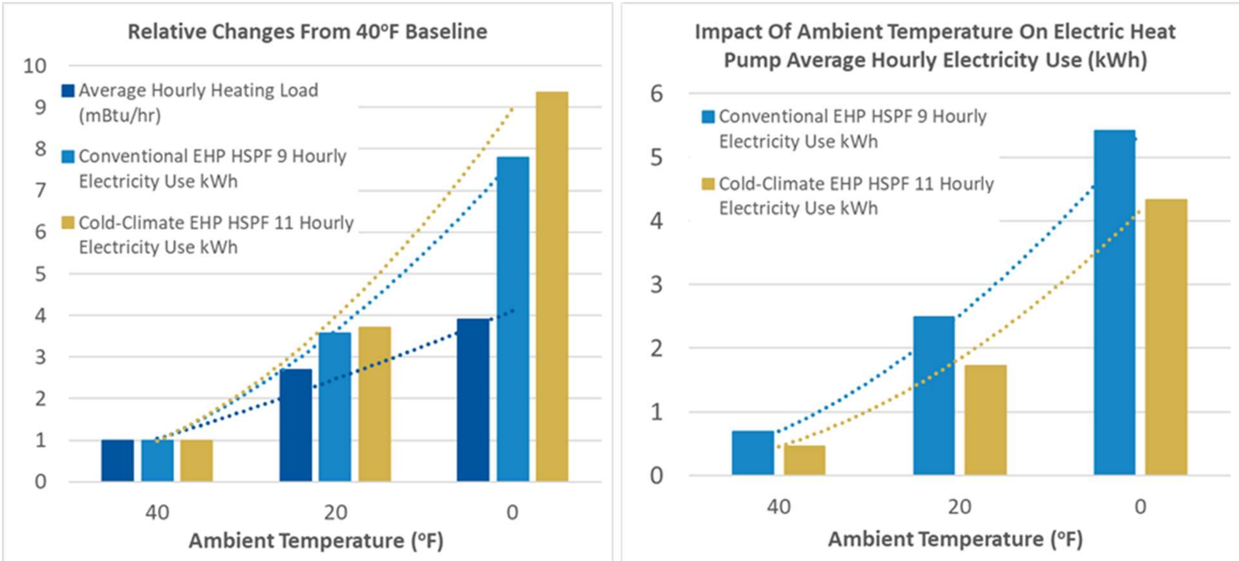


Figure 15: Impact of Ambient Temperature on Electric Heat Pump Electricity Use

Cold-climate electric heat pumps improve cold weather performance and efficiency compared with conventional EHP units by raising refrigeration compressor speeds at colder temperatures and by including more heat exchanger surface area (which results in higher capital costs). At this juncture, there is uncertainty 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) leads to a notable drop-off in heating capacity and efficiency. This has serious implications for consumer energy costs and for electric infrastructure sizing. Some manufacturers indicate electric heat pumps may shut off during extreme cold weather events (e.g., <-15°F) such as during a polar vortex event.

The limitations of electric heat pumps 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 considerations for space heating equipment: (1) equipment installed cost, (2) annual operating cost, and (3) equipment lifetime. Table 3 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 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 3: 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 16 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.

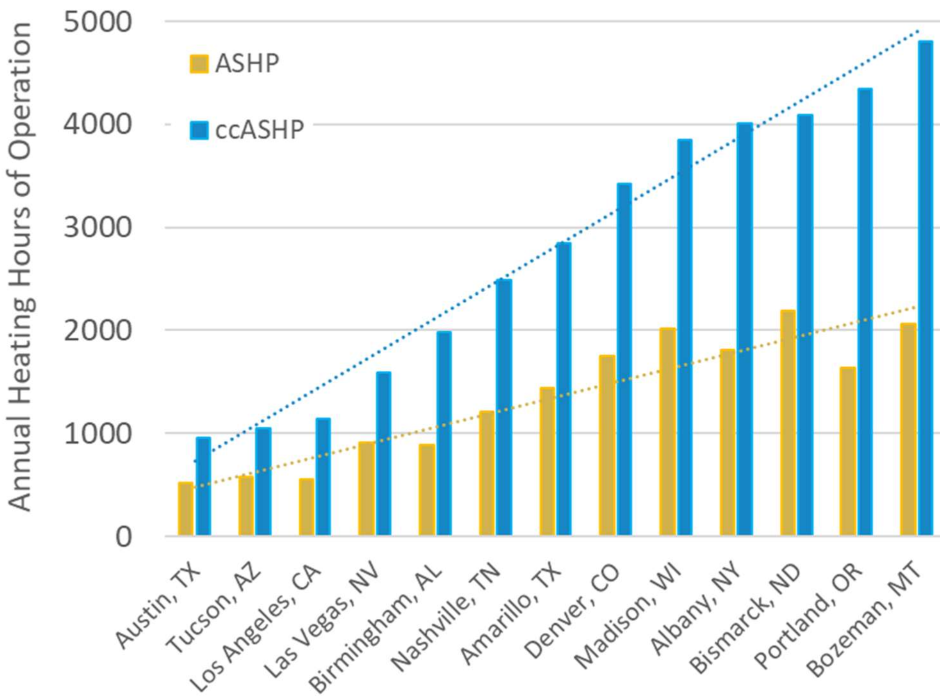


Figure 16: Electric Heat Pump Annual Heating Operating Hours in Different Climates (Source: GTI)

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 life-cycle 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 17 and Figure 18) and empowers consumers and utilities with choices. Supplemental gas heating is a cost-effective peakshaving approach to avoid significant peaks in electric 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 operating electric heating equipment mainly on dispatchable power generating systems that are likely to have higher GHG emission rates.

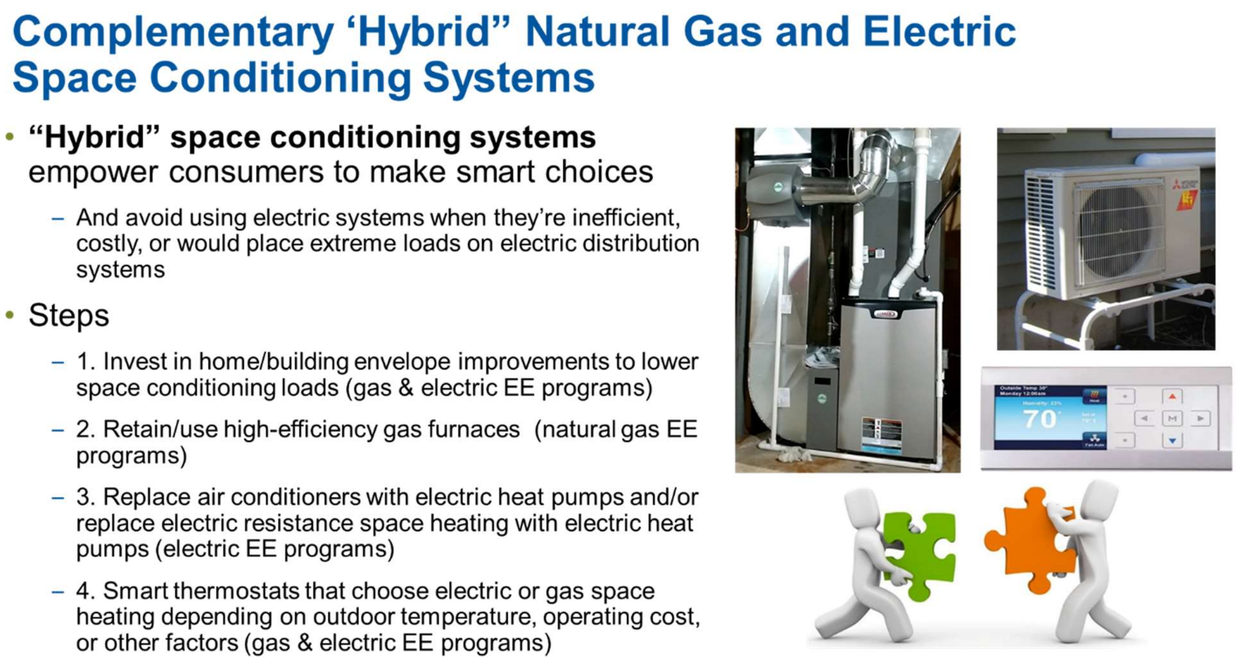
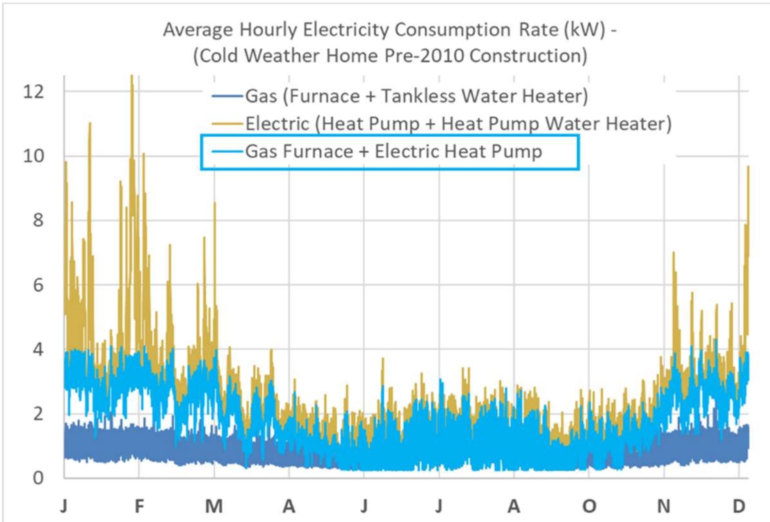


Figure 17: Natural Gas and Electric Hybrid Heating Systems



Detailed 8,760 hour residential home energy model.

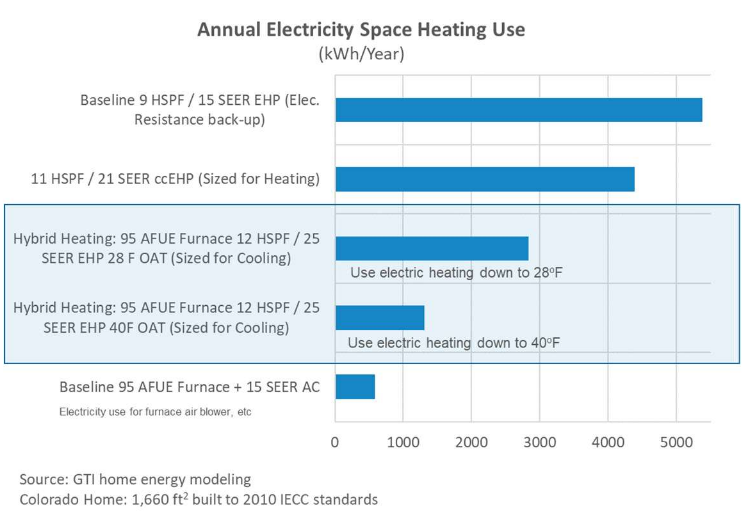
All-electric home space heating results in massive increases in peak winter demand.

Hybrid heating approach with natural gas furnace and electric heat pump (run on mild winter days) dramatically lowers peak electric demand impacts and related negative issues.

Figure 18: Hybrid Natural Gas and Electric Space Heating System (GTI)

Figure 19 shows results of GTI modeling of a 1,660 ft^2 home built to the 2010 International Energy Conservation Code (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 avoids many deleterious effects with dedicated electric heating systems in cold-weather regions.

Hybrid Natural Gas & Electric Heating Systems



Hybrid natural gas and electric heating systems – a high-efficiency gas furnace with an electric heat pump operating at milder winter temperatures – results in lower peak electricity use.

This avoids issues with grid and power generation investments upgrades to address shorter-duration seasonal loads.

Example shows a smaller home built to more modern energy efficiency standards. Larger homes and older homes would have higher electric heating use impacts.

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

Electricity Generation in the US and Kansas

This section reviews the current and potential future power generation mix in the US and Kansas. 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 20) 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).

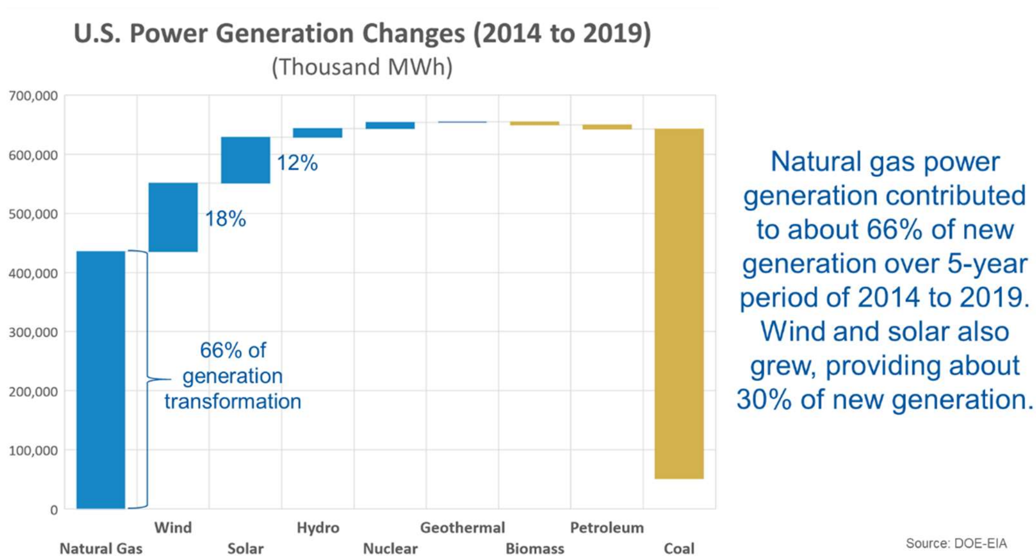


Figure 20: Changes in US Power Generation Output (2014–2019, DOE-EIA)

Figure 21 shows comparable State of Kansas power generation changes since 2014, with substantial additions in wind generation and a smaller portion of natural gas displacing coal generation.

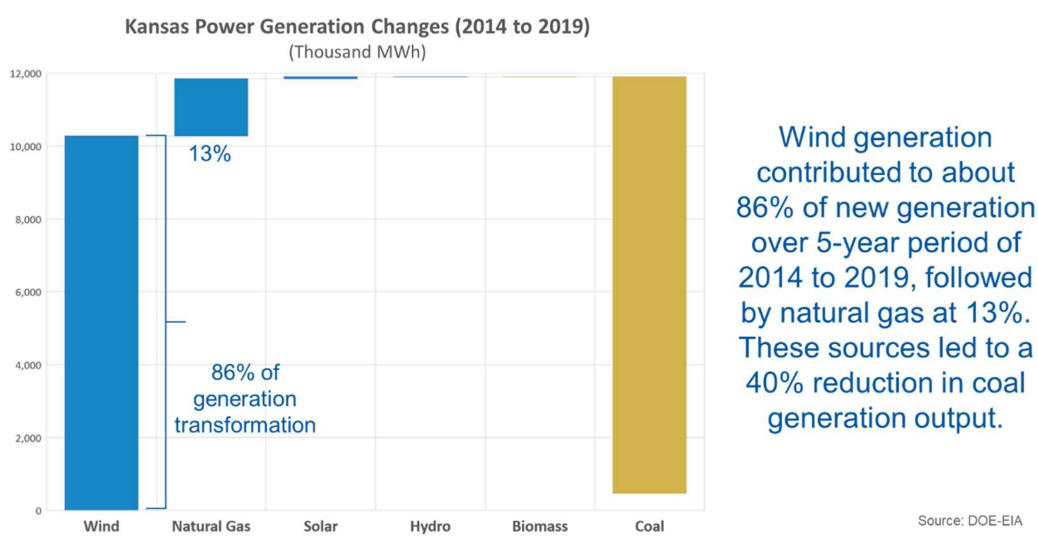


Figure 21: Kansas Power Generation Changes (2014–2019, DOE-EIA)

Figure 22 shows trends in the US power generation average CO_2 emission rate since 2005 and two annual Kansas data points. US power generation averaged about 402 grams of CO_2 emitted per kWh of electricity generated in 2019 – a roughly one-third reduction in CO_2 emission rate compared to 2005. Kansas, with its large increase in wind generation, has made tremendous strides and is now around the US average.

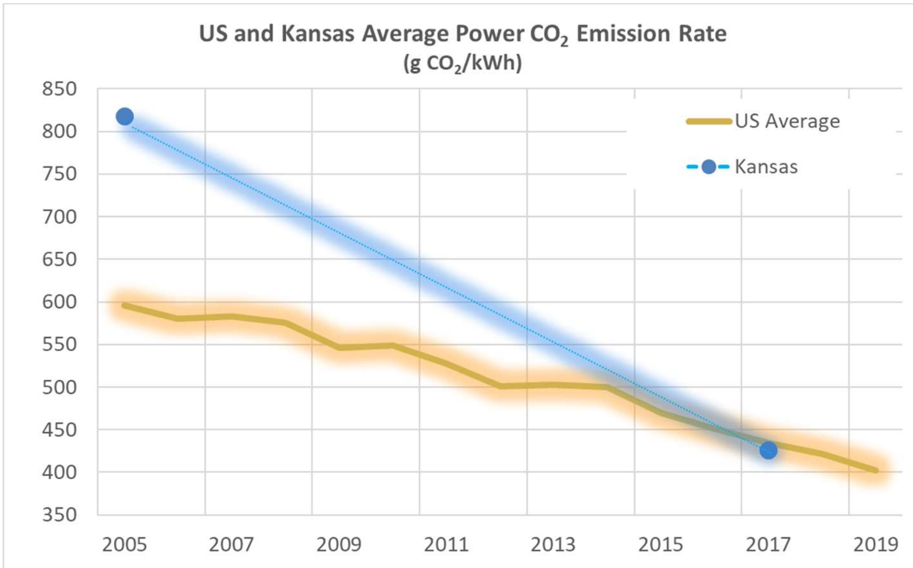


Figure 22: US Power Generation Average CO2 Emission Rate (DOE-EIA)

Table 4 compares the 2019 US and Kansas power generation mix. Kansas has a notably high level of wind generation and higher use of coal. Further displacement of coal with wind, solar, and natural gas will lead to further improvements in electric sector CO_2 intensity (e.g., in terms of grams CO_2/kWh).

Table 4: US and Kansas 2019 Power Generation Mix (DOE-EIA)

2019 Power Generation Mix	United States	Kansas
Natural Gas	38.7%	5.9%
Coal	23.6%	34.0%
Oil	0.3%	0.2%
Nuclear	19.6%	18.2%
Hydro	6.5%	0.0%
Wind	7.3%	41.5%
Solar	2.6%	0.1%
Biomass	1.4%	0.1%

For planning purposes, one can formulate hypotheses – a set of scenarios – for the future Kansas power generation mix (e.g., 2030-2050). In advance of developing such 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 around generating power for building space conditioning: seasonality. The implications of seasonality are often glossed over in policy discussions of building electrification GHG reductions – yet it is significant and highly problematic.

As shown previously in Figure 6, seasonal natural gas space heating loads are vastly larger than seasonal electricity cooling loads. The importance of seasonality, however, 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 quite significant and will be explored in detail. What is also relevant and potentially problematic is the type of power generation plants used to meet seasonal electricity use.

Seasonal or dispatchable, non-baseload power plants are different than the average or baseload power generation mix. From a GHG reduction policy perspective, seasonal power generation resources can have appreciably different CO_2 emission rates than baseload plants. Given the substantial energy used for building space heating, not properly accounting for seasonal power generation emission rates is likely to over-estimate the GHG benefits of residential electrification.

Table 5 shows an overview of Kansas state-level and area-wide power generation resources, including average as well as non-baseload or seasonal power generation resources. While Kansas's baseload power generation averages around 430 g CO_2/kWh, generation sources matched to peak seasonal use show high reliance on dispatchable coal and natural gas generation. The emission rate for Kansas's summer and winter peak generation mix is about twice that used for baseload power.

Table 5: Kansas Area Power Generation Mix (DOE-EIA, EPA eGRID)

	Average Power Generation Mix			Seasonal/Marginal Power Generation Mix		
Kansas Power Mix	DOE-EIA Kansas Average (2019)	EPA eGRID Kansas State All Plants (2018)	EPA eGRID SPNO Region All Plants (2018)	DOE-EIA 2019 Kansas Summer Seasonal	DOE-EIA 2019 Kansas Winter Seasonal	EPA eGRID SPNO Region Non-Baseload (2018)
CO_2 Emission Rate (g/kWh)	426.3	488.0	572.4	1,011	1,045	963.4
Natural Gas	5.9%	5.7%	11.4%	19.7%	4.0%	27.5%
Coal	34.0%	39.7%	47.4%	79.3%	90.7%	72.1%
Oil	0.2%	0.0%	0.0%	0.0%	0.0%	0.4%
Nuclear	18.2%	17.7%	0.0%	0.8%	5.0%	0.0%
Hydro	0.0%	0.1%	12.9%	0.0%	0.0%	0.0%
Wind	41.5%	36.6%	27.9%	0.0%	0.0%	0.0%
Solar	0.1%	0.0%	0.0%	0.2%	0.0%	0.0%
Biomass	0.1%	0.1%	0.1%	0.0%	0.2%	0.1%

Figure 23 shows the notable differences between baseload power (which includes large portions of zero-carbon wind and nuclear generation in Kansas) compared to dispatchable power generation units run for seasonal summer and winter loads (which includes large amounts of coal and some natural gas generation).

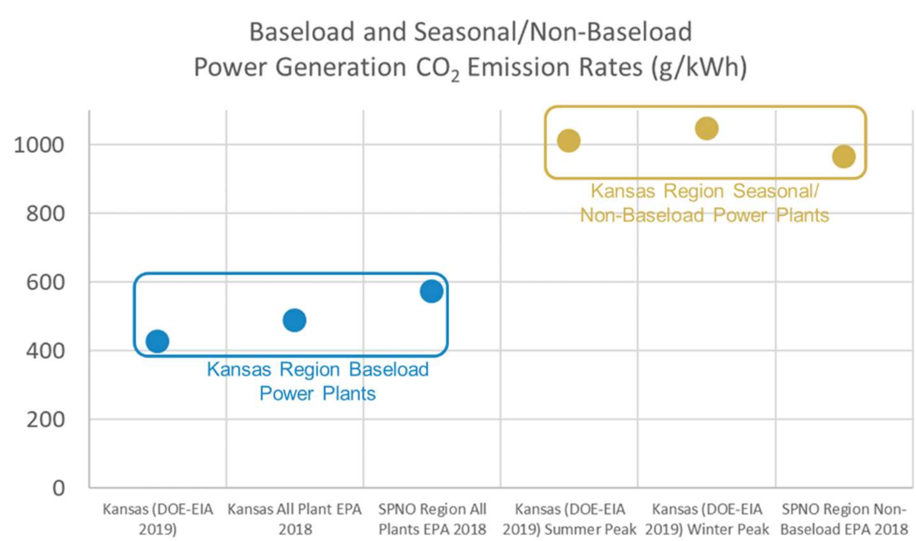


Figure 23: Kansas Region Baseload and Non-Baseload Power Generation CO_2 Emission Rates

Figure 24 shows 2019 data for Kansas on baseload, winter, and summer generation mix from coal, natural gas, wind, and solar resources; solar is currently at *de minimis* levels in Kansas. Baseload generation is the nominal spring and fall months and compared to the summer and winter peak months (e.g., July and January). The positive seasonal generation values (i.e., above the dashed lines) are the incremental, dispatchable seasonal resources that meet peak summer or winter electricity use. In Kansas, summer and winter electricity peaks are met mainly with coal and some natural gas (in the summer). Wind generation tends to peak in spring and fall months, with a decrease in the winter and summer. With high coal reliance to meet winter peaks, shifting to electric space heating today in Kansas calls upon a generation mix with roughly double the CO_2 emission rates of baseload power plants. Under the current situation, this would be highly unfavorable to realizing GHG reductions when switching residential space heating from natural gas to electricity.

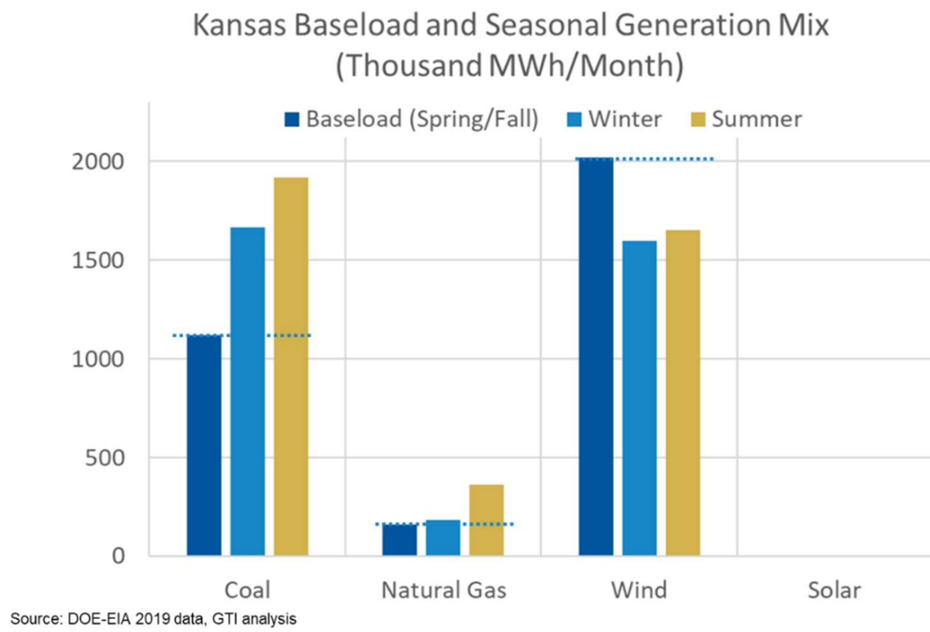


Figure 24: Kansas 2019 Baseload, Winter, and Summer Generation Mix (DOE-EIA)

Solar and wind generation varies throughout the year. Figure 25 shows monthly Kansas wind generation output. There are general spring month peaks that occur with distinct levels of winter and summer decreases in output.

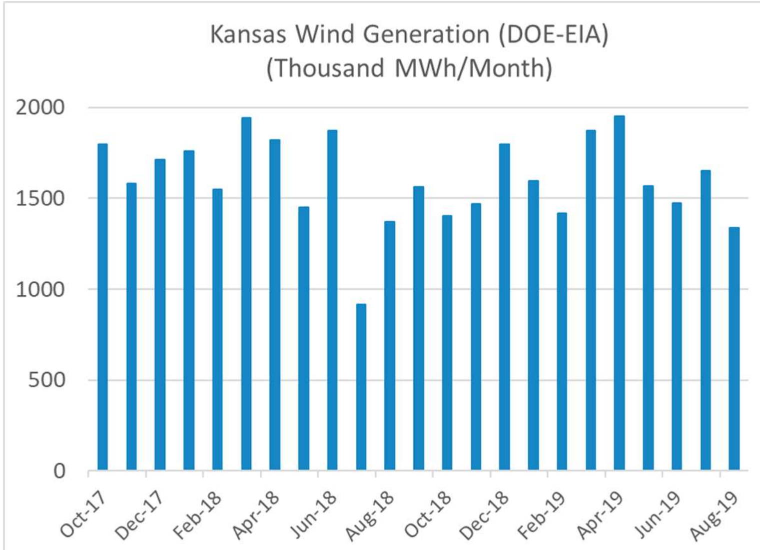


Figure 25: Monthly Kansas Wind Generation (DOE-EIA)

Solar (Figure 26) is a small percentage of the power generation mix in Kansas but this figure shows an over 50% decline during the winter compared to summer peaks. This is due to the fewer winter sunlight hours and reduced sun angle; increased cloud cover or snow accumulation can also reduce winter solar PV output. This pattern of decreased output during winter months is seen with solar in general, with larger decreases in more northern regions (i.e., higher latitude).

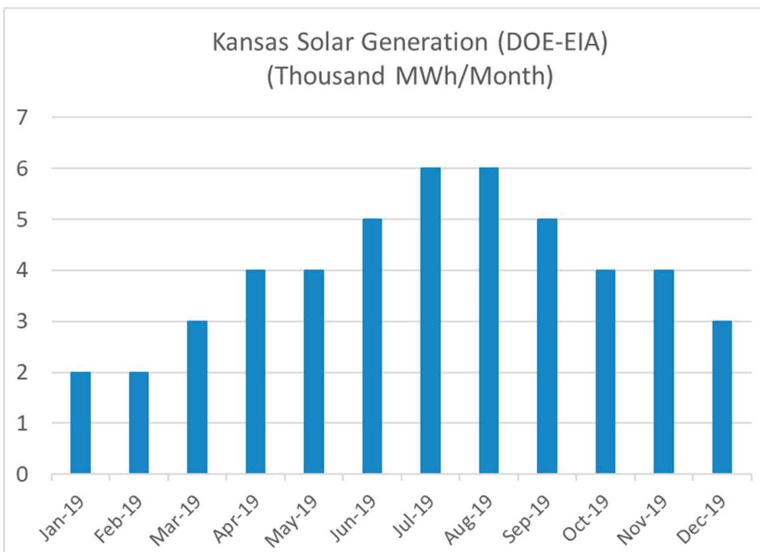


Figure 26: Monthly Kansas Solar PV Generation (DOE-EIA)

A subsequent report section provides details on full-fuel-cycle emissions from using natural gas and electricity in the Kansas residential sector. In advance, there are several key interim conclusions based on this section:

- The current average or baseload Kansas power generation CO_2 emission rate (approaching 400 g/kWh) has improved in recent years and is now around the US average

- Incremental or marginal winter seasonal power generation emission rates in Kansas are more than double the baseload emission rates in the state. Currently, this makes it particularly unattractive to replace natural gas space heating with electricity as a GHG reduction strategy.
- There is no evidence wind or solar resources can help seasonal, intensive space heating electricity peaks during Kansas winters. Furthermore, solar PV has a notable drop in winter output.

Future Power Generation Scenarios in Kansas

The future Kansas power generation outlook can be gauged based on the current generation mix, coupled with market experience in recent years, and assumptions on the continued phasing-out of coal generation. In a business-as-usual scenario, this can be feasibly done. However, there are limitations when considering a longer-term framework with widespread residential electrification as the load profiles will change in a meaningful way.

Figure 27 shows the current and projected electricity use in Kansas in a widespread residential electrification scenario. This includes a 25% in annual electricity use, 109% increase in residential peak month electricity use, and an over 30% increase in peak monthly use (a shift from the current summer peak in August to a winter peak in January). The graph identifies the nominal monthly coal generation that needs to be displaced and the new winter seasonal peak. This information will be used to craft future scenarios with a mix of baseload and seasonal, non-baseload power generation sources.

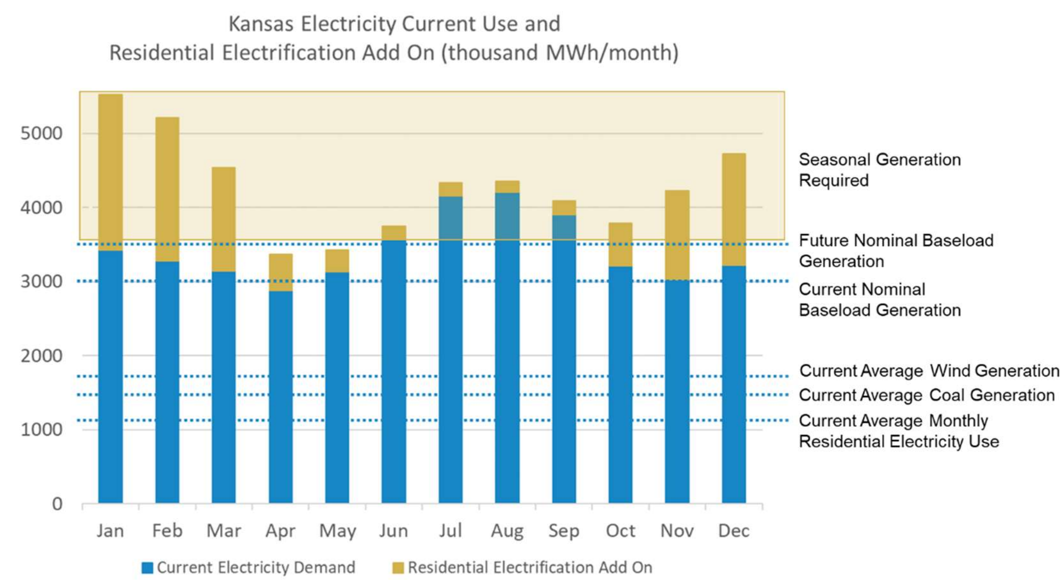


Figure 27: Kansas Current Monthly Electricity Use and Projected Impact of Full Residential Electrification

There are three major changes to address the type of demand profile change shown in Figure 27:

- Step 1: Replace Kansas coal generation with a mix of wind, solar, and natural gas.
- Step 2: Add baseload generation to address future elevated year-round baseload electricity demand.
- Step 3: Add low GHG dispatchable generation to meet increased seasonal peak electricity demand driven by electric space heating use. This step is largely addressed by dispatchable

natural gas combined-cycle generation backed up with natural gas storage (based on the current market situation).

Wind and solar have no peak winter seasonal generation capability. In addition, their baseload output drops in winter and results in a shortfall that needs to be made up with natural gas power generation or some other source. Generally hydro and pumped hydro storage can be a seasonal option but is not practicable in Kansas. 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 option power generation option for meeting about four months of winter seasonal demand (i.e., Step 3) is likely based on dispatchable natural gas generation. The GHG reduction implications of replacing natural gas space heating with mainly natural gas combined-cycle power generation will be explored in the next section – but the benefits are limited and likely 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

Using the term "baseload" for wind energy is a misnomer. While wind output can be summed up as a total monthly number, with some month-to-month variation, actual hourly wind output can and does fluctuate in an extremely dynamic manner. Figure 28 illustrates the hourly power output of the regional power mix over 30 days. In this figure, the only stable, baseload power generation source is nuclear – its hourly output remains unchanged over time. Coal and natural gas plants can operate as baseload resources, but in this example (which includes power generation plants in Kansas), coal and natural gas power plants are used to dynamically compensate for variability in wind output and demand. The hourly and intra-day wind fluctuations are dramatic and can lead to multiple days of very lower wind generation output. When wind output drops, coal and natural gas generation rise along with CO_2 emission rates.

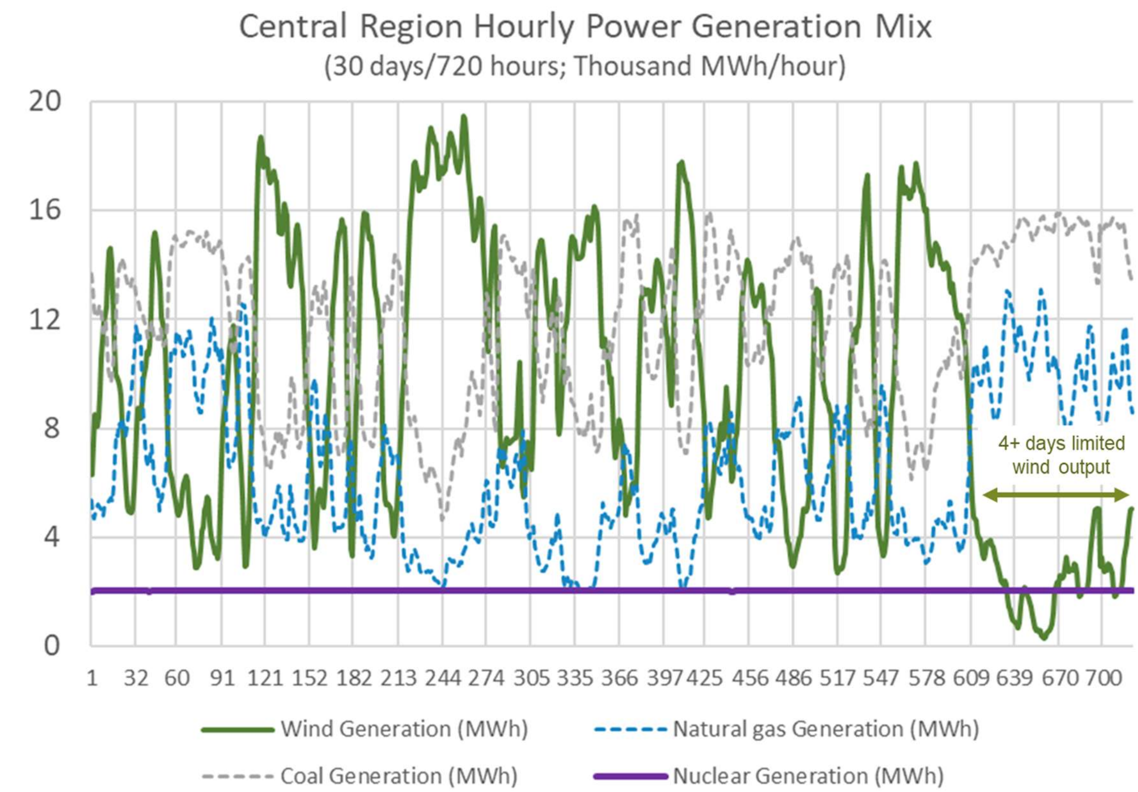


Figure 28: Hourly Central Region Power Output From Selected Resources (Dec 13, 2020 – Jan 11, 2021; Source: DOE-EIA)

As the market share of wind generation increases, there will be even greater grid operation challenges; examples include the potential need for curtailments and negative market pricing. Further, because electric space heating is such a large seasonal demand increase, a significant portion of incremental winter power generation will likely rely on dispatchable sources such as natural gas combined-cycle plants. One other area of uncertainty is the outlook for aging nuclear power plants – a problem that plagues the Kansas and US nuclear power fleet. Loss of nuclear generation could reduce grid inertia and stability.

With this backdrop, it is possible to hypothesize future scenarios for power generation in Kansas. Several key assumptions are made: (1) coal-fired generation is completely phased out in the future, (2) nuclear power output remains unchanged, and (3) a significant portion of seasonal winter electricity use (and daily grid stabilization) will come from dispatchable natural gas combined cycle plants.

Table 6 shows the current 2019 Kansas power generation mix along with two future 2030-2040 timeframe power generation scenarios. This assumes the level of dispatchable resources is a feasible approach that allows stable grid operation in the face of high intermittency from wind and solar resources, but further modeling would be warranted. These two scenarios represent sizeable reductions in CO_2 emission rates, 60% and 69% lower than the current Kansas power generation mix. This level of performance is beyond what is now realized in leading states such as California and New York GHG today. Along with the current generation mix, these future scenarios will be used in the benefit/cost analysis section of this report.

Table 6: Current and Two Future Kansas Power Generation Scenarios

Future Kansas Power Generation Mix Circa 2030-2040	Current Power Generation Mix (2019)	Scenario 1: Base Case Future Kansas Generation Mix	Scenario 2: Higher Renewables Future Kansas Generation Mix
Natural Gas	5.9%	35%	27%
Coal	34.0%	0%	0%
Wind	41.5%	45%	50%
Solar	0.1%	2%	5%
Nuclear	18.2%	18%	18%
CO_2 Emission Rate (g/kWh)	426	170.3 (-60%)	133.0 (-69%)

In addition to new wind installations, there will be a need to repower or replace existing wind turbine facilities in Kansas and to address disposition options for end-of-life wind turbine systems as pre-2015 installations start to reach the end of their useful life. Further progress is needed, for example, to establish effective materials recycling for wind turbine blades beyond landfilling. In various parts of the US, these issues will likely be of growing importance starting for wind and solar systems around 2025 and beyond.

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 29, 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.

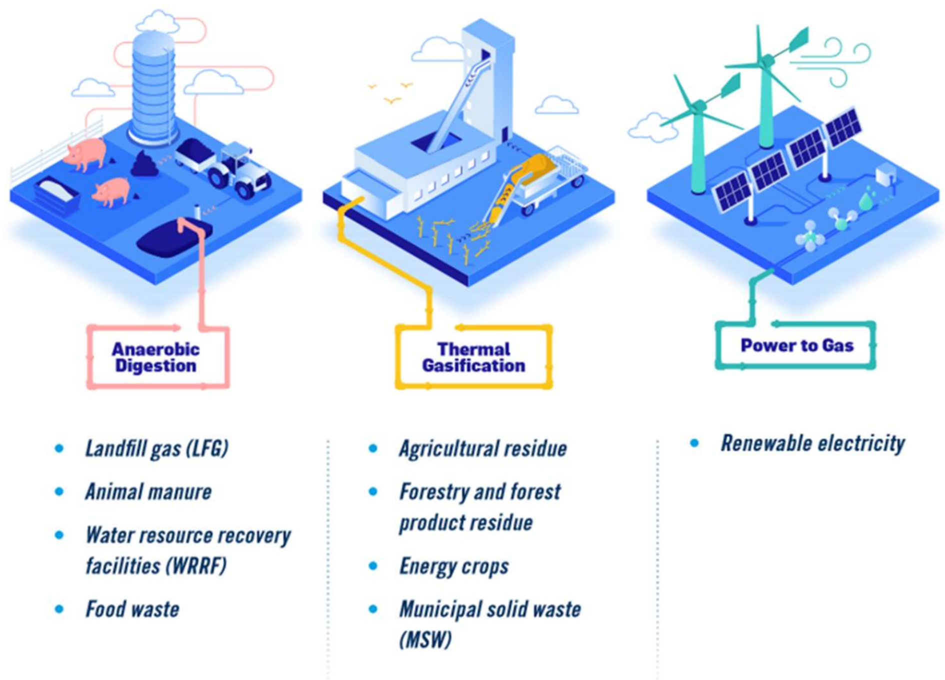


Figure 29: Renewable Gas Generation Pathways (Source: American Gas Foundation)

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 30). The 2040 renewable gas potential 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 Kansas, the AGF report indicates a technical resource potential for conventional biogas plus thermochemical-produced gases of about 600 Trillion Btu/year. Much of this could be derived from the agricultural sector and from energy crops through gasification. This amount of 600 Trillion Btu/year is significantly more than the roughly 70 Trillion Btu/year of natural gas consumed in Kansas homes. In theory, all residential natural gas use could be displaced with bio-methane produced from Kansas bio-based materials.

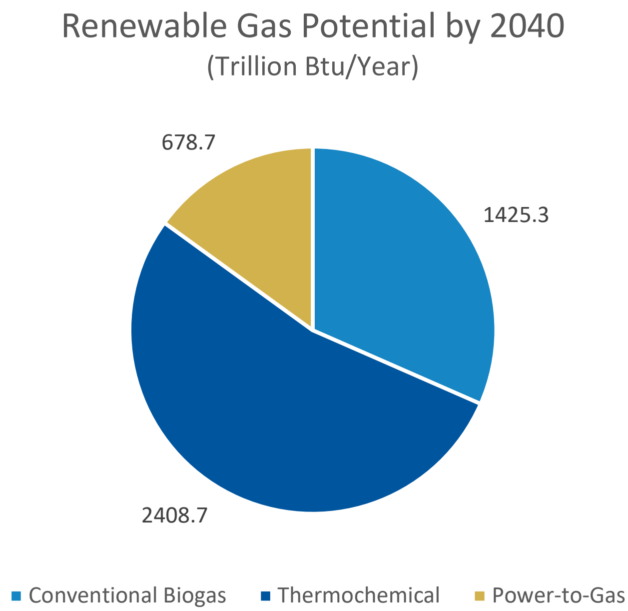


Figure 30: American Gas Foundation/ICF Renewable Gas Potential

Figure 31 is a snapshot of the operational biogas/bio-methane potential in the State of Kansas. Presently, there are about 28 bio-methane systems operating in the state. From a GHG policy perspective, these systems provide a highly effective means of (1) displacing the use of conventional natural gas and (2) reducing methane emissions that may otherwise be released to the environment.

Figure 31: American Biogas Council Kansas Operational RNG Plants

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 Kansas 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.

Lawrence, KS Residential Greenhouse Gas (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 Lawrence, KS 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 7 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 7: Lawrence, KS 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			
1800 ft^2 single-family home using Case 2 (gas) and Case 9 (electric) input; with Lifecycle Cost Analysis (LCA)	14		
Space heating only with 100% natural gas power generation for peak winter heating with electric heat pumps (HSPF = 9, HSPF = 13) compared to a 98% efficient natural gas furnace	15, 16		
Building Envelope Improvements			

The main thrust of this analysis focuses on energy used for space heating, water heating, cooking, and clothes drying applications. To properly account for capital costs, the natural gas cases include the cost of central air conditioning systems in 80% of the homes. This allows for equitable capital cost treatment of electric heat pumps which are more expensive than gas furnaces but also provide cooling. The cases with 50% renewable natural gas (RNG) assume an RNG price of $15/MMBtu.

The current Kansas power generation and future Scenario 1 and 2 power generation mixes, shown previously in Table 6, 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. In this analysis, equipment capital costs are annualized by a simple amortization achieved by dividing the capital cost by the 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 is warranted about capital costs. The EPAT tool relies on the NREL National Residential Efficiency Measures (NREM) Database for equipment costs. This NREM information resource may underestimate installed equipment costs. Further, there are likely to be instances where consumers face additional upfront costs in switching a home from natural gas to all-electric systems. This includes potential costs to upgrade the service panel and for additional home circuits. There may also be additional costs to upgrade space-conditioned air distribution systems in the home, particularly for homes currently 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 on a retrofit basis.

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).

The 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 – reported as $/metric ton of CO_2 or CO_2e reduced. In most cases, the GHG abatement cost results in 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 while also 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.

In some instances using the current Kansas power generation mix the level of GHG emissions increases over the natural gas baseline. These cases are labeled “GHG Increase” without any GHG abatement cost (i.e., it is not a GHG reduction measure).

Lawrence, KS Home GHG Reduction Pathways Cost and Benefit Results

Table 11 (at the end of this report section) provides summary data on Cases 1 through 13 described in the prior section. Detailed reports on each case are included in an appendix to this report.

> **Main Finding**: Using today’s current Kansas power generation mix, two of three electric scenarios show a net increase in GHG emissions, while the third shows a 22% decrease in emissions albeit at a high CO_2 abatement cost of $782/metric ton **(**Table 8**).** Overall, the current power mix is not compelling as a GHG reduction pathway in Lawrence, KS.

Table 8: CO_2 Emissions Change with Current Kansas Power Generation Mix

Electrification Case	Change in CO_2 Emissions
Electric Resistance (Case 5)	53% higher
HSPF 9.0 Heat Pump (Case 8)	10% higher
HSPF 13.0 Heat Pump (Case 11)	22% lower

Main Finding: All three electric scenarios result in significant increases in annual energy bills for Lawrence, KS homeowners (Table 9 and Figure 32). Mid-case electric heat pump (HSPF 9) results in a 95% increase in annual consumer energy costs (about $21 million increase).

Table 9: Annual Energy Cost Increases with Electric Systems

Electrification Case	Annual Energy Bills
Electric Resistance (Case 5)	170% higher ($37 million increase)
HSPF 9.0 Heat Pump (Case 8)	95% higher ($20.6 million increase)
HSPF 13.0 Heat Pump (Case 11)	35.4% higher ($7.7 million increase)

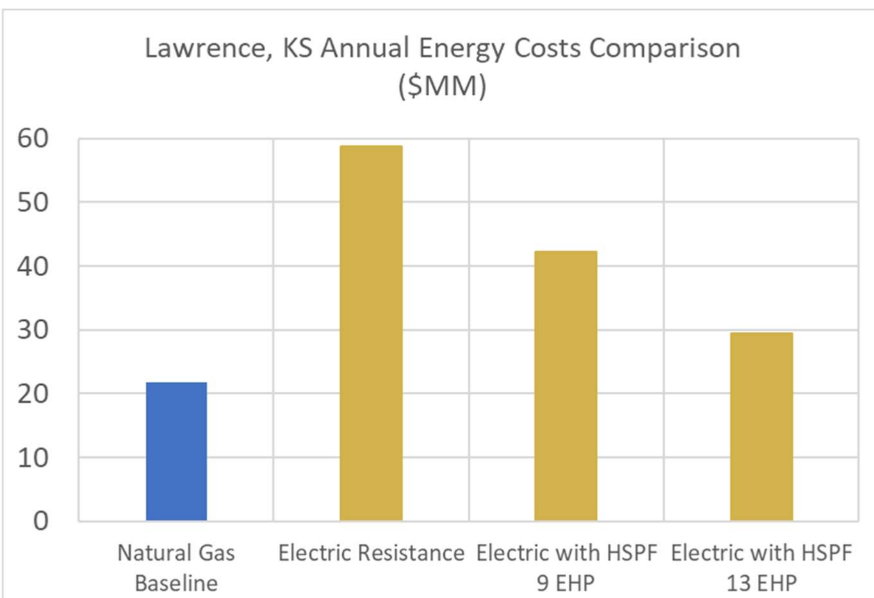


Figure 32: Lawrence, KS Annual Energy Cost Comparison

Figure 33 shows a comparison of natural gas and electric GHG reduction options. Case 1 is the most cost-effective option using available high-efficiency gas equipment followed by the use of renewable gas and emerging natural gas heat pumps. Electrification cases are higher cost, with conventional electric pumps (HSPF 9.0) and possible future power generation mixes having CO_2 abatement costs ranging around $350-410/metric ton. Higher-efficiency electric heat pumps (HSPF 13) and future power generation mix are in the range of $225-250/metric ton. Higher efficiency electric heat pumps come with high initial costs that can impede market adoption. For reference, a GHG abatement cost of $300/metric ton is like adding a $2.67/gallon tax on gasoline or adding $15.92/MMBtu to the cost of natural gas.

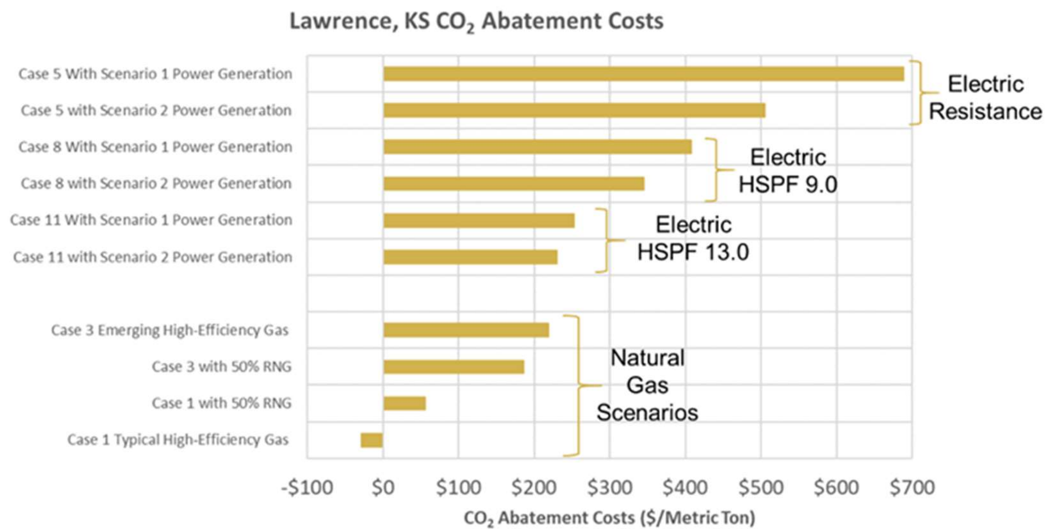


Figure 33: Comparison of CO_2 Abatement Costs ($/metric ton)[1]

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 electric space heating will use 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 34 captures Lawrence, KS 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 60%. Electrification cases require future power generation mix scenarios to effectively reduce GHG emissions and generally entail higher CO_2 abatement costs.

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.

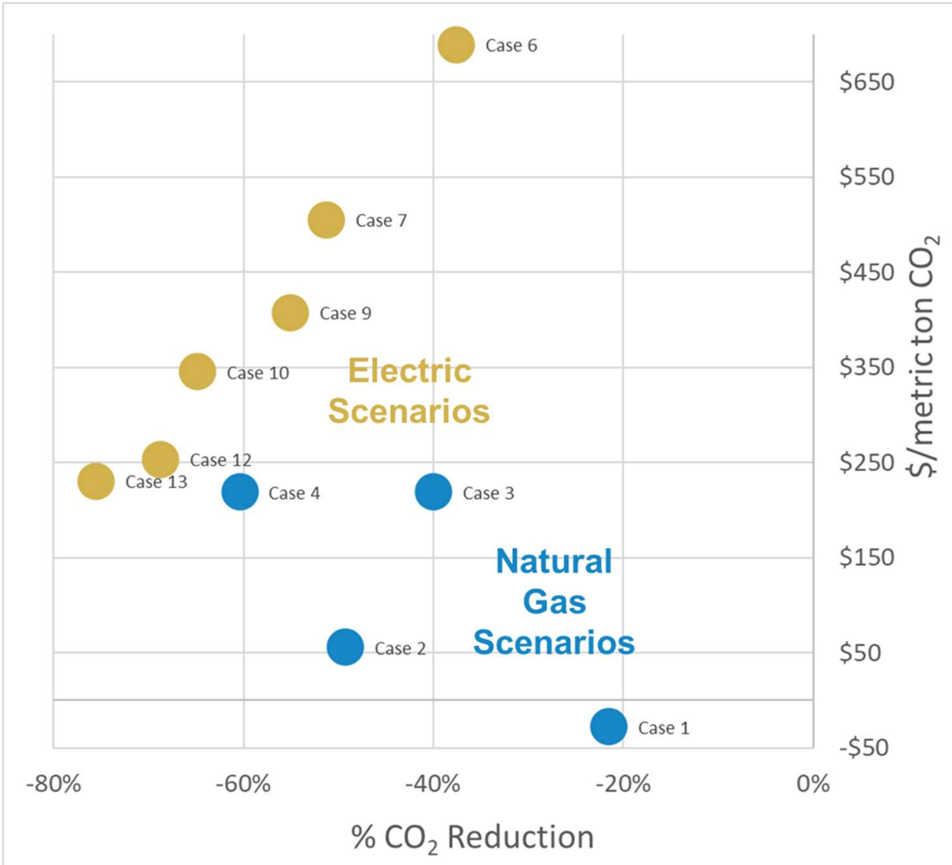


Figure 34: Lawrence, KS Residential GHG Reduction Scenarios

While EPAT serves as a suitable screening tool, it does not dynamically match electric supply sources (and emissions) with year-round real-time demand. The next section discusses the specific case of space heating with dispatchable natural gas generation to meet peak winter demand. Absent clear alternatives, these data highlight that a sizeable portion of the electrification CO_2 reduction potential shown in Figure 34 could be illusory and not likely realized in practice without specific solutions such as natural gas combined-cycle plants running on renewable gas or using carbon capture – or other uncertain alternatives.

Individual Single-Family Homes Cases

This section includes analysis cases based on a typical 1,800 ft^2 single-family home in Lawrence, KS. This provides a benchmark for understanding the impacts of electrification on an individual household.

Single-Family Home With Lifecycle Cost Analysis (LCA)

This section highlights a representative 1,800 ft^2 single-family home that now uses efficient gas appliances (Case 2) and is required to move to all-electric equipment as highlighted in Case 9 (e.g., HSPF 9 electric heat pump). The Case 14 results highlight the nominal energy bill for the gas and electric scenarios for space heating, water heating, cooking, and drying in this home. We also highlight an LCA analysis for net present lifecycle costs for a homeowner from 2020 2050, building on data from the DOE-EIA 2020 Annual Energy Outlook. More details are in the appendix.

Figure 35 shows results from this case, with today's annual energy costs for electric homes being more than twice those for a home using natural gas for these four primary energy uses (i.e., space heating, water heating, cooking, and drying). Homeowners would face significant ongoing costs – which are likely to be even higher when including home electric service upgrade costs to handle this expanded suite of electric loads.

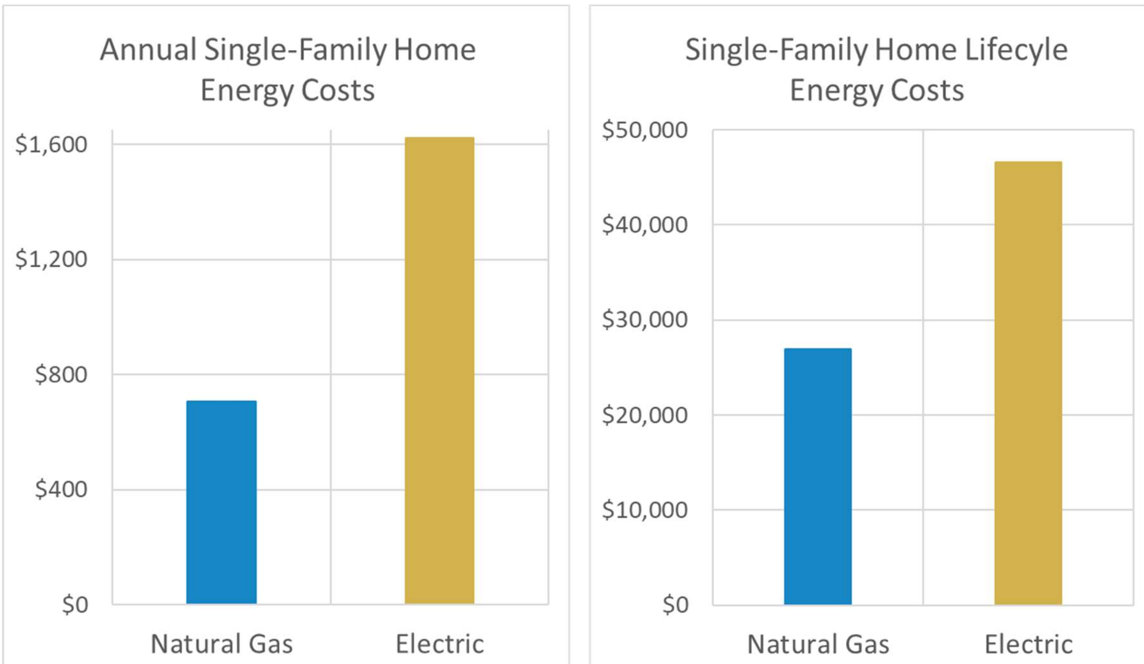


Figure 35: Annual Energy Costs and Lifecycle Costs for Typical 1,800 ft^2 Single-Family Home in Lawrence, KS

Special Space Heating Only Cases

This report has highlighted the significant real-world challenges with seasonal home space heating in cold regions such as Kansas. In particular, prior graphs – for example, Figure 6 and Figure 27 – help illustrate the challenge. 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 1,800 ft^2 single-family home using a 98% efficient gas furnace. Under these assumptions, typical electric heat pumps have notably higher GHG emissions while more efficient electric heat pumps result in a slight decrease. Each electric heat pump results in a large increase in space heating costs. The more reasonable and cost-effective GHG reduction pathway is operating a high-efficiency gas furnace.

Table 10: Comparison of Gas and Electric Heating Using 100% Natural Gas Power Generation (Case 15, 16)

Case	Heating Only Annual Cost ($MM)	CO_2 Emissions kg/year
Natural Gas 98% Furnace	$495	2,776
HSPF 9.0 Heat Pump (Case 15)	$884	3,089
HSPF 13.0 Heat Pump (Case 16)	$740	2,585

When qualitatively considering the results in Table 10 with electric space heating operating with dispatchable natural gas power generation, the real-world emission reductions from electrification will be less than anticipated and the costs will be higher. Figure 36 shows the results if 50% of electric space heating uses natural gas generation and the balance the average grid mix (orange circles). The effect is to raise the relative GHG emissions for electrification and increase the carbon abatement cost.

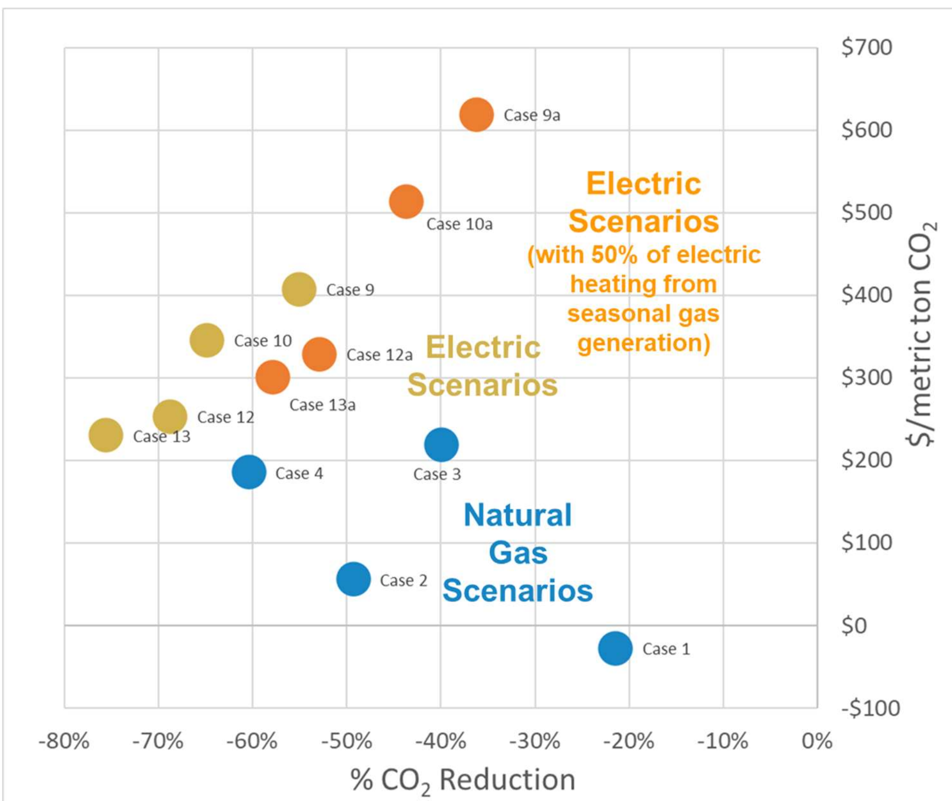


Figure 36: Directional Impact of Winter Peak Electricity Use

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	$21.71	$10.56	$32.27	0.120	0.136	--	--
1	Typical High-Efficiency Gas Equipment	$17.74	$13.82	$31.56	0.094	0.107	-$28	21.5%
2	Case 1 with 50% RNG	$21.76	$13.82	$35.57	0.061	0.073	$56	49.3%
3	Emerging High-Efficiency Gas Equipment	$15.55	$27.20	$42.75	0.072	0.081	$219	39.9%
4	Case 3 with 50% RNG	$18.51	$27.20	$45.71	0.047	0.056	$186	60.4%
5	Baseline All Electric Resistance Equipment / Current Power Generation	$58.67	$4.65	$63.31	0.183	0.192	GHG Increase	GHG Increase
6	Case 5 with Scenario 1 Power Generation	$58.67	$4.65	$63.31	0.075	0.081	$689	37.6%
7	Case 5 with Scenario 2 Power Generation	$58.67	$4.65	$63.32	0.058	0.063	$505	51.3%
8	Typical High-Efficiency Electric Equipment/Current Power Generation	$42.27	$16.87	$59.14	0.132	0.138	GHG Increase	GHG Increase
9	Case 8 with Scenario 1 Power Generation	$42.27	$16.87	$59.14	0.054	0.059	$407	55.0%
10	Case 8 with Scenario 2 Power Generation	$42.27	$16.87	$59.14	0.042	0.046	$345	64.9%
11	Emerging High-Efficiency Electric Equipment/Current Power Generation	$29.39	$23.74	$53.13	0.093	0.096	$782	22.2%
12	Case 11 with Scenario 1 Power Generation	$29.39	$23.74	$53.13	0.037	0.041	$253	68.7%
13	Case 11 with Scenario 2 Power Generation	$29.39	$23.74	$53.13	0.029	0.032	$230	75.6%

Additional Home Electrification Considerations and Challenges

This section discusses additional challenges or issues pertaining to the expanded use of electricity as a natural gas replacement in Lawrence, KS 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 37 shows results of a prior GTI analysis of space heating electrification impact on peak winter demand in 17 different states. This data highlight 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, the decreased solar PV output during the winter largely negates their ability to offset this challenge.

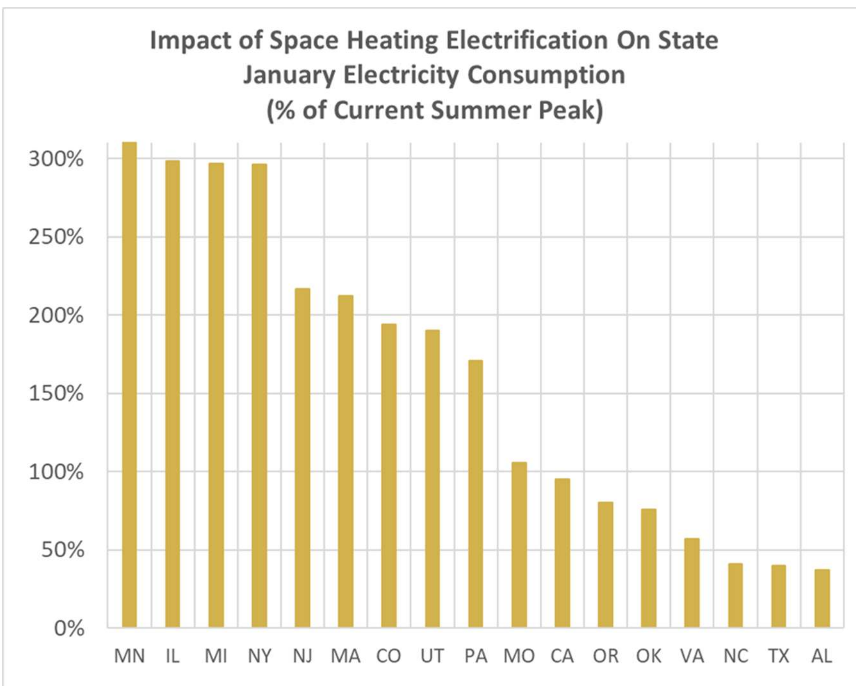


Figure 37: Impact of Electrification on Peak Winter Demand (Source: GTI)

The ability of the natural gas energy delivery system to successfully meet the most severe peak winter demand is due to the major energy-carrying capacity of gas pipelines and natural gas storage (discussed in the next section). Figure 38 and Table 12 illustrate the typical rated energy delivery capacity of an interstate natural gas pipeline relative to electric transmission lines. A typical gas transmission pipeline has 10-50 times the energy delivery capacity of electric transmission lines.

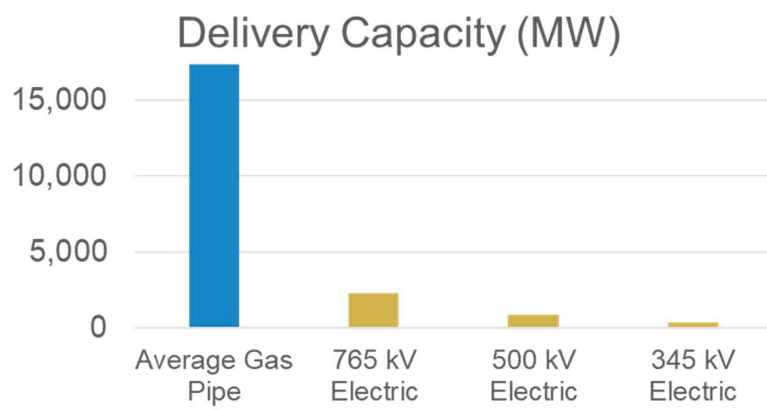


Figure 38: Major Natural Gas and Electric Transmission System Capacity (DOE, AEP)

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

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

In addition to winter peak demand 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.

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%)	69% (31%)	80% (20%)

Figure 39 illustrates 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 much larger winter heating loads discussed earlier. Replicating this capacity with electric 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.

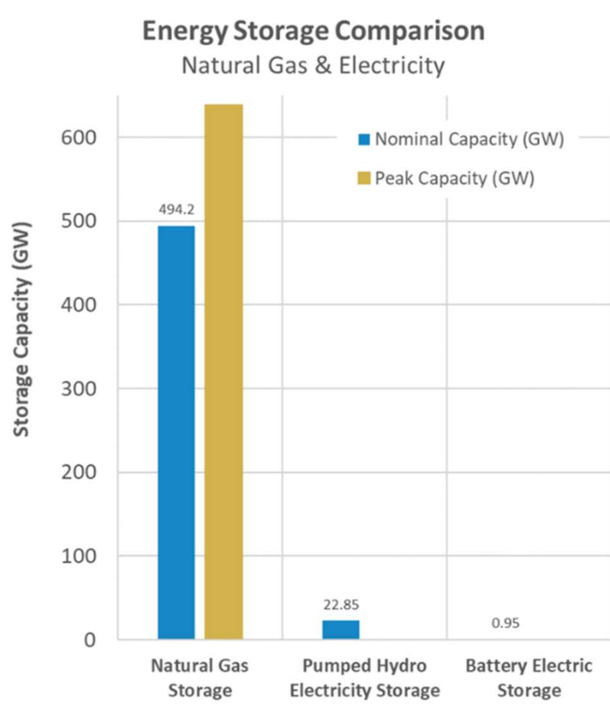


Figure 39: Nominal Energy Storage Capacity (DOE-EIA)

Figure 40 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.

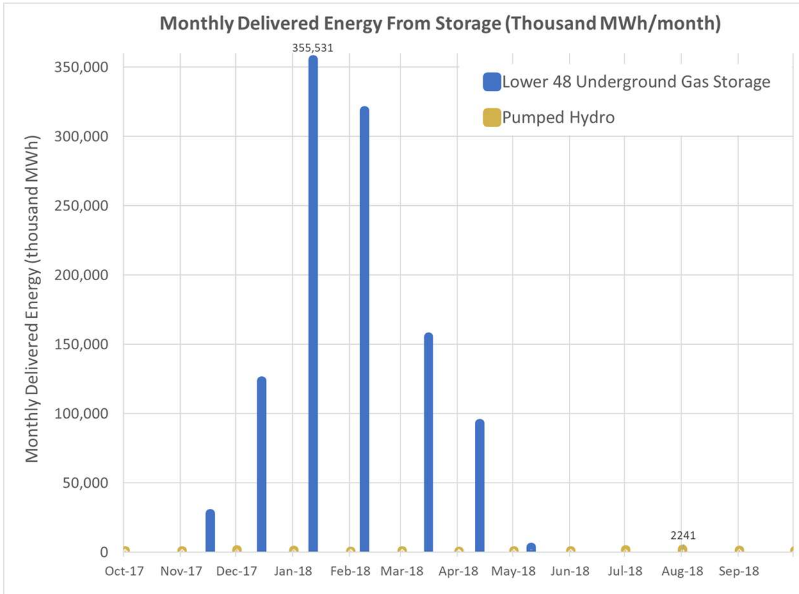


Figure 40: Example Monthly Energy Delivery for Storage (DOE-EIA)

Figure 41 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 10-30% and pumped hydro cycle losses are typically slightly higher. Electric storage system loss impacts raise electricity costs and could necessitate even larger investments in generating capacity to compensate for storage losses.

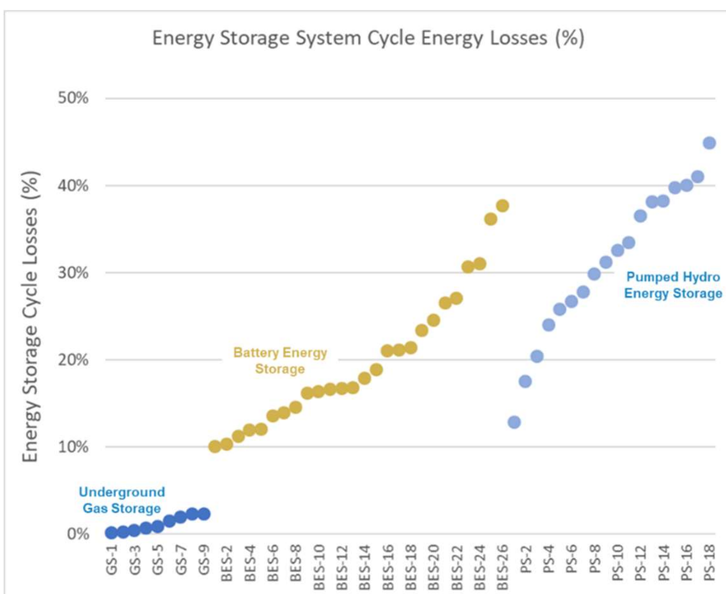


Figure 41: Energy Storage Cycle Energy Losses (DOE-EIA, GTI)

Battery energy storage lacks the seasonal storage capability needed for winter electric space heating. Figure 42 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 (supporting 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.

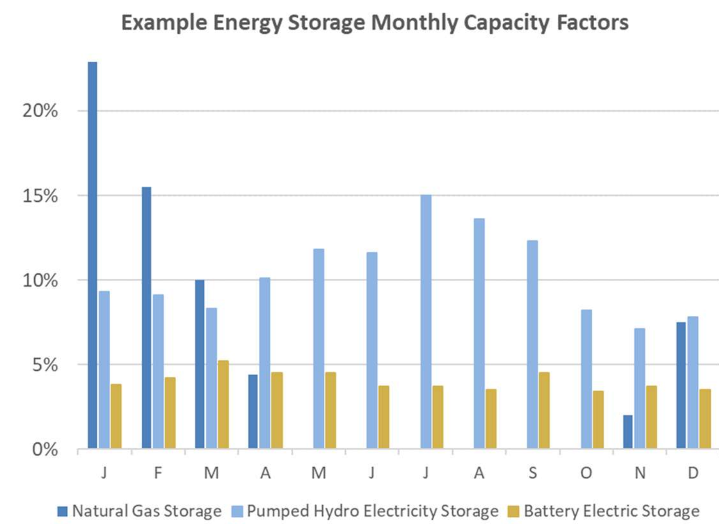


Figure 42: Example Energy Storage System Capacity Factors (DOE-EIA)

Figure 43 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.

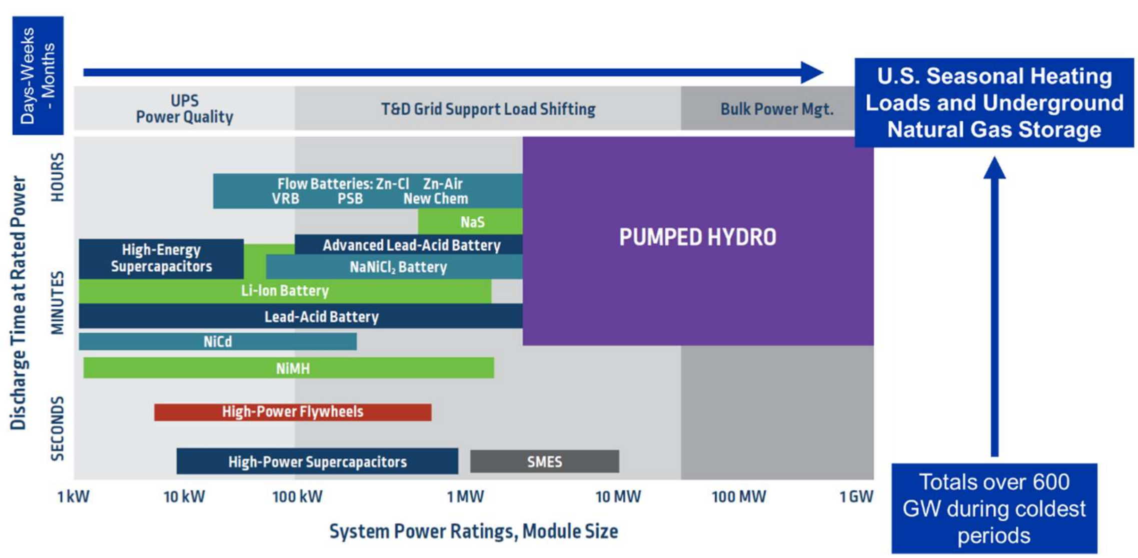


Figure 43: Size and Duration of Energy Storage Systems
(adapted from National Hydropower Association report)

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; pumped hydro is generally not topographically practical in Kansas.

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 available at all times (Figure 44).

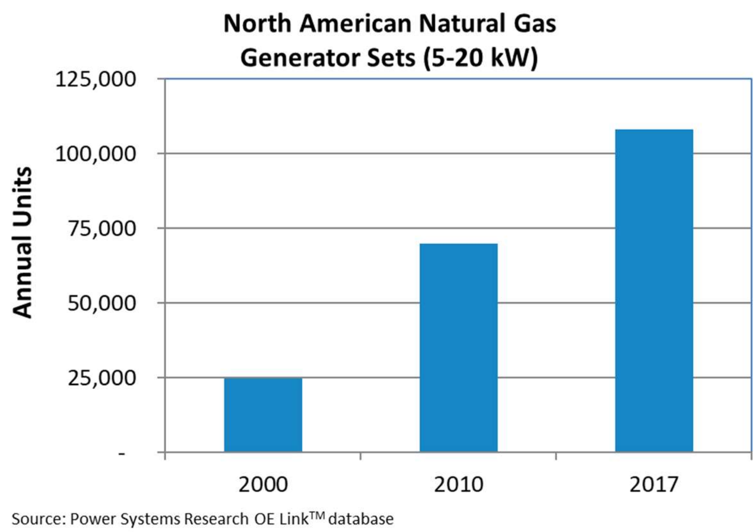


Figure 44: Trends in North American Residential Natural Gas Generators Units

Figure 45 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 are using to ensure their home's energy supply reliability and resilience (Figure 46). 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).

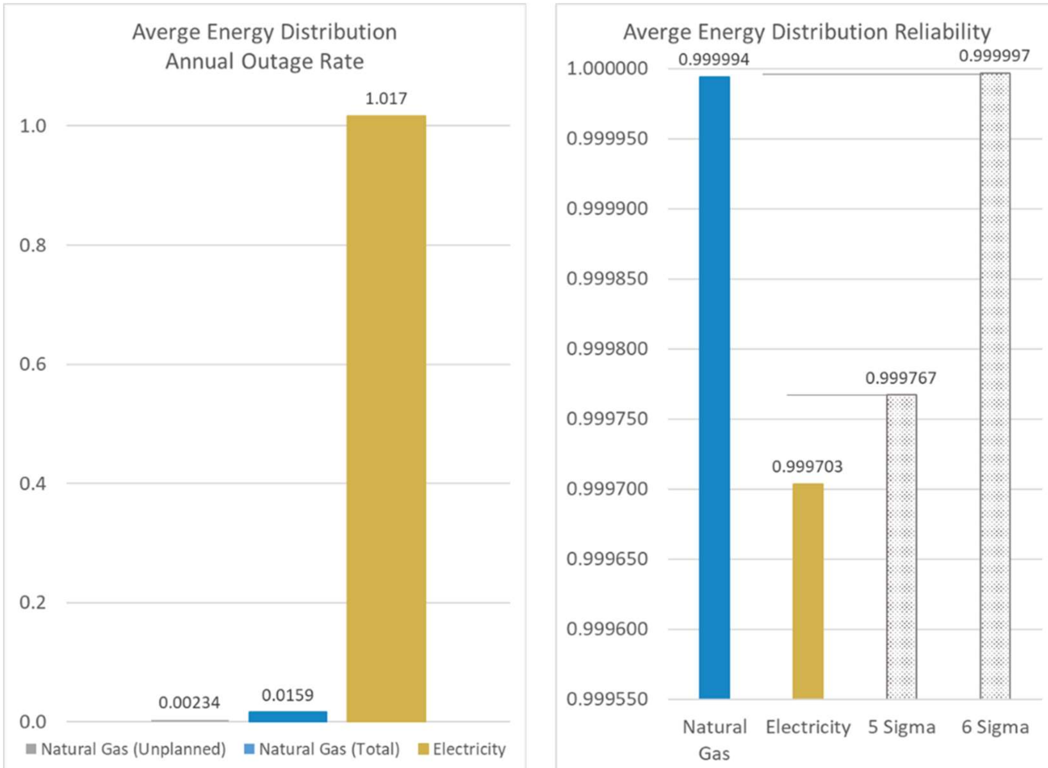


Figure 45: Natural Gas and Electric Distribution Outage Rates and Service Reliability

Figure 46: Example Residential and Commercial/Industrial Natural Gas Generator Sets

Lawrence, KS Home GHG Reduction Recommendations

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

- Natural gas is an important cost-effective, and abundant natural resource that provides tremendous value to consumers and the nation as a whole
- Two energy delivery systems – natural gas and electricity – can provide an optimized approach to energy delivery and reliability; each have corresponding GHG impacts which to varying degrees may include indirect or unforeseen impacts
- 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 move to lower GHG emissions will 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 Lawrence, KS natural gas home GHG reductions:

1. A core focus on energy efficiency improvements
2. A no regrets emphasis on building envelope efficiency improvements that help consumers – particularly older homes – lower their annual energy costs, improve indoor comfort, reduce natural gas and electric energy consumption (including peak energy demand), and minimize GHG emissions
3. 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. Expanded 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) working 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 Lawrence, KS 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 2019, Kansas homeowner electricity prices are over four 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 Lawrence, KS homeowners.** Mid-case electric heat pump (HSPF 9) results in a 95% increase in consumer energy costs, about $20.5 million annual increase, for all homes now using natural gas in Lawrence.
- Figure 47 shows annual energy costs and lifecycle net present cost comparisons (2020-2050) for a typical 1,800 ft2 home in Lawrence between gas and electric. With electrification, energy bills would nearly double today for a typical single-family home.

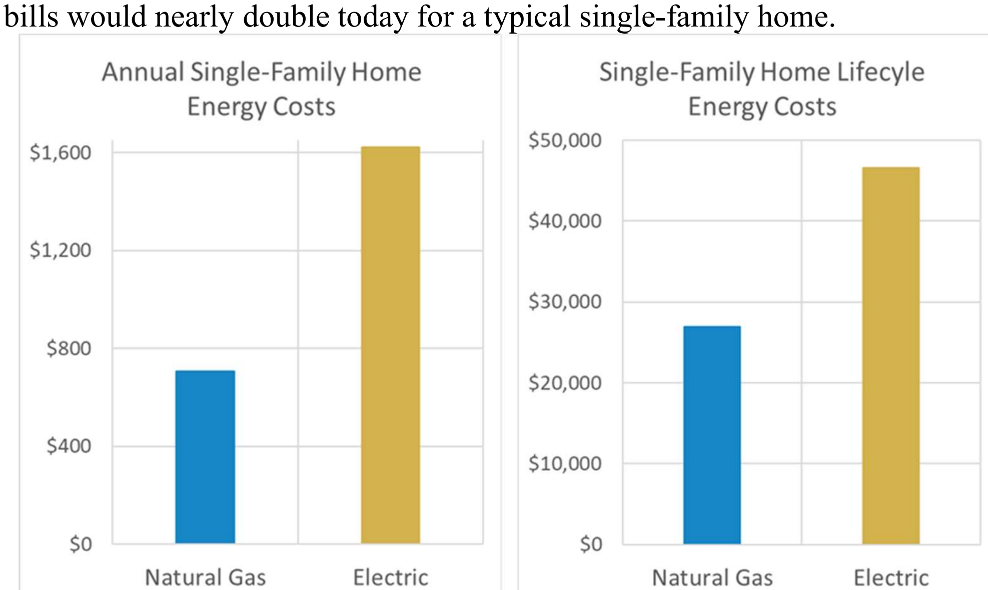


Figure 47: Annual Energy Costs and Lifecycle Costs for Typical 1,800 ft^2 Single-Family Home in Lawrence, KS

- **Existing all-electric homes in Kansas using the current average power generation mix in the state result in higher CO_2 emission rates** than a baseline home with gas appliances in most instances.
- **Natural gas pathways for GHG reductions have lower consumer and societal costs when measured in $/metric ton of CO_2 reduced (**Figure 48**).** Using currently available high-efficiency gas equipment results in very cost-effective GHG reductions (-$28/metric ton of CO_2). Renewable natural gas with existing high-efficiency equipment and next-generation

natural gas heat pumps raise total GHG reduction potential at higher costs ($55 to $220/metric ton of CO_2). Electric scenarios are all higher cost, with conventional HSPF 9 heat pumps and future grid scenarios having abatement costs of $345 to $410/metric ton.

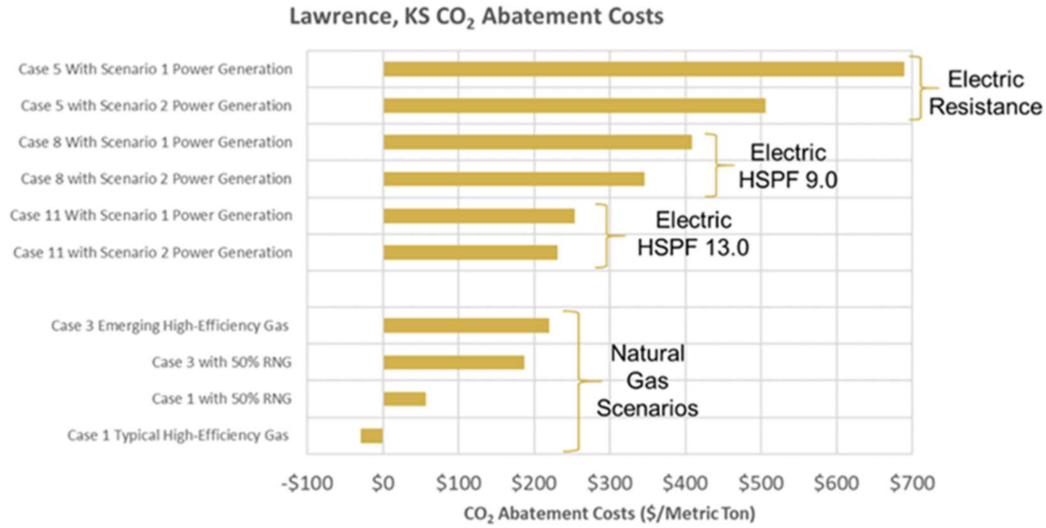


Figure 48: Comparison of CO_2 Abatement Costs ($/metric ton)

- A three-step process is outlined for Kansas power generation evolution over the next 10-20 years (from 2030 to 2040): (1) replacement of coal generation, (2) additional capacity for expanded baseload generation under an electrification scenario, and (3) strategies to address high seasonal winter electricity demand. Step 3 is the most challenging market development need and worthy of more concentrated RD&D to find solutions.
- **A significant issue with residential electrification scenarios is the intense seasonal energy demand for space heating during the coldest days**. The challenges with cold-weather space heating are often oversimplified, underestimated, or not properly conveyed in public policy electrification discussions. The potential power generation and electric infrastructure cost and reliability implications for consumers and society are significant.
- **There is no evidence wind or solar resources can address prospective seasonal energy-intensive space heating electricity peaks during Kansas winters**. Solar PV systems have a significant drop in winter output.
- Using the matching principle and reasonable options at this juncture, **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 battery energy storage can play a value-added role in meeting high winter electricity demands and pumped hydro is not a practicable option for Kansas.
- Using hybrid space heating systems whereby electric heat pumps operate at milder temperatures and natural gas heating systems operate 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.

The following is a suggested set of energy efficiency and GHG reduction measures for Lawrence, KS natural gas homes:

1. A core focus on energy efficiency improvements
2. A no regrets emphasis on building envelope efficiency improvements that help consumers – particularly older homes – lower their annual energy costs, improve indoor comfort, reduce natural gas and electric energy consumption (including peak energy demand), and minimize GHG emissions
3. 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. Expanded 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) working 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)

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.

William Liss, Vice President – GTI

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.

Patricia Rowley, R&D Manager – GTI

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.

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

CASE 1

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	Natural Gas, AFUE 98% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 9,679 (10^3 Therm) Installed Cost: 2,807 $/Unit + 3.86 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 14,827 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 1,455 (10^3 kWh) Gas Consumption: 4,114 (10^3 Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.91	1.09	1.15

Composite Emission Factors

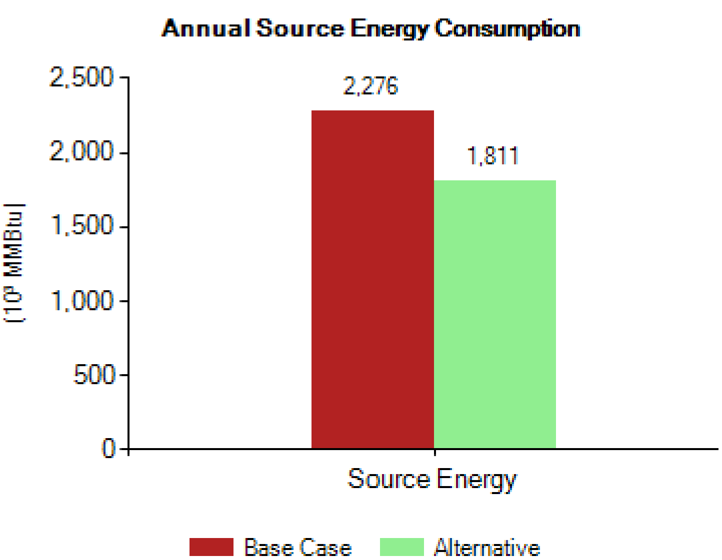
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	324.0	0.090	0.930	0.988	0.0010	351.8
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

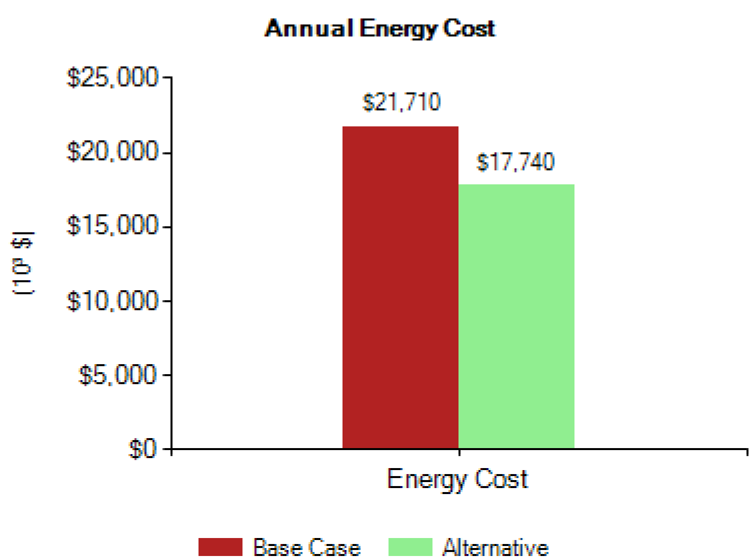
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 19,885 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 1,988.50 0.00 0.00 2,045.33	108.54 0.00 2,167.47 0.00 0.00 2,276.00	2,223 0 19,487 0 0 21,710	152,042 +$75.08
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	19,458 (10^3 kWh) 0 (10^3 kWh) 15,451 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	66.39 0.00 1,684.16 0.00 0.00 1,611.49	126.81 0.00 1,684.16 0.00 0.00 1,810.97	2,598 0 15,142 0 0 17,740	221,980 +$75.08

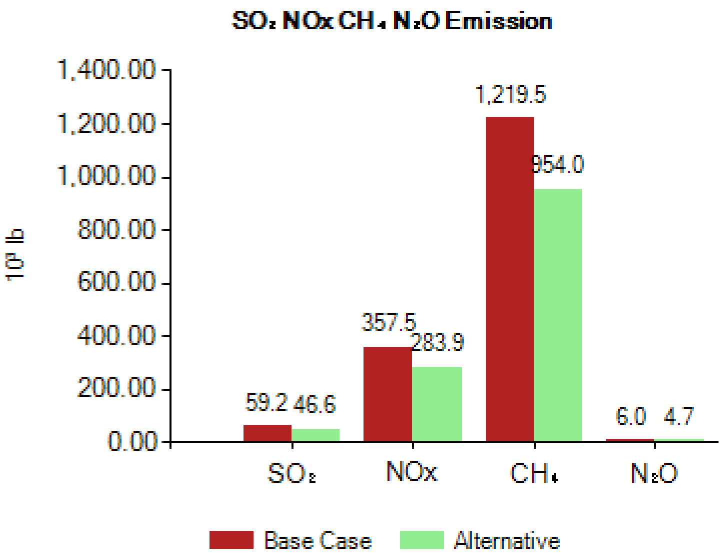
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	3,970	69,938	17.6

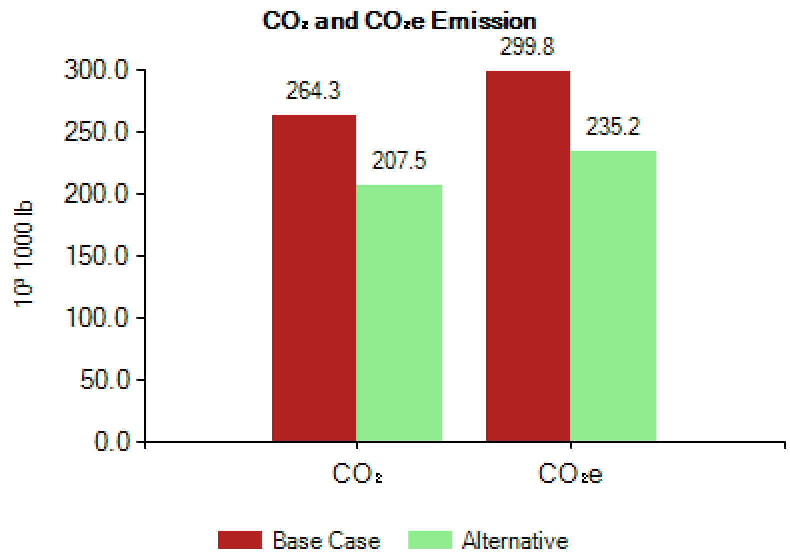




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	59.17	357.51	264.30	1,219.50	5.98	299.76
Alternative	46.56	283.85	207.48	954.01	4.65	235.21





CASE 2

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: User-Specified prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	Natural Gas, AFUE 98% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 9,679 (10^3 Therm) Installed Cost: 2,807 $/Unit + 3.86 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 14,827 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 1,455 (10^3 kWh) Gas Consumption: 4,114 (10^3 Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.91	1.09	1.15

Composite Emission Factors

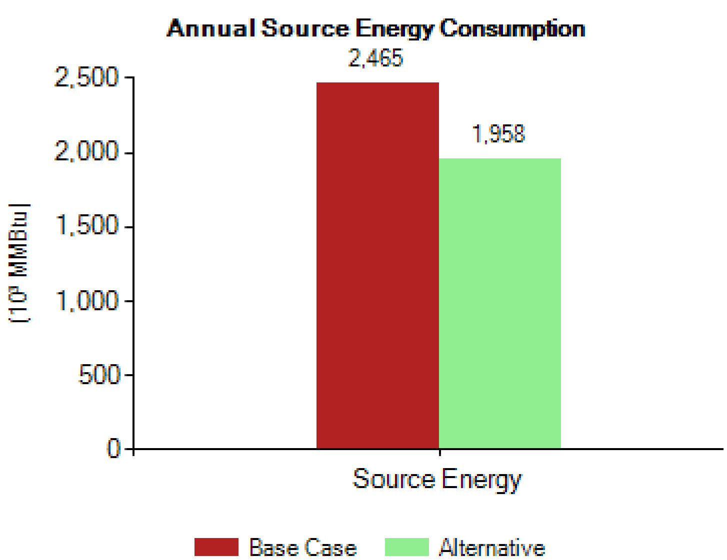
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	324.0	0.090	0.930	0.988	0.0010	351.8
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

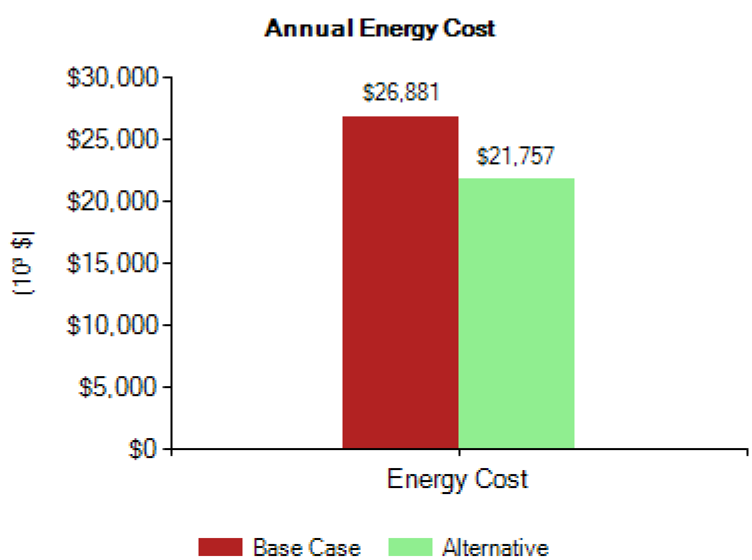
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 9,943 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 994.25 0.00 0.00 2,045.33	108.54 0.00 1,083.73 0.00 0.00 2,464.91	2,223 0 9,744 0 0 26,881	152,042
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	19,458 (10^3 kWh) 0 (10^3 kWh) 7,726 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	66.39 0.00 842.08 0.00 0.00 1,611.49	126.81 0.00 842.08 0.00 0.00 1,957.75	2,598 0 7,571 0 0 21,757	221,980 +$75.08

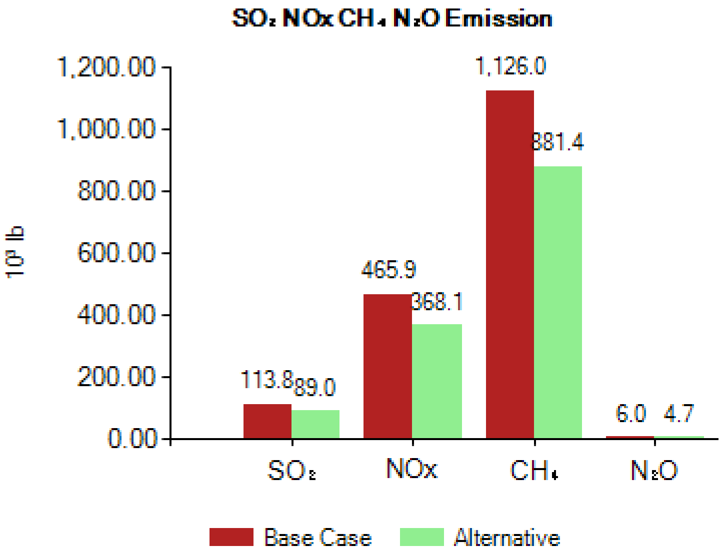
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	5,124	69,938	13.6

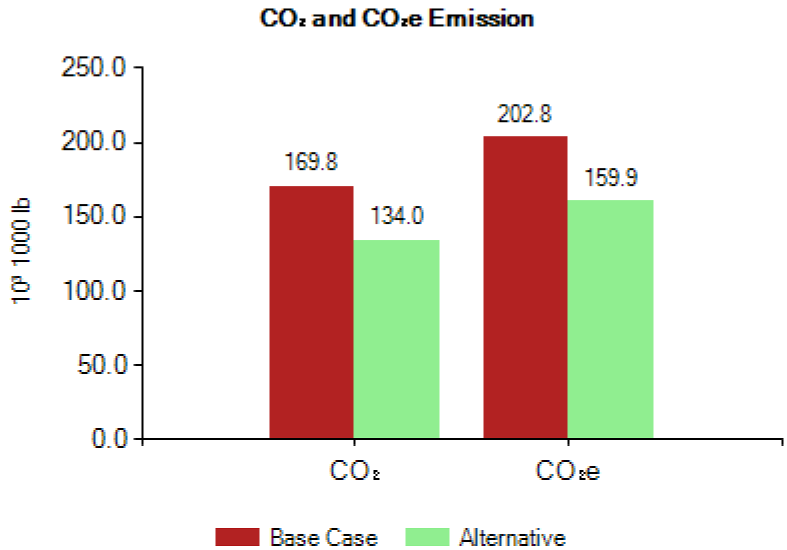




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	113.85	465.88	169.75	1,126.04	5.98	202.82
Alternative	89.05	368.06	134.01	881.39	4.65	159.89





CASE 3

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	1.4 AFUE Natural Gas Absorption Heat Pump (Prototype) Electric Consumption: 5,018 (10^3 kWh) Gas Consumption: 6,413 (10^3 Therm) Installed Cost: 5,000 $/Unit + 2,500 $/Unit Unit Capacity: 80 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal	Natural Gas EF 1.30 - Absorption Heat Pump Electric Consumption: 11,342 (10^3 kWh) Gas Consumption: 3,299 (10^3 Therm) Installed Cost: 2,250 $/Unit

		Unit Capacity: 40 Gal	Unit Capacity: 60 Gal
	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.91	1.09	1.15

Composite Emission Factors

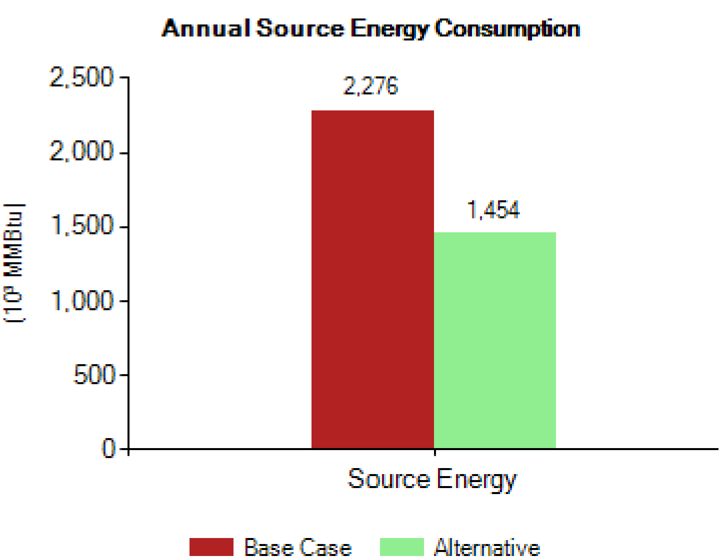
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	324.0	0.090	0.930	0.988	0.0010	351.8
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

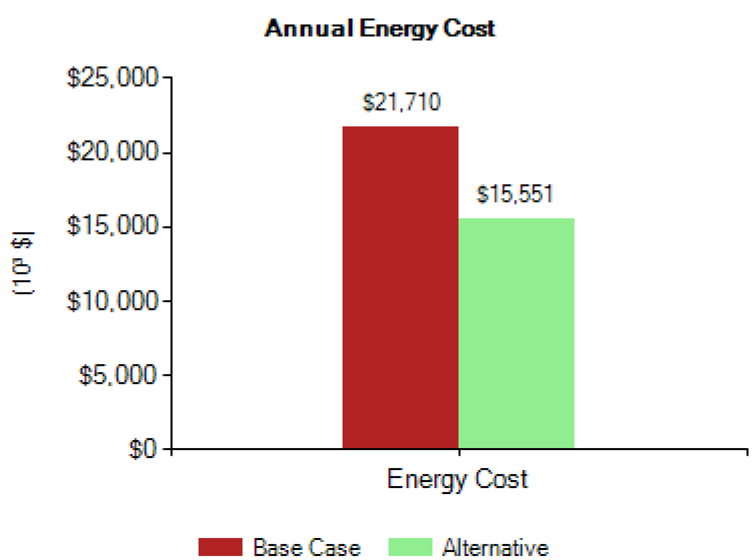
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 19,885 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 1,988.50 0.00 0.00 2,045.33	108.54 0.00 2,167.47 0.00 0.00 2,276.00	2,223 0 19,487 0 0 21,710	152,042
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	33,015 (10^3 kWh) 0 (10^3 kWh) 11,370 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	112.65 0.00 1,239.33 0.00 0.00 1,249.65	215.16 0.00 1,239.33 0.00 0.00 1,454.49	4,408 0 11,143 0 0 15,551	346,571 +$75.08

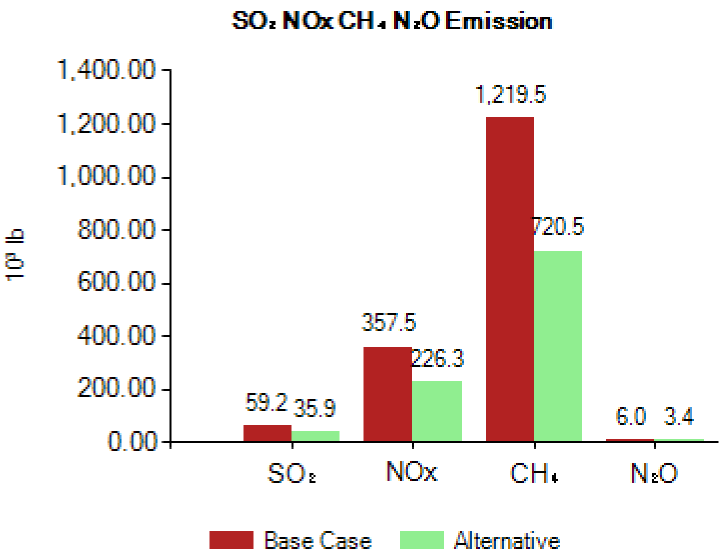
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	6,159	194,529	31.6

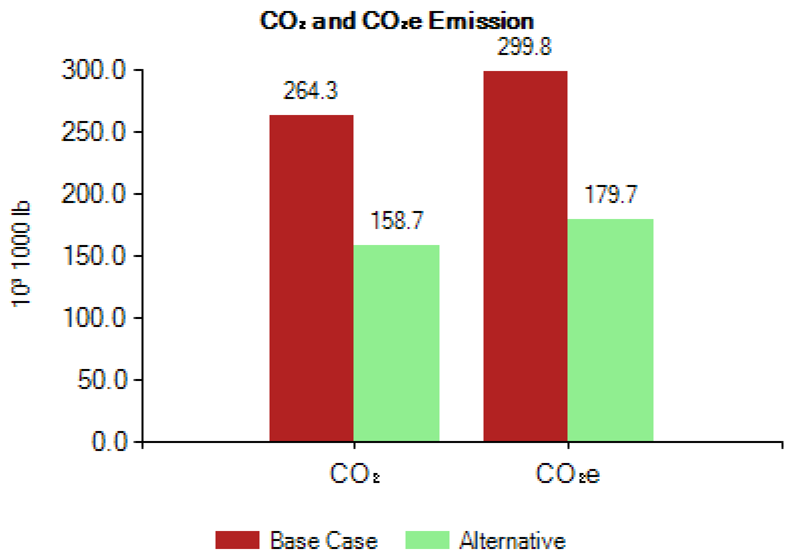




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	59.17	357.51	264.30	1,219.50	5.98	299.76
Alternative	35.94	226.27	158.73	720.50	3.44	179.66





CASE 4

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: User-Specified prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	1.4 AFUE Natural Gas Absorption Heat Pump (Prototype) Electric Consumption: 5,018 (10^3 kWh) Gas Consumption: 6,413 (10^3 Therm) Installed Cost: 5,000 $/Unit + 2,500 $/Unit Unit Capacity: 80 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal	Natural Gas EF 1.30 - Absorption Heat Pump Electric Consumption: 11,342 (10^3 kWh) Gas Consumption: 3,299 (10^3 Therm) Installed Cost: 2,250 $/Unit

		Unit Capacity: 40 Gal	Unit Capacity: 60 Gal
	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 therm) Installed Cost: 823 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.91	1.09	1.15

Composite Emission Factors

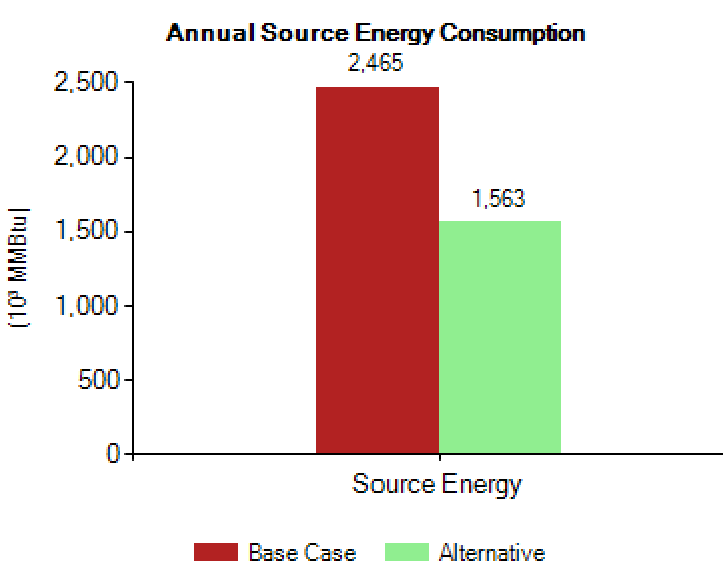
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	324.0	0.090	0.930	0.988	0.0010	351.8
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

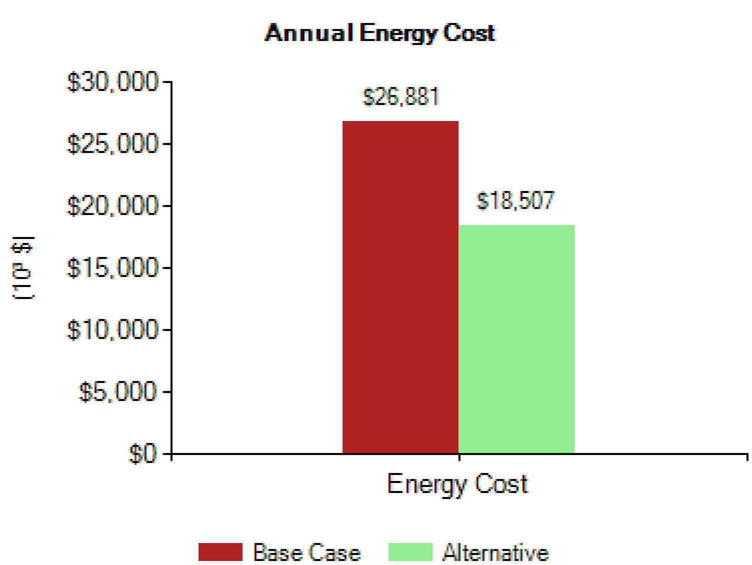
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 9,943 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 994.25 0.00 0.00 2,045.33	108.54 0.00 1,083.73 0.00 0.00 2,464.91	2,223 0 9,744 0 0 26,881	152,042
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	33,015 (10^3 kWh) 0 (10^3 kWh) 5,685 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	112.65 0.00 619.67 0.00 0.00 1,249.65	215.16 0.00 619.67 0.00 0.00 1,562.50	4,408 0 5,571 0 0 18,507	346,571 +$75.08

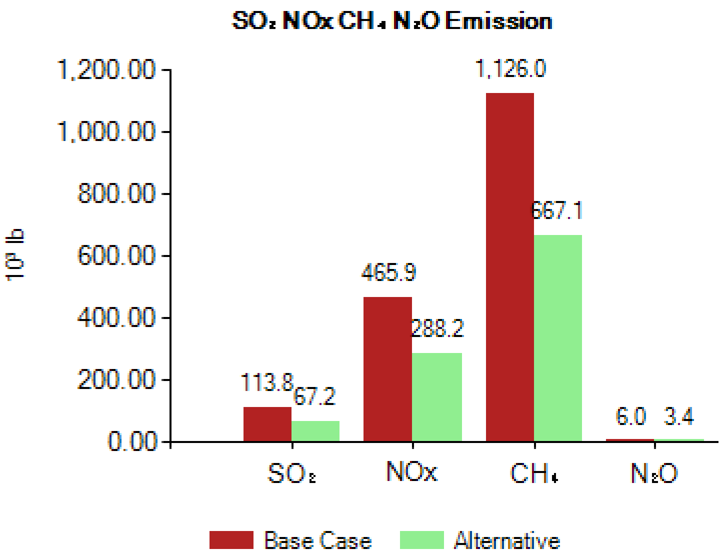
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	8,374	194,529	23.2

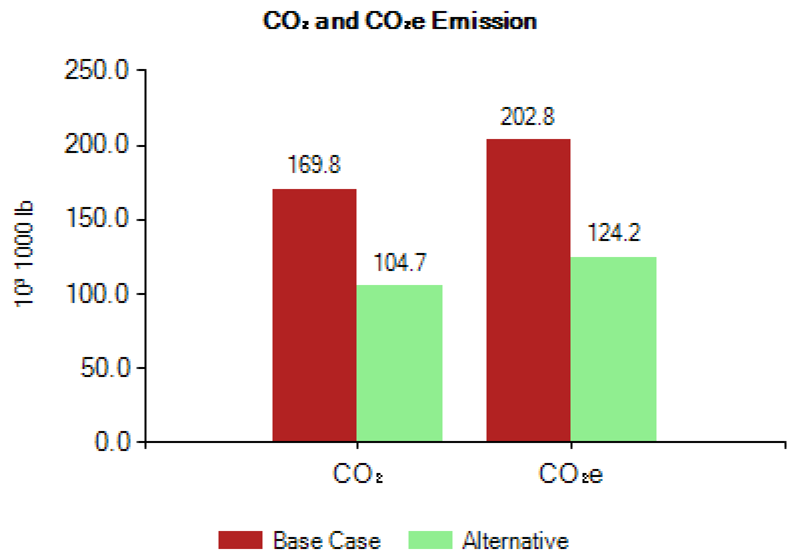




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	113.85	465.88	169.75	1,126.04	5.98	202.82
Alternative	67.21	288.23	104.67	667.06	3.44	124.23





CASE 5

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	Electric, Efficiency 100% Electric Consumption: 261,777 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 450 $/Unit + 10.00 $/kBtuh Unit Capacity: 50 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 122,056 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 13,301 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit	Electric Standard EF 3.1 Electric Consumption: 28,829 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 760 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	2.42	1.09	1.15

Composite Emission Factors

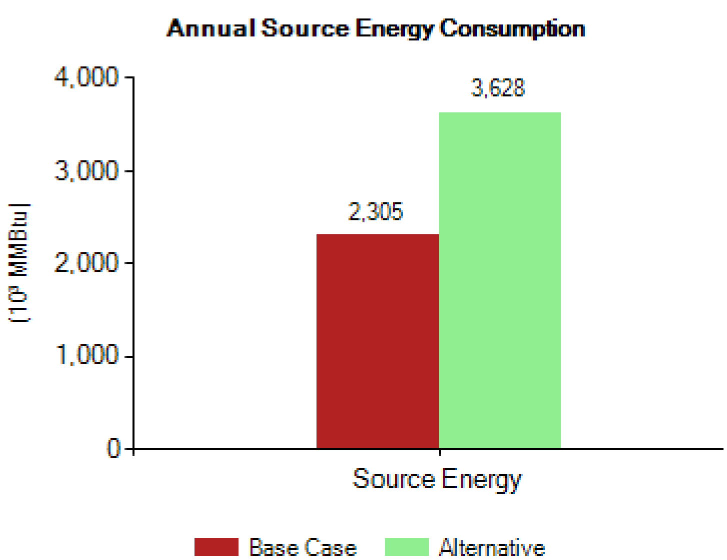
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	919.9	0.290	0.800	1.508	0.0080	964.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

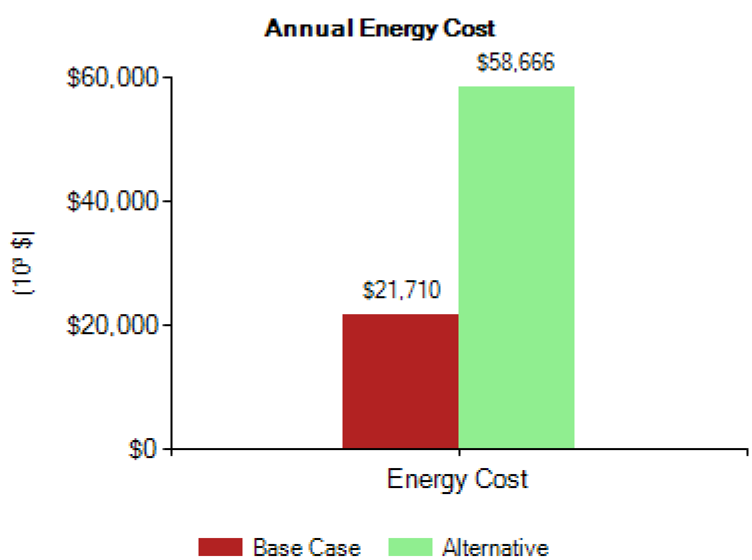
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 19,885 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 1,988.50 0.00 0.00 2,045.33	137.52 0.00 2,167.47 0.00 0.00 2,304.99	2,223 0 19,487 0 0 21,710	152,042
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	439,442 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	1,499.38 0.00 0.00 0.00 0.00 1,499.38	3,628.49 0.00 0.00 0.00 0.00 3,628.49	58,666 0 0 0 0 58,666	99,877

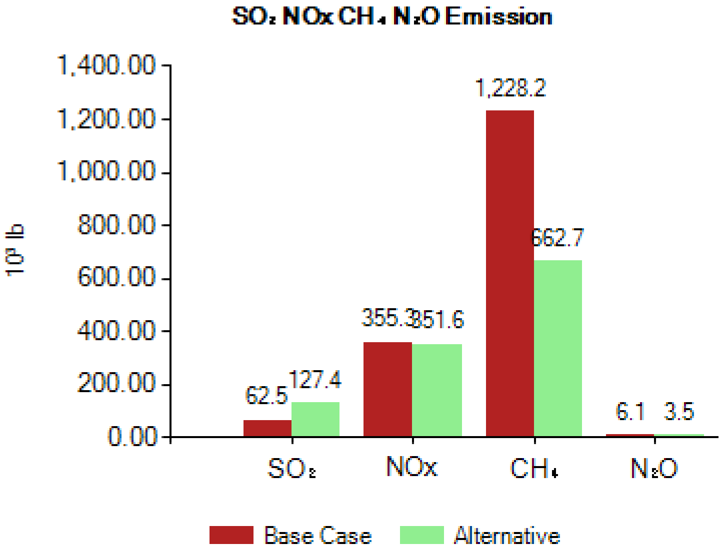
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-36,956	-52,165	Never

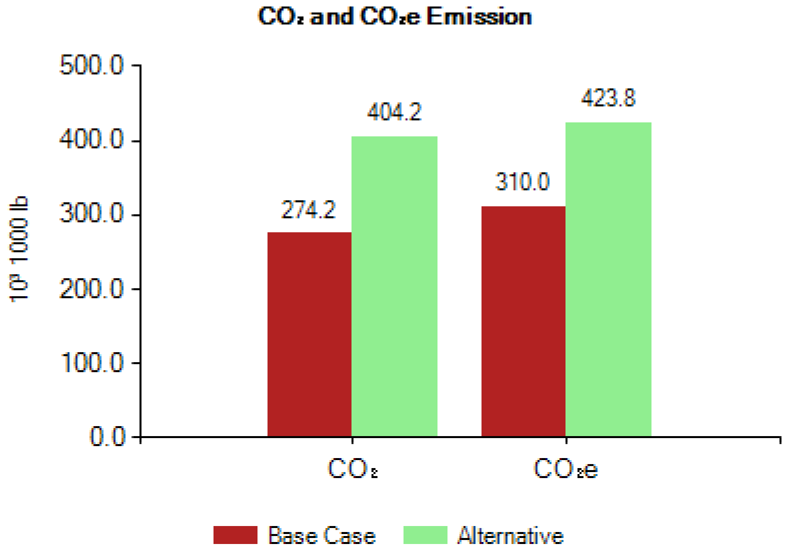




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	62.50	355.35	274.22	1,228.16	6.10	309.96
Alternative	127.44	351.55	404.24	662.68	3.52	423.80





CASE 6

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	Electric, Efficiency 100% Electric Consumption: 261,777 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 450 $/Unit + 10.00 $/kBtuh Unit Capacity: 50 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 122,056 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 13,301 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 1,030 (10^3 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 28,829 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 760 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.99	1.09	1.15

Composite Emission Factors

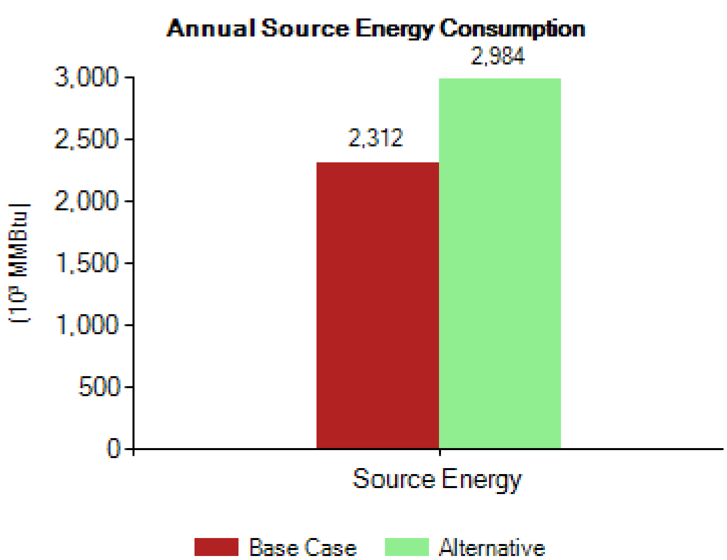
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	375.4	0.100	1.080	1.146	0.0010	407.7
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

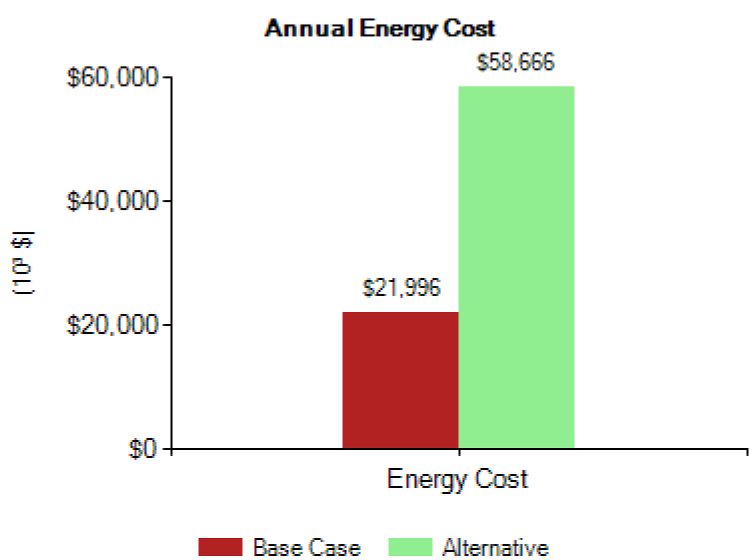
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 20,177 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 2,017.70 0.00 0.00 2,074.53	113.09 0.00 2,199.29 0.00 0.00 2,312.38	2,223 0 19,773 0 0 21,996	149,073
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	439,442 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	1,499.38 0.00 0.00 0.00 0.00 1,499.38	2,983.76 0.00 0.00 0.00 0.00 2,983.76	58,666 0 0 0 0 58,666	99,877

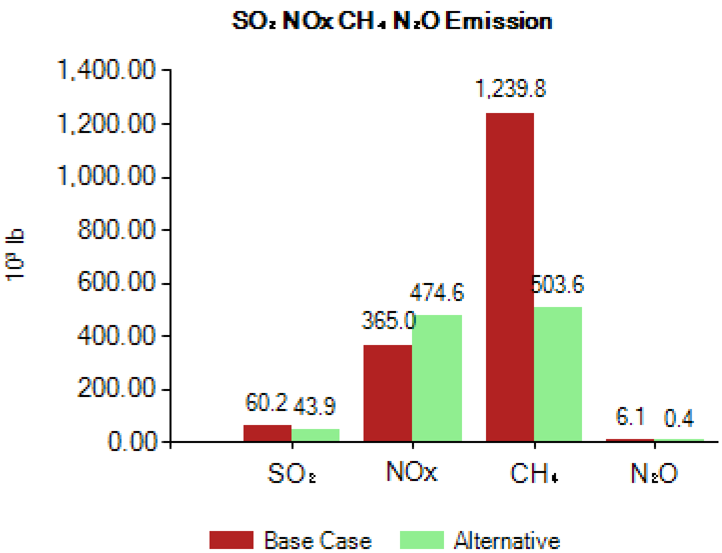
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-36,670	-49,196	Never

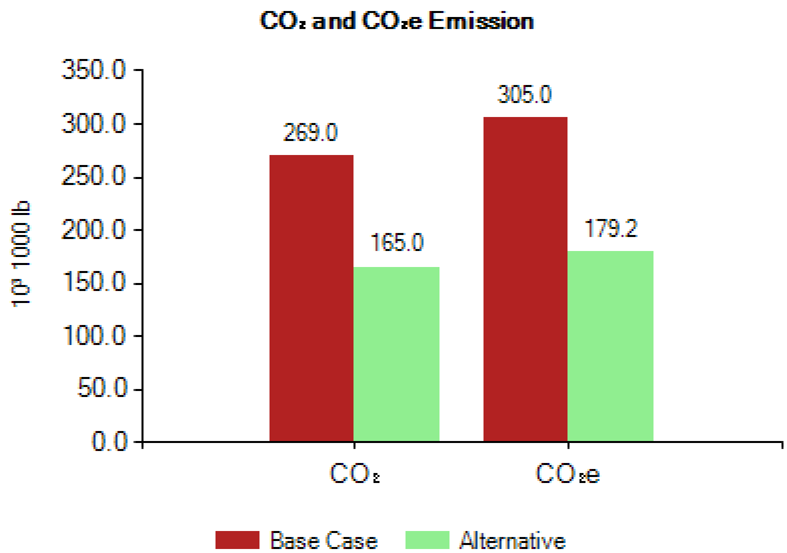




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	60.18	365.03	268.96	1,239.80	6.07	305.01
Alternative	43.94	474.60	164.97	503.60	0.44	179.16





CASE 7

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	Electric, Efficiency 100% Electric Consumption: 261,777 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 450 $/Unit + 10.00 $/kBtuh Unit Capacity: 50 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 122,056 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 13,301 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 1,030 (10^3 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 28,829 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 760 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.87	1.09	1.15

Composite Emission Factors

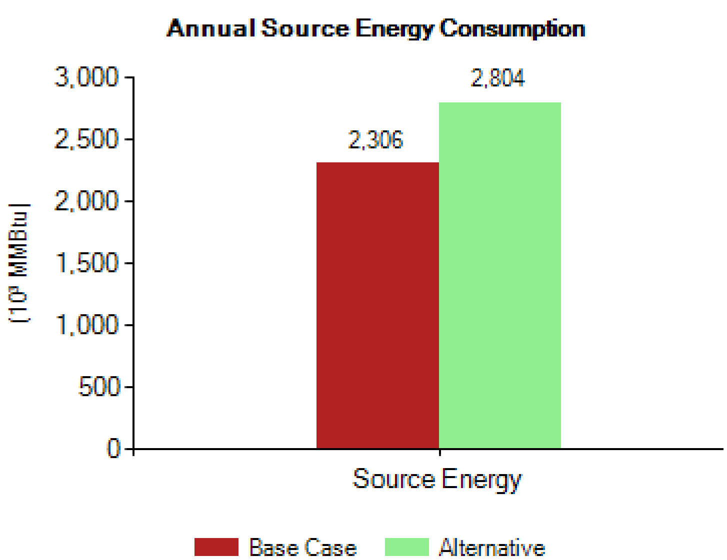
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	293.2	0.080	0.840	0.893	0.0010	318.3
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

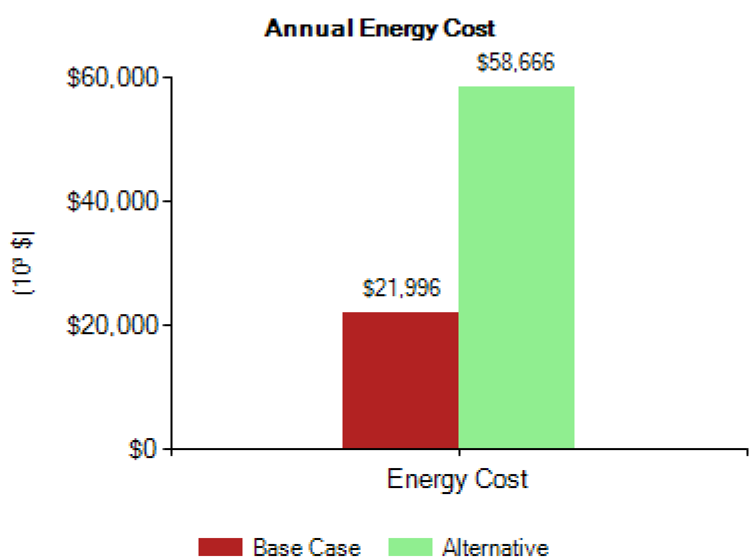
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 20,177 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 2,017.70 0.00 0.00 2,074.53	106.27 0.00 2,199.29 0.00 0.00 2,305.56	2,223 0 19,773 0 0 21,996	149,073
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	439,442 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	1,499.38 0.00 0.00 0.00 0.00 1,499.38	2,803.83 0.00 0.00 0.00 0.00 2,803.83	58,666 0 0 0 0 58,666	99,877

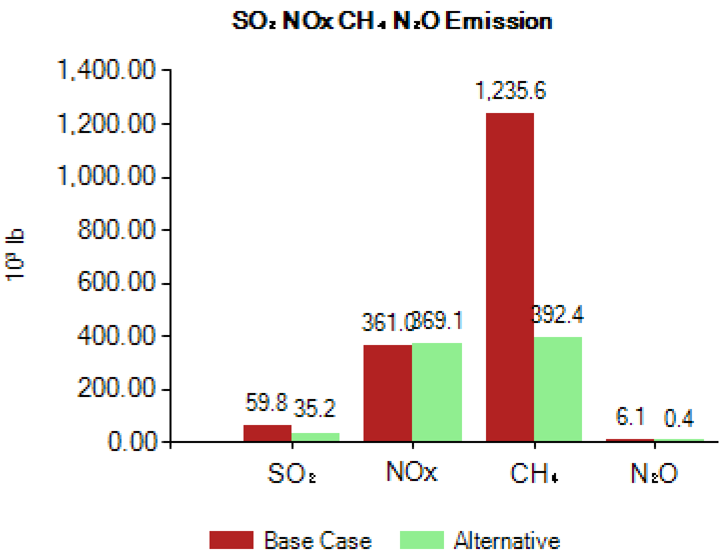
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-36,670	-49,196	Never

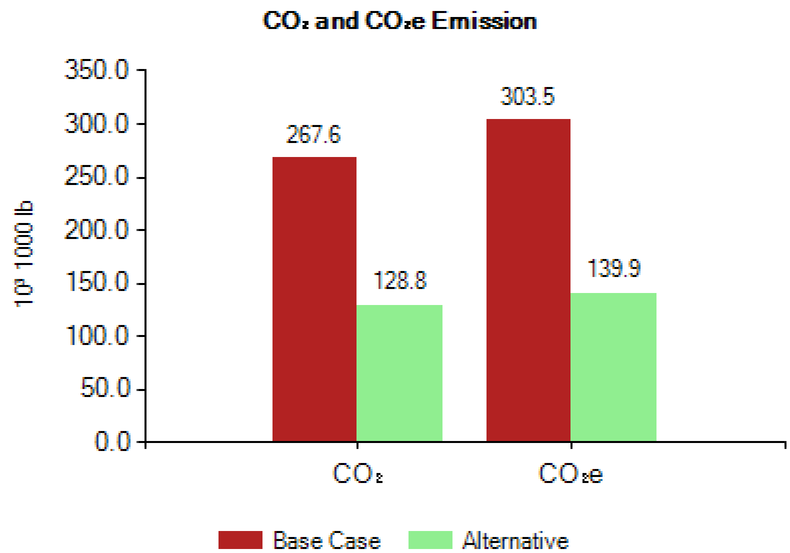




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	59.85	361.03	267.59	1,235.58	6.07	303.52
Alternative	35.16	369.13	128.84	392.42	0.44	139.87





CASE 8

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit +2.70 $/kBtuh Unit Capacity: 70 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 138,949 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 3,873 $/Unit +42.00 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 24 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 21,614 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 0 $/Unit +0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit +10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 122,056 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 13,301 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit	Electric Standard EF 3.1 Electric Consumption: 28,829 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 760 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	2.42	1.09	1.15

Composite Emission Factors

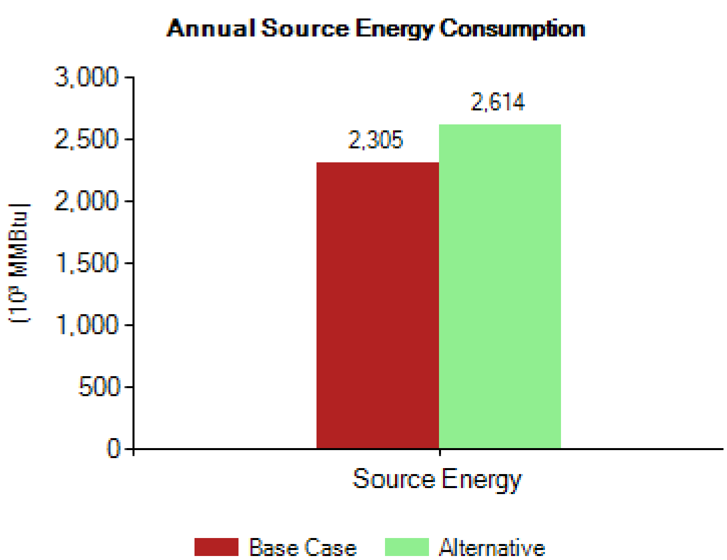
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	919.9	0.290	0.800	1.508	0.0080	964.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

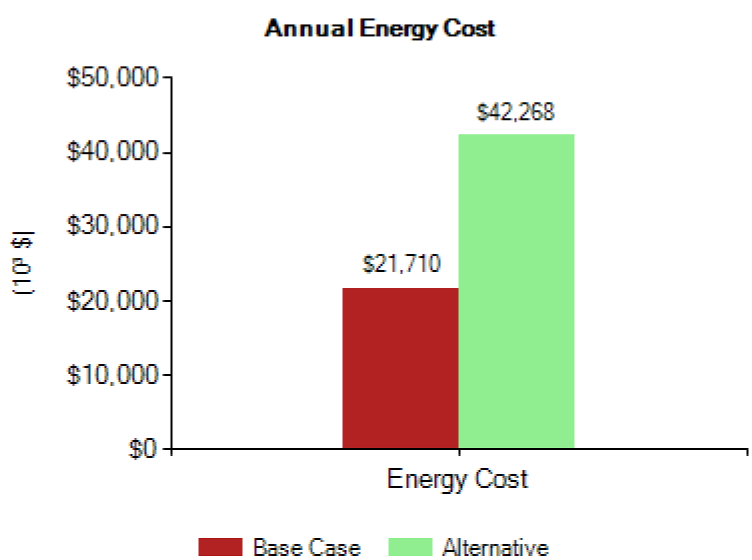
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 19,885 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 1,988.50 0.00 0.00 2,045.33	137.52 0.00 2,167.47 0.00 0.00 2,304.99	2,223 0 19,487 0 0 21,710	152,042
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	316,614 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	1,080.29 0.00 0.00 0.00 0.00 1,080.29	2,614.29 0.00 0.00 0.00 0.00 2,614.29	42,268 0 0 0 0 42,268	261,480

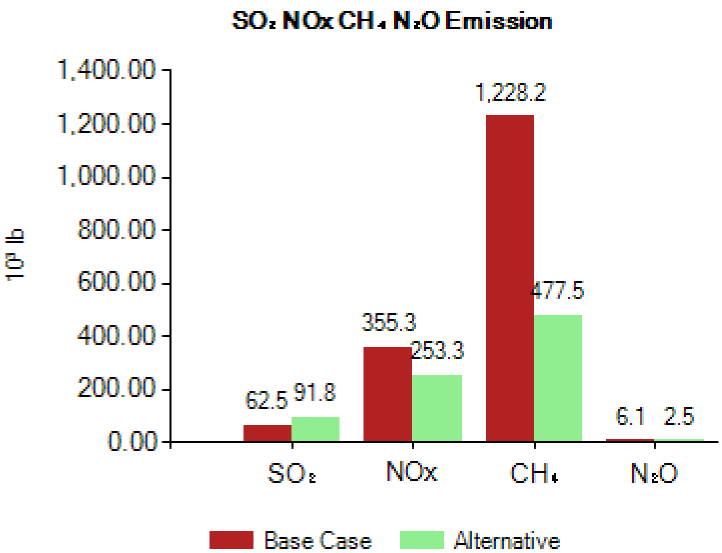
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-20,558	109,437	Never

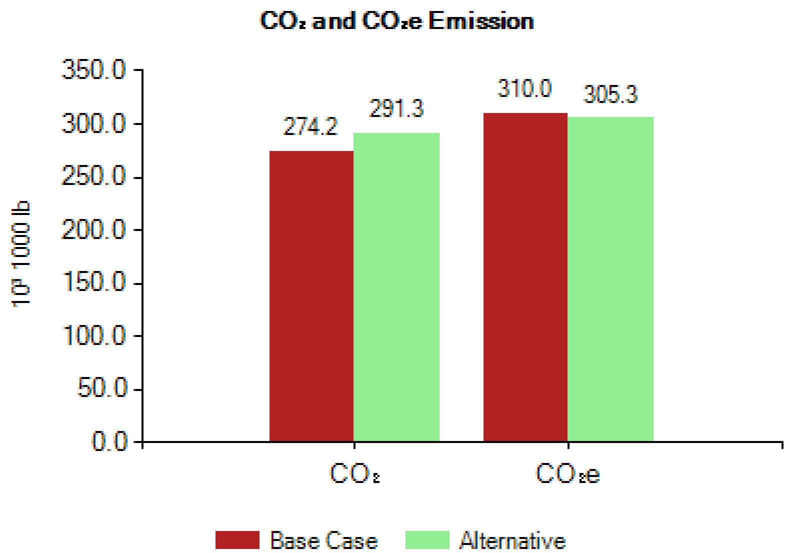




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	62.50	355.35	274.22	1,228.16	6.10	309.96
Alternative	91.82	253.29	291.25	477.45	2.53	305.34





CASE 9

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 138,949 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 3,873 $/Unit + 42.00 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 21,614 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 122,056 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 13,301 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 1,030 (10^3 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 28,829 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 760 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.99	1.09	1.15

Composite Emission Factors

Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	375.4	0.100	1.080	1.146	0.0010	407.7
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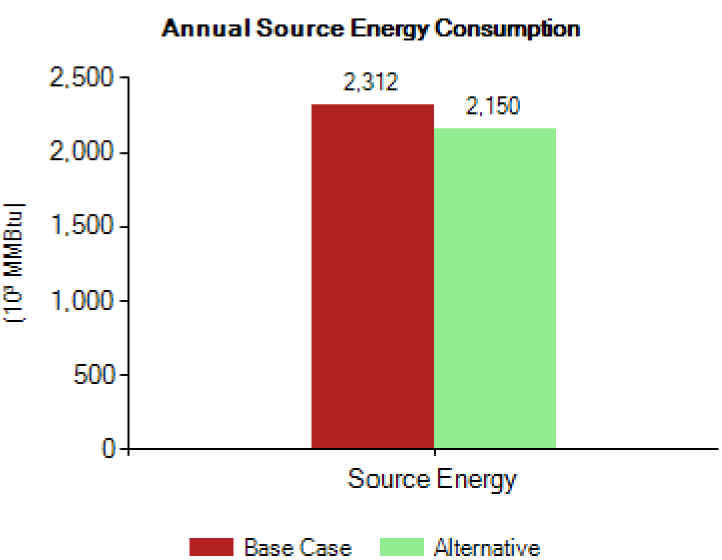
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

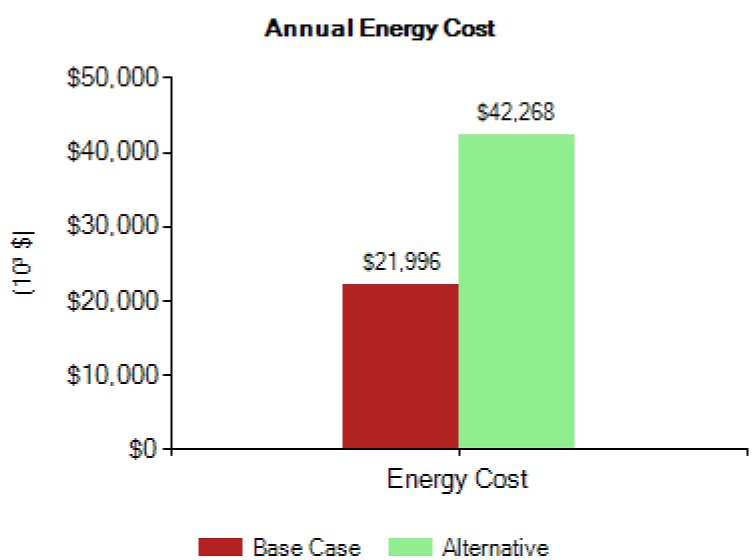
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 20,177 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 2,017.70 0.00 0.00 2,074.53	113.09 0.00 2,199.29 0.00 0.00 2,312.38	2,223 0 19,773 0 0 21,996	149,073
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	316,614 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	1,080.29 0.00 0.00 0.00 0.00 1,080.29	2,149.77 0.00 0.00 0.00 0.00 2,149.77	42,268 0 0 0 0 42,268	261,480

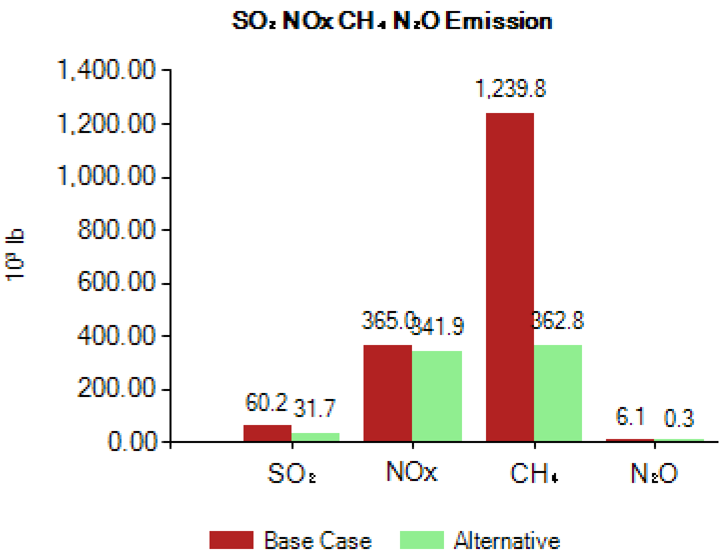
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-20,272	112,406	Never

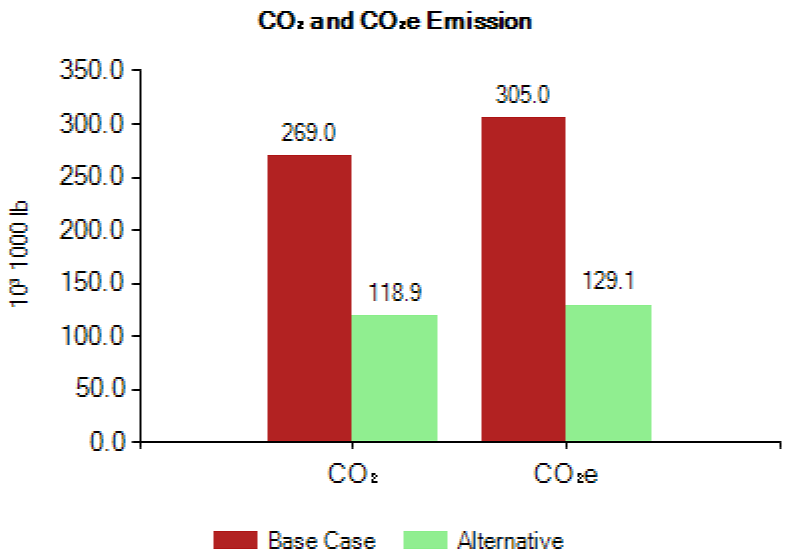




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	60.18	365.03	268.96	1,239.80	6.07	305.01
Alternative	31.66	341.94	118.86	362.84	0.32	129.08





CASE 10

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 138,949 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 3,873 $/Unit + 42.00 $/kBtuh Unit Capacity: 60 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 21,614 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Resistance EF, 0.95 Electric Consumption: 122,056 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 40 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 13,301 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 923 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 1,030 (10^3 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.1 Electric Consumption: 28,829 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 760 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.87	1.09	1.15

Composite Emission Factors

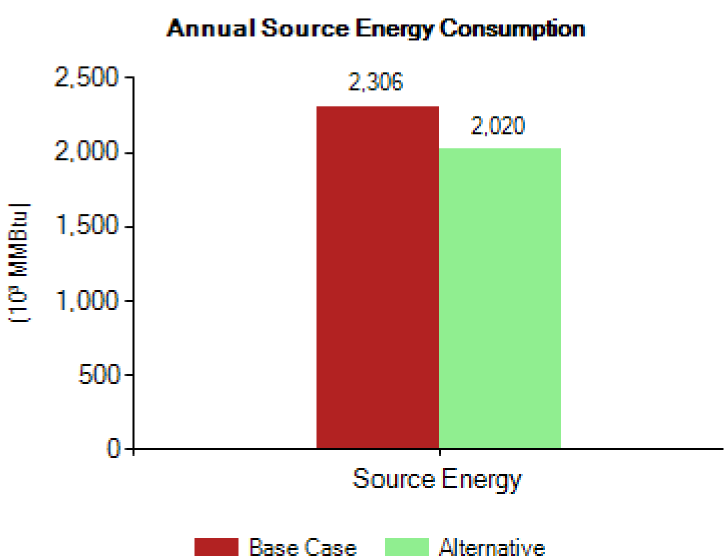
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	293.2	0.080	0.840	0.893	0.0010	318.3
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

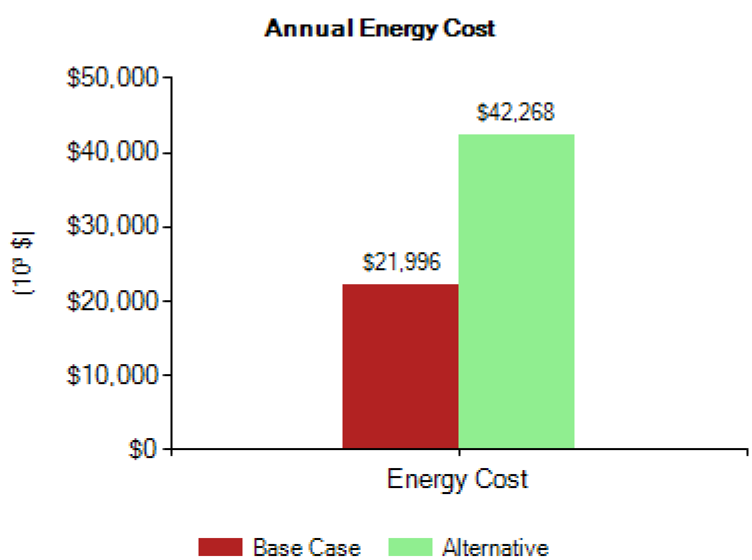
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 20,177 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 2,017.70 0.00 0.00 2,074.53	106.27 0.00 2,199.29 0.00 0.00 2,305.56	2,223 0 19,773 0 0 21,996	149,073
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	316,614 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	1,080.29 0.00 0.00 0.00 0.00 1,080.29	2,020.14 0.00 0.00 0.00 0.00 2,020.14	42,268 0 0 0 0 42,268	261,480

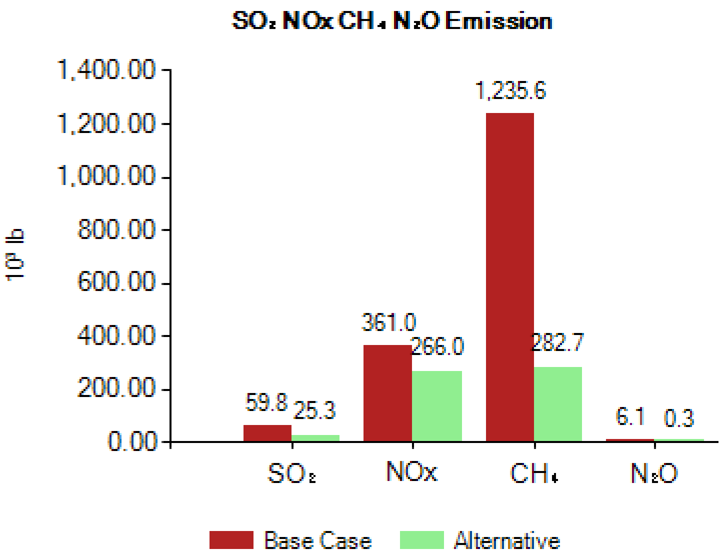
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-20,272	112,406	Never

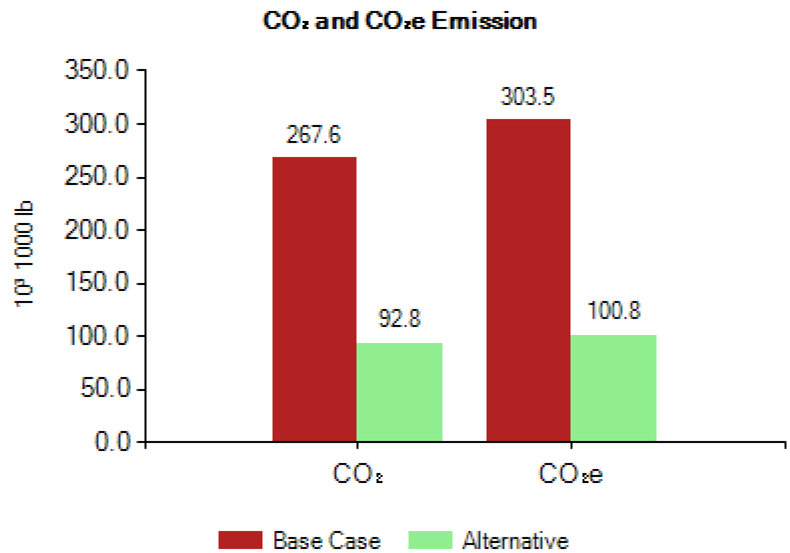




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	59.85	361.03	267.59	1,235.58	6.07	303.52
Alternative	25.33	265.96	92.83	282.74	0.32	100.78





CASE 11

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 114,217 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 4,745 $/Unit + 42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 16,448 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Heat Pump EF, 2.00 Electric Consumption: 57,985 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 1,900 $/Unit Unit Capacity: 50 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Induction EF 0.84 Electric Consumption: 11,728 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 1,879 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 738 (10^3 Therm) Installed Cost: 1,100 $/Unit	Electric Standard EF 3.93 Electric Consumption: 22,743 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 930 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	2.42	1.09	1.15

Composite Emission Factors

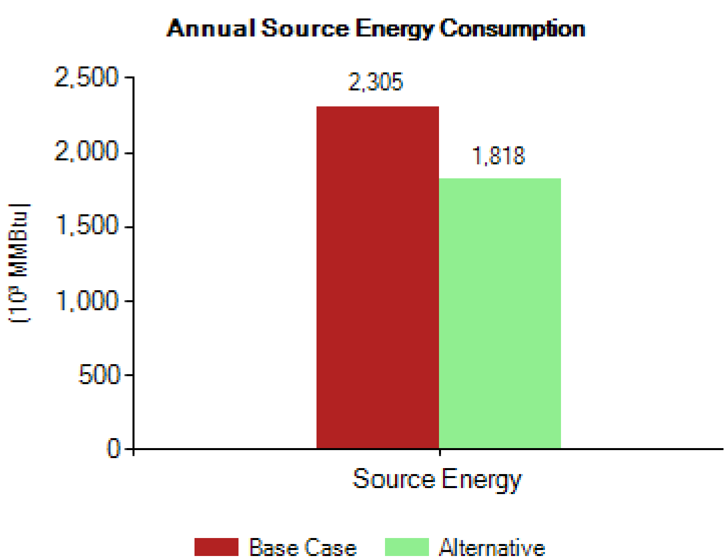
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	919.9	0.290	0.800	1.508	0.0080	964.4
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

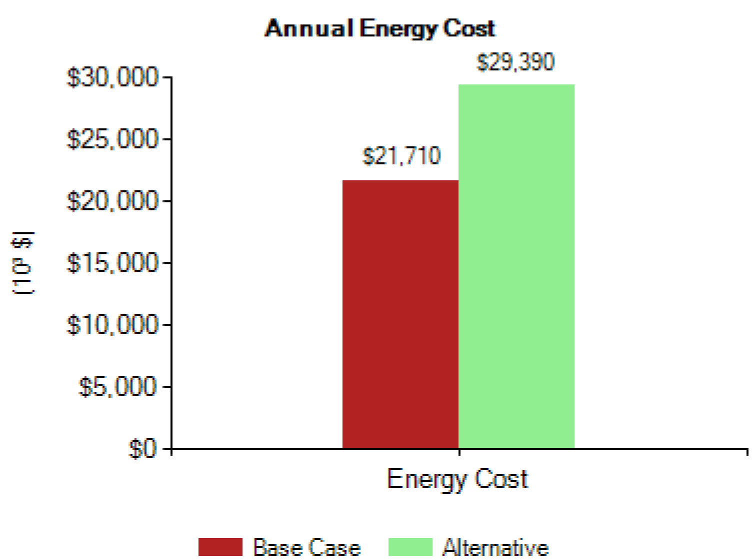
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 19,885 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 1,988.50 0.00 0.00 2,045.33	137.52 0.00 2,167.47 0.00 0.00 2,304.99	2,223 0 19,487 0 0 21,710	152,042
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	220,152 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	751.16 0.00 0.00 0.00 0.00 751.16	1,817.80 0.00 0.00 0.00 0.00 1,817.80	29,390 0 0 0 0 29,390	367,978

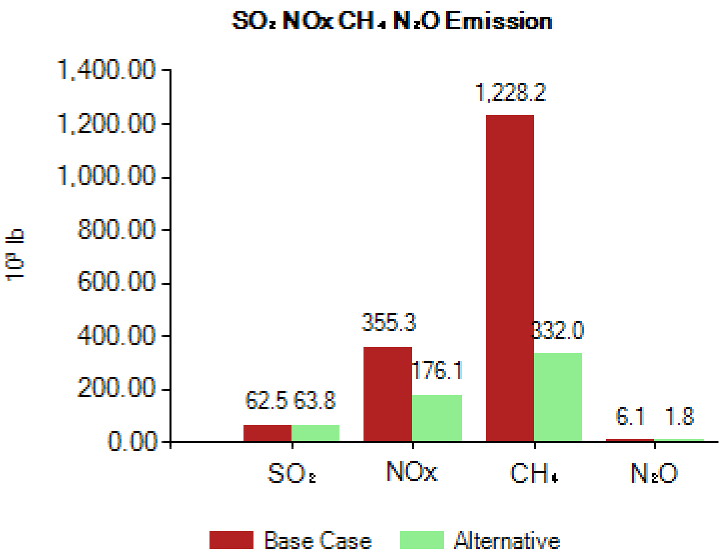
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-7,680	215,935	Never

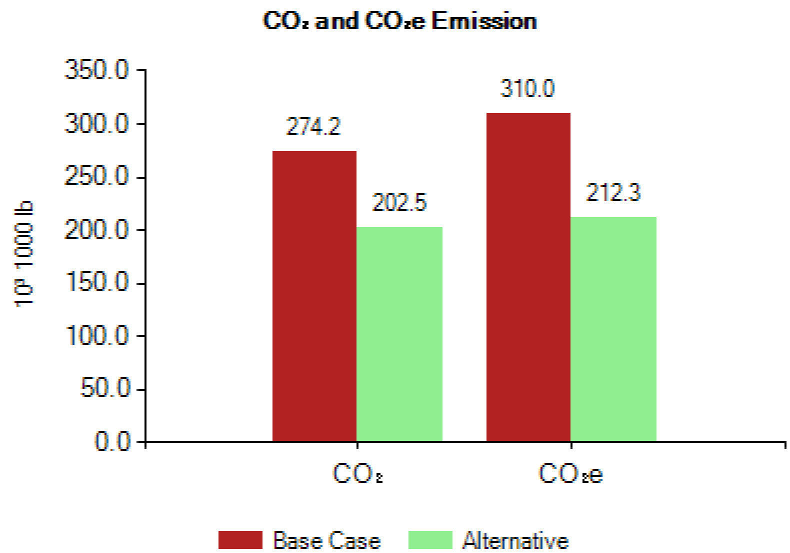




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	62.50	355.35	274.22	1,228.16	6.10	309.96
Alternative	63.84	176.12	202.52	331.99	1.76	212.31





CASE 12

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 114,217 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 4,745 $/Unit + 42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 16,448 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Heat Pump EF, 2.00 Electric Consumption: 57,985 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 1,900 $/Unit Unit Capacity: 50 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Induction EF 0.84 Electric Consumption: 11,728 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 1,879 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 1,030 (10^3 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.93 Electric Consumption: 22,743 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 930 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.99	1.09	1.15

Composite Emission Factors

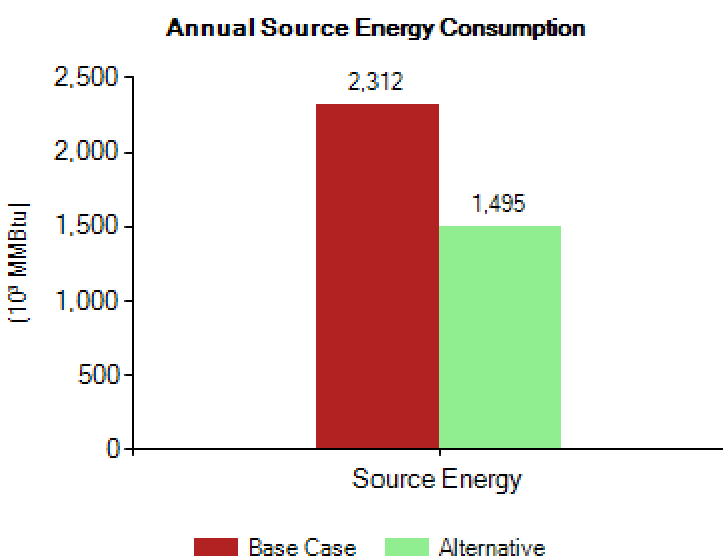
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	375.4	0.100	1.080	1.146	0.0010	407.7
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

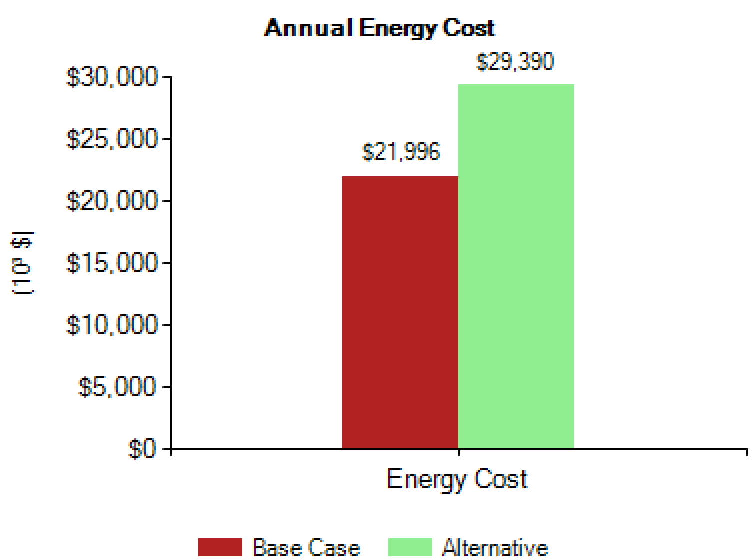
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 20,177 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 2,017.70 0.00 0.00 2,074.53	113.09 0.00 2,199.29 0.00 0.00 2,312.38	2,223 0 19,773 0 0 21,996	149,073
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	220,152 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	751.16 0.00 0.00 0.00 0.00 751.16	1,494.81 0.00 0.00 0.00 0.00 1,494.81	29,390 0 0 0 0 29,390	367,978

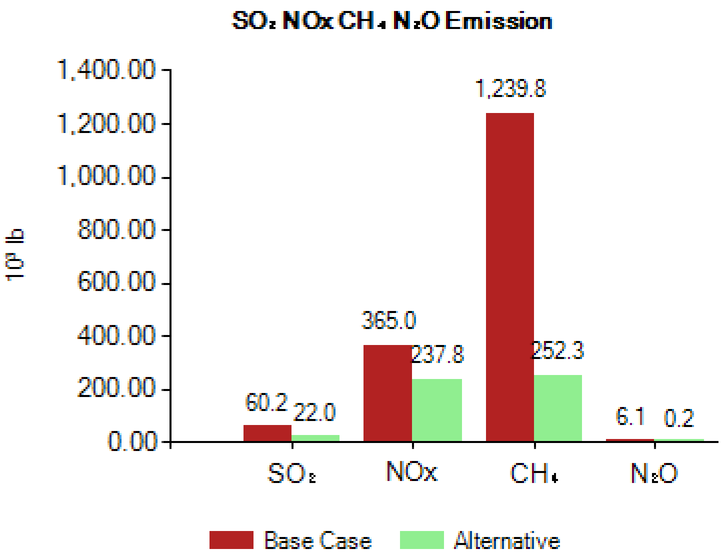
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-7,394	218,904	Never

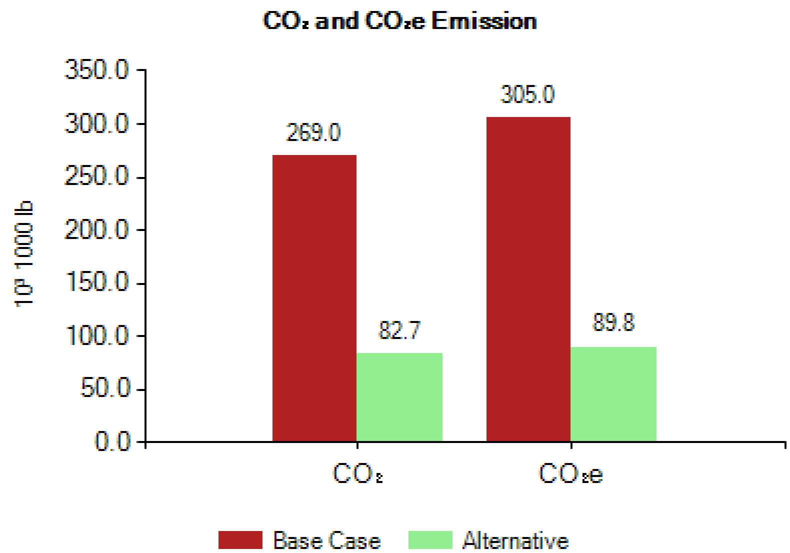




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	60.18	365.03	268.96	1,239.80	6.07	305.01
Alternative	22.02	237.76	82.65	252.29	0.22	89.76





Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
x	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,803	3
x	Single Fam. Attached	3,250	375	3
x	Apt. Building 2 to 4 units	3,400	610	3
x	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	29,690	1,227	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

All Houses

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 80% Electric Consumption: 0 (10^3 kWh) Gas Consumption: 11,846 (10^3 Therm) Installed Cost: 1,881 $/Unit + 2.70 $/kBtuh Unit Capacity: 70 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 114,217 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 4,745 $/Unit + 42.00 $/kBtuh Unit Capacity: 70 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 27,730 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 24 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 16,448 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 24 kBtuh
x	HVAC Blower	Electric Consumption: 13,479 (10^3 kWh)	Electric Consumption: 13,479 (10^3 kWh)
x	Water Heating	Natural Gas EF 0.62 - Min. Eff. Storage Electric Consumption: 0 (10^3 kWh) Gas Consumption: 6,381 (10^3 Therm) Installed Cost: 728 $/Unit + 10.00 $/gal Unit Capacity: 40 Gal	Electric Heat Pump EF, 2.00 Electric Consumption: 57,985 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 1,900 $/Unit Unit Capacity: 50 Gal

	Lighting & Plug-in Loads	Electric Consumption: 52,823 (10^3 kWh)	Electric Consumption: 52,823 (10^3 kWh)
x	Cooking Range	Gas Standard Electric Consumption: 920 (10^3 kWh) Gas Consumption: 920 (10^3 Therm) Installed Cost: 823 $/Unit	Electric Induction EF 0.84 Electric Consumption: 11,728 (10^3 kWh) Gas Consumption: 0 (10^3 therm) Installed Cost: 1,879 $/Unit
	Refrigerator	How many: 1 Electric Consumption: 0 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
	Dishwasher	How many: 1 Electric Consumption: 5,107 (10^3 kWh)	How many: 1 Electric Consumption: 5,107 (10^3 kWh)
	Washer	How many: 1 Electric Consumption: 2,613 (10^3 kWh)	How many: 1 Electric Consumption: 0 (10^3 kWh)
x	Clothes Dryer	Gas Standard EF 2.75 Electric Consumption: 2,256 (10^3 kWh) Gas Consumption: 1,030 (10^3 Therm) Installed Cost: 1,000 $/Unit	Electric Standard EF 3.93 Electric Consumption: 22,743 (10^3 kWh) Gas Consumption: 0 (10^3 Therm) Installed Cost: 930 $/Unit
	Micro CHP	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW	None Electric Reduced: 0 (10^3 kWh) Electric Export to Grid: 0 (10^3 kWh) NG Building Used Reduction: 0 (10^3 therm) mCHP NG Consumption: 0 (10^3 therm) Installed Cost: 0 $/Unit +0 $/kW

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.87	1.09	1.15

Composite Emission Factors

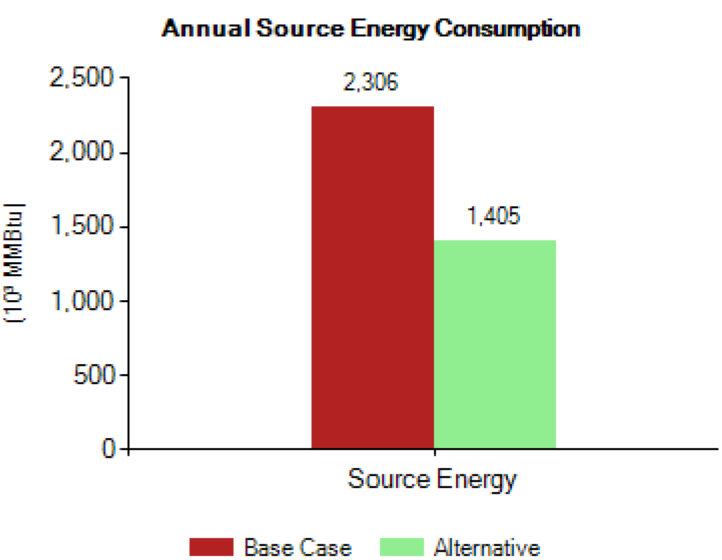
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	293.2	0.080	0.840	0.893	0.0010	318.3
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

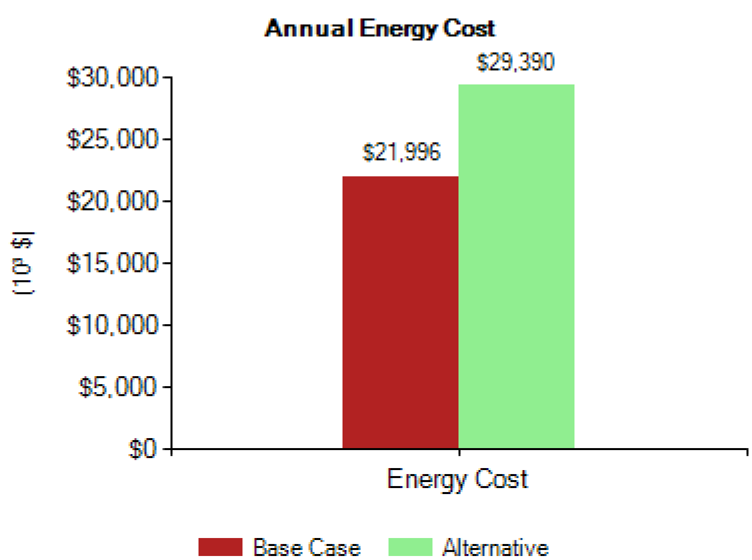
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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
			(10^3 MMBtu)	(10^3 MMBtu)	(10^3 $)	(10^3 $)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	16,655 (10^3 kWh) 0 (10^3 kWh) 20,177 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	56.83 0.00 2,017.70 0.00 0.00 2,074.53	106.27 0.00 2,199.29 0.00 0.00 2,305.56	2,223 0 19,773 0 0 21,996	149,073
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	220,152 (10^3 kWh) 0 (10^3 kWh) 0 (10^3 Therm) 0 (10^3 Therm) 0 (10^3 Gal)	751.16 0.00 0.00 0.00 0.00 751.16	1,404.67 0.00 0.00 0.00 0.00 1,404.67	29,390 0 0 0 0 29,390	367,978

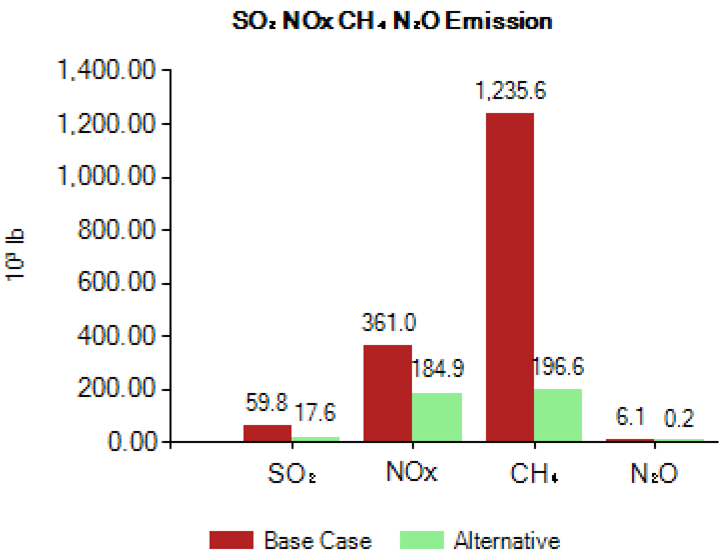
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	(10^3 $)	(10^3 $)	(Year)
Comparison	-7,394	218,904	Never

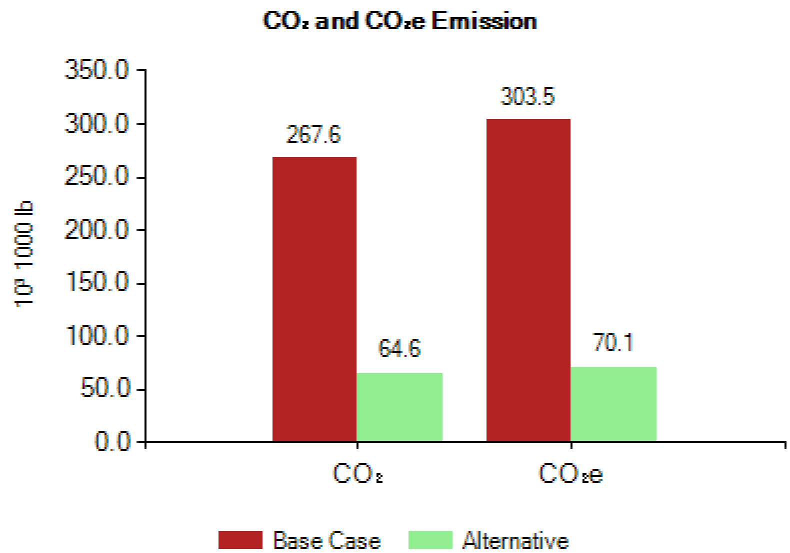




Annual Source Emissions

	SO2 (10^3 lb)	NOx (10^3 lb)	CO2 (10^6 lb)	CH4 (10^3 lb)	N2O (10^3 lb)	CO2e (10^6 lb)
Baseline	59.85	361.03	267.59	1,235.58	6.07	303.52
Alternative	17.61	184.93	64.55	196.60	0.22	70.07





CASE 14

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,800	3
	Single Fam. Attached	3,250	375	3
	Apt. Building 2 to 4 units	3,400	610	3
	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	16,100	1,800	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

Single House

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 98% Electric Consumption: 0 (kWh) Gas Consumption: 422 (Therm) Installed Cost: 2,807 $/Unit +3.86 $/kBtuh Unit Capacity: 80 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 6,068 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 3,873 $/Unit +42.00 $/kBtuh Unit Capacity: 90 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 1,100 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 36 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 857 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 0 $/Unit +0.00 $/kBtu Unit Capacity: 36 kBtuh
x	HVAC Blower	Electric Consumption: 609 (kWh)	Electric Consumption: 554 (kWh)
x	Water Heating	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 49 (kWh) Gas Consumption: 139 (Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h	Electric Resistance EF, 0.95 Electric Consumption: 4,111 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 60 Gal
	Lighting &	Electric Consumption: 2,610 (kWh)	Electric Consumption: 2,610 (kWh)

<table>
<tr><td></td><td>Plug-in Loads</td><td></td><td></td></tr>
<tr><td>x</td><td>Cooking Range</td><td>Gas Standard
Electric Consumption: 31 (kWh)
Gas Consumption: 31 (Therm)
Installed Cost: 823 $/Unit</td><td>Electric Standard EF 0.74
Electric Consumption: 448 (kWh)
Gas Consumption: 0 (therm)
Installed Cost: 923 $/Unit</td></tr>
<tr><td></td><td>Refrigerator</td><td>How many: 1
Electric Consumption: 0 (kWh)</td><td>How many: 1
Electric Consumption: 0 (kWh)</td></tr>
<tr><td></td><td>Dishwasher</td><td>How many: 1
Electric Consumption: 172 (kWh)</td><td>How many: 1
Electric Consumption: 172 (kWh)</td></tr>
<tr><td></td><td>Washer</td><td>How many: 1
Electric Consumption: 88 (kWh)</td><td>How many: 1
Electric Consumption: 0 (kWh)</td></tr>
<tr><td>x</td><td>Clothes Dryer</td><td>Gas Standard EF 3.84
Electric Consumption: 76 (kWh)
Gas Consumption: 25 (Therm)
Installed Cost: 1,100 $/Unit</td><td>Electric Standard EF 3.1
Electric Consumption: 971 (kWh)
Gas Consumption: 0 (Therm)
Installed Cost: 760 $/Unit</td></tr>
<tr><td></td><td>Micro CHP</td><td>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</td><td>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</td></tr>
</table>

Source Energy Factors And Composite Emission Factors

Geographic Area: State: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	1.99	1.09	1.15

Composite Emission Factors

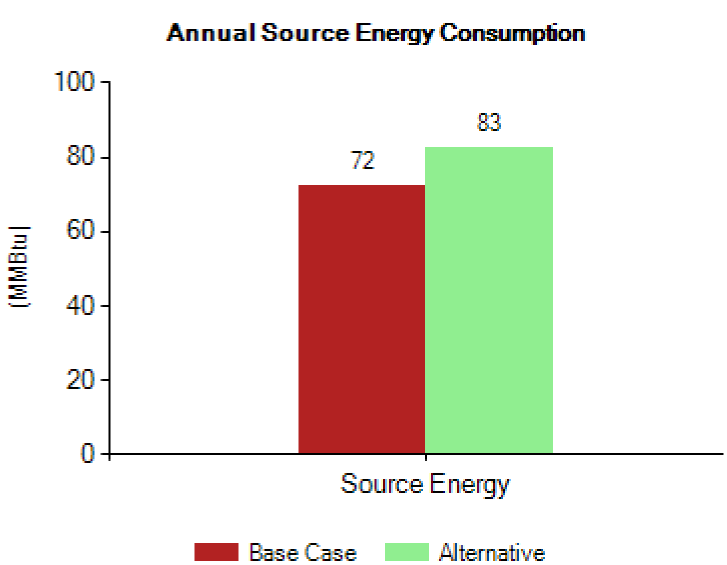
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	375.4	0.100	1.080	1.146	0.0010	407.7
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

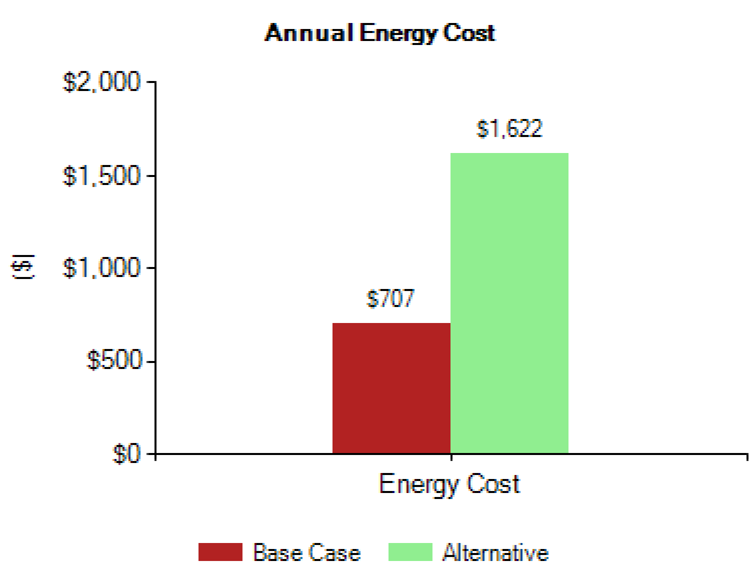
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	765 (kWh) 0 (kWh) 617 (Therm) 0 (Therm) 0 (Gal)	2.61 0.00 61.70 0.00 0.00 64.31	5.19 0.00 67.25 0.00 0.00 72.45	102 0 605 0 0 707	7,554
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	12,152 (kWh) 0 (kWh) 0 (Therm) 0 (Therm) 0 (Gal)	41.46 0.00 0.00 0.00 0.00 41.46	82.51 0.00 0.00 0.00 0.00 82.51	1,622 0 0 0 0 1,622	10,137

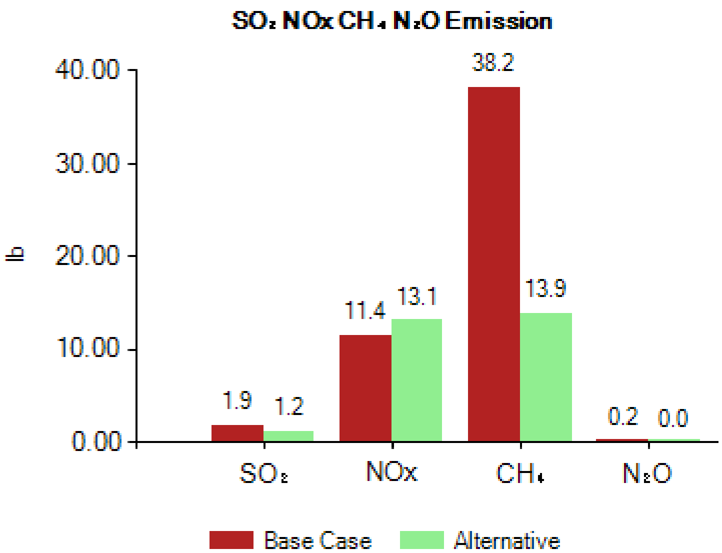
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	($)	($)	(Year)
Comparison	-915	2,583	Never

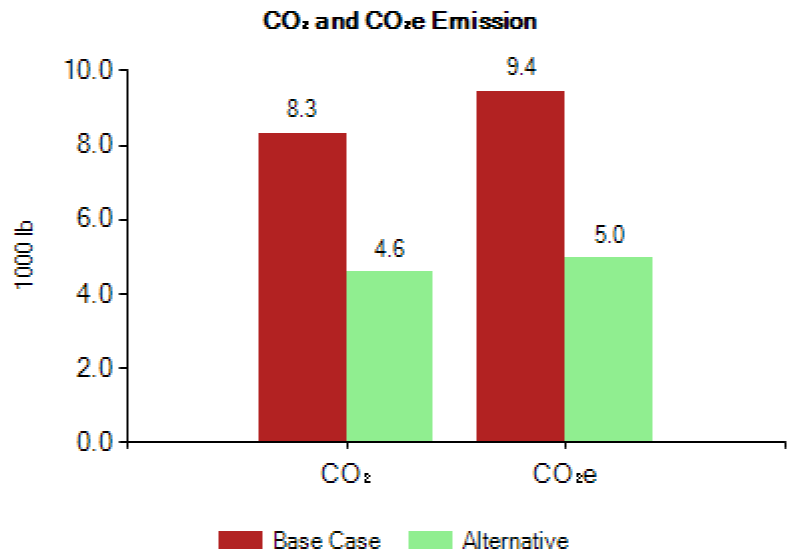




Annual Source Emissions

	SO2 (lb)	NOx (lb)	CO2 (1000 lb)	CH4 (lb)	N2O (lb)	CO2e (1000 lb)
Baseline	1.87	11.44	8.32	38.21	0.19	9.43
Alternative	1.22	13.12	4.56	13.93	0.01	4.95





Energy Planning Analysis Tool

Home | Residential City Level Comparison | Residential State Level Comparison | Tool Description | Contact

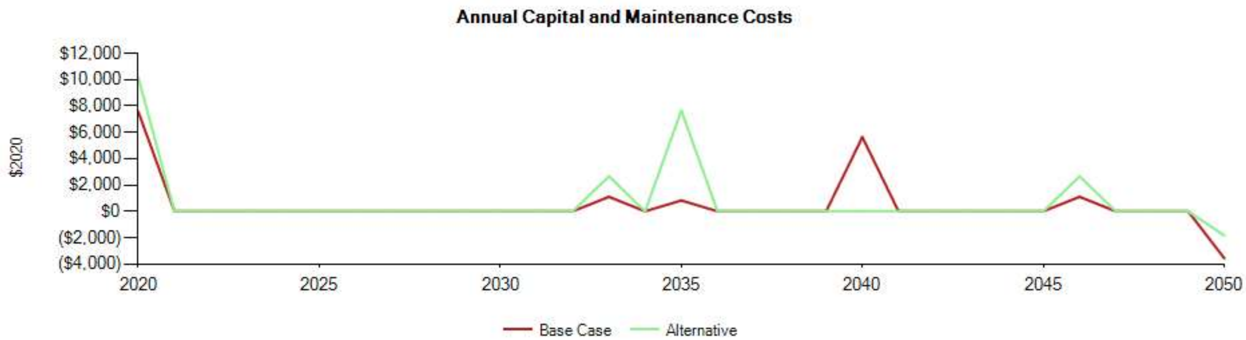
Residential State Level House: Life Cycle Assessment Results

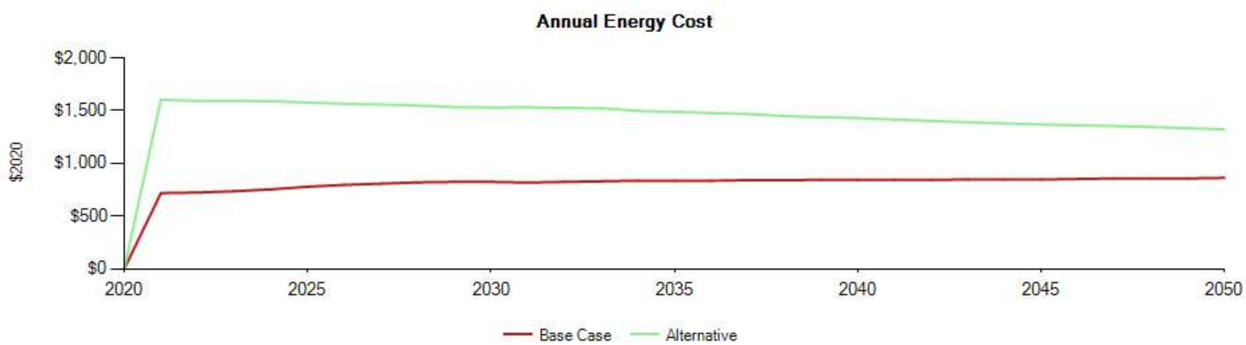
<< Back to LCCA Input

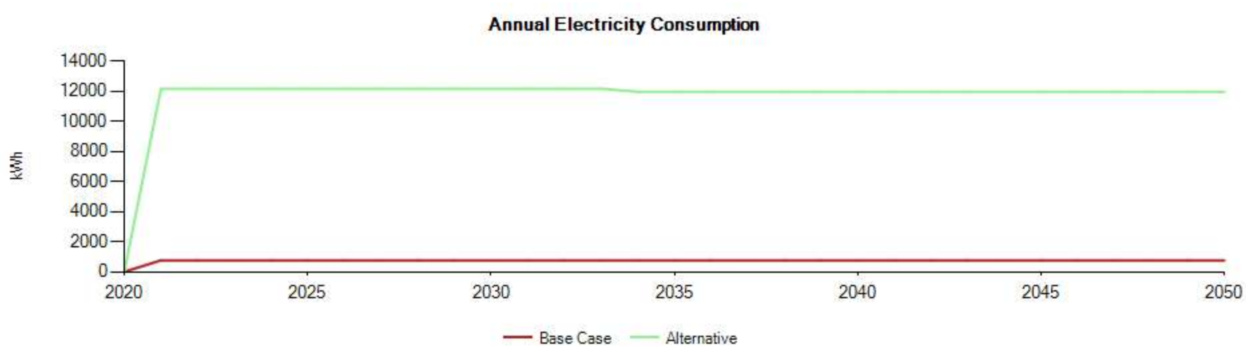
View Life Cycle

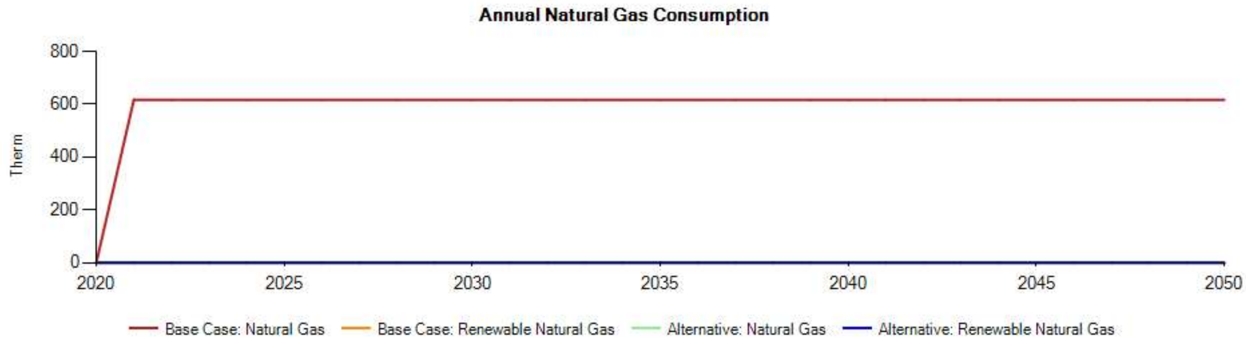
Life Cycle Costs and Energy Consumption

	Net Present Value ($2020)	Equivalent Annual Cost ($2020)	Electricity Usage (kWh)	Natural Gas Usage (Therm)	Renewable Natural Gas Usage (Therm)	Propane Usage (Gal)	Re
Base Case	26,907	1,373	22,950	18,510	0	0	
Alternative	46,626	2,379	361,075	0	0	0	



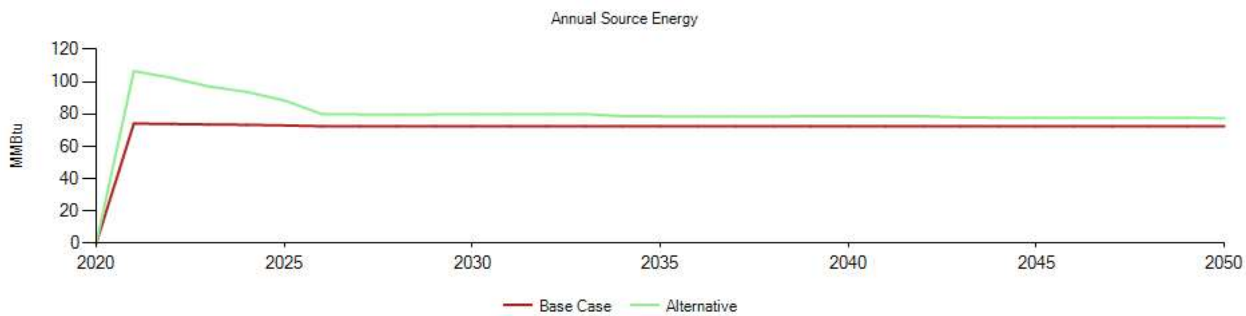


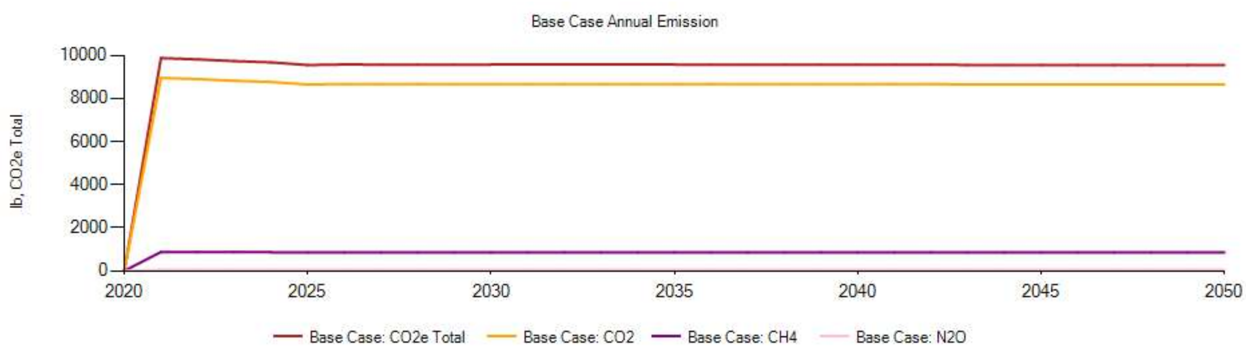


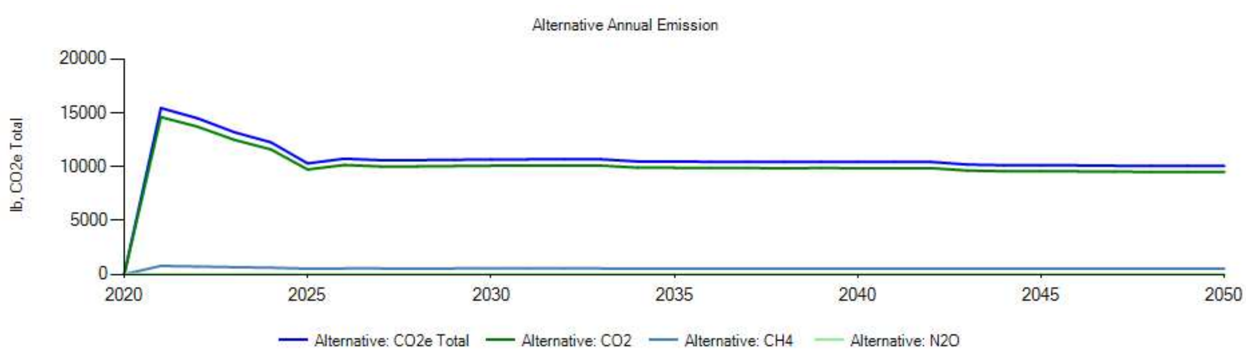


Life Cycle Source Energy and Emissions

	Total Source Energy (MMBtu)	Total Emissions CO2 (1000 lb)	SO2 (lb)	NOx (lb)	CH4 (lb)
Base Case	2,180	261	75	336	921
Alternative	2,458	308	328	260	600



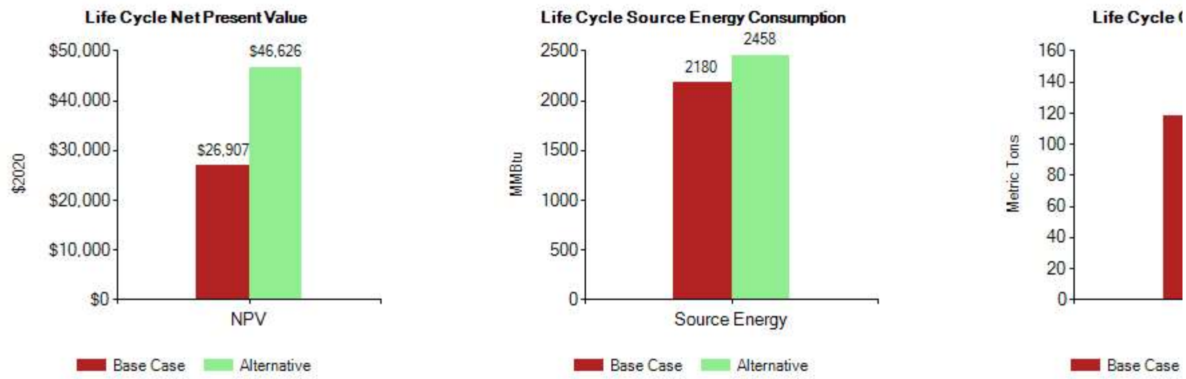




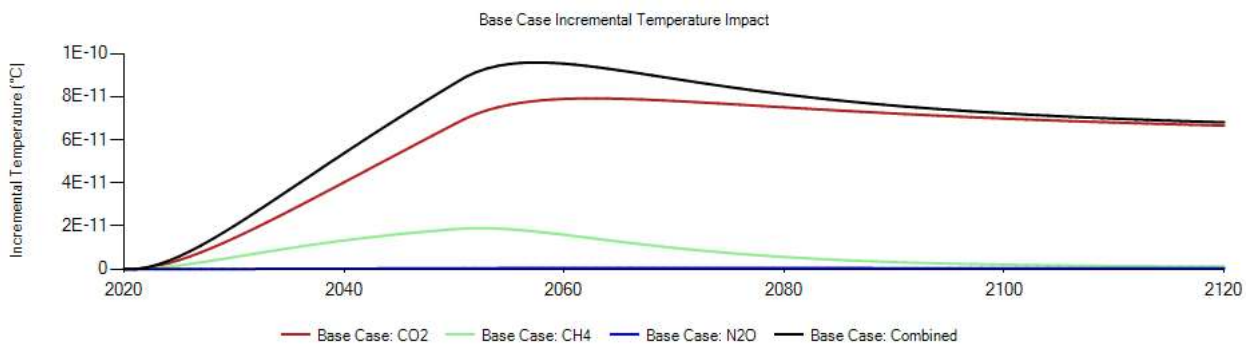
Case Comparison: Alternative vs. Base Case

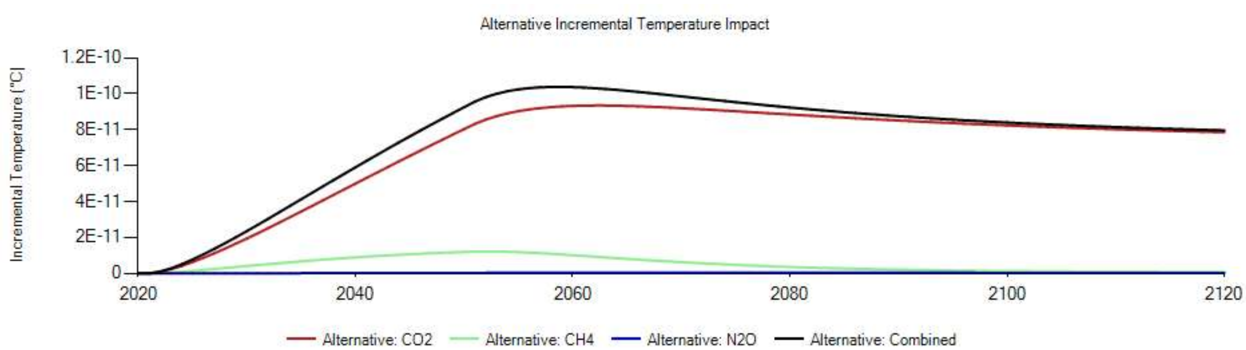
NPV Savings (Base Case - Alternative) ($2020)	Life Cycle Cost of Source Energy Savings (Base Case - Alternative) ($2020/MMBTU)	Cost of CO2 Emission Alternative) ($20

Comparison	-19719	No Reduction	No Re



Climate Impact Prediction





View Clin

CASE 15

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,800	3
	Single Fam. Attached	3,250	375	3
	Apt. Building 2 to 4 units	3,400	610	3
	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	16,100	1,800	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

Single House

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 98% Electric Consumption: 0 (kWh) Gas Consumption: 422 (Therm) Installed Cost: 2,807 $/Unit +3.86 $/kBtuh Unit Capacity: 80 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 6,068 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 3,873 $/Unit +42.00 $/kBtuh Unit Capacity: 90 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 1,100 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 2,153 $/Unit +42.00 $/kBtu Unit Capacity: 36 kBtuh	16 SEER /9.0 HSPF Heat Pump Electric Consumption: 857 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 0 $/Unit +0.00 $/kBtu Unit Capacity: 36 kBtuh
x	HVAC Blower	Electric Consumption: 609 (kWh)	Electric Consumption: 554 (kWh)
	Water Heating	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 49 (kWh) Gas Consumption: 139 (Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h	Electric Resistance EF, 0.95 Electric Consumption: 4,111 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 591 $/Unit +3.50 $/gal Unit Capacity: 60 Gal
	Lighting &	Electric Consumption: 2,610 (kWh)	Electric Consumption: 2,610 (kWh)

	Plug-in Loads		
	Cooking Range	Gas Standard Electric Consumption: 0 (kWh) Gas Consumption: 31 (Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 0 (kWh) Gas Consumption: 0 (therm) Installed Cost: 923 $/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)
	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 76 (kWh) Gas Consumption: 25 (Therm) Installed Cost: 1,100 $/Unit	Electric Standard EF 3.1 Electric Consumption: 971 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 760 $/Unit
	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: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	2.52	1.09	1.15

Composite Emission Factors

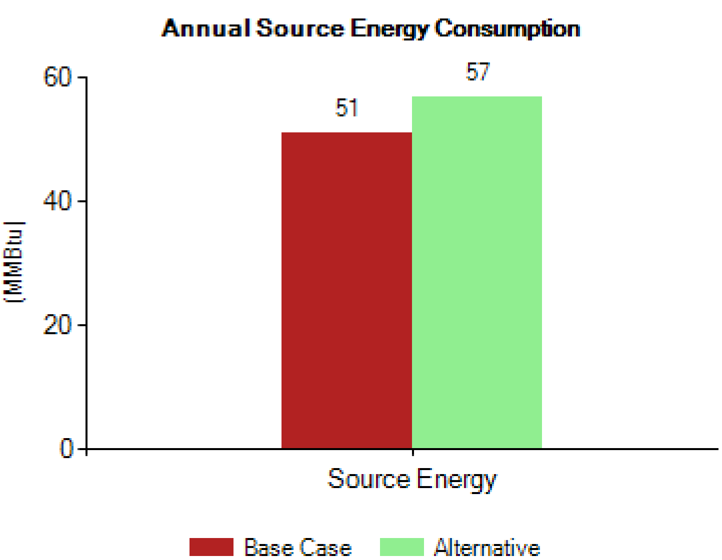
Energy Form	CO2	SO2	NOx	CH4	N2O	CO2e
Electricity (lb/MWh)	1,028.6	0.210	3.020	3.167	0.0010	1,117.6
Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
Natural Gas (mCHP Fuel Cell Used, lb/MMBtu)	43.5	0.101	0.281	0.013	0.0110	47.0

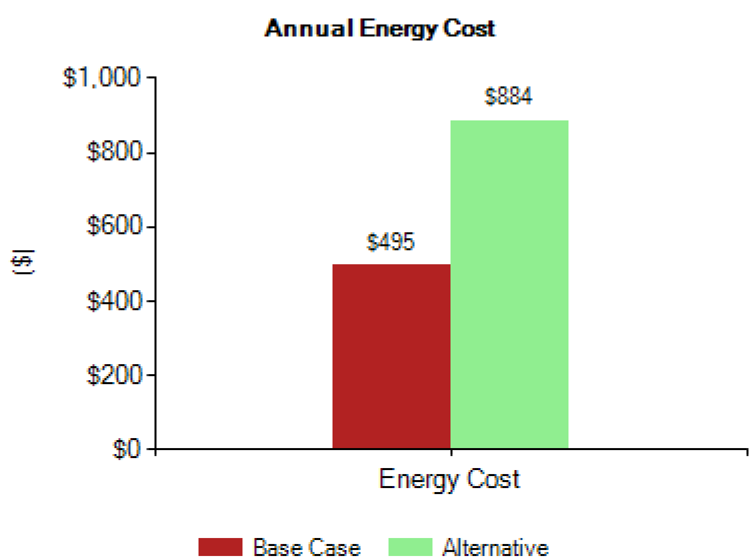
Source Energy and Emission Factors are calculated for KS: Energy conversion efficiency and specific emissions data for electricity generated using fossil fuels and biomass are based on user specified data Electric distribution efficiency data are based on User-specified data. Electricity generation fuel 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	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	609 (kWh) 0 (kWh) 422 (Therm) 0 (Therm) 0 (Gal)	2.08 0.00 42.20 0.00 0.00 44.28	5.24 0.00 46.00 0.00 0.00 51.23	81 0 414 0 0 495	3,116
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	6,622 (kWh) 0 (kWh) 0 (Therm) 0 (Therm) 0 (Gal)	22.59 0.00 0.00 0.00 0.00 22.59	56.94 0.00 0.00 0.00 0.00 56.94	884 0 0 0 0 884	7,653

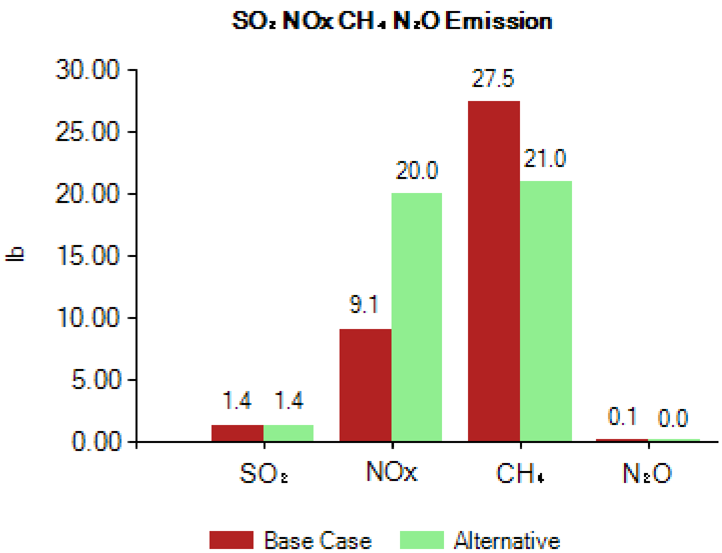
	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	($)	($)	(Year)
Comparison	-389	4,537	Never

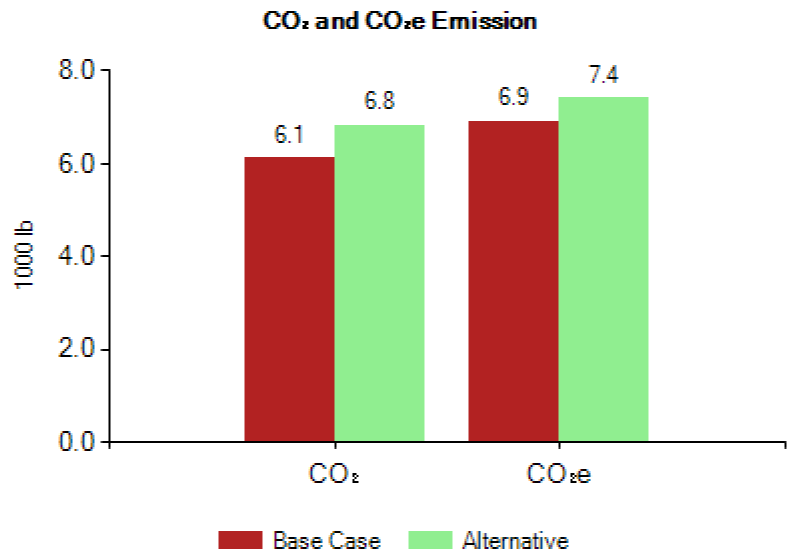




Annual Source Emissions

	SO2 (lb)	NOx (lb)	CO2 (1000 lb)	CH4 (lb)	N2O (lb)	CO2e (1000 lb)
Baseline	1.35	9.10	6.12	27.46	0.13	6.92
Alternative	1.39	20.00	6.81	20.97	0.01	7.40





CASE 16

Energy Planning Analysis Tool

Building Location and Configuration

State:	Kansas	Population:	2,853,118	Total State Home:	1,107,357

State Residential Electric Houses

Included?	House Type	Number of Units	Average Size (ft2)	Number of People per Unit
	Moblile	140	635	3
x	Single Fam. Detached	16,100	1,800	3
	Single Fam. Attached	3,250	375	3
	Apt. Building 2 to 4 units	3,400	610	3
	Apt. Building 5+ units	6,800	589	3
	All Residential Electric Houses	16,100	1,800	3

State Energy Price *

Electric Price (Cents/kWh)	Gas Price ($/Therm)	Propane Price ($/Gal)
13.35	0.98	1.60

*Note: EIA 2018 state annual prices

Select Building Configurations

Single House

		Baseline	Alternative
Included?	Application	Equipment and Appliances	Equipment and Appliances
x	Space Heating	Natural Gas, AFUE 98% Electric Consumption: 0 (kWh) Gas Consumption: 422 (Therm) Installed Cost: 2,807 $/Unit + 3.86 $/kBtuh Unit Capacity: 80 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 4,988 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 4,745 $/Unit + 42.00 $/kBtuh Unit Capacity: 100 kBtuh
	Space Cooling	13 SEER(11.07 EER) A/C Electric Consumption: 1,100 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 2,153 $/Unit + 42.00 $/kBtu Unit Capacity: 36 kBtuh	20.5 SEER /13 HSPF Heat Pump Electric Consumption: 650 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 0 $/Unit + 0.00 $/kBtu Unit Capacity: 36 kBtuh
x	HVAC Blower	Electric Consumption: 609 (kWh)	Electric Consumption: 554 (kWh)
	Water Heating	Natural Gas EF 0.95 - Condensing Tankless Electric Consumption: 49 (kWh) Gas Consumption: 139 (Therm) Installed Cost: 2,515 $/Unit Unit Capacity: 199 kBtu/h	Electric Resistance EF, 0.95 Electric Consumption: 4,111 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 591 $/Unit + 3.50 $/gal Unit Capacity: 60 Gal
	Lighting &	Electric Consumption: 2,610 (kWh)	Electric Consumption: 2,610 (kWh)

	Plug-in Loads		
	Cooking Range	Gas Standard Electric Consumption: 0 (kWh) Gas Consumption: 31 (Therm) Installed Cost: 823 $/Unit	Electric Standard EF 0.74 Electric Consumption: 0 (kWh) Gas Consumption: 0 (therm) Installed Cost: 923 $/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)
	Clothes Dryer	Gas Standard EF 3.84 Electric Consumption: 76 (kWh) Gas Consumption: 25 (Therm) Installed Cost: 1,100 $/Unit	Electric Standard EF 3.1 Electric Consumption: 971 (kWh) Gas Consumption: 0 (Therm) Installed Cost: 760 $/Unit
	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: Kansas

eGrid Database: eGRID 2018 data - eGRID plant level database

Source Energy Factors

	Electric	Natural Gas	Propane
Btu/Btu	2.52	1.09	1.15

Composite Emission Factors

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Natural Gas (Building Used, lb/MMBtu)	130.2	0.029	0.172	0.605	0.0030	147.8
Oil (lb/MMBtu)	35.1	0.084	0.281	0.511	0.0030	50.3
Natural Gas (mCHP NG Engine Used, lb/MMBtu)	163.2	0.055	0.225	0.079	0.0110	168.3
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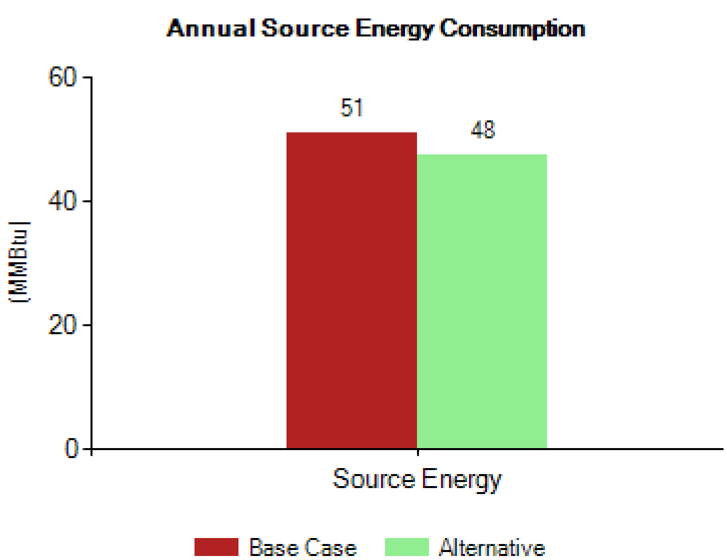
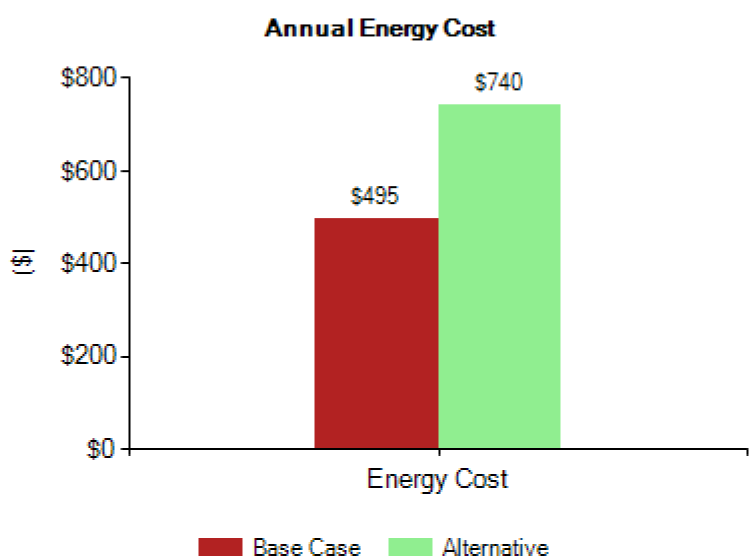
Energy Consumption and Cost

	Energy	Annual Site Consumption	Annual Site Consumption	Annual Source Consumption	Annual Energy Cost	Equipment Invest Cost
			(MMBtu)	(MMBtu)	($)	($)
Baseline	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	609 (kWh) 0 (kWh) 422 (Therm) 0 (Therm) 0 (Gal)	2.08 0.00 42.20 0.00 0.00 44.28	5.24 0.00 46.00 0.00 0.00 51.23	81 0 414 0 0 495	3,116
Alternative	Electric (Building Used) Electric (mCHP to Grid) Natural Gas (Building Used) Natural Gas (mCHP Used) Propane (Building Used) Total	5,542 (kWh) 0 (kWh) 0 (Therm) 0 (Therm) 0 (Gal)	18.91 0.00 0.00 0.00 0.00 18.91	47.65 0.00 0.00 0.00 0.00 47.65	740 0 0 0 0 740	8,945

	Energy Cost Savings (Baseline-Alternative)	Equipment Invest Cost (Alternative-Baseline)	Simple Payback (Year)
	($)	($)	(Year)
Comparison	-245	5,829	Never





Annual Source Emissions

	SO2 (lb)	NOx (lb)	CO2 (1000 lb)	CH4 (lb)	N2O (lb)	CO2e (1000 lb)
Baseline	1.35	9.10	6.12	27.46	0.13	6.92
Alternative	1.16	16.74	5.70	17.55	0.01	6.19