

NATURAL GAS AND DECARBONIZATION—THE POWERFUL AND HIDDEN ROLE

Allen Dusault, Senior Program Manager, Franklin Energy
Thomas Manjarres, Senior Energy Analyst, Peoples Gas and North Shore Gas

ABSTRACT

Natural gas is often characterized as a transitional fuel on the road to decarbonizing our energy future. Electrification is increasingly promoted as the singular method of decarbonization, made possible by the expansion and eventual dominance of wind and solar energy. This view is incomplete. Methane as a fuel is immensely important to our energy system resilience, energy efficiency and affordability. And with decarbonized gas, the environmental sustainability of our energy supply. This paper provides a sampling of that importance. The higher efficiency and lower greenhouse gas emissions from existing natural gas heating appliances, compared to electric heat pumps in cold climates as one example, is presented below. The important roles that carbon-neutral fuels such as renewable natural gas (RNG) and renewable hydrogen can play in decarbonization is also presented. They can potentially serve as energy storage media for intermittent renewable energy sources (wind, solar, tidal energy, etc.), facilitating the expansion of dispatchable renewable energy. They can also serve as blend for gas pipelines and/or as transportation fuels, thus providing additional pathways to accelerate decarbonization. R&D investments in emerging technologies, including new methods of generating H₂ and RNG that lower the cost of production and use, as well as their environmental footprint, will provide wider opportunity for adoption, where those alternative pathways are allowed to compete.

BACKGROUND

Electrification refers to the transition across all economic sectors to electricity-powered end-use technologies. It has become a national movement, resulting in legislation and building codes that prohibit new natural gas hook-ups in some areas of the country. Despite the growing body of evidence that electrification will increase electricity demand^{1,2 34} potentially by as much as 52% nationwide⁵, policymakers and environmental advocates are promoting mandated residential electrification as a method of reducing residential greenhouse gas emissions. In the residential sector, electrification most notably affects space heating and water heating. Proponents often focus in on the building-level analysis and tout the energy efficiency and greenhouse gas (GHG) emission reductions that would result from electrification. However, analysis at the building-level is incomplete because it fails to account for all the losses and inefficiencies in the electricity lifecycle that occur off site, and upstream of the utility meter. An example of this would be an 80% AFUE natural gas furnace compared to electric resistance heating. At design conditions, the furnace is combusting natural gas on-site and converting it to useful heat at ~80% efficiency. The resistance heater is 100% efficient from this perspective because 100% of the incident electricity is converted to heat. When the energy required to produce and transport that electricity is added in, the resistance heater is typically *less* efficient than a standard 80% efficient (AFUE) natural gas furnace. Quantitative comparisons between electric heat pumps, natural gas furnaces, and natural gas heat pumps in Chicago, Illinois are included to highlight this point. For this analysis, two terms are used to compare the lifecycle costs of equivalent electricity-driven and combustion-driven technologies: site energy and full-fuel-cycle-energy.

Site energy is the energy used in the home as recorded by the utility meter⁶. To date, most energy efficiency programs are designed to reduce site energy consumption by incentivizing measures and products that will maximize site energy savings.

Full-fuel-cycle (FFC) energy represents the most inclusive and most equitable boundary conditions on which to analyze the impact of building or appliance energy consumption. FFC energy is the energy used in the home (site energy) plus the total energy required to produce and transport that energy to the home. This includes the following:

1. Energy required at the wellhead to extract the raw fuel
2. Energy required to process and transport fuel to the power plant
3. Energy required to convert fuel to electricity
4. Energy required for transmission and distribution to the site

¹ [U.S. National Electrification Assessment](#). Electric Power Research Institute (EPRI). April 2018.

² [Implications of Policy-Driven Residential Electrification](#). American Gas Association (AGA). 2018

³ [A Shared Future: Electrification and Renewable Energy](#). American Wind Energy Association (AWEA). January, 2019

⁴ Murphy, Caitlin, Trieu Mai, Yinong Sun, Paige Jadun, Matteo Muratori, Brent Nelson, and Ryan Jones. 2021. Electrification Futures Study: Scenarios of Power System Evolution and Infrastructure Development for the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72330.

⁵ [Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections Through 2050](#). National Renewable Energy Lab (NREL). 2017.

⁶ [ENERGY STAR Portfolio Manager Technical Reference Manual](#). U.S. Environmental Protection Agency (EPA). 2019.

The differences between site energy and full-fuel-cycle energy are a result of the boundary conditions that define each term. Site energy is a necessary and convenient metric to track because it can be easily measured directly at the energy-consuming appliance or the utility meter. However, site energy is a misleading and incomplete metric on which to base any program, regulation, policy or investment decision whose goal is to reduce total energy consumption, energy costs, or greenhouse gas (GHG) emissions, especially when comparing appliances that are fueled by different energy sources (i.e. natural gas furnace vs. electric heat pump).⁷ Before site energy can be used for equitable comparisons, it must always be converted into meaningful metrics such as energy cost, full-fuel-cycle energy, or GHG emissions. This is because additional energy is required to produce and deliver that site energy to the building.

For electric end-use technologies, site energy measurements do not include: the energy consumed in the extraction, processing and transportation of raw fuels; the energy consumed in conversion of fuels to electricity at power-generating plants; and the energy consumed in transmission and distribution of that electricity to the building site. About 2/3 of electric energy is lost as heat in generation and transmission.⁸ For natural gas end-use technologies, site energy measurements do not include the energy consumed in the extraction, processing, transportation, and distribution of natural gas to the building site.

Furthermore, most energy efficiency initiatives based on site energy savings do not account for the total energy consumed when more than one energy source is used in an appliance, such as a natural gas furnace containing an electric blower fan. Conversely, the full-fuel-cycle energy consumption calculation accounts for all forms of energy consumed on-site in addition to all the energy needed to produce and transport that energy to the site.

ELECTRICITY AND FULL-FUEL-CYCLE ENERGY

Full-fuel-cycle energy conversion factors can be used to calculate the impact of every kWh and therm consumed. FFC energy conversion factors are the ratio of total energy consumed globally for every unit of energy used on-site. The annual full-fuel-cycle energy consumption of an appliance is calculated by multiplying the appliance's annual consumption by the appropriate FFC energy conversion factor(s). Similarly, the greenhouse gas emissions resulting from the annual full-fuel-cycle electricity consumption are calculated using data from the U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID). This is done by multiplying the annual full-fuel-cycle energy consumption by the corresponding eGRID emissions rates.

eGRID Subregions

It is nearly impossible to attribute the movement of electrons to specific electricity generation stations when multiple facilities are feeding electricity into the same network/grid. Therefore, eGRID subregions are drawn using transmission system operator (TSO) maps, distribution grids, and utility service territories to determine the generation stations most likely to be serving customers within a defined geographic area at any given time. Figure 1 includes a map of eGRID subregions across the U.S. The analysis of heating systems presented below is specific to Chicago, IL, which resides in the RFCW subregion.

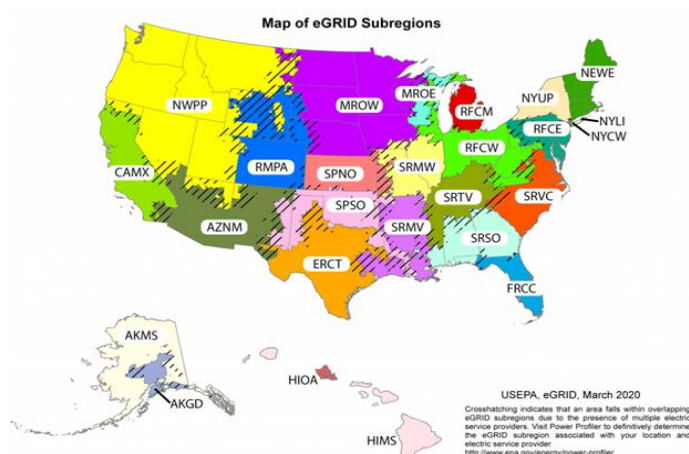


Figure 1. Subregions are defined using transmission, distribution and utility service territories of power plants.⁹

⁷ [Full-Fuel-Cycle Energy and Emission Factors for Building Energy Consumption—2018 Update](#), N. Leslie, AGA, January 2019.

⁸ [Source Energy and Emission Factors for Energy Use in Buildings](#), M. Deru and P. Torcellini, NREL/TP-550-38617, 2007

⁹ [The Emissions & Generation Resource Integrated Database Technical Support Document for eGRID with Year 2018 Data](#), U.S. EPA, January 2020.

Marginal Electricity Generation

Electric loads and renewable generation fluctuate throughout the day. Therefore, marginal power plants, also referred to as non-baseload plants, are ramped up and down as necessary to meet the needs of the grid. Because marginal plants are the ones turned up and down, the DOE and EPA use marginal output emissions to rate efficient products and calculate the emissions benefits of reduced electricity use. In fact, according to the EPA, the non-baseload (marginal) output emission rates were specifically developed to provide an estimate of emission reduction benefits resulting from energy efficiency programs and clean energy projects.¹⁰ In this context, “baseload” refers to those power plants that supply electricity to the grid when demand for electricity is low. Baseload plants are called upon to provide electricity to the grid at steady levels of power over the course of days and weeks, without significant shifts in generation, and generally operate continuously, except during maintenance.

Average GHG emissions rates include both baseload and marginal generation. If electric loads were to *increase*, which typically happens when a natural gas-heated home is electrified, the marginal power plants will be the ones that increase electricity production. Therefore, using marginal emissions rates to calculate the impacts of electrification is more accurate than using national, regional, or state average emissions because these averages include baseload power plants that typically will not be the ones responding to the load increase. Also note that intermittent renewables are typically not marginal power generators.

In eGRID, capacity factor is used as a surrogate for determining the amount of non-baseload generation that occurs at each power plant. While other factors can influence a particular generator’s capacity factor besides dispatch or load order (i.e. scheduled and unscheduled maintenance), capacity factor is used as a surrogate for dispatch-order in this calculation. Non-baseload emissions rates are the weighted average output emissions from plants that combust fuel and have capacity factors less than 0.8. Further explanation of the non-baseload emissions calculation methodology can be found in the eGRID Technical Support Document¹¹.

The eGRID subregion non-baseload CO₂ emission rates are the underlying data used in the EPA’s Greenhouse Gas Equivalencies Calculator¹² and Green Power Equivalency Calculator¹³. The analysis below also uses eGRID non-baseload (marginal) emissions rates to calculate the near current environmental impact of electrifying space heating in a representative cold climate. The non-baseload electricity generation fuel mix for the RFCW subregion is included in Figure 2.

Fuel mix of non-baseload power plants in RFCW subregion

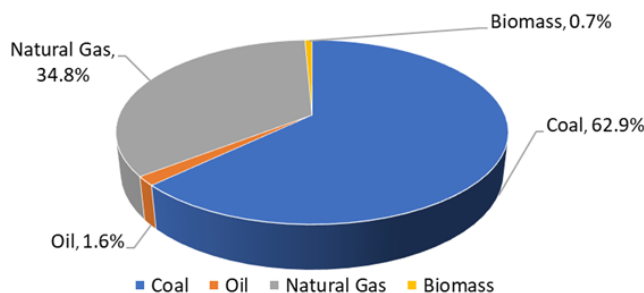


Figure 2. Marginal fuel mix based on the most recent eGRID 2018 data, released in January 2020.

The Case for Using a 100% Natural Gas Marginal Mix

The authors of this paper propose to use a marginal electricity generating fuel mix of 100% natural gas to represent the most likely near to intermediate term future scenario. As state and local efforts to retire coal plants continue to succeed, the most likely scenario is that coal’s non-baseload electricity generation will be supplanted by natural gas. How to best make up for coal’s *baseload* generation (e.g. using intermittent renewables like wind and solar with storage batteries, high capacity factor renewables like biomass, or supplies of renewable natural gas, hydrogen, etc. for power generation), and the feasibility of those alternatives, is an important debate that deserves to be engaged, but it is not the topic of this paper.

¹⁰ [Total, Non-baseload, eGRID Subregion, State? Guidance on the Use of eGRID Output Emission Rates](#). S. Rothschild, A. Diem. U.S. EPA. 2009.

¹¹ [The Emissions & Generation Resource Integrated Database Technical Support Document for eGRID with Year 2018 Data](#). U.S. EPA. January 2020.

¹² <https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>

¹³ <https://www.epa.gov/greenpower/green-power-equivalency-calculator>

The assertion that natural gas generation will increase is supported by the U.S. National Electrification Assessment published by the Electric Power Research Institute (EPRI) in 2018¹⁴. According to EPRI research, electrification may result in a total natural gas consumption *increase* of anywhere from 18%-40% over the baseline, which is taken from the U.S. Energy Information Administration's Annual Energy Outlook 2017. These estimates are consistent with the national average full-fuel-cycle efficiency of natural gas delivered to the home (91.5%) compared to the average full-fuel-cycle efficiency of marginal natural gas-generated electricity (39.4%). These values, as well as the full-fuel-cycle efficiencies specific to the RFCW subregion are displayed in Table 1. When natural gas use is shifted from inside the home to power plants, the result is often a drop in system or source energy efficiency and an increase in total gas consumption.

Natural Gas Full-Fuel-Cycle Efficiency

Due to the inherent inefficiency associated with generating electricity, average and marginal electricity generation FFC efficiencies are significantly lower than the average natural gas FFC efficiency. This means significantly more energy input is required for every Btu of electricity used in a home when compared to the energy input required for every Btu of natural gas used in the home. As depicted in Table 1, the U.S. average natural gas FFC efficiency is **91.5%** whereas the national average electricity generation FFC efficiency is **36.7%**. That has powerful implications for total system efficiency of installed measures.

BENEFITS OF NATURAL GAS IN COLD CLIMATES

In colder climates, electric heat pump efficiency and overall environmental impact depend on two factors: outdoor air temperature and efficiency of the supplemental heat source. As outdoor air temperatures drop, there is less heat available for the heat pump to extract. This forces the heat pump to work increasingly harder and reduces efficiency by a factor of two or more, depending on the outdoor air temperature. To meet the space heating demands in cold climates, electric heat pumps are equipped with auxiliary/supplemental heat sources. Even where cold climate heat pumps are designed with higher capacities at lower temperatures, they have lower efficiencies and are much more expensive. The auxiliary heat typically provided by a less efficient electric resistance heating element or gas furnace. In the full electrification scenario, the choice for auxiliary heat is resistance heating, which is expensive to operate and will contribute to significantly larger wintertime peak demands.

When outdoor air temperatures drop below the balance point temperature, which is in the range of 5-20 °F for cold climate heat pumps¹⁵ and approximately 30-45 °F for conventional electric heat pumps¹⁶, auxiliary heating is required to adequately heat the home. Increasingly more auxiliary heat is required as temperatures drop below the balance point temperature. When the auxiliary heat source is electric resistance, this causes a sharp increase in both electricity consumption and operating cost.

Energy Form	Process Efficiency					Full-Fuel-Cycle Efficiency
	Extraction	Processing	Transportation	Conversion	Distribution	
Natural Gas, Building Use¹⁷ (U.S. Avg.)	96%	97%	99%	---	99%	91.5%
Natural Gas-Generated Electricity¹⁸ (U.S. Avg.)	96%	97%	99%	41%	95%	36.7%
Electricity¹⁶ (U.S. Avg.)	98%	98%	99%	41%	95%	36.7%
Non-Baseload Electricity¹⁶ (RFCW subregion)	98%	99%	98%	34%	95%	32.3%

Table 1. Full-fuel-cycle energy efficiency of electricity and natural gas delivered to the home.

¹⁴ [U.S. National Electrification Assessment](#). Electric Power Research Institute (EPRI). April 2018.

¹⁵ [Guide to Sizing & Selecting Air-Source Heat Pumps in Cold Climates](#). Northeast Energy Efficiency Partnerships (NEEP). Rev 12/07/18.

¹⁶ [Strategy Guideline: HVAC Equipment Sizing](#). U.S. DOE Building Technologies Program. February 2012.

¹⁷ [The greenhouse gases, Regulated Emissions, and Energy use in Technologies Model \(GREET\)](#). Argonne National Laboratory. Rev 10/9/20.

¹⁸ [Emissions & Generation Resource Integrated Database \(eGRID\) 2018](#). U.S. Environmental Protection Agency. March 9, 2020.

In locations where natural gas is the predominant heating fuel, sector-wide residential electrification will lead to new wintertime peak demands. In many northern states, new winter peaks can be two- and three-times greater than the current hourly peak demands, which now occur in the summer¹⁹.

Cold climate heat pumps are effective down to low outdoor air temperatures, but they will still contribute to larger wintertime peak demands because each electric heat pump that displaces a fuel-burning heating source represents a new winter electric load that our current grid, built to serve summer peaks, was not designed to handle. It also means new infrastructure is needed.

Furthermore, if electrification is legislatively mandated, not everyone that would benefit from a cold climate electric heat pump will end up purchasing a cold climate heat pump. The installed cost of a cold climate heat pump is ~\$6,000²⁰ more than a conventional heat pump and can be over \$10,000²¹ more than a gas furnace. Some consumers will value significantly lower upfront costs and higher monthly bills (conventional heat pump) over higher upfront costs and lower monthly bills (cold climate heat pump) and end up with a conventional electric heat pump. Others, particularly the low-income sector, will be unable to afford the cold climate heat pump altogether and choose a cheaper available option, likely a conventional electric heat pump, .

For these reasons, the analysis below compares a highly efficient conventional electric heat pump to natural gas heating alternatives. This comparison represents the more likely scenario of homeowners and landlords that will select the lower cost conventional heat pump in a cold climate such as Chicago (which will still likely require substantial subsidy to gain adoption).

Natural Gas Technologies vs. Electric Heat Pumps in Chicago

For the comparison scenarios presented below, natural gas heating technologies were compared to an electric heat pump using climate data and the average annual heating load for Chicago, Illinois. The reference case is a conventional 1,200 sq. ft, 2-bedroom townhome. The annual full-fuel-cycle energy consumption, the resulting annual greenhouse gas emissions, and annual operating costs for the reference home were calculated using the Carbon Management Information Center (CMIC) Source Energy and Emissions Analysis Tool (SEEAT)²².

SEEAT uses five public domain data sources to calculate FFC energy and emission conversion factors for electricity and fossil fuels typically used in residential and commercial buildings. The five data sources are the EPA, Energy Information Administration (EIA), Argonne National Laboratory (ANL), National Renewable Energy Laboratory (NREL), and the National Hydropower Association²³.

Chicago resides in the RFCW eGRID subregion, therefore the fuel mix of the marginal power plants in the RFCW subregion were used to calculate the annual full-fuel-cycle energy consumption and greenhouse gas emissions attributable to each technology. The annual operating costs were calculated using the 2019 average residential utility rates in Illinois published by the Energy Information Administration. The 2019 average natural gas rate in Illinois was \$0.78/therm and the average electricity rate was \$0.1303/kWh.

The 80% annual fuel utilization efficiency (AFUE) natural gas furnace represents the most common baseline scenario today and the 90% AFUE furnace represents the most likely baseline in the immediate future. The 96% AFUE modulating, condensing gas furnace represents an efficient natural gas option that is widely available in the market today. The electric heat pump with HSPF of 13 represents the most efficient conventional electric heat pump in the market today. The heating performance of natural gas-driven heat pumps for the residential market is currently in the late stages of field demonstrations. Their performance has demonstrated that natural gas heating deployed in the RFCW subregion will typically be more efficient and cause less GHG emissions than the efficient, conventional electric heat pumps.

Gas Absorption Heat Pumps (GAHP)

Gas absorption heat pumps are air-source heat pumps driven not by electricity, but by a heat source—typically natural gas (propane, hydrogen, renewable natural gas, biomethane and other fuels also possible). Residential gas absorption heat pumps typically use an ammonia-water absorption cycle. As with an electric heat pump, the refrigerant (ammonia in the case of gas absorption heat pumps) is condensed in one area to release heat and evaporated elsewhere to absorb heat. The differences between electric and gas heat pumps, besides fuel source, is primarily in the refrigerant and how the refrigerant is pressurized.

¹⁹ [Environmental Consequences of Electrifying Space Heating](#). P. Vaishnav, A.M. Fatimah. Environmental Science & Technology. 2020, 54,16, 9814-9823.

²⁰ [The Gas Heat Pump Technology and Market Roadmap](#). GTI and Brio. November 2019. Industry White Paper.

²¹ [The Role of Gas Heat Pumps in Zero Net Energy Buildings](#). P. Glanville, et al. 2016 ACEEE Summer Study proceedings

²² [Source Energy Emissions Analysis Tool \(SEEAT\)](#). Accessed March 2020.

²³ [CMIC Source Energy and Emissions Analysis Tool Version 9.0 Description](#). Accessed March 2020.

Gas heat pumps do not use environmentally damaging hydrofluorocarbons (HFCs) or chlorofluorocarbons (CFCs) as the refrigerant. Instead, ammonia (NH₃), considered a natural refrigerant by the EPA, is used as the working fluid. In a gas heat pumps, the evaporated ammonia is absorbed into water and a relatively low power pump then pumps the solution up to a higher pressure. The natural gas heat source is then used to boil ammonia out of the ammonia-water mixture, and the ammonia vapor continues through the cycle. Note that not factored into our analysis is GHG impact of HFC leakage from electric heat pumps.

The first two scenarios presented below focus on how “energy efficiency” can impact carbon emissions; specifically, how replacing natural gas furnaces with electric heat pumps in cold climates has potential to increase total energy consumption, increase greenhouse gas emissions, and increase customer utility bills. Two subsequent scenarios that are analyzed indicate that using a lower carbon fuel mix can benefit decarbonization efforts, thereby providing a pathway parallel to electrification.

ANALYSIS FROM ENERGY EFFICIENCY SCENARIOS 1 AND 2

Because fuel switching (from natural gas and fuel oil, for example, to electricity) will increase electricity demand, the electricity powering the electric heat pumps will most likely come from the existing marginal power plants in the region or new plants built with dispatchable capability. Findings from the analysis indicate that natural gas heating options have lower carbon emissions than the electric heat pump. This is true for each of the four scenarios evaluated in this study location (Chicago, IL).

In the four scenarios evaluated, carbon dioxide equivalents, abbreviated CO_{2e}, are used to compare total greenhouse gas emissions across devices. This is based on the 100-year global warming potential of each greenhouse gas. The amount of each greenhouse gas emitted is converted to the equivalent amount of CO₂ required to produce the same global warming potential (GWP). For example, the GWP of carbon dioxide is one, and the global warming potential of methane (CH₄) from the direct release of natural gas is approximately 28. Therefore, one ton of CH₄ released is approximately equal to 28 tons CO_{2e}.

Annual operating costs were calculated using the 2019 average utility rates in Illinois. According to the Energy Information Administration²⁴, the average natural gas rate for IL residential customers in 2019 was **\$0.78 per therm** and the average electricity rate for residential customers in 2019 was **\$0.1295 per kWh**.

Scenario 1: Immediate Impacts of space heating electrification

Results from Scenario 1 are based on the current marginal electricity generating fuel mix (eGRID 2018 data was released in March 2020). This scenario shows the immediate impact of fuel switching from natural gas to electricity for space heating today. The results displayed in Figure 3 show that, in Chicago, an electric heat pump causes nearly **1.3 times the greenhouse gas emissions of a baseline 80% AFUE furnace and more than twice the greenhouse gas emissions of a gas heat pump**.

Additionally, the data show that not only is the electric heat pump responsible for more GHG emissions, it is also more expensive to operate. As seen in Figure 3, **the electric heat pump is nearly twice as expensive to operate as the efficient gas furnace (96% AFUE) and nearly 2.5 times as expensive as the gas heat pump**. Note that this is also only considering

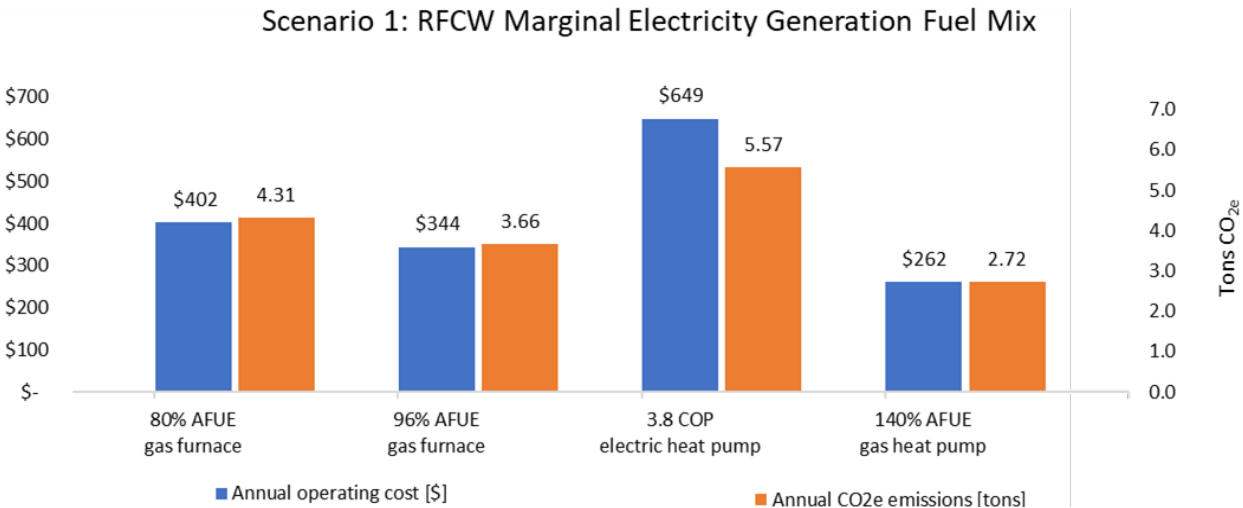


Figure 3. Heating system operating cost and emissions comparisons for 1,200 ft² Chicago, IL townhome.

²⁴ U.S. Energy Information Administration, [Illinois State Profile and Energy Estimates](#). Accessed February 2020.

operating costs, not any cost premiums associated with the installation. Electric heat pump installations are expensive and may also require costly upgrades to the electrical service panel in some residences.

Furthermore, the data provided in tables 2 and 3 show why focusing solely only *site energy* consumption can be misleading. Although electric heat pump are the most efficient option according to site energy rankings in Table 2, they are not from *source energy* metric. This is due to inefficiencies embedded in the energy production and delivery system that the electric heat pump relies, the electric grid. When the total energy required to produce and transport electricity (versus natural gas) to the home are included (full-fuel-cycle energy in Table 3), the electric heat pump is the least efficient heating system analyzed. Conversely, the natural gas heat pump is the most efficient system analyzed as well as the cheapest of all the heating systems to operate.

Scenario 1 – Annual Site Energy		
Rank	Heating System	Site Energy (MMBtu)
1	Electric heat pump (3.8 COP)	17.0
2	Natural gas heat pump (1.4 COP)	26.8
3	Condensing gas furnace (96% AFUE)	39.5
4	Baseline gas furnace (90% AFUE)	42.0

Table 2. Site energy consumption in a 1,200 sq. ft. townhome in Chicago, IL

Scenario 1 – Annual Full Fuel Cycle Energy		
Rank	Heating System	FFC Energy (MMBtu)
1	Natural gas heat pump (1.4 SCOP)	32.7
2	Condensing gas furnace (96% AFUE)	45.4
3	Baseline gas furnace (90% AFUE)	48.1
4	Electric heat pump (3.8 SCOP)	52.5

Table 3. Full-fuel-cycle energy consumption in a 1,200 sq. ft. townhome in Chicago, IL

Scenario 2: Near-Term Impacts of Electrification

As previously discussed, the most likely near-term impact of electrification initiatives and concurrent efforts to retire coal plants is that coal’s non-baseload generation will be supplanted by natural gas. Therefore, to simulate the immediate to near-term future, scenario 2 was created using a marginal electricity generating fuel mix of 100% natural gas. The baseline furnace used for comparison was upgraded to a 90% AFUE furnace to also reflect the most likely near-term future scenario.

The results from Scenario 2 are different in magnitude, but the conclusion from Scenario 1 remains the same: The electric heat pump will cause the most greenhouse gas emissions while the gas heat pump will cause the least. These results are depicted below in Figure 4. The electric heat pump also remains the most expensive system to operate.

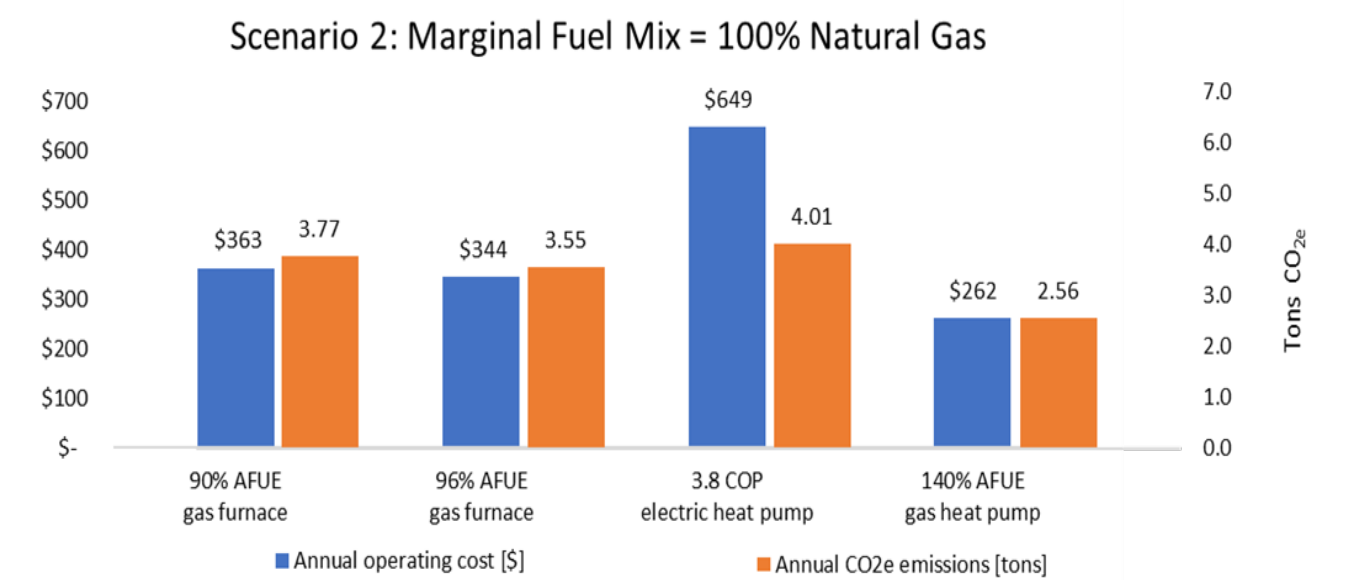


Figure 4. Heating system operating cost and emissions comparisons for 1,200 ft² Chicago, IL townhome.

ANALYSIS FROM GAS GRID DECARBONIZATION – SCENARIO 3 & 4

Hydrogen

Renewable hydrogen offers a range of advantageous in decarbonizing the residential, commercial, industrial sectors and/or transport sectors²⁵. At low percentages, less than 5%-15% depending on location, hydrogen can be blended into existing natural gas pipelines²⁶. Hydrogen can also provide much needed flexibility in renewable energy systems via the power-to-gas (P2G) pathway. The P2G pathway converts excess renewable electricity into hydrogen gas that can be stored and used as a fuel in a variety of applications. Most importantly, when P2G is integrated into the electric grid, it can reduce the amount of renewable energy lost due to real-time curtailment of intermittent sources, such as wind and solar generation. Producing hydrogen from renewable power when there is excess renewable electricity in the system avoids having to curtail renewable assets, thereby increasing the amount of renewable energy in the system while potentially improving the benefits of intermittent renewables.

Once the hydrogen is produced, there are several options in terms of its use. One option is to store it and feed it through a fuel cell to produce renewable electricity later when the intermittent asset is not producing. Hydrogen may also be a better long-term storage solution compared to electrochemical storage (batteries), including due to its negligible self-discharge rate. As such, hydrogen could be used to help with seasonal variations in intermittent renewable output. A second option is producing hydrogen gas and blending it into the existing natural gas grid, typically at relatively low percentages. Or it can serve as the first step in producing renewable natural gas from hydrogen made through methanation (using a renewable carbon source).

Renewable Natural Gas

Renewable natural gas (RNG) is pipeline quality gas that is fully interchangeable with fossil natural gas but is produced from a renewable feedstock. It can be a 100% substitute for fossil natural gas, or it can be blended with fossil natural gas streams. Renewable natural gas can be either carbon-neutral or carbon-negative, depending on the source.

Feedstocks for the production of renewable natural gas include, but are not limited to, the following:

- Animal manure
- Agricultural and wood waste/biomass
- Landfill gas
- Municipal solid waste
- Wastewater treatment plants
- Energy crops
- Electricity generated from renewable sources (wind, solar, hydro, geothermal)

Blending renewable natural gas into the existing pipeline infrastructure has the potential to significantly decarbonize the natural gas grid while enabling increased renewable energy use in major sectors of the energy economy, including industrial, residential, and commercial buildings. Increasing RNG production can also preserve consumer choice. As high carbon fuels are decarbonized, RNG and other alternatives would allow consumers to choose between the most efficient and cost effective electric and gas appliances.

Decarbonized gas

Natural gas decarbonization has several potential pathways, including producing hydrogen through electrolysis from wind and/or solar produced electricity. Another example is plasma-arc methane pyrolysis. It involves the splitting methane into gaseous hydrogen and solid carbon without producing CO₂ and has been demonstrated at industrial scale.²⁷ Other pathways to achieve decarbonization of current natural gas infrastructure are not elaborated here. But a key element of that capability is the dynamic nature of the technology under development. Advancements in methods to decarbonize natural gas may not be as visible as the work with electric batteries; but there are promising new developments that will likely change the landscape of what is economically feasible, and include getting to zero carbon gas.

Blending decarbonized gas into the pipelines can increase total carbon-free gas capacity beyond what would be possible with renewable natural gas alone. Natural gas decarbonization can also bolster the power-to-gas pathway. Additionally, it could include enabling the use of hydrogen in the system without the additional cost of adding hydrogen storage, keeping CH₄ the main energy carrier and utilizing existing gas distribution infrastructure.

²⁵ [Clean Energy and the Hydrogen Economy](#), N.P. Brandon, Z. Kurban. Philosophical Transactions of The Royal Society. June 2017.

²⁶ [Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues](#), National Renewable Energy Laboratory (NREL). March 2013.

²⁷ [Natural Gas Decarbonization as Tool for Greenhouse Gases Emission Control](#), A. Abanades. Frontiers in Energy Research. 19 June 2018.

Scenarios three and four presented below indicate that carbon-free renewable natural gas could be an attractive pathway to achieving system-wide decarbonization.

Scenario 3: Mid-term Impacts With 10% RNG

Scenario 3 represents a midterm time horizon when renewable natural gas is blended into existing gas pipelines at a rate of 10% by volume. This means 10% of the gas supplied to gas powerplants is RNG and 10% of the gas supplied to the gas heat pump and furnaces is RNG. While it is true that in this future scenario wind and solar electricity generation will likely also increase, solar will be limited in the winter heating season. And with both wind and solar having no seasonable storage, they will not provide significant or reliable marginal generation, particularly with dramatically increased winter loads. Therefore, the marginal electricity generating fuel mix used for this comparison was 10% carbon-free renewable natural gas and 90% fossil natural gas.

As depicted in Figure 5, the gas heat pump and 96% AFUE gas furnace continue to cause less greenhouse gas emissions than the electric heat pump. However, the addition of 10% renewable natural gas does decrease emissions across the board. Operating costs were not compared in this scenario because the cost of renewable natural gas at this scale is speculative and how the cost of electricity produced from RNG might be passed on to the electricity and gas consumer is not well established.

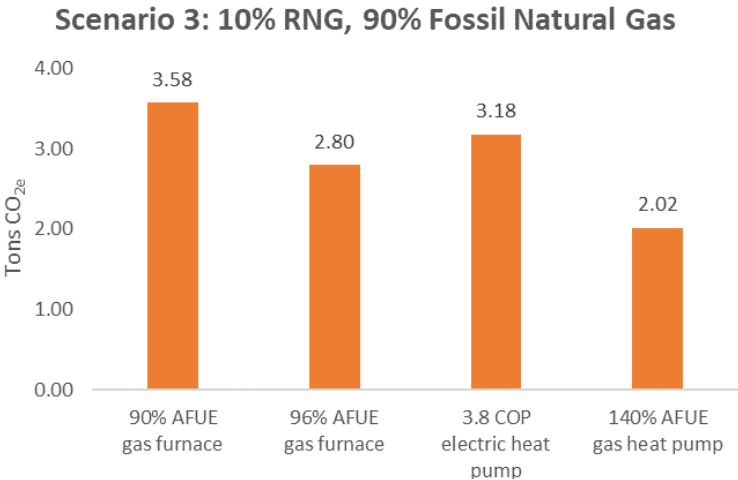


Figure 5. Annual emissions by heating system type in 1,200 ft² Chicago townhome.

Scenario 4: Long Term Impacts With 50% Decarbonized Gas

Scenario 4 represents the long-term impacts when 50% of the fuel consumed by gas appliances and gas powerplants would be made up of decarbonized gases (RNG, hydrogen or others). The marginal electricity generating fuel mix in this scenario is 50% decarbonized gas and 50% fossil natural gas. As depicted above in Figure 6 (below), the gas heat pump and 96% AFUE

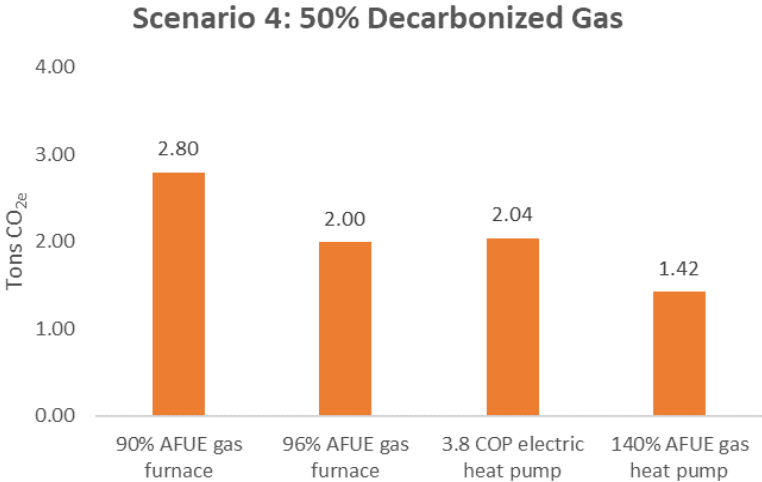


Figure 6. Annual emission

furnace continue to emit less greenhouse gas emissions than the electric heat pump. This is again due to the inherent inefficiencies embedded within the electric grid. Because the electric heat pump requires the most full-fuel-cycle energy (Table 3), it continues to have the highest GHG emissions even when 50% of the electricity it consumes is produced by non-carbon emitting gas.

In each scenario evaluated, the gas heat pump and 96% AFUE gas furnace are more efficient (full-fuel-cycle efficiency) and contribute to less greenhouse gas emissions than the conventional electric heat pump. Furthermore, the last three scenarios evaluated show a clear trend: as the percentage of decarbonized gas in the system increases, the greenhouse gas emissions from both electric and gas appliances decrease. These results demonstrate the potential for decarbonized gases (hydrogen, RNG, etc.) to reduce greenhouse gas emissions for both the electricity and natural gas sectors. That can accelerate decarbonization.

Concurrent Decarbonization of the Electric and Gas Grids

Renewable and decarbonized gases (hydrogen, RNG, low carbon blends, etc.) should be seen as complimentary and beneficial decarbonization options for both the electricity and gas grids. The gas decarbonization pathway is making technical advances, changing what is feasible. Existing gas pipeline infrastructure can also be used as a means to store surplus renewable electricity. The stored RNG and hydrogen can be used to produce electricity on-demand, either through the use of fuel cells or combined cycle gas plants. If hydrogen, RNG and other decarbonized gas capacity is incentivized to grow, they could provide the dispatchable capability necessary to eliminate fossil fuels from both the baseload and marginal electricity generating fuel mixes. These renewable or decarbonized gases can also be incorporated into existing pipeline infrastructure, allowing them to be used in highly efficient residential appliances, such as gas absorption heat pumps, or in many commercial and industrial applications.

CONCLUSION

It is sometimes assumed, that site energy savings that come from electrification are a good reason to fuel switch from gas furnaces to electric heat pumps. This view is misleading because it fails to recognize the additional energy required to, and GHG emissions resulting from, producing and transporting that energy to the site. Results from Scenario 1 (Illinois cold climate and immediate impacts) show that the electric heat pump consumes the most full-fuel-cycle energy even though it consumes the least amount of site energy. Consequently, in cold regions where fossil fuels dominate the marginal powerplant fuel mix, heating with natural gas may be the more efficient alternative and have lower greenhouse gas emissions than heating with an electric heat pump. And that is likely to be true for many years into the future, even allowing for the phasing out of coal plants and for a substantial increased contribution from wind and solar in the power generation mix.

Another misconception is that the average electricity generating fuel mix should be used for comparison instead of the marginal generating fuel mix. The average fuel mix includes both baseload and marginal generation. Using the average mix typically underrepresents the GHG impacts of increasing electricity consumption, particularly in winter when needed most. In Illinois and other cold areas of the country, winter loads can be two to three times summer peak loads. That will require significant new baseload and dispatchable power that doesn't rely on intermittent electricity generation. Seasonal battery storage doesn't yet exist, and any such storage comes with a cost premium. Low-income families are particularly vulnerable. They can't install their own back-up generators, or move south in the winter. On cold still nights in January, a reliable source of heat is needed.

If large-scale increases in greenhouse gas emissions are to be avoided, marginal electricity generation in the North American electric grid must be decarbonized. Increasing green and blue hydrogen and decarbonized gas use can help to accomplish this. Innovations emerging from research labs and green tech investment will only expand these decarbonization opportunities.