

Electric and Gas Decarbonization Options for Homes: The Best Option Can Vary by Building Type, System Type, and Climate

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ABSTRACT

Many states and utilities are making long-term decarbonization commitments. For homes, some stakeholders believe this means full electrification. Others tout opportunities to use clean fuels, such as biogas and hydrogen, also noting opportunities for gas-driven heat pumps. This paper reports on the results of a home-by-home analysis we conducted on several thousand homes across the United States, looking at decarbonization options for space and water heating beginning in 2030.

We find that for 1- to 4-family buildings, below about 6,000 heating degree days (HDD; the climate in Detroit), lifecycle costs are generally lowest for electric heat pumps under our medium cost assumptions. These findings assume use of cold climate heat pumps above 4000 HDD. Above about 6,000 HDD, electric heat pumps with a fuel backup that is used below 5°F often minimizes costs. For apartments served by central boilers, use of largely decarbonized fuels generally has the lowest lifecycle cost. Electrifying these apartments is expensive, and with their generally modest energy needs, it is hard to recoup the cost of electrification investments. For water heating, electric heat pump water heaters have the lowest lifecycle costs in every home analyzed, followed by gas heat pump water heaters, then gas condensing tankless water heaters.

While decarbonization will require both electrification and alternative fuels, as long as inexpensive fossil fuels are available, market adoption will proceed slowly. Policies, including research and development, minimum efficiency standards, incentives, restructuring electric (and perhaps gas) rates, clean heat standards, and a price on carbon will accelerate this transition.

Introduction

Many states and utilities are making long-term decarbonization commitments. In the buildings sector, some stakeholders believe this means fully electrifying buildings and generating power only from clean energy (renewables, nuclear, and fuels with carbon capture, utilization and storage). Other stakeholders, including many involved with the natural gas industry, tout opportunities to use clean fuels, such as biogas and hydrogen, also noting opportunities for gas-driven heat pumps and heat pump water heaters to promote efficient use of these fuels.

Many prior studies have compared fossil fuel heat furnaces and boilers to electric heat pumps, but these analyses largely assume current prices of natural gas, propane, fuel oil, and electricity (e.g., Nadel 2016, Nadel 2018, Bilimoria et al. 2018). But if we are truly going to reach zero net emissions from buildings, we will no longer be able to use fossil fuels in homes or to generate electricity; instead, we will need to use carbon-free (or nearly carbon-free) energy.

A variety of issues will affect the question of how best to decarbonize the buildings sector. For example, the best solution may vary with climate; it is easier to get heat from heat pumps in Florida than Alaska. Alternative fuel availability and costs will be issues. While electricity is widely available, how will costs change if vehicles and homes are electrified? Meeting winter peak demand during infrequent polar vortex events may be particularly challenging. Efforts to reduce loads through energy efficiency and control loads through demand

flexibility will also affect electricity peaks and economics. Biofuels and hydrogen are generally more expensive than natural gas, particularly “green” hydrogen, which is made with carbon-free electricity. If many customers are electrified, what will that mean for allocation of costs to maintain a gas distribution network? There are also important differences between new construction and existing buildings, and there are regional differences in energy prices, how clean the electric grid is, and potential availability of biofuels and hydrogen.

In an effort to help policymakers, utilities, and other interested parties understand appropriate building decarbonization strategies for different building types and regions, ACEEE conducted an analysis looking at the emissions and economic implications of different decarbonization scenarios. Our analysis evaluates strategies to be applied starting in 2030, after gas heat pumps and strategies to decarbonize both the electric grid and gas network are more established. Decisions made in the 2030s will affect equipment operating in 2050 and therefore efforts to fully decarbonize buildings by 2050. We use 2040 energy prices because 2040 is about the midpoint of the life of equipment installed in 2030.

The goal of this analysis is to assist policymakers and others in objectively assessing and comparing different decarbonization options for buildings in the medium and long terms, helping to inform discussions on near- and mid-term steps. The “Next Steps” section toward the end of this paper discusses policy strategies that can be put in place in the 2020s to lay a foundation for the 2030 decisions we analyze.

Analysis Approach

We conducted an analysis on many of the approximately 5,000 homes in the 2015 Residential Energy Consumption Survey (RECS) compiled by the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE). RECS contains detailed data on the building characteristics and energy use of a national sample chosen to represent the U.S. housing stock across regions and building types (EIA 2018). For each of the homes and apartments in RECS that used natural gas, propane, or fuel oil in 2015, we analyzed several decarbonization options, including electric and gas heat pump options and alternative fuel options. Our analysis assumes that equipment is installed in 2030 and that this new equipment replaces existing equipment that is at the end of its service life. We look at both space heat and water heat. In homes with central air conditioners, we look at installing an electric heat pump instead when the air conditioner needs replacement. In other homes, we look at installing heat pumps when the existing furnace or boiler needs replacement. For water heating, we look at options when the existing equipment needs to be replaced. This new equipment will operate until nearly 2050 (varying with the life of the equipment). We use estimated electricity and fuel prices assuming mostly decarbonized electricity and fuel (further described below). This enables us to compare decarbonization options using electricity and/or alternative fuels.

Specifically, we conduct a complex modeling analysis on decarbonization options using many alternative assumptions. We look at single-family homes and multifamily buildings of various ages. We consider different climates and equipment types, as well as projections for future power and fuel prices. Our analysis considers energy efficiency options as well as options to combine use of electricity and clean fuels (so-called “hybrid” options). Our analysis shows which decarbonization options may be best in different building types and climates under “most likely” conditions and also explores the impact of changes in key assumptions.

For the electric options, we examine a variety of heat pumps, including:

- Ducted heat pumps for homes and buildings that already have warm-air ducts.

- Air-to-water heat pumps for homes and buildings that circulate hot water to radiators or baseboard heating units.
- Ductless mini-split systems for other homes and buildings, such as those with steam heat.
- In cold and temperate climates (those with 4,000 heating degree days or more), we apply heat pumps designed for use in cold climates.
- In climates where the temperature (99% design temperature) can get below 5°F for a significant portion of the heating season, we consider a hybrid system that uses a fuel-based system as a backup to an electric heat pump.
- Heat pump water heaters for water heating.

Ground-source heat pumps are another option, but we did not include them in our analysis because costs are highly site-specific and we do not have information on each site to estimate these costs.

For the alternative fuel scenarios we include:

- Biogas (largely from bio-wastes).
- Synthetic natural gas made from “green” hydrogen.
- “Renewable” fuel oil (very similar to biodiesel) and renewable propane.

For natural gas and propane we consider both condensing systems and gas heat pumps for space and water heating. For oil we examine high-efficiency non-condensing systems.

The Cost of Alternative Fuel and Electricity

A key driver of our analysis is the cost of decarbonized electricity and alternative fuels. For electricity, we start with electricity prices in 2015 as paid by each home in the RECS dataset. In this way we capture utility-specific and home-specific effects. For our primary (medium) case we then include two multipliers: (1) an adjustment for the average national electricity price in 2040 relative to the price in 2015 using EIA data and projections, and (2) an adjustment for increased costs due to higher winter peaks caused by electrification. This second adjustment is based on published studies from several different regions and varies based on climate, with no adjustment in warm climates (the south), a moderate adjustment in mild climates such as Maryland, and a large adjustment in cold climates such as Minnesota. We do not include an adjustment for fully decarbonized power as these effects will be local based on the balance between low-priced renewable energy (new renewable energy is often less expensive than fossil-fuel generation – Lazard 2021) and costs of storage and backup power for when intermittent renewable power is not available. Some of these costs are included in our winter-peak adder, since in much of the country growing winter peaks will drive investment needs (EPRI 2018). We also do not include an adjustment for growing electricity sales due to electrification, which can allow utilities to spread fixed costs over a wider base. The national average electricity price in 2040, adjusted for winter peaks, is illustrated in figure 1. For our low and high cases we reduce and increase the electricity price by 25%. These prices are approximations; ultimately more detailed local analyses are needed to estimate state- and utility-specific prices.

For gas, we also start with 2015 prices as paid by each home and then add a multiplier based on the projected increase in the national average gas price between 2015 and 2040 using EIA data and projections. To this we then make two adjustments. First, we assume that this fuel will need to be net-zero carbon and assume a mix of 45% biogas and 55% synthetic natural gas made from “green” hydrogen. Biogas is in limited supply, hence the need for another gaseous fuel. We assume this fuel is synthetic natural gas because it can be used in existing distribution pipes and existing residential furnaces, boilers, and water heaters without modification. We use

estimates of future wholesale decarbonized natural gas costs from consulting firms ICF (NYC 2021) and E3 (E3 2022) and then scale these to retail costs using EIA data. Second, as gas use declines due to electrification, gas rates will go up to recover fixed costs across the lower volume of sales. We use estimates of these effects from Davis and Hausman (2022). Residential gas prices used are also summarized in figure 1. Again, these prices are approximations; ultimately local analyses are needed to estimate state- and utility-specific prices.

Further details are provided in the full project report (Nadel and Fadali 2022).

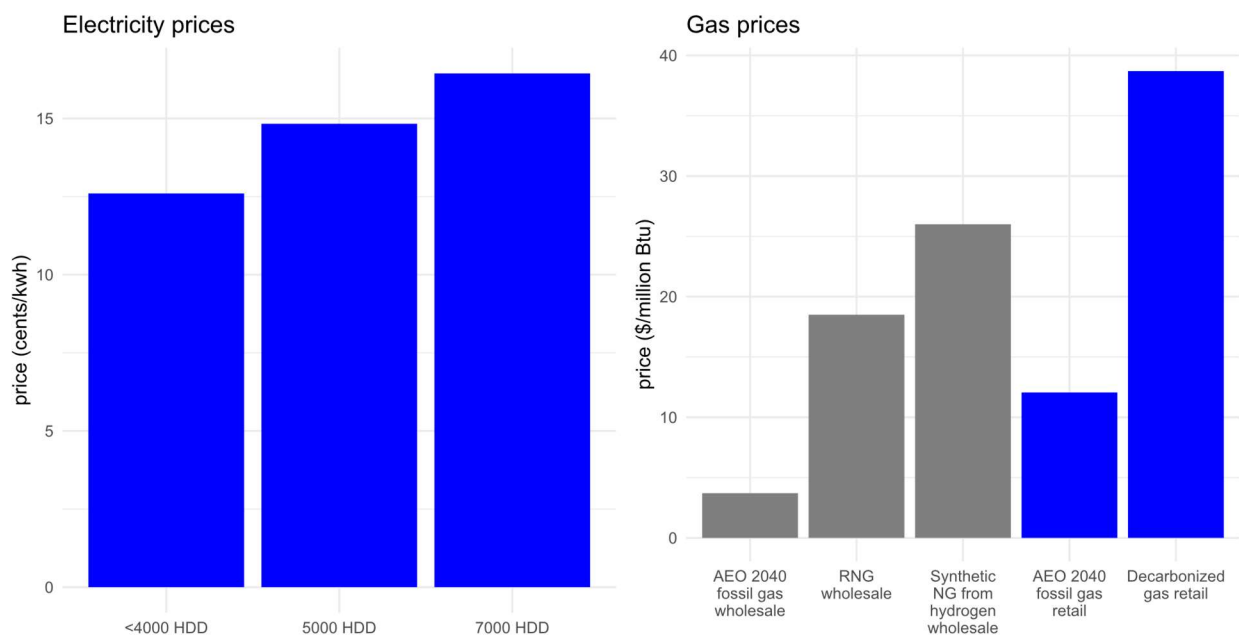


Figure 1. Medium estimates of national electricity price in 2040 as a function of heating degree days on the left and of gas prices on the right. The electricity prices incorporate winter peak demand impacts due to extensive electrification of space and water heating for climates above 4,000 heating degree days. Figures in 2020\$.

Results

We conducted our analysis for different building types and different base-case equipment types. In this paper we present the results of the analyses that apply to the most homes:

1. Space conditioning in single-family homes
2. Space conditioning in multifamily apartments
3. Water heaters in buildings with 1-4 living units

Space Conditioning in Single-Family Homes

Single-family homes represent 79% of the homes and apartments in RECS and thus are a particularly important focus for this analysis. Our analysis looks at decarbonization options for homes now using gas, propane, or oil for space and/or water heating. Of the 2,539 homes in RECS that use fossil fuel central furnaces and boilers for space heating (but not homes that use electricity or “other”), 2,063 use gas furnaces for space heating. In this paper we discuss our results for gas furnaces and briefly summarize results for the other fuels and system types as well as for other energy price cases.

Our primary metric is lifecycle cost (equipment, installation, and energy costs) for each of the options using our medium-case estimates for system, electricity, and alternative fuel costs. In our medium and high costs, we include allowances for electric panel upgrades for homes that presently do not have central air conditioning. We do not include maintenance costs for the different systems. Our analysis assumes an 18-year equipment life for furnaces and heat pumps and a 13-year life for water heaters. We calculated a lifecycle cost for each of the 2,539 homes in the RECS database now using fossil fuels and each system option and then calculated best-fit regression lines across all the homes, using heating degree days as an independent variable. For example, figure 2 shows a comparison of electric and gas air-source heat pumps and gas condensing furnaces, with dots representing individual homes and the lines representing the best-fit regression equation.

Under our medium assumptions, the electric heat pump generally has the lowest lifecycle costs, with the gas heat pump generally second lowest. The gas and electric heat pump lines meet at about 7,000 heating degree days, which corresponds to the climate of Madison, WI. Under our medium cost assumptions, the electric heat pump has lower lifecycle costs than the gas heat pump in 72%% of the homes we analyzed and lower lifecycle costs than the gas condensing furnace in 77% of the homes we analyzed.

Results were broadly similar if we use our low-cost or high-cost electricity and gas price assumptions. While costs increase for the high-cost assumptions and decrease for the low-cost assumptions, these changes affect both gas and electricity and roughly offset each other.

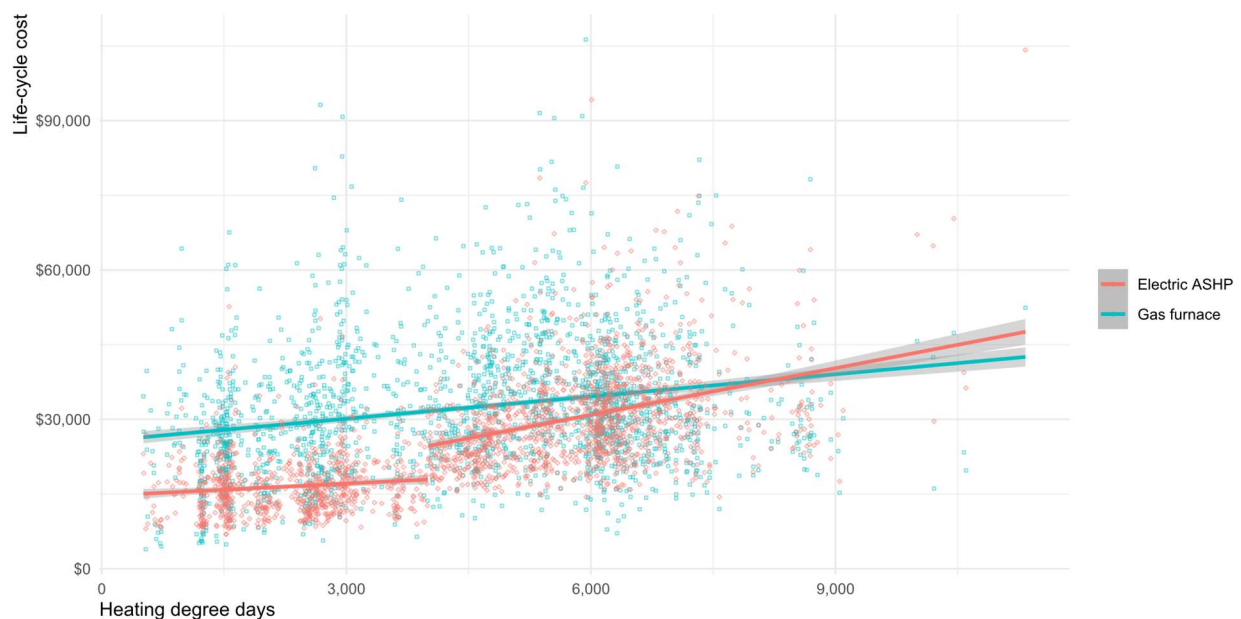


Figure 2. Lifecycle cost for electric heat pumps, condensing gas furnaces, and gas heat pumps using medium-cost assumptions for single-family homes now heated with natural gas. The gap in the electric heat pump line shows the impact of costs for cold climate heat pumps for locations with 4,000 HDD or more. Costs are in 2020\$.

Looking at figure 2, a gas proponent might argue that the costs of alternative fuels will be lower than our medium case or that the price of electricity will be higher than our medium case. We found that at a medium electricity cost and a low gas cost, the point at which condensing furnaces on average have lower lifecycle costs than electric heat pumps is above 6,000 heating degree days, about the climate in Detroit. If we use the high electric cost and the low gas cost,

condensing gas furnaces have lower average lifecycle costs above about 5,000 heating degree days, approximately the climate in Philadelphia.

We also did some analyses using lower and higher equipment costs but found that, while lower equipment costs are favorable to both electric and gas heat pumps and higher equipment costs are unfavorable to them, for the most part the results differ only a little from the results discussed above. When lifecycle costs are in the tens of thousands of dollars, the differences in equipment costs we modeled generally do not have a large impact on lifecycle cost.

For homes with oil and propane furnaces, under our medium cost assumptions, the electric heat pump generally has lower cost than either a propane condensing furnace, a propane heat pump, or a high-efficiency oil furnace, with the electric heat pump having lower lifecycle costs in the homes analyzed relative to 98% of propane furnaces and propane heat pumps and 91% of oil furnaces.

We also looked at hybrid heat pumps that combine a cold-climate electric heat pump with a minimum efficiency gas, propane, or oil furnace as backup for when the temperature gets below about 5°F (about the temperature when even cold climate heat pumps are unable to provide adequate heat) for more than 3% of the heating season. This threshold corresponds to about 6,000 heating degree days (about the climate of Detroit). For the hybrid analysis we reduced the additional cost of meeting winter peaks by half, due to lower peak generation needs (Hopkins et al. 2018). Best-fit lines are shown in figure 3, which shows that hybrid systems on average have lower lifecycle costs in climates above 6,000 heating degree days.

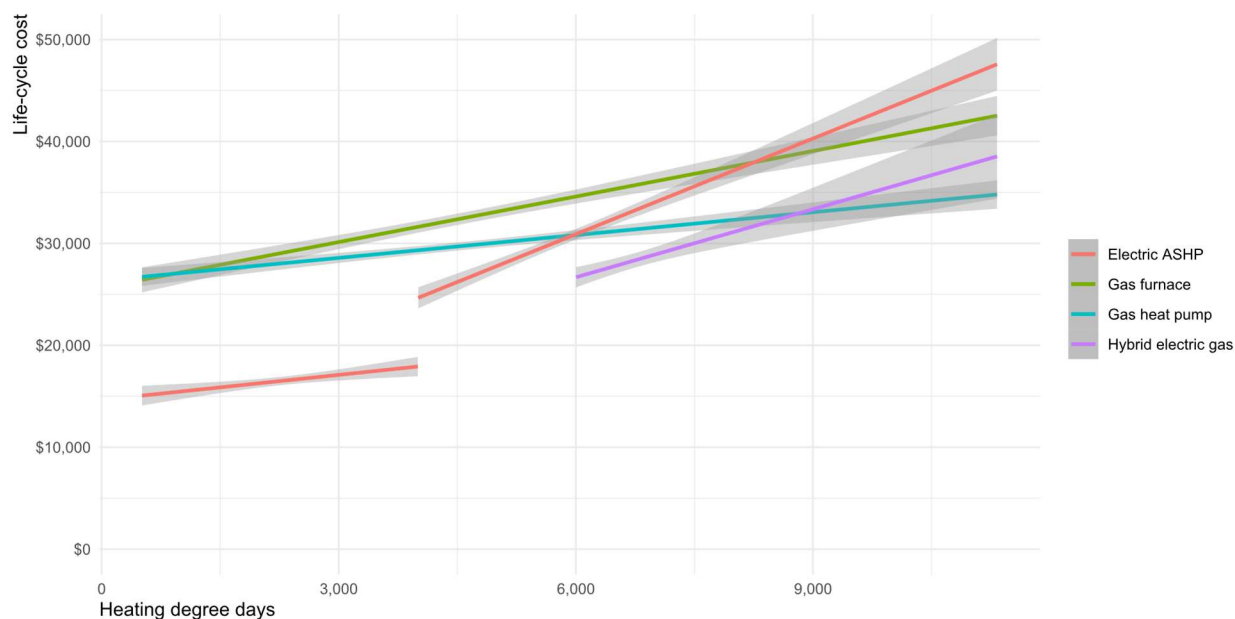


Figure 3. Lifecycle cost best-fit lines for electric heat pumps, condensing gas furnaces, gas heat pumps, and hybrid electric heat pump/gas furnace systems for single-family homes now heated with natural gas using medium cost assumptions. Costs are in 2020\$.

We also compared air-to-water heat pumps with gas and oil boilers, using equipment and prices from the United Kingdom, where these heat pumps are widely available. The electric heat pump had lower lifecycle costs than condensing gas boilers in 95% of the cases we analyzed and than oil boilers in 97.5% of the cases.

Space Conditioning in Multifamily Apartments

For buildings with 5 or more units, RECS has data on 297 units now heated with fossil fuel furnaces or boilers. We analyzed the two most common systems, gas furnaces (161 units) and gas and oil boilers (125 units).

Gas furnaces generally serve individual units, with each unit having its own furnace. We used the same assumptions as for single-family homes. Results of our analysis are in figure 4. On average, lifecycle costs are lowest for electric heat pumps below 4,000 heating degree days and for hybrid systems above 6,000 heating degree days. Between 4,000 and 6,000 heating degree days, lifecycle costs are lowest for the condensing gas furnace.

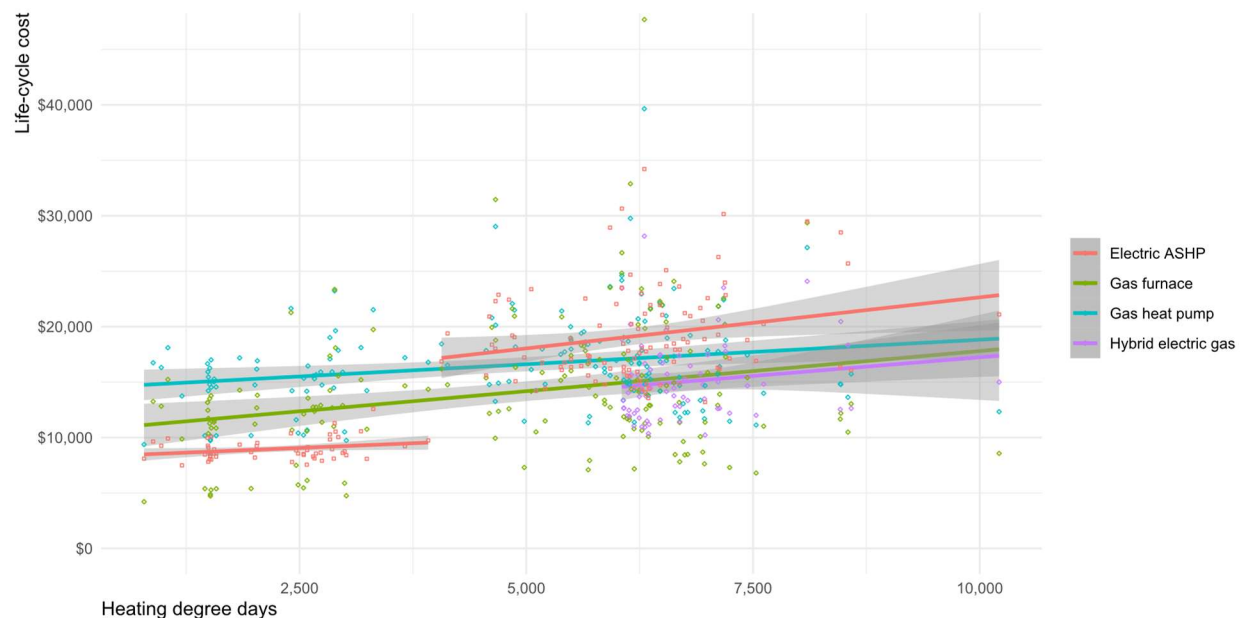


Figure 4. Lifecycle cost and best-fit lines for electric heat pumps, condensing gas furnaces, gas heat pumps and hybrid systems for apartments in buildings with 5 or more units now heated with natural gas furnaces. These use medium cost assumptions and are in 2020\$.

Our multifamily boiler analysis is much cruder than the prior analyses due to both a smaller sample size and limited data on electrification costs. This should be considered a preliminary analysis; we recommend further analysis on a larger sample of buildings when more data on electrification costs and how these costs vary by building type is available.

RECS has data on 125 apartment units heated with boilers in buildings with 5 or more units. For the central boiler systems we examined, the only source of electrification costs we could find was a study by Urban Green (2020), which examined the costs of electrification in 12 buildings in New York City. This study estimated an average cost per apartment of \$14,900 for buildings that could be heated using ductless mini-split units and \$18,200 for buildings that could use central variable refrigerant flow (VRF) systems. RECS does not provide information on building size, so we had no way to estimate which buildings could use mini-splits and which would need VRF systems. To address this unknown, we examined all units in the dataset for both system types. For the VRF system, some recent research indicates that VRF systems are costing more for New York City apartments than Urban Green estimated, so we increased those costs by 25% (results not yet published).

In considering electrification options for these buildings, it is important to note that apartments in these buildings are often smaller than single-family homes, and that they have many shared walls, which reduces heat loss from apartments. As a result, energy use in these buildings is often modest. For the multifamily apartments in the RECS data set, 2015 annual energy expenditures for space heating averaged \$160 per apartment for buildings heated with natural gas and \$333 for buildings heated with oil (EIA 2018).

Given the high cost of electrification per apartment and low energy consumption per apartment, it is not surprising that electrification economics are challenging for these buildings. Figure 5 shows the lifecycle costs for the multifamily apartments served by boilers in the RECS data set using our medium cost assumptions. For all but one home (99% of apartments analyzed), a gas or oil system using alternative fuels has lower lifecycle costs than mini-split electric heat pumps and much lower lifecycle costs than VRF systems. In this case, lifecycle costs are dominated by initial cost, with operating costs less important.

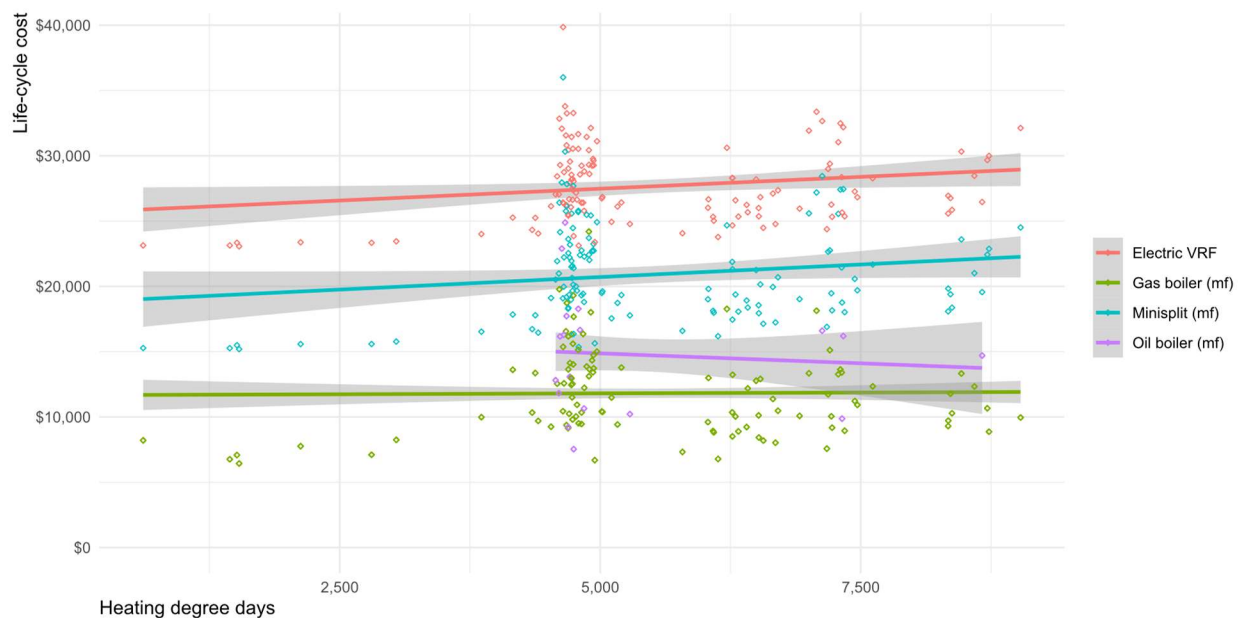


Figure 5. Lifecycle cost and best-fit lines for electric heat pumps (mini-split and VRF) and condensing gas boilers for apartments using medium costs in buildings with 5 or more units. Costs are in 2020\$.

Because this analysis depends on our system cost estimates, we also looked at the lifecycle cost economics using the low-cost estimates for electric heat pumps (25% lower than the primary estimates) while keeping the gas and oil boiler replacement costs the same as in the primary analysis. These results show electric heat pump costs somewhat closer to the gas and oil system costs, but 96.0% of the apartments examined still have lower lifecycle costs using alternative fuels. We also did the same analysis using low fuel and electricity costs (not shown in any figure) and the results differ only slightly from what is shown in figure 5.

Water Heating

We also evaluated the lifecycle cost of water heating for homes not presently using electricity for water heating. This analysis looked at homes in 1-4 unit buildings. National-level results are summarized in figure 6. Electric heat pump water heaters have the lowest lifecycle

cost in 100% of homes analyzed, followed by gas heat pump water heaters. Lifecycle costs are highest for propane and oil tank-type water heaters. Condensing gas tankless and tank-type water heaters have similar lifecycle costs, falling behind gas heat pump water heaters.

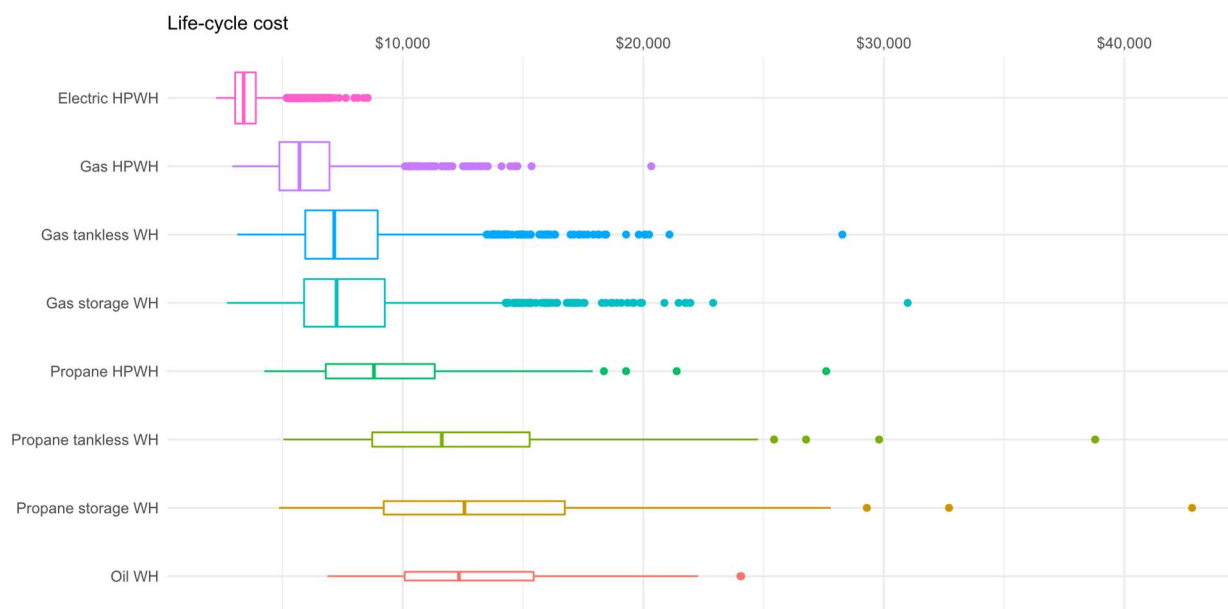


Figure 6. Lifecycle costs for water heating by system type. The lines in the middle of the boxes are the medians, the boxes show the upper and lower quartiles, the whiskers off the boxes show the most extreme data points within 1.5 times the interquartile range, and the dots are individual outliers. Used medium costs; costs are in 2020\$.

Extrapolating to the Entire Housing Stock

RECS was designed to be a representative sample of the U.S. housing stock. The EIA provides a weighting factor for each home to enable estimates for the entire housing stock. In this section, we use these weighting factors to extrapolate to the entire U.S. housing stock. We look at eight scenarios, each of which builds on the prior scenarios. The scenarios are:

1. All homes now using fossil fuels for space and water heating switch to alternative fuels using gas heat pumps where feasible.
2. All homes now using fossil fuels for space & water heating switch to electric heat pumps.
3. Same as #2, but also upgrade homes with electric heat to high-efficiency electric heat pumps.
4. Same as #3, except buildings with five or more units use alternative fuels and not heat pumps.
5. Same as #4, except use hybrid systems above 6,000 heating degree days.
6. Same as #5 but add moderate energy efficiency above 4,000 heating degree days.
7. Same as #6, but add moderate energy efficiency below 4,000 heating degree days for homes with energy bills above the median.
8. Same as #7, but further assume that energy efficiency reduces electric rates 4% relative to business as usual.

These scenarios build on our prior analyses. For example, in scenario 1 we include gas heat pumps because these, on average, reduce lifecycle costs relative to condensing gas furnaces. Scenario 4 reflects the fact that our main analysis found that lifecycle costs are generally lower

for alternative fuels in multifamily buildings. Scenario 5 reflects our findings on hybrid systems, while scenarios 6 and 7 reflect our findings on energy efficiency. Two of these scenarios (3 and 8) are entirely new. Scenario 3 also includes replacing electric resistance heat and existing heat pumps with high-efficiency heat pumps. In this scenario we replace electric resistance furnaces with ducted heat pumps and replace electric baseboard heaters with ductless heat pumps (one ductless unit for each 600 sq. ft. of living space). Scenario 8 is an illustrative scenario, reflecting the fact that while energy efficiency programs have costs, these costs are frequently less than the costs of needing to expand generation, transmission, and distribution to serve growing electric loads. The 4% figure used comes from an illustrative example by Relf and Baatz (2022) and is just indicative; this price difference will vary from utility to utility.

In conducting our analysis, we include all of the assumptions and data from our prior analyses, using the medium cost estimates. Our analysis includes equipment costs for space and water heating, as well as electricity and fuel costs for space and water heating and for space cooling in homes that already have air conditioning. We conduct our analysis for an 18-year period and discount future costs using a 5% real discount rate.

RESULTS

Results of our eight scenarios are summarized in figure 7. Lifecycle costs over our analysis period are in the trillions of dollars. Lifecycle costs are highest for scenario 1 (use of alternative fuels, no electrification) and lower for scenario 5, which is shown in orange (electric heat pumps with hybrid systems above 6,000 heating degree days except alternative fuels for buildings of 5 or more units). Scenarios 6 (moderate energy efficiency above 4,000 heating degree days) reduces lifecycle costs further. Scenario 8 has the lowest lifecycle costs; this scenario includes our moderate energy efficiency package for all homes and a modest rate discount for the role of energy efficiency in reducing power system costs. Scenario 3 includes homes with electric heat that are not included in scenario 2, so the results of scenarios 2 and 3 cannot be directly compared.

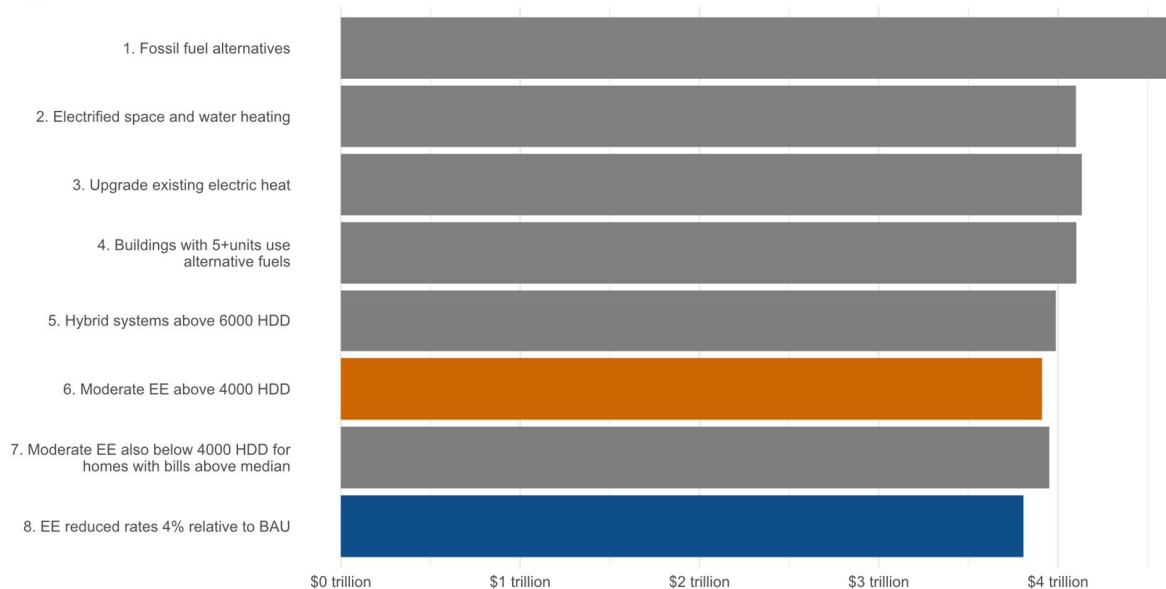


Figure 7. Lifecycle cost of decarbonization scenarios at a national level for the United States.

Next Steps

Analysis

This analysis is based on estimates of energy costs and system installation costs at the national level, adjusted for local prices and climate as shown in the 2015 Residential Energy Consumption Survey. The biggest unknowns are the future price of alternative fuels, the impact of electrification on winter peaks, and the cost to serve these peaks. The latter in particular will vary depending on the local distribution system. Therefore, we suggest additional state-level and regional studies, along the lines of studies on Maryland, Massachusetts, and Minnesota (Maryland Commission on Climate Change 2021; E3 2022; GPI and CEE 2021). We note that the latter two studies found that hybrid systems make sense for their climates, while the Maryland study found that future peaks could be managed with increased energy efficiency. These results are generally consistent with our findings. Studies on more states would be useful, particularly studies that look at the full range of options in regions colder than Maryland and warmer than Massachusetts.

It would also be useful to examine whether there might be regional differences in the price of alternative fuels, depending on the availability of biogas feedstocks and carbon-free electricity to produce hydrogen via electrolysis.

Another area for further study is multifamily buildings (5 or more units) using boilers. Our analysis indicates lifecycle costs are generally lower using alternative fuels, but this is based on electrification costs from New York City. Analysis is needed on buildings and costs from other cities and in general, larger samples are needed.

Policy

Our analyses suggest that electric heat pumps will usually—but not always—have lower lifecycle costs than using alternative fuels. However, as long as fossil gas and fuel oil are readily available to consumers, they will often choose these fossil fuels over the substantially more expensive decarbonized versions of these fuels. Some policy measures can begin to address this issue. In the following paragraphs we discuss several of these policy options:

- Research and development
- Minimum efficiency standards
- Incentives
- Changes to structure of electric rates
- Clean heat standards
- Price on carbon

We will need to pursue most, if not all, of these paths to advance decarbonization.

Research and Development

Many of the decarbonization options examined in this report could benefit from additional research and development. Efforts are underway to improve the performance and reduce the cost of electric cold climate heat pumps and gas heat pumps (e.g. DOE 2022a, GTI 2022). Likewise, significant attention is being paid to reducing the costs of green hydrogen and to technologies to distribute and burn hydrogen (e.g. IEA 2019). But more efforts would be useful, as our analysis indicates that each of these technologies will have a role to play in decarbonization, and improving these technologies and reducing their costs will make decarbonization easier.

Minimum Efficiency Standards

Minimum efficiency standards require that all equipment meet a specified minimum efficiency level. Furnaces, boilers, water heaters, and heat pumps are all subject to national minimum efficiency standards in the United States. The standards are administered by DOE, which updates the standards approximately every eight years. A new gas furnace standard is scheduled to be proposed in June 2022, which will take effect in 2029. A key issue will be whether to mandate that new gas furnaces be condensing, up from the 80% efficiency that is now required. New water heater standards are also due to be proposed in 2022. This new standard could take effect in 2028. The present standard requires water heaters larger than 55 gallons to effectively be condensing if they burn gas and to use a heat pump if they are electric. A key question will be whether and how much to reduce these size thresholds. And a new standard for electric central air conditioners and heat pumps is scheduled to be finalized in late 2024, to take effect no sooner than five years later. The most recent standard, to take effect Jan. 1, 2023, requires an HSPF2 of 7.5 for split heat pumps and 6.7 for single-package systems. A future rule will raise this requirement and could consider separate standards for the north and the south, as is now the case for central air conditioners. These new standards will improve efficiencies, moving equipment toward the efficiency levels for 2030 that we examined in this report.

Incentives

Utilities and governments can provide financial incentives for advanced heat pumps and alternative fuels. A recent ACEEE study found 42 programs that offer incentives to encourage electrification, up from 22 programs a year earlier (Cohn and Efram 2022). Many programs also offer incentives for condensing gas furnaces, boilers, and water heaters, and a few programs provide incentives for gas heat pumps. If DOE updates furnace, boiler, and water heater standards to require condensing levels of performance, then future gas incentives are likely to be limited to gas heat pumps. Federal tax incentives for high-efficiency electric heat pumps, heat pump water heaters, and condensing furnaces and water heaters are now pending, as is a new federal program to provide incentives for high-efficiency electric equipment (House Rules Committee 2021). The tax incentives are scheduled to be in effect for 10 years; the proposed incentive program being has only enough money for a few years of incentives. Depending on how well the program works, Congress should consider providing additional funding.

Incentives can also be provided for the production, distribution, and sale of alternative fuels. The federal government presently has tax incentives for renewable diesel fuel (EIA 2020). The federal government and some states also have incentives for some uses of hydrogen (DOE 2022b). Additional incentives for hydrogen are pending. For example, there is a large 10-year production tax incentive for hydrogen in the pending Build Back Better bill (House Rules Committee 2021).

Changes to Structure of Utility Rates

The economics of electric and gas equipment are strongly affected by the prices of these energy sources, which in turn are affected by the underlying prices of this energy and rate structures. Presently, many electric utilities have a single rate structure for residential customers, ranging from customers that use electricity only for lights and appliances to customers with all-electric homes. Typically, utilities recoup fixed costs in part through monthly service charges and in part from variable energy charges. In such a situation, high users, such as all-electric customers, pay more for fixed costs. One option is to establish separate rate classes for customers with electric heat and hot water, which would often reduce the variable cost of electricity for

these customers, making electric heat pumps more competitive. Such rates used to be common, and some utilities still have such rate structures. This, in turn, would raise electricity rates for homes now using fossil fuel space and water heating systems, providing them with an incentive to electrify. However, utilities must take care to avoid increasing bills for low-income customers.

If electric heat rates are offered by utilities, rate designers should consider including time-of-use rates that decrease rates during off-peak times and increase rates during peak times to encourage reduced use during peak times. Because winter peaks tend to be early in the morning on cold days, such rates could encourage such measures as preheating hot water outside of peak periods or reducing temperature settings at peak times.

Rates for gas service will also have an impact on decarbonization economics. For example, some gas utilities have increased their monthly service fees, sometimes making switching to all-electric more attractive (A. Evens, Elevate Energy, personal communication, April 12, 2022). There may also be ways to provide rate discounts for use of alternative fuels.

While cost allocation principles underly both electric and gas rates, there are multiple ways these allocations can be made, and the choices can be influenced by policy preferences, such as whether and how much to encourage decarbonization.

Clean Heat Standards

In 2021, Colorado adopted Senate Bill 21-264, which includes a new Clean Heat Standard. Under this new law, Colorado gas distribution utilities that serve 90,000 or more customers are required to develop and submit cost-effective plans to the Colorado Public Utilities Commission (PUC) for achieving reductions in the emissions that result from delivering fuel to homes and businesses. The bill requires gas distribution utilities to cut emissions by 4% by 2025 and by 22% by 2030. The legislation directs the PUC to set standards for 2035 by 2025, and to set standards for 2040, 2045, and 2050 by 2032. The bill identifies several “clean heat resources” that utilities can use to achieve the targets, such as energy efficiency, electrification, green hydrogen, and recovered methane. This last item includes non-fossil sources of methane, such as biogas from agricultural facilities and coal mine methane, as well as reducing leaks of conventional fossil gas (Henchon and Overturf 2021, Colorado 2021).

The Minnesota legislature enacted a somewhat similar but less aggressive program in 2021. The Natural Gas Innovation Act encourages (but does not require) gas companies to file with regulators “innovation plans” that decarbonize their operations. Utilities can recover costs of pilot projects and use results to meet their goals in the state’s Conservation Improvement Program. The legislation is aimed at helping gas utilities introduce renewable natural gas, develop hydrogen-based fuels from renewables, fund energy efficiency projects, and encourage district energy, carbon capture, and geothermal heating (Jossi 2021).

It is unclear how far clean heat standards can go. The Colorado 22% by 2030 standard was developed via negotiation as aggressive but feasible goal. Higher standards will be possible in the future, but how far they can ultimately go is an open question.

Price on Carbon

Putting a price on carbon can aid fuel decarbonization in two ways. A price on carbon would increase the cost of fossil fuels, making alternative fuels and electricity more competitive, and it would raise funds that could be used for R&D, incentives, and other strategies. Carbon pricing can be a specified carbon fee or it can be a cap-and-trade program under which regulators set emissions limits and carbon emissions allowances are auctioned, having the market set the carbon price. The World Bank notes that 68 carbon pricing initiatives are now being

implemented around the world, including 46 national-level programs and 36 at the subnational level (e.g., state or province) (World Bank 2022). In North America, carbon pricing is now in effect in Canada and California and soon will take effect in Washington State. Electricity in many Northeast and Mid-Atlantic states is subject to the cap-and-trade program administered by the Regional Greenhouse Gas initiative (Nadel, Gaede, and Haley 2021; Department of Ecology 2021).

There have been numerous proposals for a U.S. federal price on carbon, but given political divides in Congress, none of these proposals have advanced. While the situation could change in the future, at the present time additional state policies are more likely.

Conclusions

In general, our analysis results show that for 1- to 4-family homes below about 6,000 heating degree days (the climate in Detroit), among the various options for decarbonization, lifecycle costs under our medium cost assumptions are generally lowest for using electric heat pumps. Above about 6,000 heating degree days, hybrid systems often make the most sense to reduce winter peak loads at very cold temperatures. These results all assume use of cold climate heat pumps in locations with 4,000 heating degree days (the climate in Washington DC) or more. Presently such heat pumps are becoming more common in locations with roughly 6,000 heating degree days or more. Our analysis suggests we need to popularize cold climate heat pumps farther south to constrain growth in winter peak demand and thereby constrain growth in the price of electricity needed to serve this peak demand.

Our analysis of multifamily buildings finds that for apartments using gas furnaces, on average lifecycle costs are lowest for electric heat pumps below 4,000 heating degree days and for hybrid systems above 6,000 heating degree days. Between 4,000 and 6,000 heating degree days, lifecycle costs are lowest for condensing gas furnaces. For apartments served by central boilers, use of alternative fuels will generally have the lowest lifecycle costs. Electrification of these apartments is expensive, and because energy needs are generally modest, it is hard to recoup the cost of electrification investments.

For water heating, electric heat pump water heaters have the lowest lifecycle costs, followed by gas heat pump water heaters.

While meeting decarbonization goals will require both electrification and alternative fuels, market adoption will proceed slowly as long as inexpensive fossil fuels are available. Policies, including research and development, minimum efficiency standards, incentives, restructuring electric (and perhaps gas) rates, clean heat standards, and a price on carbon will be needed to accelerate this transition.

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