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RAP

Combating High Fuel Prices with Hybrid Heating

The Case for Swapping Air Conditioners for Heat Pumps

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PARTNER ORGANIZATION HVAC 2.0™

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Executive Summary

Despite the benefits of electric heat pumps for air quality, climate, and consumers' pocketbooks, retrofitting tens of millions of existing homes in the US is no easy task. Every home is different. Homeowners, and often heating contractors, can be skeptical of big changes. Many have limited knowledge, or poor past experiences, with the alternative options for heating and cooling needs.

The need to address this challenge is becoming more urgent by the minute. Every six seconds a new residential furnace or air conditioner starts up in the US, and that decarbonization opportunity is lost until 2035-2040. Fossil fuel prices are increasing the pain of home energy bills for families, and Russia's invasion of Ukraine spotlights the importance of decreasing reliance on fossil fuels and developing sustainable, reliable energy sources that improve energy security.

Thankfully, there is a practical and cost-effective strategy to supercharge home electrification: swapping traditional air conditioners (AC) to heat pumps. Even though the existing heating system (furnace or boiler) would stay in place, the super-efficient heat pump would take on some of the load, providing the benefits described in this paper. Replacement of existing "one-way" central ACs with "two-way" heat pumps means lower costs, and reduced fossil fuel use and pollution.

A major attraction is that the swap can be a painless "no brainer" for customers and installers. The idea is to replace existing air conditioning units at the end of their useful life with look-alike electric heat pumps (i.e., nearly identical units, but with the two-way superpower) while keeping legacy heating systems in place. Upfront heat pump costs are likely to be modestly higher than a one-way air conditioner, but this can be mitigated by smart policy.

> **We need to address this challenge urgently. Every six seconds a new residential furnace or air conditioner starts up in the US, and that decarbonization opportunity is lost until 2035-2040.**

In this paper, we expand on the findings and recommendations of the 2021 3H Hybrid Heat Homes Report and present new estimates showing the case for the swap from one-way air conditioners to two-way heat pumps:

- 54 million homes have heating and one-way central ACs that can be easily swapped for a two-way heat pump, which will run in a hybrid configuration,[i] with the existing heating system as backup.
- Methane gas[ii] is currently the most common form of household heating with 33 million hybrid heat pump installation opportunities, with significant emission reductions (32 $MtCO_2e$, equivalent to the annual emissions of 6.9 million passenger vehicles[1]).
- The second most common form of household heating, electric resistance, represents 16 million hybrid heat pump installation opportunities and 29 $MtCO_2$ in national emissions reductions (equivalent to 6.2 million passenger vehicles). In addition, swapping heat pumps into electric resistance homes provides high per-household bill savings ($555 per year). Since electric resistance heat is more common among low-income households[2], hybrid heat pumps could significantly reduce the energy burdens on low-income households.
- Making the swap in homes that currently use heating oil and propane, although smaller in number, would provide substantial per-household benefits by decreasing utility bills by five to seven times compared to methane gas, and offering households up to two times higher per-household CO_2 reductions.

i. We refer to heat pumps run in a hybrid configuration with a back-up source as "hybrid heat pumps" for short. Also, this paper is limited to central (ducted) ACs and heat pumps, as these represent the majority of the stock and would be easiest to convert.

ii. Methane is the primary component of gas piped into homes, usually marketed as "natural" gas. We use "methane gas" in this paper to differentiate from propane, another "fossil" gas, and call attention to the fuel's additional global warming impacts from leakage.

These are highly conservative estimates. Four factors mean the case is even stronger than these estimates suggest:

1. **Fossil fuel prices are high and volatile.** Our estimates are based on recent retail price levels for gas, heating oil, and propane, which are high by the standard of recent years. However, prices are even higher as of the latest data release in April 2022, which was published after we finalized our estimates. The volatility of fuel prices represents an ongoing risk to oil and propane customers, while methane gas customers face the prospect of rising bills to pay for the legacy gas distribution system as their neighbors electrify.[1]
2. **The electric grid is getting cleaner.** Driven by improving clean technology as well as federal and state goals, the grid will largely shift to clean energy during the lifetime of heating and cooling appliances installed today.[iii] Building new wind and solar generation capacity is less expensive in some cases than simply fueling existing fossil-fired power plants.[3] Coal generation is continuing to retire, while the share of renewables is growing.[4] That means that emission cuts from displacing fossil fuel with heat pumps will be larger than our estimates suggest.
3. **Heat pumps are getting more efficient for heating and cooling.** The amount of electricity heat pumps require for heating and cooling has declined in recent years as efficiency and cold-temperature performance improve. Our estimates make conservative assumptions about the temperatures at which heat pumps will operate in a hybrid context.
4. **The demand for air conditioning is increasing.** The data we use to estimate the number of homes with central air conditioning is somewhat backward looking, due to survey availability. However, air conditioning is becoming more common, including in places where it was previously rare, like New England and the Pacific Northwest. This means the opportunity for two-way heat pumps is likely to grow.

The proposed air conditioner to heat pump swap would help launch a powerful virtuous cycle of electrification. More heat pump installations will support increased innovation and scale in manufacturing and increase experience and capacity on the part of installers. This, in turn, should lead to lower upfront costs for consumers and higher levels of awareness and acceptance of the technology, which will motivate yet more installations. These factors will also help support heat pumps in other contexts, including full building electrification. **In short, a big push for a swap of air conditioners to heat pumps over the next 5-10 years will smooth the way for full-building electrification.**

This proposal also overcomes the most difficult barrier to installing heat pumps en masse: 85% of HVAC replacements are done on an emergency basis. It is a large and unexpected expense, so most consumers try to cut upfront costs. A heat pump is usually $300-600 more at wholesale than the equivalent air conditioner, so most customers take the cheaper option. **Our proposal could make heat pumps the cheaper option or the only option available. This is critical because in an emergency the only thing that gets installed is what's in stock.**

We discuss a range of policy options to kickstart the process of switching over households to hybrid systems. The positive consumer economics means the swap should already be appealing to homeowners. Nevertheless, a decisive boost from policy can help overcome remaining barriers, such as the emergency replacement issue, and speed the transition. There are important steps that states and municipalities can take to speed the effort, which will complement proposals under consideration for federal incentives.

We recommend:

- **States should revise energy efficiency resource standards (EERS) to be fuel neutral.**
- **Utilities should phase out incentives for one-way air conditioners and provide heat pump incentives instead.**
- **Public utility commissions and utilities should provide on- and off-bill financing to consumers.**
- **States should implement appliance standards that require ACs to have two-way operation.**
- **Cities and counties should require AC to heat pump conversions through building codes and other local ordinances.**

These are proven energy efficiency tools. Policy innovations would push the transition even further.

iii. For example, one commonly used forecast scenario has the grid emission factor falling by half from 401 kgCO_2e/MWh in 2019 and 192 kgCO_2e/MWh in 2032 National Renewable Energy Laboratory (2020), "Standard Scenarios 2020", Cambium Model, Accessed April 22, 2021. https://cambium.nrel.gov/download/?project=c3fec8d8-6243-4a8a-9bff-66af71889958

Introduction

Because of their high efficiency, heat pumps can greatly reduce the cost and pollution burdens of heating US homes.

Heat pumps operate at over 300% efficiency for a large portion of the year, compared to 99% for the most efficient fossil fuel furnaces or boilers, and 80% for baseline-efficiency products.[iv] This high heat pump efficiency translates into lower operating costs and CO_2 emissions. As the proportion of renewables in the electricity generation mix increases and their costs continue to fall, we would expect these benefits to increase. Even before the recent surge in fossil fuel prices, heat pumps that run in a "hybrid" or "dual-fuel" configuration with backup fossil-fuel systems have been shown to reduce customer utility bills.[5] Meanwhile, heat pumps contribute to national energy security by reducing US demand for fossil fuels and freeing up limited global supplies for US allies.

Over 11 million households across all parts of the US (10%) are already using electric heat pumps as their primary source of heat;[6] almost 4 million are sold each year.[7] However, this is only the beginning: tens of millions more households will need to convert to heat pumps in the coming years and decades if we are to meet our climate goals.

In 2021 CLASP released a proposal to accelerate this transition by replacing all one-way central (ducted) air conditioners (ACs) with reversible heat pumps (2021 Hybrid Heat Homes or 3H paper).[8] Since 6 million central ACs are currently sold each year,[9] this would more than double the pace of heat pump installations, allowing homes to benefit from the high efficiency and cost savings, while retaining their existing fossil fuel furnace or boiler to use as backup during the coldest parts of the year. This paper is an extension and refinement of the 2021 analysis.

The 2021 3H paper looked at all fossil fuel and electric homes,[10] but did not separate out the benefits of displacing oil, propane, or electric resistance, which tend to have the highest costs, and therefore would benefit the most from heat pumps. These three heating methods are therefore the focus of this paper, which provides new state-by-state analysis using updated costs. **We find that the benefits of displacing propane, heating oil, and electric resistance heat through hybrid heat pumps is even stronger than the case for displacing methane gas outlined in the 2021 3H paper.**

The paper begins with a background on space heating, the cost of fuels, typical efficiencies, and resultant operating costs. We then present the key benefits of displacing each of the high-cost fuels by replacing central ACs with heat pumps in a hybrid configuration. We then discuss policy and regulatory options for ramping up such an AC to heat pump conversion effort. State-level policy will likely be crucial to supporting this hybrid approach. The appendix includes all modeling assumptions and results.

We emphasize that throughout the process of swapping ACs to heat pumps, concerned entities must:

- Prioritize support toward remaining pockets of propane and heating oil as well as toward the much larger number of households with electric resistance heat. Households using these fuels tend to be lower-income and are being hit hard by surging energy prices.
- End support for traditional central ("one-way") ACs in favor of ("two-way") heat pumps. Traditional central ACs are still heavily supported by state-level efficiency programs.

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iv. Efficiency is a measure of heating delivered divided by the fuel energy required by the system. Because heat pumps pull heat out of the surrounding air, they are calculated to exceed 100%. An efficiency greater than 100% is also called coefficient of performance (COP).

This paper is an extension and refinement of CLASP's 2021 Hybrid Heat Homes analysis. The report found that heat pumps can replace central (ducted) ACs in existing residential buildings with a small incremental upfront cost (approximately $150 in parts).

Installing a new heat pump that works in conjunction with existing fossil fuel or electric resistance heating equipment creates a hybrid system – providing a more approachable strategy to ease consumers and installers into accepting heat pumps across the country.

Along with the strategic benefits, the hybrid approach cost-effectively displaces significant amounts of gas or electricity consumption. The 2021 paper found that an average home in the contiguous US would reduce fossil fuel consumption by 38%, while reducing annual operating costs and CO_2 emissions by 11%. The average household would see $169 in annual cost savings, with methane gas-heated homes in only a few states experiencing cost increases (the worst was Michigan, where households would see an additional $13 in operating costs per year).

Over the next 10 years, heat pumps could replace one-way ACs in 33% of homes, a total of 45 million additional installations. This transformation would lead to the following benefits in 2032:

- A savings of $27 billion on the nation's heating and cooling bills. Over that same period, the authors estimated that lower air pollution would lead to $80 billion or more in additional societal benefits due to improved health from decreased pollution.
- Reduction of 49 million tons of CO_2e, and
- Cleaner air that would result in approximately 1000 fewer premature deaths, 1000 fewer emergency room visits, 1000 fewer nonfatal heart attacks, 25,000 fewer asthma exacerbations, 37,000 fewer respiratory and acute bronchitis incidents, 571,000 fewer minor restricted activity days, and 98,000 fewer lost workdays.

The 2021 paper encouraged a federal manufacturer/upstream incentive, where manufacturers are paid around $400 dollars for each unit sold if they commit to no longer manufacture one-way central ACs. **Continue reading the rest of the current 2022 paper for a detailed look at different backup fuels and other policy options, including at the state and local levels.**

Background

SUMMARY OF HEATING SYSTEMS IN THE US

Space heating accounts for 43% of residential final energy use[11] and 27% of residential CO_2 emissions,[12] or 13% of total US final energy use[13] and 7% of total US CO_2 emissions.[14] Space heating is followed by water heating on the list of most energy consuming home equipment, accounting for 19% of residential final energy use and 14% of residential CO_2 emissions. While not covered by this paper, water heating is also in the process of improving efficiency and cutting CO_2 emissions through the deployment of heat pump water heaters.

The equipment and fuel required to heat indoor spaces varies by building age, type, and location. Boilers and oil are found in older homes in the Northeast, while heat pumps are already common in the Southeast. Methane gas is a widely used heating fuel in urban and suburban areas with established underground distribution networks. Propane and heating oil are more common in rural areas that do not have the infrastructure for gas transport. Electric resistance heaters are used throughout the country, particularly by lower-income consumers.[2] In addition to fossil fuels and electricity, wood is also used as a heating fuel by a significant number of homes in parts of the US, like New England.

The table below summarizes the main fuels and equipment in US homes[15] as well as the prevalence of central air conditioning, which could be replaced with a heat pump in a hybrid system, giving a sense of the total opportunity (47% of homes). In addition, homes without central air conditioning but with a furnace (an additional 12% of homes) will have pre-existing ducts, so could also be candidates for hybrid heating. The next section discusses the relative prices of the different fuels and heating methods.

THE URGENT NEED TO QUIT FOSSIL FUELS

As illustrated in Table 1, below, the majority of US homes are directly heated with non-renewable fossil fuels like methane gas, oil, and propane. These fuels, along with electric resistance heating, are unsustainable for three main reasons, their: high and volatile prices; high CO_2 and other emissions which contribute to climate change; and sensitivity to global political disruptions.

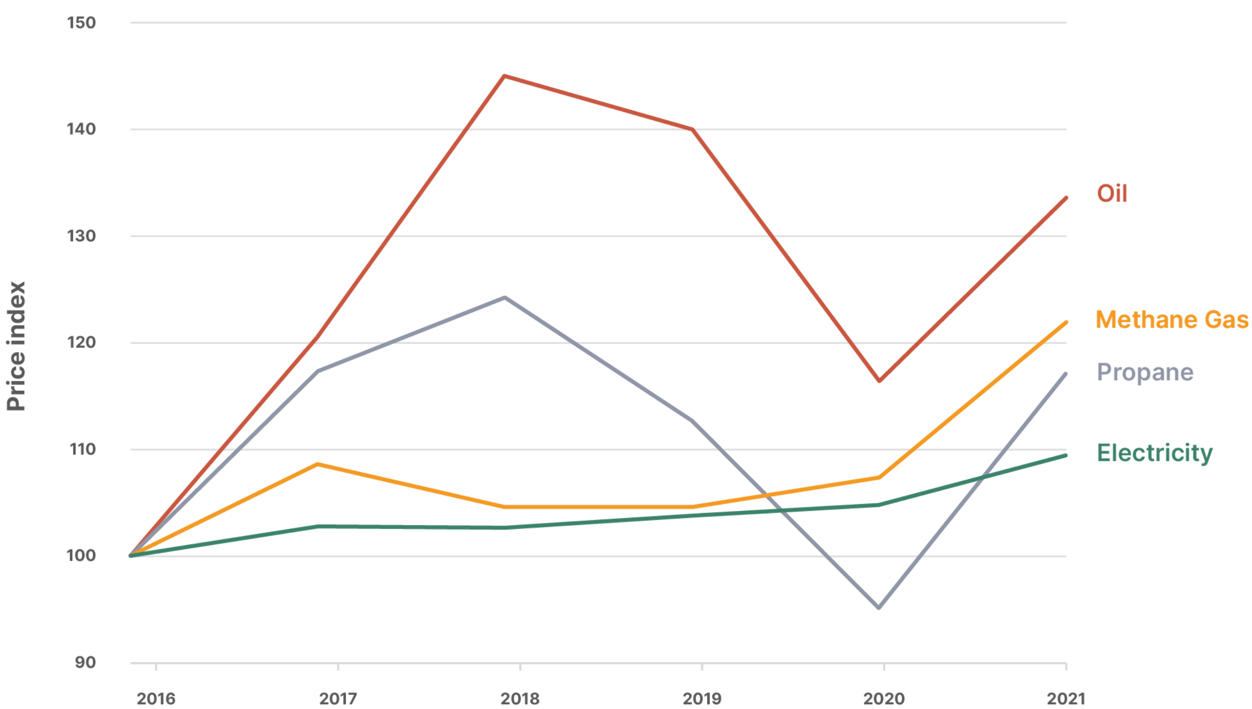
TABLE 1. SHARE OF US HEATING SYSTEMS IN 2015 BY FUEL AND TYPE (DUCTED AND NON-DUCTED) AS WELL AS PRESENCE OF ONE-WAY CENTRAL AC (INDIVIDUAL ENTRIES MAY NOT SUM TO THE TOTALS DUE TO ROUNDING)

MAIN FUEL/HEATING METHOD	DUCTED SYSTEM (FURNACE, CENTRAL HEAT PUMP)	NON-DUCTED SYSTEM (BOILER, RADIATORS, BASEBOARD HEATERS, SPACE HEATERS, MINI-SPLIT HEAT PUMPS)	TOTAL HOMES WITH GIVEN FUEL	HOMES WITH GIVEN FUEL AND ONE-WAY CENTRAL AC (CANDIDATES FOR AC TO HP SWAP)
Methane Gas	39%	9%	**49%**	**29%**
Oil	3%	2%	**5%**	**1%**
Propane	3%	1%	**4%**	**2%**
Electric Resistance	14%	11%	**25%**	**12%**
Electric Heat Pump	9%	1%	**10%**	**NA**
Wood	0%	3%	**3%**	**0%**
Other	0%	0%	**0%**	**0%**
None	NA	NA	**4%**	**1%**
Total	**68%**	**28%**	**100%**	**47%**

AVOIDING HIGH FUEL PRICES AND VOLATILITY

Over the last 5 years, US homeowners experienced significant price increases in residential fossil fuel, i.e., oil, propane, and methane gas, relative to electricity.[16] The residential retail price of electricity increased by 9%, compared to steeper price spikes for propane by 17%, methane gas by 22%, and oil by 33%. (See Figure 1). The increases may have been even greater were it not for a temporary slump in demand coinciding with the COVID pandemic. These price hikes have now been joined by 6% core inflation over the past year,[17] threatening the financial security of many households.

FIGURE 1. ANNUAL AVERAGE RESIDENTIAL PRICE FOR EACH FUEL (INDEX; 2016 = 100)



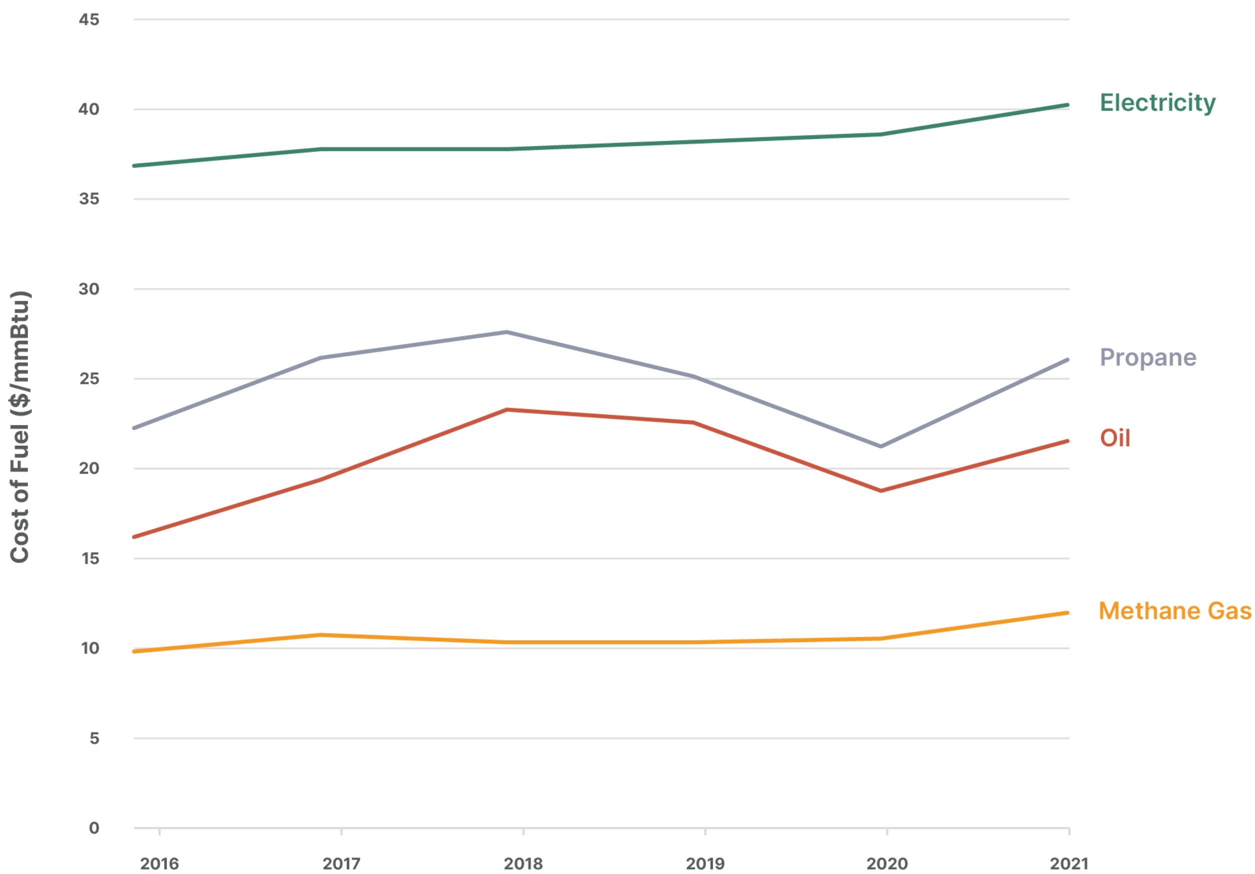
Even before recent price spikes, oil and propane were more expensive than methane gas. Their relative unaffordability is illustrated in Figure 2, where fuel prices per gallon, thousand cubic feet (mcf), and kWh were converted to common units of energy (million British thermal units or mmBtu).[v] Illustrating one of the more counterintuitive relationships here, electricity is 2–3 times more expensive on an energy basis than the fossil fuels.[vi] However, once the efficiency of heat pumps is factored in, heating with electricity can become one of the least expensive methods of heating.

Electricity is 2–3 times more expensive on an energy basis than the fossil fuels.[vi] However, once the efficiency of heat pumps is factored in, heating with electricity can become one of the least expensive methods of heating.

v. Using the assumptions on energy content in Table 2.

vi. This is partly because electricity is generated from these fuels, in an inefficient combustion process.

FIGURE 2. AVERAGE ANNUAL PRICE FOR ENERGY DELIVERED TO RESIDENCE



The different fuels are then converted to heat once they reach the home. The heating systems' relative efficiencies are listed in Table 2.[vii] Taking conversion efficiency into account does not significantly alter the relative costs of the fossil fuels and electric resistance heating, as these heating types are all 80–100% efficient. However, the much higher average efficiency—353%—of heat pumps running in a hybrid configuration significantly cuts the cost of heating with electricity. This makes heat pump costs competitive with methane gas, the least expensive fuel on an energy-delivered basis, and far less expensive than oil and propane, as can be seen in Figure 3.

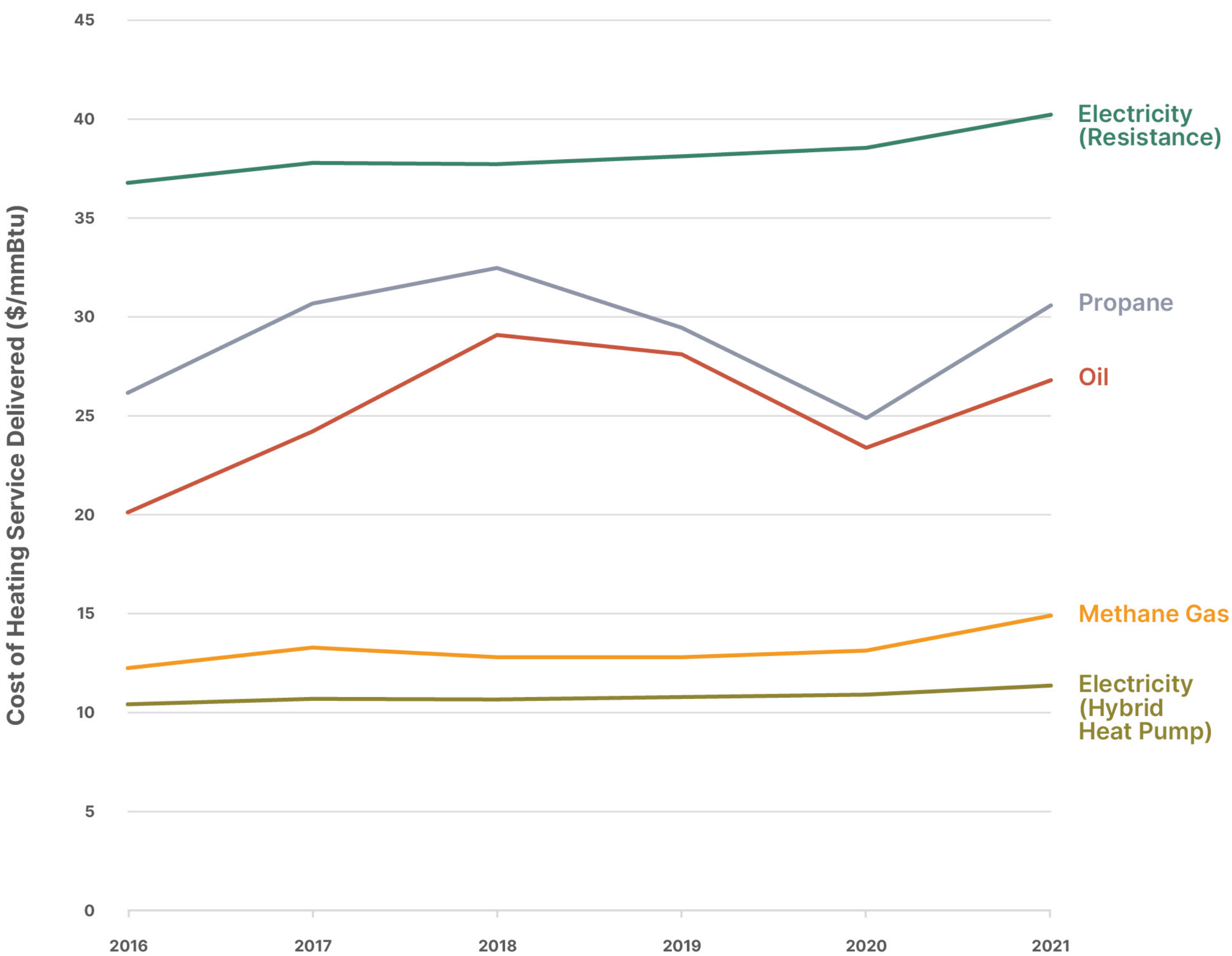
However, the much higher efficiency—353%— of heat pumps running in a hybrid configuration significantly cuts the cost of heating with electricity. This makes heat pump costs competitive with methane gas, the least expensive fuel on an energy-delivered basis, and far less expensive than oil and propane, as can be seen in Figure 3.

vii. These values are typical and individual heating systems will vary. Nonetheless, these conversions were used throughout the modeling for this report, with the exception of heat pump efficiency, which depends on temperature.

TABLE 2. COMPARISON OF ENERGY CONTENT AND HEATING EFFICIENCY FOR EACH FUEL AND SYSTEM TYPE

FUEL	ENERGY CONTENT[18]	HEATING EFFICIENCY[VIII]
Oil (Residential #2)	0.138 mmBtu/gallon	80%
Propane	0.091 mmBtu/gallon	80%
Methane Gas	0.001026 mmBtu/standard cubic foot	85%
Electricity (Resistance)	0.003412 mmBtu/kwh	100%
Electricity (Heat Pump)	0.003412 mmBtu/kwh	353%

FIGURE 3. AVERAGE ANNUAL PRICE FOR HEATING SERVICE PROVIDED



viii. Assumes a mix of condensing and non-condensing furnaces representative of current housing stock for gas (85%; same as in Pantano et al, 2021), existing home propane furnace or oil furnace efficiency (80%, based on Nadel 2018, p. 33); 100% efficient electric resistance; and the weighted average COP of a heat pump run in a hybrid configuration with fossil fuels from our modeling. For comparison the minimum energy performance standard level for heat pumps starting on January 1, 2023, is 7.5 HSPF2, which corresponds to an average annual COP of 2.2 or efficiency of 220%.

REDUCING CO_2 EMISSIONS

Upon publication of "Climate Change 2021: the Physical Science Basis,"[ix] UN Secretary-General António Guterres described the report as nothing less than "a code red for humanity. The alarm bells are deafening, and the evidence is irrefutable."[19] In the "Intergovernmental Panel on Climate Change (IPCC) 2022: Summary for Policymakers," the authors conclude that "human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability.[20] These adverse impacts, they note, include, effects on "ecosystems, people, settlements, and infrastructure," and have resulted from "observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land and in the ocean, heavy precipitation events, drought and fire weather."[21]

While the previous section analyzed the different fuels and heating methods in terms of cost, Table 3 summarizes the same fuels and heating methods in terms of emissions. As with cost, the CO_2 emissions of each fuel vary, with electricity having the highest emissions due to the conversion inefficiencies from generating electricity from fossil fuels. However, if the electricity is converted to heat using heat pumps with an average efficiency of 353%, the CO_2 emissions per unit of heat delivered fall below those of fossil fuels. This means that transitioning heat load from legacy heating to heat pumps will reduce climate impacts, a finding supported by others.[22]

IMPROVING GLOBAL ENERGY SECURITY

Russia's recent invasion of Ukraine has contributed to driving up oil and methane gas prices globally to their highest levels in nearly a decade.[23] European countries are seeking alternative sources of supply and are turning to allies, like Canada and the US, to increase their supply of liquified methane gas (LNG).[24, 25]

Meanwhile US fossil fuel prices appear to be responding to the increased demand from Europe. The Energy Information Administration reports that, as of the end of April, methane gas futures had increased by more than 50%[26] compared to December 2021. Additionally, as of the end of March 2022, propane and fuel oil prices rose by 8% and 50%, respectively.[27] Moving to more efficient use of electric energy with the help of heat pumps can protect consumers by decreasing their exposure to these price increases.

TABLE 3. COMPARISON OF EMISSION FACTOR, TYPICAL HEATING SYSTEM EFFICIENCY AND RESULTANT CO_2 EMISSIONS PER UNIT OF HEATING SERVICE

FUEL	EMISSION FACTOR[x]	EFFICIENCY[xi]	CO_2 EMISSIONS PER UNIT OF HEATING SERVICE (kg/MMBTU)
Oil (Residential #2)	73.96 kg CO_2/mmBtu	80%	92
Propane	62.87 kg CO_2/mmBtu	80%	79
Methane Gas	66 kg CO_2/mmBtu	85%	78
Electricity (Resistance)	884.2 lb/MWh	100%	118
Electricity (Heat Pump)	884.2 lb/MWh	353%	33

ix. This is the IPCC Working Group 1's contribution to the Sixth Assessment Report which addresses the most up-to-date physical understanding of the climate system and climate change, bringing together the latest advances in climate science.

x. US Environmental Protection Agency, "Emission Factors for Greenhouse Gas Inventories", April 1, 2021. Gas emission factor is listed as 53.06 kgCO_2/mmBtu in the EPA source, but this has been increased to 66 to account for methane leakage (per Source 9 in Waite & Modi, 2021), and could be higher still. Losses in the transmission and distribution system (e.g., 5% for electricity) were not factored in; neither was refrigerant leakage and end-of-life emissions for heat pumps; nor the leakage of propane, which is assumed minimal as it is not transmitted by pipes and has global warming potential only 3 times that of CO_2. US-average total emission factor for electricity; eGRID subregion emission factors used in later modeling, which will weight colder regions more heavily than this national estimate.

xi. See footnote viii, above.

What is a Heat Pump?

One way to think about heat pumps is that they are ACs that can run in reverse. In the summer, they work the same as ACs, cooling the interior of our homes. However, in the winter, they collect heat from outside a building—even when it is cold out—and bring that heat indoors.

Like central ACs, heat pumps consist of an outdoor heat exchanger or condenser, a refrigerant loop, and an indoor air handler (or multiple handlers). The air handler can be hidden from view and use ducts to deliver conditioned air to multiple rooms in the house ("central" or "unitary"; the more common variety), or it can be mounted on the wall and deliver conditioned air primarily to a single room ("mini-split" or "multi-split"). There are also air-to-water heat pumps that work with radiators, but these are rare in the US.

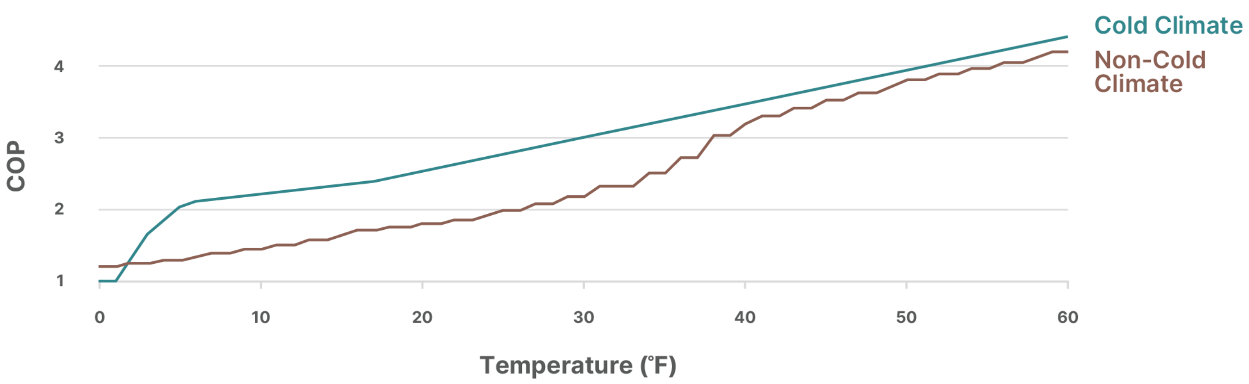
Because they do not generate heat, but move heat contained in outside air, heat pumps can reach efficiencies higher than 400%. This means that heat pumps use one unit of electricity to deliver four units of heat. By contrast, neither oil, methane gas, propane, nor electric resistance can ever exceed 100% efficiency.

Heat pump efficiency is sometimes converted to a decimal and reported as a coefficient of performance (COP). This efficiency or COP will vary with temperature as the heat pump must work harder to extract less and less heat from the air in colder climates and deal with challenges such as frost on the outdoor coil. Therefore, any efficiency calculations must account for the outdoor temperature. For example, the federal test procedure used by the US Department of Energy estimates average efficiency over a typical heating season, and then multiplies it by 3.412 to convert to Btus, such that a 220% average efficiency is equivalent to a 7.5 heating seasonal performance factor, also known as "HSPF" or "HSPF2".

Heat pumps vary in terms not only of efficiency, but also capacity (how big a house they can heat or cool) and cold-climate performance (how much efficiency decreases with temperature). The graph below shows the COP with temperature of two types of heat pumps. The blue line reflects the performance of "cold climate" heat pumps that maintain efficiency over 200% down to 5 degrees Fahrenheit, while the red line reflects a non-cold climate model that can nonetheless cost effectively heat a home when paired with a backup system in a hybrid configuration.

CENTRAL OR DUCTED

DUCTLESS MINI-SPLIT



HYBRID HEATING WITH AC-HP REPLACEMENTS

We argue that traditional ACs should no longer be replaced like-for-like when they fail. Instead, central AC systems should be replaced with heat pumps, which can not only cool but also heat. In the colder months, the heat pump will be supported by the existing heating system.

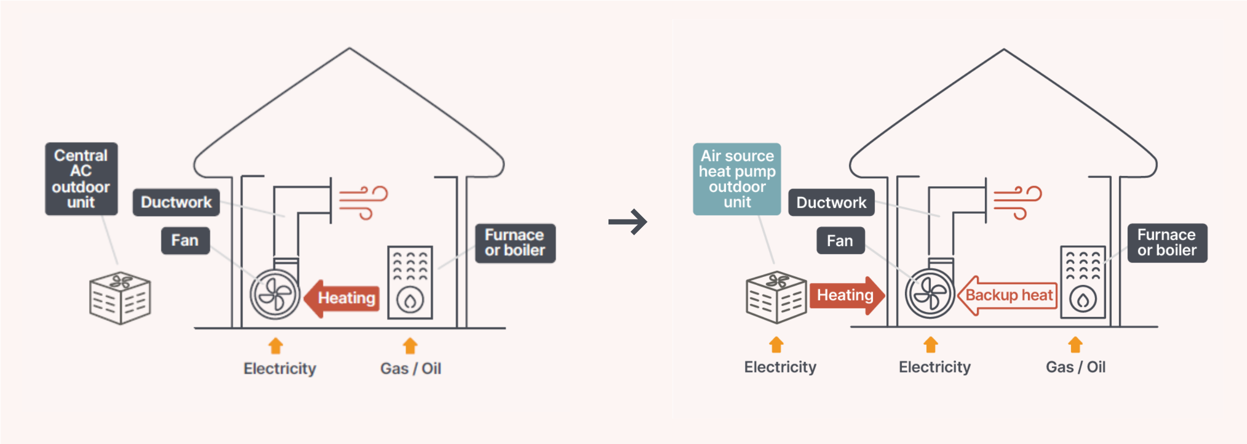
This approach is illustrated in Figure 4, where the outdoor AC unit in the left part of the diagram is replaced with a heat pump in the right part. The heat pump uses the same ducts as the AC (and furnace, if present), and provides the same cooling in the summer. However, it also provides heat in the winter, with the existing heating system offering backup during the coldest days. As we demonstrate, a hybrid configuration can cost-effectively eliminate 36% of fossil fuel heating in the 47% of homes that cool with central AC but heat with fossil fuel or with electric resistance heat.

> A hybrid configuration can cost-effectively eliminate 36% of fossil fuel heating in the 47% of homes that cool with central AC but heat with fossil fuel or with electric resistance heat.

While this solution does not completely electrify heat, it does offer speed and scale. 16,000 one-way ACs are installed every day; so what if each of these ACs were a heat pump, decarbonizing at significant share of the home's heating load?

Because the fossil fuel furnace or boiler remain as backups, providing heat on the coldest days (assumed below 41 °F), it is not necessary to install a cold-climate heat pump. Instead, manufacturers offer versions of their standard ACs that are reversible at a small incremental cost. The market price of a non-cold climate heat pump is $1,000–$2,000 more than an equivalent AC.[xii, xiii] A potential cost-effective solution to increasing heat pump adoption across the US would be to provide incentives for manufacturers to produce heat pumps so that customers can enjoy clean, comfortable heat for a part of the cold season, while saving money on methane gas, propane, or oil bills.

FIGURE 4. ILLUSTRATION OF HEAT PUMP REPLACING A ONE-WAY CENTRAL AC, WHILE THE EXISTING FOSSIL FUEL HEATING SYSTEM REMAINS AS BACKUP.



xii. Total installed cost for a replacement 15 SEER AC is $1700–$3000 versus $2000–$4300 for an equivalent heat pump according to National Renewable Energy Laboratory, "Retrofit Measures for Central Air Conditioner", and "Retrofit Measures for Air Source Heat Pump", *National Residential Efficiency Measures Database*, January 8, 2018, though these costs have recently been increasing.

xiii. Estimated parts cost is approximately $150 in today's dollars. US Department of Energy, "Technical Support Document: Energy Efficiency Program For Consumer Products: Residential Central Air Conditioners and Heat Pumps", December2016, pp. 5-21, 5-23.

Then, whenever they are ready, or the oil furnace or boiler fails, households can fully electrify with a cold-climate heat pump if needed (in the North) or by running their existing heat pump at lower temperatures (in the South and West Coast; see also discussion on electric households, below). Cold climate heat pumps are more expensive, and are often paired with home insulation projects, meaning much higher costs (though also potentially higher incentives). A hybrid heat pump can serve as a bridge, providing benefits today, while households plan out full decarbonization for when their furnace or boiler reaches end-of-life.

The pages that follow show the potential benefits to the nation and to individual households of replacing all the central ACs with heat pumps for homes heated by each common fuel type. We modeled these results using an hourly, census-tract level model of heating energy consumption developed at Columbia University and used in the 2021 3H paper. We updated all housing stocks to 2015 (the latest census-tract level numbers available) and prices to December 2021. Finally, we limited the opportunity to the proportion of houses of each heating type that also have one-way central AC, also from 2015. For a full methodology and detailed results, please see the Appendix.

1.7 million oil, 3.1 million propane, 16 million electric resistance, and 33 million methane gas households—across the country—can benefit from swapping one-way ACs for a hybrid heat pump. Households will reduce their heating bills by $77–$555 per year, while reducing CO_2 emissions by 11%–20%, depending on fuel. While methane gas and electric resistance provide the largest national cost and CO_2 reductions, due to the sheer number of homes using these fuels, oil and propane nonetheless provide a high per-household benefit: five to seven times higher bill savings compared to methane gas, and two times higher per-household CO_2 reductions.

1.7 million oil, 3.1 million propane, 16 million electric resistance, and 33 million methane gas households—across the country—can benefit from swapping one-way ACs for a hybrid heat pump. Households will reduce their heating bills by $77–$555 per year, while reducing CO_2 emissions by 11%–20%, depending on fuel.

Key Findings

In the following section we break down the benefits of switching from oil, propane, methane gas, and electric resistance powered heating to hybrid heat systems.

Overall, we found that the US would cut annual emissions by 67 MT/CO_2 and reduce national heating costs by $13.6 billion.

If all 53.8 million households that are ready to switch from reliance on oil, propane, methane, and electric resistance fueled heating to hybrid heating systems did, the US would:

Cut annual emissions by

67 MT/CO_2

Reduce national heating costs by

$13.6 billion

Oil

Heating oil is the second most expensive and most carbon-intensive fossil heating fuel in the US, requiring millions of households to spend more than $2,000 annually for heat. These already high costs are expected to increase 28% year-over-year in 2022, compared to only 4% for electricity.[27]

Oil continues to heat a significant share of homes in the Northeast, with the largest totals in New York, Pennsylvania, and Massachusetts. Central AC is not as common in oil-heated homes (around a third versus half for all US homes) and winter temperatures where oil is used are often below 40° F, when we do not expect the heat pump to operate, reducing estimated benefits.

Nonetheless, switching these homes to a hybrid heat pump would eliminate 35% of their oil use and reduce their heating bills by an average of $400 (21%), resulting in a total of $670 million in heating bill savings across the country. National CO_2 reductions would be 3 $MtCO_2$/year (6% of current oil heating emissions).

1.7 million

oil homes ready for hybrid heat[xiv]

$1,962

average annual oil heating bills

$400 (21%)

average annual heating bill savings from hybrid heat pumps

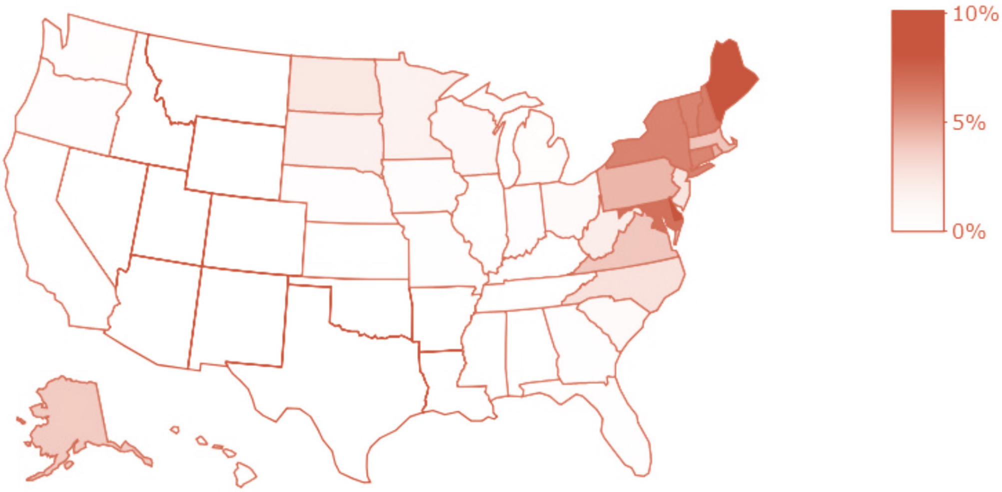
$670 million

in national annual heating bill savings

3 $MtCO_2$

in national annual emissions reductions

PERCENTAGE OF HOMES HEATED WITH OIL WITH CENTRAL AC



xiv. This is the first of four places where we use the term "ready for hybrid heat". This refers to the subset of homes using a particular fuel that also have central (one-way) AC, which can be replaced with a heat pump. The 2015 national estimate of oil-heated homes was 6.5 million. Of these, 1.7 million had one-way central AC. Note that there is a more recent (2019) estimate of 5.4 million oil homes. However, we used the 2017 as that was the latest census-level tract available required for analysis.

Propane

Propane is the most expensive fossil heating fuel in the US. Compared to oil, propane heating is more widely distributed throughout the country, though primarily in rural areas without a methane gas distribution network. AC penetration is higher for propane, at around 54%, meaning a higher number of homes can be converted to hybrid heat pumps.

Switching these homes to a hybrid heat pump system would eliminate 36% of their propane use and reduce their heating bills by an average of $545 (28%), resulting in a total of $1.7 billion in annual heating bill savings across the country. National CO_2 reductions would be 3 $MtCO_2$/year (11% of current propane heating emissions).

3.1 million

propane homes ready for hybrid

$2,145

average annual propane heating bills

$545 (28%)

average annual heating bill savings from hybrid heat pumps

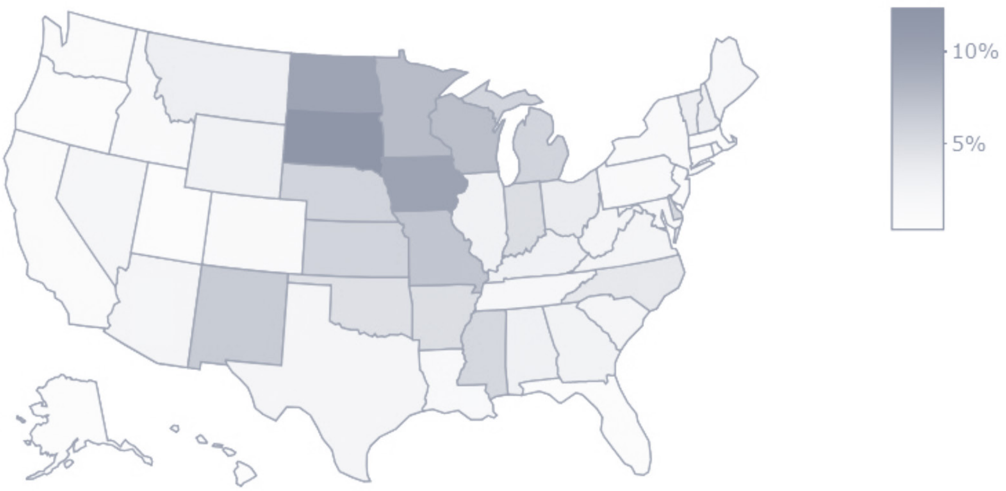
$1.7 billion

in national annual heating bill savings

3 $MtCO_2$

in national emissions reductions

PERCENTAGE OF HOMES HEATED WITH PROPANE WITH CENTRAL AC



Methane Gas

Methane gas is the most common home heating fuel in the US, with 57 million homes reliant on it. The fuel is widely distributed throughout the nation, especially in urban areas.

Due to methane's low cost, the per-user and national cost savings are low compared to the other fuels; however, the high number of households makes for significant climate benefits from hybrid heat pumps.

Switching the central ACs in methane gas homes to heat pumps would eliminate 36% of methane gas use and reduce their heating bills by an average of $77 (12%), resulting in a total of $2.6 billion in heating bill savings across the country. National GHG reductions would be 32 $MtCO_2e$/year (14%).

33 million

gas homes ready for hybrid heat

$753

average annual gas heating bills

$77 (12%)

average annual heating bill savings from hybrid heat pumps

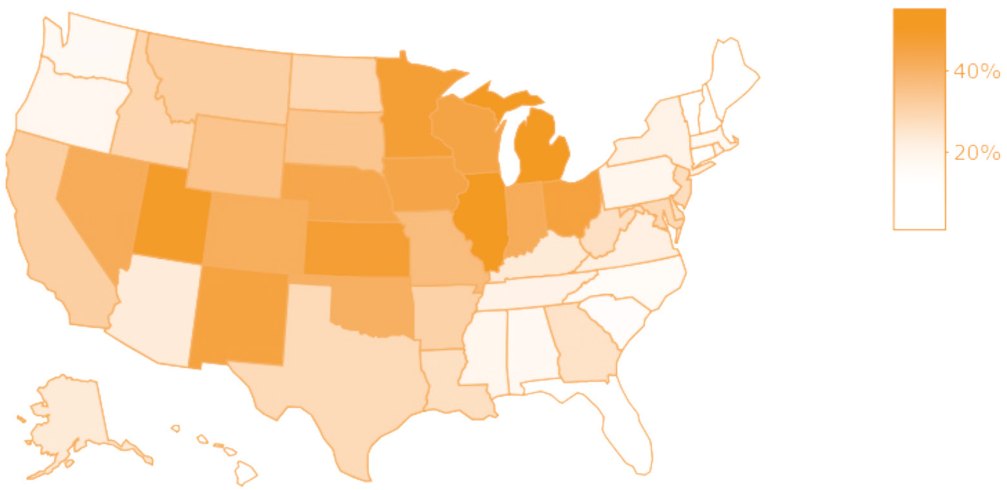
$2.6 billion

in national annual heating bill savings

32 $MtCO_2e$

in national emissions reductions

PERCENTAGE OF HOMES HEATED WITH METHANE GAS WITH CENTRAL AC



Electric Resistance

Electric resistance is the second most popular heating type after methane gas. It is particularly popular in the South, where electricity is on average cheaper and winters mild, but most states outside the Northeast have more than 10% households with electric resistance heat and central AC.

Unlike with the other fuels, electric resistance can be better integrated with the heat pump controls, so that it supplements any shortfalls in heat pump capacity with lower temperature, leading to a more gradual transition between heat pump and backup heat (see Appendix for an illustration). This results in even larger savings.

Switching these homes would reduce their heating bills by an average of $555 (55%), resulting in a total of $9 billion in heating bill savings across the country. National GHG reductions would be 29 $MtCO_2e$/year (20%).

16 million

electric resistance homes ready for hybrid heat

$1,006

average annual electric resistance heating

$555 (55%)

average annual heating bill savings from hybrid heat pumps

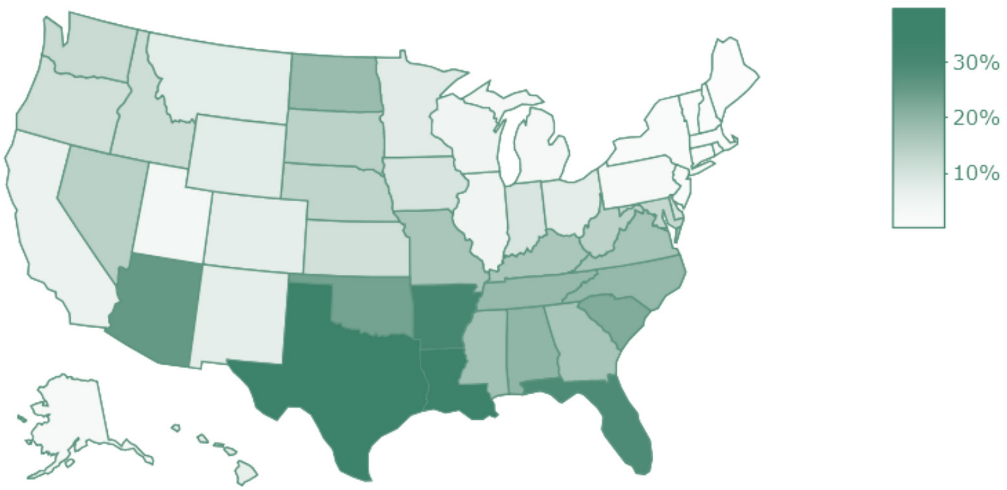
$9 billion

in national annual heating bill savings

29 $MtCO_2e$

in national annual emissions reductions

PERCENTAGE OF HOMES HEATED WITH ELECTRIC RESISTANCE WITH CENTRAL AC



Barriers & Policy Recommendations

BARRIERS

The preceding discussion and empirical analysis find strong benefits from displacing propane, heating oil, and electric resistance heat by converting central air conditioning systems to heat pumps, thus creating hybrid heating systems. We argue that such a conversion will result in significant energy bill savings for consumers, with little additional upfront cost.

This raises a question: given the positive economics from the consumer point of view, why are consumers not rapidly investing in this type of conversion?

One answer may be that the option is only recently becoming widely available and that consumers may soon begin taking advantage of it. However, there is reason to believe that consumer uptake may be suboptimal. Consumer decisions on heat pump installation are likely to be constrained by the common, existing barriers to the widespread adoption of energy efficient equipment. Broader literature on energy efficiency analyzes the reasons consumers often do not invest in energy efficiency measures, despite the promise of positive payback.[28] The barriers include:

- **Emergency replacement:** 85% of HVAC replacements occur on an emergency basis. The time required to research options and deal with unfamiliar parties may act as a transaction cost.
- **Split incentives:** The party (the landlord or builder) making the equipment choices is often not the same party that pays the monthly energy bill (the tenant or buyer).
- **Imperfect information:** The consumer may lack information about technology options. This information problem often extends to equipment distributors, installers, builders, and architects.
- **Financing constraints:** Customers often focus on upfront costs and not future energy savings (an implicit high discount rate). Even consumers who understand the positive present value may not be able to finance an upgrade from savings. Borrowing options may be limited or have high interest rates.

These barriers can be overcome with policy and regulatory measures that unlock the positive consumer and social benefits of energy efficiency improvements. A package of such measures is sometimes referred to as a "market transformation" strategy. Market transformation works, in part, by supporting rapid increase in the general adoption of an appliance. This strategy creates a virtuous cycle by helping reduce up-front costs and increasing consumer awareness of the benefits of the efficient option.

In the following discussion, we briefly outline a selective list of measures that could be assembled into such a strategy. In practice, an effective strategy may require a combination of approaches at the federal, state, and local levels.

States should revise energy efficiency resource standards to be fuel neutral.

Energy efficiency resource standards (EERSs) are state-level policies that set binding energy savings targets for utilities or independent statewide program administrators.[29] The standards are traditionally designed to require savings of specific energy resources, namely electricity and methane gas. At least 31 states have some form of an EERS for electricity, and 19 have an EERS for methane gas.[30] Most EERSs set savings targets as a percentage of retail sales, meaning that each year the savings from energy efficiency measures must equal a certain percentage of the utility's retail sales of that same product. EERS have been successful at driving energy savings: In 2017, states with an EERS achieved incremental electricity savings of 1.2% of retail sales on average, compared with 0.2% savings in states without an EERS.[31]

EERSs set to just one type of fuel, however, constitute a barrier to electrification. Heat pumps, for example, are far more energy efficient than comparable fossil fuel heating technologies. For this reason, Wisconsin, Massachusetts, and New York measure energy savings not only on a fuel-specific basis, but also on a *fuel-neutral* basis.[32] This approach measures total Btus and captures the benefits of, for example, switching homes from fossil fuel heating to electric air-source heat pumps that may increase electric energy use, but will reduce overall energy use on a total Btu basis.[33] *A fuel-neutral EERS would allow an electric utility to get credit for displacing non-electric fuels, such as an air conditioning to heat pump conversion that displaces oil, methane gas, or propane.*[34]

Utilities should phase out incentives for one-way ACs and provide heat pump incentives instead.

The 2021 3H paper estimates that an incentive of $400 to $500 per unit, declining by $60 to $75 each year, would be sufficient to encourage manufacturers to convert all new central ACs to heat pumps with a total cost between $3 and $12 billion over the 4-to-7-year program period. Federal funding could provide this incentive—there is scope under the Infrastructure Investment and Jobs Act and other potential legislation to provide funding. As the 3H paper notes, "The incentive could be delivered as a cash payment, or potentially as some form of tax adjustment, and it could either be targeted upstream at manufacturers or mid-stream at distributors." In practice, these incentives, even if supported by federal funding, may flow through state-run programs.

In many states, utilities or other state-level administrators run energy efficiency programs, which are typically funded by ratepayers. Improving energy efficiency is often the least-cost resource option and brings substantial net benefits, including cost savings for consumers from reduced energy and avoided power system infrastructure investment for the utility. Other sources of savings can include lower costs of compliance with environmental regulations and reduced social costs of pollution.

Energy efficiency programs address market barriers and market failures that prevent consumers from making cost-effective energy efficiency investments. This includes offering incentives for uptake of efficient options, consumer education, and sometimes extension of loans. *Managers of state-level energy efficiency programs, and the regulatory commissions that oversee them, should consider providing incentives for heat pump conversion measures detailed in this paper, given their strong net benefits for consumers, utilities, and society.*

The corollary of providing incentives for conversion of central air conditioning to heat pumps is to end incentives for one-way central air conditioning systems. Many state-level efficiency programs provide such incentives for one-way air conditioning systems. *We recommend these incentives should be phased out so that the only systems receiving incentives are efficient two-way systems.*[xv]

xv. Continued program support for one-way central air conditioning systems might be justified in warm weather geographies where heating demand is very limited.

Utilities and public utility commissions should provide on- and off-bill financing to consumers.

In case direct funding for program incentives is not available at sufficient scale to capture the heat pump conversion opportunity outlined in this paper, utilities and public utility commissions can unlock financing to support heat pump conversion. This would allow consumers to enjoy the benefits of lower energy bills and pay back the initial cost over time, helping to overcome potential "financial constraints".

Financing mechanisms to support energy efficiency financing are growing in the US and could readily provide support for the heat pump conversion effort. For residential consumers, the financing programs include:[35]

- **On-bill financing.** As the name suggests, on-bill financing refers to financing which a consumer pays back in the form of a line item on the utility bill. Financing may be extended by banks, utilities, or other entities. Tariffed on-bill financing is an approach where the utility provides financing that is legally not a loan. The repayment is assigned to the meter and not to the individual consumer. This can avoid barriers such as weak customer credit rating.[xvi]
- **Off-bill financing.** There is a growing range of programs and options. First, some utilities offer consumers low-rate loans for purchase of heat pumps and other efficient appliances. Second, there is a model called property assessed clean energy (PACE) which, although not itemized as part of the consumer bill, is attached to the property, not the individual consumer, and thus has some similarities to an on-bill scheme.

States should implement appliance standards requiring ACs to have two-way operation.

Appliance standards play a critical role in removing the worst-performing products from the market, empowering consumers to purchase more efficient appliances. These standards can be revised to support heat pumps and discourage the sale of one-way central ACs.

Federal appliance standards, set and periodically updated by US Department of Energy, are mandatory minimum energy efficiency standards on products manufactured and imported for sale into the US.[36] State legislatures or state agencies also set energy efficiency standards.[37] Federal standards preempt state standards, but states can establish standards in the absence of federal standards.[xvii]

Appliance standards can be based on characteristics other than an appliance's energy efficiency. Washington State and Oregon, for example, have adopted standards[38] requiring all new water heaters to have a modular demand response communications port to control the appliance's time of electricity use and take advantage of lower cost and cleaner electricity generation.[xviii] The California South Coast Air Quality Management District,[xix] along with other California air districts and the state of Utah, have appliance standards requiring all gas-fired water heaters for sale to meet nitrogen oxide (NOx) emissions requirements.[39] Policymakers could develop similar standards that require two-way operation for ACs, or otherwise encourage hybrid heating in homes installing or replacing an AC.

xvi. For a discussion of the use of tariffed on-bill finance models to support distributed solar generation, see NREL. (2022). "Model Brief: Tariff On-Bill Financing (TOBF)". https://www.nrel.gov/docs/fy22osti/81838.pdf Also see Gilleo A. (2019). "On-Bill Financing Gains Ground but Faces Barriers to Wider Adoption". https://www.aceee.org/blog/2019/04/bill-financing-gains-ground-faces

xvii. 10 CFR § 430.33.- Preemption of State regulations. Often, once a number of states have adopted a standard, manufacturers and other stakeholders will undertake efforts to develop a national standard using that state standard as a model. According to NEEP, "consensus recommendations are the starting point for the majority of national standards." Id.

xviii. US DOE uses the term "grid-interactive efficient buildings" or "GEBs" to describe buildings that use controllable appliances like heat pumps, heat pump water heaters, and even electric vehicles to provide electric utilities with demand flexibility or "demand response." See Heating, Ventilation and Air Conditioning (HVAC), Water Heating, Appliances, and Refrigeration GEB Technical Report, US DOE, December 2019.

xix. The South Coast Basin is a four-county region of roughly 10,000 square miles with almost 17 million residents.

Cities and counties should require AC to heat pump conversions in building codes and other local ordinances.

A Clean Heat Standard or "CHS" is a policy to encourage fossil fuel providers to decarbonize the fuels they supply, and to give consumers low- or no-carbon choices. Like a renewables portfolio standard, a CHS is a performance standard that requires some percentage of a utility's energy services to be from low or no emissions resources.[40] The purpose of a CHS is to drive the market toward greater adoption of carbon-free or low-carbon fuels for space heating, cooling, and water heating.[41] CHSs also expand the delivery infrastructure for these services and products, making it easier and potentially less expensive for consumers to choose these alternatives to fossil fuels when making purchasing decisions.

As a performance standard, a CHS provides suppliers the choice of how to transition from current practices—through their own activities or by purchasing credits from the activities of others. Compliance entities earn credits for converting ACs to heat pumps, as discussed in this paper. Municipalities that engage in energy efficiency and weatherization investment as well as low emissions clean heating options, including advanced wood heat, biofuels, biogas, and district heating, would be eligible for credits. States and cities that increase electrification of heating using heat pumps for space and water heating can also receive these credits.

Colorado recently adopted Clean Heat Plan legislation, containing greenhouse gas (GHG) reduction targets for gas distribution utilities.[42] These utilities are now required to develop cost-effective plans for review by the state utilities commission to achieve GHG emissions reductions from the fuel they provide to homes and businesses—reductions of 4% by 2025 and by 22% by 2030. Compliance pathways in Colorado include electrification, efficiency, green hydrogen, recovered methane, and biogas from agricultural facilities. Legislation in Vermont passed both houses of the legislature to develop a CHS that would apply to gas distribution companies and companies delivering propane and heating oil and provide compliance pathways that include biofuels, biogas, and electrification. This legislation was vetoed by the Governor which the legislature was unable to override.[xx, 43]

Municipal buildings policy is fertile ground for advancing air conditioning heat pump conversion. As more cities pursue climate goals, local governments are using levers like permitting, zoning regulations, inspection requirements, benchmarking policies, building labeling, energy audit requirements, building codes, and building performance standards.

For new construction and major renovations, municipal building codes offer a direct pathway to more efficient buildings and lower GHG emissions. In cities that are authorized under state law[44], codes and stretch codes[xxi,45] can specify no traditional central air conditioning and only two-way heat pumps in all new construction. Beyond codes, building performance standards (BPS) are emerging in several cities, offering a policy mechanism designed to improve the energy and water use efficiency of existing building stock.[xxii]

To meet aggressive decarbonization targets, cities are moving beyond regulatory approaches to directly address the cost of home retrofits. In its Efficiency Retrofitting and Thermal Load Electrification Program, the City of Ithaca, New York is leveraging private equity financing and philanthropic funding to offer low- to no-cost home retrofit loans to support its goal for full building decarbonization by 2030.[46] Cities with municipally owned utilities, like Ithaca, are well-positioned to support electrification ambition at the local level with coordinated financing, customer education and technical assistance provided by the utility. In addition to public power, cities can expand local control through the use of city-utility partnership agreements[47] and by conditioning franchise agreements.[48]

xx. As H.715 was vetoed at the end of the 2022 legislative session, the CHS has not yet been enacted in Vermont. However, the bill provides an excellent overview of issues and structural elements for those considering a CHS.

xxi. Ambitious examples of code adoption in California, Massachusetts (Green Communities), New York City and Washington, DC.

xxii. See National BPS Coalition, https://nationalbpscoalition.org/; See also American Cities Challenge, Building performance standards: A framework for equitable policies to address existing buildings. July 2021. https://www.usdn.org/uploads/cms/documents/bps-framework_july-2021_final.pdf

Field Results

This paper uses detailed modeling to make the case for hybrid heat pumps for homes heated with a variety of fuels. But how do these switchovers work out in practice? We examine three case studies where legacy heating systems were supplemented with heat pumps, in a manner comparable to the one addressed in this report. These studies are just the tip of the iceberg, as EIA has found that there are 5.8 million US homes currently operating hybrid systems with a fossil fuel backup,[xxiii,49] demonstrating the real-life benefits of this approach.

UPPER MIDWEST

Two field studies in the upper Midwest found average fossil fuel reductions of 64% for four propane homes in Minnesota[50] and 52% for 8 propane homes in Michigan.[51] This is higher than the 19% and 23% fossil fuel reduction than we estimated for these states and seems to be driven by the use of cold climate heat pumps in the first study and lower switchover temperatures (20–30° F) in the second study.

The systems were also generally more expensive than envisioned by a simple AC-to-HP swap ($14,125 average for average 3.5 ton ducted units in the first study,[52] which also included a new condensing propane furnace; and $10,381 for ducted units, sized to mainly meet the cooling load, in the second study). Despite these high up-front costs, these hybrid systems were cost effective, providing 6.5 and 4 year paybacks, respectively.

VERMONT

Vermont's long-standing efficiency programs have recently been supplemented by electrification. A 2020 climate law requires a 50% reduction in GHG emissions by 2050, which has spurred the Vermont Gas System utility to experiment with installing heat pumps and heat pump water heaters.[53]

A recent pilot of 350 hybrid heat pump installations, found that they were able to displace only 3.8% of gas consumption.[54] This is much lower than our modeled result of 36% for methane gas displacement in Vermont. One potential fix is better controls that ensure that the heating system switches over to the heat pump at the right temperature; for example, Massachusetts's energy efficiency program keeps a list of qualified thermostats for this purpose.[55]

xxiii. Sum of total sample weight of homes with "Main space heating fuel" equal to "Natural gas from underground pipes", "Fuel oil/kerosene", or "Propane (bottled gas)" and "Central air conditioner is a heat pump?" equal to "Yes".

Looking Toward Full Electrification

This proposal is not intended to delay or distract from full electrification of the building stock. Rather, it seeks to accelerate this transition, especially in existing buildings, through low cost and speed. Due to the facts that ACs have a shorter lifetime than furnaces or boilers and a small cost difference from heat pumps, this opportunity for accelerated heat pump deployment has the potential to electrify a significant share of space heating over the next 5-10 years, while increasing customer and contractor familiarity with and acceptance of heat pumps.

Once the furnace or boiler fails, however, a home would be a candidate for full electrification. In the South and much of the West Coast, where winters are mild and electricity rates are low, our model found that the hybrid heat pump displaced a majority of the fossil fuel. Running a non-cold-climate heat pump (with electric resistance backup) could meet the heating needs of customers in these regions.

COLD CLIMATE HEAT PUMPS

Fully electrifying heating in the North will require cold-climate heat pumps, potentially also using electric resistance as a backup during the coldest parts of Northern winters. Cold-climate heat pumps are more expensive than the non-cold-climate versions typically found in the South and considered for hybrid systems in this paper; however, these high-powered pieces of equipment are able to maintain their heat output and efficiency well below freezing, keeping homes warm and bills low.

Cold-climate heat pumps cost between $10,000–25,000 each[xxiv] (including equipment and labor and avoiding the cost of a new AC and fossil fuel heating system). Prices vary depending on the size, temperature performance, and complexity of the installation.

We modeled that installing cold-climate heat pumps in the 6.5 million homes with **oil heating** would save consumers $859 in utility bills per household per year, or $5.5 billion across the nation (43% savings), while reducing CO_2 emissions from heating these homes by 28 million metric tons per year (a 70% reduction) and almost 10 times greater than the 3 $MtCO_2$ achieved through hybrid heat pumps.

An even greater cost savings would be seen in the 4.8 million homes with **propane**, which would save $1,466 in annual heating bills, or $7.0 billion across the nation (64% savings), while reducing CO_2 emissions from heating these homes by 10 million metric tons per year (a 44% reduction), 3 times greater than the 3 $MtCO_2$ achieved through hybrid heat pumps.

Next, the 29 million homes with **electric resistance** would save $774 in annual heating bills or $22.2 billion across the nation (62%), while reducing CO_2 emissions from heating these homes by 67 million metric tons per year (a 45% reduction). The percentage reductions are comparable to the non-cold-climate hybrid case, due to the prominence of electric resistance in warmer climates where cold-climate heat pumps provide less benefit and the better coordination between the hybrid heat pump and electric resistance backup, which improves overall efficiency (discussed further in the Appendix).

xxiv. Ducted tend to be at the lower end of the range, and ductless at the higher end. Interviews held with VEIC and Center for Energy and Environment in 2021 and 2022 found a range of $10,000 to $20,000, though recent inflation may have increased these costs by as much as 40%.

Finally, the 57 million homes with **methane gas** would save $33 in annual heating bills or $1.9 billion across the nation (6%), while reducing CO_2 emissions from heating these homes by 118 million metric tons per year (a 50% reduction). However, in contrast to the more expensive fuels analyzed above, there are a number of colder states that would see high cost increases due to the lower relative price of methane gas versus electricity, and the inability of the heat pump to overcome that difference at low temperatures despite cold-climate performance (a heat pump efficiency of 200%–450% is unable to overcome the 4-6x price premium of electricity over methane gas in 16 states).

These results from a full cold-climate transition are summarized in Table 4 below.

Despite the higher up-front costs of cold-climate heat pumps, with average household bill savings around $1000 and equipment lifetimes between 10—20 years, heat pump replacements of oil, propane, and electric resistance systems are cost effective now and would be even more so with moderate incentives to reduce the initial price tag for consumers. In fact, the national cost benefits of electrifying these fuels ($35 billion) greatly outweigh those of electrifying methane gas ($1.9 billion), while the GHG reductions are comparable (105 versus 118 $MtCO_2e$/yr).

Despite the lower prevalence of oil, propane, and electric resistance, electrifying these fuels is cost effective and should be a top priority for US federal, state, and municipal governments.

TABLE 4. SUMMARY OF COST AND CO_2 REDUCTIONS FROM FULL ELECTRIFICATION OF THE VARIOUS HEATING FUELS WITH COLD CLIMATE HEAT PUMPS.

FUEL	AVERAGE HOUSEHOLD UTILITY COST SAVINGS ($/YR)	NATIONAL HOUSEHOLD UTILITY COST SAVINGS ($ BILLION/YR)	NATIONAL CO_2 REDUCTIONS ($MTCO_2E$/YR)
Oil	$859	$5.5	28
Propane	$1,466	$7.0	10
Electric Resistance	$774	$22.2	67
Methane Gas	$33	$1.9	118

Appendix

APPENDIX

Modeling Methodology and Results

In this paper, we modeled two scenarios:

1. In most of the paper, we focused on a hybrid scenario whereby a central AC was replaced by a standard heat pump (we used performance data for a single-speed, 15 SEER/9 HSPF model that will just meet the 2023 DOE minimum standard, shown in red, below).[56]

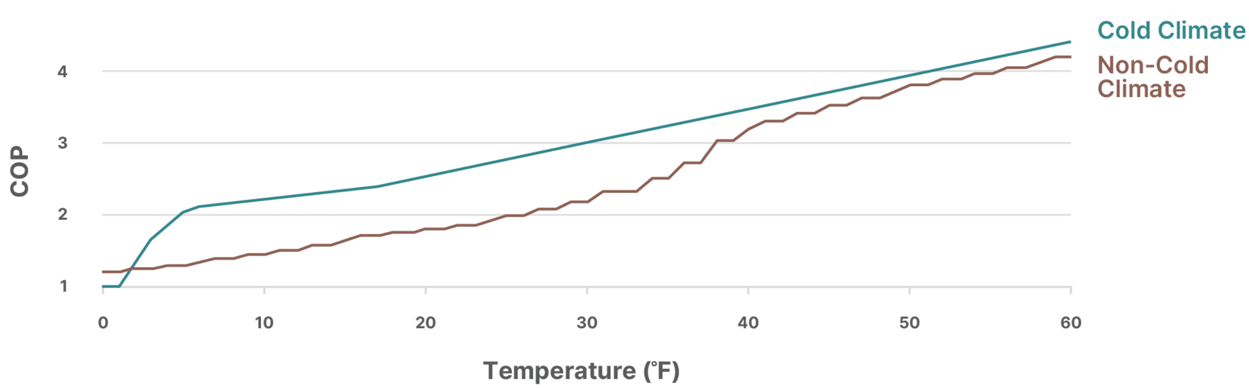
   We assumed that homeowners would only use these non-cold-climate heat pumps at warmer temperatures: turning off the oil furnace or boiler and turning on the heat pump at or above 41° Fahrenheit/5° Celsius. This is a conservative assumption and different switchover temperatures could potentially result in greater cost and CO_2 reductions depending on specific equipment performance, local fossil fuel and electricity prices, and electric grid emissions.

2. In the last section, we also analyzed a full electrification scenario, involving replacement of the existing heating system with a cold-climate heat pump. (We used the median performance of heat pumps on NEEP's Cold Climate list, as reported by Waite & Modi, shown in blue).

HYBRID HEATING MODELING METHODOLOGY

We used a model originally developed at by Michael Waite and Vijay Modi at Columbia University,[57] which estimates the heating demand of each census tract in the contiguous US (48 states plus DC) in hourly intervals. By feeding different heating system characteristics into the model, it is possible to model the impacts of temperature-dependent efficiency (in the case of heat pumps) or switch between different types of heating systems at different temperatures (in the case of hybrid systems).

CLASP modified the model in in 2021 to reflect partial electrification through a Hybrid Heat Home (3H), where the heat pump provides heat during warmer temperatures, but the legacy heating system remains as backup. For this paper, we further modified the model to reflect December 2021 prices, 2015 stocks of heating systems[xxv, 58] and 2015 distribution of one-way ACs.[xxvi, 59]



xxv. More recent 1-year data from 2019 does not have census tract-level resolution needed for analysis.

xxvi. Sum of total sample weight of homes with "Central air conditioner is a heat pump?" equal to "No" for various primary heating fuels.

Oil

MODELING ASSUMPTIONS FOR OIL

- 80% efficient oil boiler or furnace[xxvii]
- 0.138 mmBtu per gallon heat content[60]
- 73.96 kg CO_2 per mmBtu emission factor[61]
- Dec 2021 average retail prices [xxviii, 62]

MODELING RESULTS

Replacing one-way ACs with heat pumps in a hybrid system with oil heat would save consumers $400 in utility bills per household per year, and $670 million across the nation (21% savings compared to heating with oil alone), while reducing CO_2 emissions from heating by 3 million metric tons (6% reduction).

The tables that follow first list the household cost impacts and then the statewide CO_2 impacts of electrifying oil heat with hybrid heat pumps.[xxix]

xxvii. Assumption for legacy stock in Steven Nadel, "Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps", ACEEE Report A1803, July 2018, p. 33.

xxviii. US average used when no state data available.

xxix. Missing data in the table is due to EIA's RECS 2015 not providing the data for oil heat for certain census divisions, due to its lower popularity there.

State	Number of Households	% with Oil Heating and Central AC	Number of Oil Households Ready for Hybrid Heat	Electric Rate ($/kWh)	Oil Rate ($/gal)	Ratio of Electric to Oil Rates per Site Btu	Current Oil Household Heating Annual Bill	Oil Household Heating Annual Bill Under Program (HP + Oil Backup)	Annual Heating Bill Savings ($)	Annual Heating Bill Savings (%)
AL	1,848,325	0%	-	$0.10	$2.22	1	$1,038	-	-	-
AZ	2,412,212	0%	-	$0.13	$2.22	2	$664	-	-	-
AR	1,138,025	0%	-	$0.11	$2.22	1	$1,265	-	-	-
CA	12,717,801	0%	4,139	$0.23	$2.22	3	$1,591	$1,178	$414	26%
CO	2,024,468	0%	-	$0.14	$2.22	2	$2,441	-	-	-
CT	1,352,583	6%	81,041	$0.21	$2.17	3	$2,367	$1,999	$367	16%
DE	344,022	10%	34,749	$0.13	$2.41	1	$1,639	$1,162	$478	29%
DC	273,390	2%	4,180	$0.13	$2.22	2	$1,535	$1,060	$476	31%
FL	7,300,494	0%	9,805	$0.12	$2.22	1	$270	$110	$160	59%
GA	3,574,362	0%	4,977	$0.12	$2.22	1	$1,274	$778	$496	39%
ID	589,320	0%	-	$0.10	$2.22	1	$2,201	-	-	-
IL	4,786,388	0%	3,174	$0.14	$2.22	2	$1,980	$1,625	$355	18%
IN	2,501,937	0%	7,624	$0.14	$2.19	2	$1,822	$1,475	$346	19%
IA	1,236,409	1%	6,228	$0.12	$1.91	2	$1,634	$1,389	$245	15%
KS	1,113,472	0%	988	$0.13	$2.22	2	$1,711	$1,336	$375	22%
KY	1,708,499	0%	-	$0.12	$2.09	2	$1,579	-	-	-
LA	1,727,919	0%	-	$0.12	$2.22	1	$828	-	-	-
ME	553,284	9%	48,902	$0.18	$2.07	2	$1,930	$1,687	$243	13%
MD	2,166,389	7%	148,756	$0.14	$2.34	2	$2,085	$1,526	$558	27%
MA	2,549,721	4%	101,695	$0.24	$2.21	3	$2,211	$1,958	$253	11%
MI	3,841,148	0%	17,609	$0.17	$2.07	2	$2,309	$2,027	$282	12%
MN	2,124,745	2%	36,356	$0.13	$2.26	2	$2,275	$1,989	$286	13%
MS	1,096,593	0%	-	$0.12	$2.22	1	$1,009	-	-	-
MO	2,364,688	0%	3,816	$0.11	$2.22	1	$1,551	$1,151	$399	26%
MT	409,394	0%	-	$0.11	$2.22	1	$2,597	-	-	-
NE	736,613	0%	2,360	$0.10	$1.84	1	$1,537	$1,270	$266	17%
NV	1,016,709	0%	-	$0.12	$2.22	1	$2,383	-	-	-
NH	520,251	6%	32,850	$0.21	$2.17	3	$1,854	$1,642	$212	11%
NJ	3,189,486	3%	82,269	$0.16	$2.33	2	$2,172	$1,684	$487	22%
NM	763,603	0%	-	$0.13	$2.22	2	$1,750	-	-	-
NY	7,262,279	6%	445,202	$0.20	$2.33	2	$1,952	$1,578	$373	19%
NC	3,775,581	3%	104,416	$0.11	$2.18	1	$1,688	$1,176	$512	30%
ND	299,638	2%	7,193	$0.09	$2.22	1	$2,434	$2,093	$341	14%
OH	4,585,084	1%	39,512	$0.13	$2.16	2	$1,827	$1,481	$347	19%
OK	1,455,321	0%	-	$0.11	$2.22	1	$1,471	-	-	-
OR	1,533,430	0%	4,815	$0.11	$2.22	1	$1,683	$950	$733	44%
PA	4,958,859	4%	220,100	$0.14	$2.12	2	$1,930	$1,539	$391	20%
RI	410,602	5%	18,714	$0.25	$2.20	3	$2,407	$2,109	$298	12%
SC	1,815,094	1%	14,929	$0.13	$2.22	2	$1,233	$763	$471	38%
SD	330,858	2%	5,964	$0.12	$2.22	1	$1,815	$1,544	$271	15%
TN	2,504,556	0%	-	$0.12	$2.22	1	$1,732	-	-	-
TX	9,149,196	0%	-	$0.13	$2.22	2	$1,117	-	-	-
UT	906,292	0%	-	$0.10	$2.22	1	$2,119	-	-	-
VT	257,167	6%	15,633	$0.20	$2.11	2	$2,095	$1,874	$220	11%
VA	3,062,783	4%	119,953	$0.12	$2.23	1	$1,852	$1,322	$530	29%
WA	2,668,912	0%	7,710	$0.10	$2.22	1	$1,839	$934	$905	49%
WV	740,890	2%	15,084	$0.12	$2.22	1	$1,866	$1,431	$435	23%
WI	2,299,107	1%	22,370	$0.14	$1.95	2	$1,730	$1,511	$219	13%
WY	226,865	0%	-	$0.11	$2.22	1	$3,168	-	-	-
Total			1,673,112				$3,282,442,556	$2,612,380,895	$670,061,661	
Average							$1,962	$1,561	$400	21%

State	Number of Households	% with Oil Heating and Central AC	Number of Oil Households Ready for Hybrid Heat	Current Oil Heating Energy Consumption (mmBtu)	Current Oil CO_2 Emissions ($MtCO_2$)	Effective Electrification (Reduction in Oil Energy Use)	CO_2 Emissions of Unconverted and Backup Oil Heating ($MtCO_2$)	CO_2 Emissions of Heat Pumps ($MtCO_2$)	CO_2 Emissions Reductions ($MtCO_2$)	CO_2 Emissions Reductions (%)
AL	1,848,325	0%	-	157,274	0.0	-	0.0	-	-	0%
AZ	2,412,212	0%	-	46,187	0.0	-	0.0	-	-	0%
AR	1,138,025	0%	-	58,055	0.0	-	0.0	-	-	0%
CA	12,717,801	0%	4,139	2,165,297	0.2	65%	0.1	0.0	0.0	6%
CO	2,024,468	0%	-	215,817	0.0	-	0.0	-	-	0%
CT	1,352,583	6%	81,041	58,967,016	4.4	35%	4.2	0.0	0.2	4%
DE	344,022	10%	34,749	3,082,673	0.2	42%	0.2	0.0	0.0	21%
DC	273,390	2%	4,180	376,974	0.0	48%	0.0	0.0	0.0	24%
FL	7,300,494	0%	9,805	155,426	0.0	86%	0.0	0.0	0.0	40%
GA	3,574,362	0%	4,977	372,426	0.0	57%	0.0	0.0	0.0	25%
ID	589,320	0%	-	911,524	0.1	-	0.1	-	-	0%
IL	4,786,388	0%	3,174	738,103	0.1	28%	0.0	0.0	0.0	5%
IN	2,501,937	0%	7,624	1,648,821	0.1	30%	0.1	0.0	0.0	6%
IA	1,236,409	1%	6,228	673,226	0.0	23%	0.0	0.0	0.0	9%
KS	1,113,472	0%	988	96,261	0.0	33%	0.0	0.0	0.0	14%
KY	1,708,499	0%	-	1,136,434	0.1	-	0.1	-	-	0%
LA	1,727,919	0%	-	33,946	0.0	-	0.0	-	-	0%
ME	553,284	9%	48,902	30,422,842	2.3	25%	2.2	0.0	0.1	3%
MD	2,166,389	7%	148,756	17,297,005	1.3	41%	0.9	0.1	0.3	20%
MA	2,549,721	4%	101,695	68,031,484	5.0	32%	4.8	0.0	0.2	4%
MI	3,841,148	0%	17,609	5,102,210	0.4	24%	0.3	0.0	0.0	4%
MN	2,124,745	2%	36,356	4,629,567	0.3	19%	0.3	0.0	0.0	8%
MS	1,096,593	0%	-	63,632	0.0	-	0.0	-	-	0%
MO	2,364,688	0%	3,816	336,907	0.0	36%	0.0	0.0	0.0	11%
MT	409,394	0%	-	509,398	0.0	-	0.0	-	-	0%
NE	736,613	0%	2,360	249,382	0.0	26%	0.0	0.0	0.0	10%
NV	1,016,709	0%	-	652,517	0.0	-	0.0	-	-	0%
NH	520,251	6%	32,850	18,732,878	1.4	26%	1.3	0.0	0.0	3%
NJ	3,189,486	3%	82,269	28,475,340	2.1	37%	1.9	0.1	0.1	7%
NM	763,603	0%	-	61,192	0.0	-	0.0	-	-	0%
NY	7,262,279	6%	445,202	138,440,028	10.2	37%	9.3	0.3	0.7	7%
NC	3,775,581	3%	104,416	10,550,180	0.8	43%	0.5	0.1	0.2	22%
ND	299,638	2%	7,193	996,820	0.1	19%	0.1	0.0	0.0	8%
OH	4,585,084	1%	39,512	8,681,270	0.6	29%	0.6	0.0	0.0	6%
OK	1,455,321	0%	-	114,575	0.0	-	0.0	-	-	0%
OR	1,533,430	0%	4,815	2,664,257	0.2	61%	0.2	0.0	0.0	6%
PA	4,958,859	4%	220,100	74,556,033	5.5	33%	5.1	0.1	0.3	6%
RI	410,602	5%	18,714	13,655,400	1.0	37%	1.0	0.0	0.0	4%
SC	1,815,094	1%	14,929	1,081,626	0.1	58%	0.0	0.0	0.0	30%
SD	330,858	2%	5,964	616,191	0.0	21%	0.0	0.0	0.0	9%
TN	2,504,556	0%	-	735,292	0.1	-	0.1	-	-	0%
TX	9,149,196	0%	-	479,566	0.0	-	0.0	-	-	0%
UT	906,292	0%	-	100,483	0.0	-	0.0	-	-	0%
VT	257,167	6%	15,633	10,387,936	0.8	23%	0.7	0.0	0.0	3%
VA	3,062,783	4%	119,953	12,953,991	1.0	41%	0.7	0.1	0.2	20%
WA	2,668,912	0%	7,710	4,660,756	0.3	67%	0.3	0.0	0.0	6%
WV	740,890	2%	15,084	1,653,958	0.1	34%	0.1	0.0	0.0	14%
WI	2,299,107	1%	22,370	5,173,944	0.4	22%	0.4	0.0	0.0	4%
WY	226,865	0%	-	87,902	0.0	-	0.0	-	-	0%
Total			1,673,112	532,990,022	39	36%	36	1	3	6%

Propane

MODELING ASSUMPTIONS FOR PROPANE

- 80% efficient propane boiler or furnace[xxx]
- 0.091 mmBtu per gallon heat content[63]
- 62 kg CO_2 per mmBtu emission factor[64]
- Dec 2021 average retail prices[xxxi, 65]

MODELING RESULTS

Replacing one-way ACs with heat pumps in a hybrid system with propane heat would save consumers $545 in utility bills per household per year, and $1.7 billion across the nation (28% savings compared to heating with propane alone), while reducing CO_2 emissions from heating by 3 million metric tons (11% reduction).

The tables that follow first list the household cost impacts and then the statewide CO_2 impacts of electrifying propane heat with hybrid heat pumps.

xxx. Assumption for legacy stock in Steven Nadel, "Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps", ACEEE Report A1803, July 2018, p. 33.

xxxi. US average used when no state data available.

State	Number of Propane Households	Percentage of Propane Households	Number of Propane Households Ready for Hybrid Heat	Electricity Rate ($/kWh)	Propane Price ($/gal)	Ratio of Electricity to Propane Prices per Site Btu	Current Propane Household Annual Heating Bills	Propane Household Heating Annual Bill Under Program (HP + Propane Backup)	Annual Heating Bill Savings ($)	Annual Heating Bill Savings (%)
AL	1,848,325	3%	55,997	$0.10	$3.28	1	$1,562	$858	$704	45%
AZ	2,412,212	2%	53,458	$0.13	$2.70	1	$1,448	$908	$540	37%
AR	1,138,025	5%	55,201	$0.11	$2.49	1	$1,486	$956	$530	36%
CA	12,717,801	1%	125,281	$0.23	$2.70	2	$1,509	$914	$595	39%
CO	2,024,468	1%	26,754	$0.14	$2.54	1	$3,079	$2,540	$538	17%
CT	1,352,583	1%	9,994	$0.21	$3.57	2	$3,962	$3,045	$917	23%
DE	344,022	5%	18,374	$0.13	$3.28	1	$2,478	$1,631	$847	34%
DC	273,390	1%	1,411	$0.13	$2.70	1	$1,928	$1,279	$649	34%
FL	7,300,494	1%	40,121	$0.12	$4.85	1	$718	$215	$502	70%
GA	3,574,362	3%	94,034	$0.12	$3.04	1	$1,762	$978	$785	45%
ID	589,320	1%	7,830	$0.10	$2.69	1	$3,355	$2,592	$762	23%
IL	4,786,388	3%	133,166	$0.14	$2.16	2	$2,022	$1,654	$369	18%
IN	2,501,937	5%	122,563	$0.14	$2.63	1	$2,266	$1,799	$466	21%
IA	1,236,409	10%	124,174	$0.12	$1.90	2	$1,622	$1,376	$245	15%
KS	1,113,472	6%	64,829	$0.13	$2.18	2	$1,715	$1,341	$375	22%
KY	1,708,499	3%	48,567	$0.12	$2.80	1	$2,068	$1,509	$559	27%
LA	1,727,919	2%	27,139	$0.12	$2.70	1	$1,092	$521	$571	52%
ME	553,284	2%	9,609	$0.18	$3.25	1	$3,282	$2,702	$579	18%
MD	2,166,389	2%	36,515	$0.14	$3.38	1	$3,098	$2,125	$973	31%
MA	2,549,721	1%	15,829	$0.24	$3.52	2	$3,820	$3,050	$770	20%
MI	3,841,148	6%	220,757	$0.17	$2.44	2	$2,903	$2,508	$395	14%
MN	2,124,745	8%	163,077	$0.13	$2.35	1	$2,429	$2,111	$318	13%
MS	1,096,593	5%	59,969	$0.12	$2.95	1	$1,356	$777	$579	43%
MO	2,364,688	7%	164,528	$0.11	$2.38	1	$1,723	$1,265	$458	27%
MT	409,394	3%	13,488	$0.11	$2.27	1	$2,784	$2,244	$541	19%
NE	736,613	6%	42,921	$0.10	$1.98	1	$1,679	$1,370	$308	18%
NV	1,016,709	2%	21,675	$0.12	$2.70	1	$2,185	$1,620	$565	26%
NH	520,251	3%	15,818	$0.21	$3.66	2	$3,269	$2,701	$568	17%
NJ	3,189,486	1%	23,653	$0.16	$3.57	1	$3,323	$2,399	$925	28%
NM	763,603	7%	49,823	$0.13	$2.70	1	$1,834	$1,295	$539	29%
NY	7,262,279	1%	96,713	$0.20	$3.35	2	$3,666	$2,949	$717	20%
NC	3,775,581	4%	150,464	$0.11	$3.36	1	$2,301	$1,404	$897	39%
ND	299,638	10%	29,594	$0.09	$2.02	1	$2,246	$1,935	$311	14%
OH	4,585,084	4%	164,253	$0.13	$2.70	1	$2,292	$1,816	$476	21%
OK	1,455,321	5%	68,147	$0.11	$2.59	1	$1,681	$1,088	$594	35%
OR	1,533,430	1%	8,027	$0.11	$2.70	1	$2,300	$1,278	$1,022	44%
PA	4,958,859	2%	74,489	$0.14	$2.91	1	$2,899	$2,234	$665	23%
RI	410,602	1%	2,186	$0.25	$3.70	2	$4,141	$3,208	$933	23%
SC	1,815,094	2%	40,780	$0.13	$2.70	1	$1,448	$824	$623	43%
SD	330,858	12%	40,824	$0.12	$2.16	1	$1,688	$1,433	$255	15%
TN	2,504,556	2%	46,823	$0.12	$3.23	1	$2,397	$1,612	$785	33%
TX	9,149,196	2%	201,981	$0.13	$2.90	1	$1,214	$611	$603	50%
UT	906,292	1%	5,639	$0.10	$2.60	1	$2,384	$1,843	$541	23%
VT	257,167	3%	8,217	$0.20	$3.49	1	$3,724	$3,148	$576	15%
VA	3,062,783	2%	70,841	$0.12	$3.45	1	$3,035	$2,042	$993	33%
WA	2,668,912	1%	25,463	$0.10	$2.70	1	$2,639	$1,260	$1,379	52%
WV	740,890	2%	16,864	$0.12	$2.70	1	$2,324	$1,744	$580	25%
WI	2,299,107	8%	172,599	$0.14	$2.29	2	$2,460	$2,132	$328	13%
WY	226,865	3%	6,405	$0.11	$2.70	1	$3,227	$2,638	$589	18%
Total			**3,076,864**				**$6,600,091,358**	**$4,921,759,414**	**$1,678,331,944**	
Average							**$2,145**	**$1,600**	**$545**	**28%**

State	Number of Households	% w Propane Heating and Central AC	Number of Propane Households Ready for Hybrid Heat	Current Propane Heating Energy Consumption (mmBtu)	Current Propane CO_2 Emissions ($MtCO_2$)	Effective Electrification (Reduction in Propane Energy Use)	CO_2 Emissions of Unconverted and Backup Propane Heating ($MtCO_2$)	CO_2 Emissions of Heat Pumps ($MtCO_2$)	CO_2 Emissions Reductions ($MtCO_2$)	CO_2 Emissions Reductions (%)
AL	1,848,325	3%	55,997	5,456,405	0.3	54%	0.3	0.0	0.0	13%
AZ	2,412,212	2%	53,458	3,318,841	0.2	51%	0.1	0.0	0.0	22%
AR	1,138,025	5%	55,201	4,482,204	0.3	48%	0.2	0.0	0.1	19%
CA	12,717,801	1%	125,281	20,270,289	1.3	76%	1.0	0.1	0.2	19%
CO	2,024,468	1%	26,754	10,671,394	0.7	25%	0.6	0.0	0.0	3%
CT	1,352,583	1%	9,994	4,794,104	0.3	35%	0.3	0.0	0.0	6%
DE	344,022	5%	18,374	2,421,252	0.2	44%	0.1	0.0	0.0	15%
DC	273,390	1%	1,411	175,813	0.0	47%	0.0	0.0	0.0	17%
FL	7,300,494	1%	40,121	1,037,538	0.1	81%	0.0	0.0	0.0	26%
GA	3,574,362	3%	94,034	9,510,842	0.6	58%	0.4	0.1	0.1	17%
ID	589,320	1%	7,830	3,221,854	0.2	29%	0.2	0.0	0.0	5%
IL	4,786,388	3%	133,166	16,535,427	1.0	29%	0.8	0.1	0.1	6%
IN	2,501,937	5%	122,563	13,988,744	0.9	29%	0.7	0.1	0.1	10%
IA	1,236,409	10%	124,174	12,707,346	0.8	23%	0.6	0.1	0.1	9%
KS	1,113,472	6%	64,829	6,117,331	0.4	33%	0.3	0.0	0.0	12%
KY	1,708,499	3%	48,567	7,334,179	0.5	36%	0.4	0.0	0.0	9%
LA	1,727,919	2%	27,139	1,492,748	0.1	69%	0.0	0.0	0.0	28%
ME	553,284	2%	9,609	4,195,331	0.3	26%	0.2	0.0	0.0	4%
MD	2,166,389	2%	36,515	5,841,181	0.4	41%	0.3	0.0	0.1	14%
MA	2,549,721	1%	15,829	7,428,315	0.5	34%	0.4	0.0	0.0	5%
MI	3,841,148	6%	220,757	34,860,402	2.2	23%	1.8	0.2	0.2	7%
MN	2,124,745	8%	163,077	20,257,252	1.3	19%	1.1	0.1	0.1	7%
MS	1,096,593	5%	59,969	5,644,405	0.3	56%	0.3	0.0	0.1	15%
MO	2,364,688	7%	164,528	14,295,202	0.9	36%	0.6	0.2	0.1	10%
MT	409,394	3%	13,488	5,448,744	0.3	27%	0.3	0.0	0.0	5%
NE	736,613	6%	42,921	4,364,513	0.3	26%	0.2	0.0	0.0	10%
NV	1,016,709	2%	21,675	2,031,140	0.1	35%	0.1	0.0	0.0	18%
NH	520,251	3%	15,818	6,103,091	0.4	26%	0.4	0.0	0.0	4%
NJ	3,189,486	1%	23,653	5,215,314	0.3	38%	0.3	0.0	0.0	10%
NM	763,603	7%	49,823	3,918,074	0.2	41%	0.2	0.0	0.0	17%
NY	7,262,279	1%	96,713	25,040,984	1.6	30%	1.4	0.0	0.1	9%
NC	3,775,581	4%	150,464	17,978,626	1.1	48%	0.8	0.1	0.2	17%
ND	299,638	10%	29,594	3,947,067	0.2	19%	0.2	0.0	0.0	7%
OH	4,585,084	4%	164,253	18,495,334	1.1	29%	0.9	0.1	0.1	10%
OK	1,455,321	5%	68,147	6,021,728	0.4	46%	0.3	0.1	0.1	17%
OR	1,533,430	1%	8,027	1,979,839	0.1	58%	0.1	0.0	0.0	12%
PA	4,958,859	2%	74,489	17,542,765	1.1	32%	1.0	0.0	0.1	8%
RI	410,602	1%	2,186	1,058,150	0.1	37%	0.1	0.0	0.0	6%
SC	1,815,094	2%	40,780	3,815,297	0.2	60%	0.2	0.0	0.1	21%
SD	330,858	12%	40,824	3,835,783	0.2	22%	0.2	0.0	0.0	8%
TN	2,504,556	2%	46,823	7,106,574	0.4	41%	0.4	0.0	0.0	10%
TX	9,149,196	2%	201,981	11,524,772	0.7	66%	0.4	0.1	0.2	26%
UT	906,292	1%	5,639	1,704,547	0.1	29%	0.1	0.0	0.0	5%
VT	257,167	3%	8,217	3,787,958	0.2	23%	0.2	0.0	0.0	4%
VA	3,062,783	2%	70,841	10,894,928	0.7	41%	0.5	0.1	0.1	14%
WA	2,668,912	1%	25,463	7,205,529	0.4	67%	0.4	0.0	0.1	14%
WV	740,890	2%	16,864	2,532,572	0.2	33%	0.1	0.0	0.0	9%
WI	2,299,107	8%	172,599	24,611,829	1.5	21%	1.3	0.1	0.1	5%
WY	226,865	3%	6,405	2,519,738	0.2	24%	0.1	0.0	0.0	3%
Total			**3,076,864**	**414,743,294**	**26**	**36%**	**21**	**2**	**3**	**11%**

Electric Resistance

MODELING ASSUMPTIONS FOR ELECTRIC RESISTANCE

- 100% efficiency[xxxii]
- Emission factor depends on eGrid region[66]
- Dec 2021 average retail prices[67]

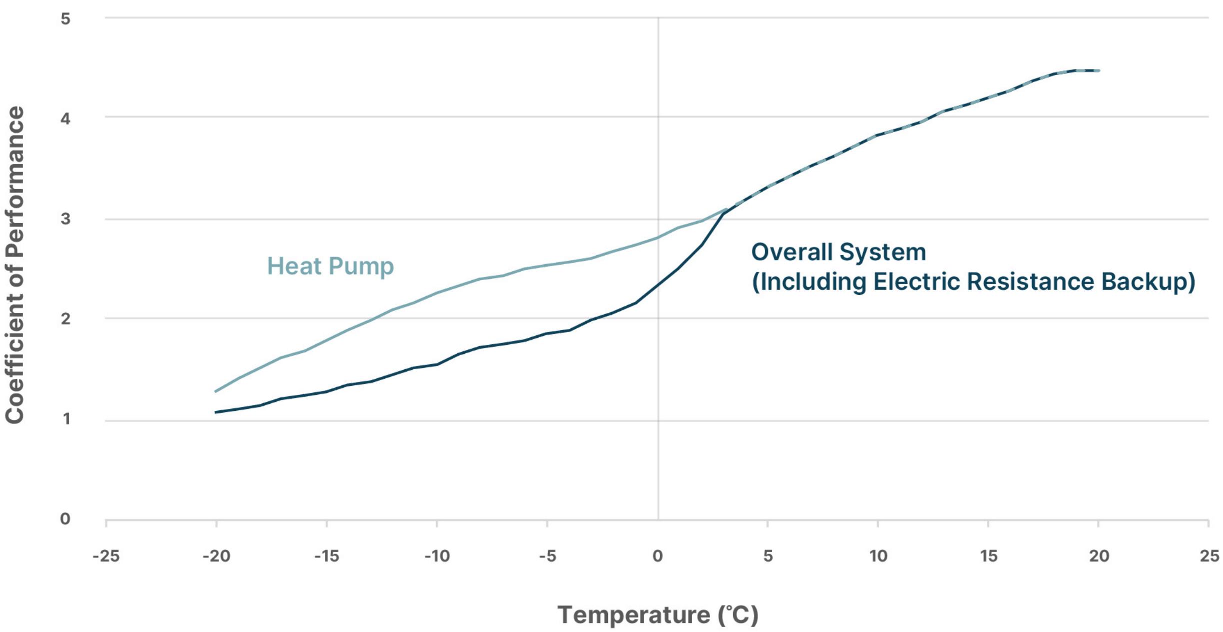
In contrast to other fuels, we did not model a complete switchover to the legacy heating system when the temperature fell below 41 °F/5 °C, as we did for fossil fuel heating. Rather, we assumed that the heat pump would use an integrated electric resistance backup (a.k.a. emergency or strip heater), that supplements the capacity of the heat pump (the amount of heat it provides) as that also falls at lower temperatures.

Below is a graph of the efficiency of the non-cold climate heat pump that we used for modeling, showing its temperature performance. As the heat pump's capacity declines and the electric resistance heat adds, the efficiency of the heat pump declines—that is, the efficiency of the *system* is a combination of the efficiency of the heat pump (still greater than 100%) and the efficiency of the electric resistance (100%). Nonetheless, as can be seen in the graph, the combination is still higher than the 100% efficiency for electric resistance alone, generating significant savings across all realistic temperatures.[xxxiii]

MODELING RESULTS

Replacing one-way ACs with heat pumps in electric resistance households would save consumers $555 in utility bills per household per year, and $9 billion across the nation (55% savings compared to heating with electric resistance alone), while reducing GHG emissions from heating by 29 million metric tons (20% reduction).

The tables that follow first list the household cost impacts and then the statewide GHG impacts of replacing electric resistance heat with hybrid heat pumps.



xxxii. In the 2021 3H and Waite & Modi papers, legacy electric was assumed to be 120% efficient factoring in legacy heat pumps in addition to electric resistance.

xxxiii. Cold-climate heat pumps minimize need for supplemental electric resistance heat by maintaining efficiency and capacity at lower temperatures, further reducing utility bills and CO_2 emissions, but at a higher up-front cost.

State	Number of Households	% with Electric Res. and Central AC	Number of Elec. Res Ready for Hybrid Heat	Electric Rate ($/kWh)	Current Electric Res. Household Heating Annual Bill	Electric Res. Household Heating Annual Bill Under Program (HP + Electric Res. Backup)	Annual Heating Bill Savings ($)	Annual Heating Bill Savings (%)
AL	1,848,325	20%	368,253	$0.10	$811	$299	$511	63%
AZ	1,138,025	31%	348,616	$0.11	$975	$423	$552	57%
AR	2,412,212	25%	614,376	$0.13	$574	$167	$407	71%
CA	12,717,801	6%	735,883	$0.23	$1,212	$446	$766	63%
CO	2,024,468	7%	143,978	$0.14	$1,684	$1,087	$597	35%
CT	1,352,583	1%	10,799	$0.21	$3,222	$1,692	$1,530	47%
DE	273,390	12%	32,457	$0.13	$890	$662	$228	26%
DC	344,022	10%	34,731	$0.13	$1,434	$708	$727	51%
FL	7,300,494	29%	2,113,524	$0.12	$169	$67	$102	61%
GA	3,574,362	17%	594,256	$0.12	$945	$402	$543	57%
ID	1,236,409	10%	119,968	$0.12	$2,106	$863	$1,243	59%
IL	589,320	11%	66,859	$0.10	$2,074	$824	$1,250	60%
IN	4,786,388	5%	240,316	$0.14	$2,446	$1,051	$1,395	57%
IA	2,501,937	9%	234,268	$0.14	$2,362	$947	$1,415	60%
KS	1,113,472	11%	121,013	$0.13	$1,979	$767	$1,211	61%
KY	1,708,499	16%	275,599	$0.12	$1,442	$717	$725	50%
LA	1,727,919	40%	684,426	$0.12	$549	$230	$319	58%
ME	2,549,721	1%	19,225	$0.24	$3,411	$1,892	$1,519	45%
MD	2,166,389	13%	271,807	$0.14	$1,414	$921	$493	35%
MA	553,284	0%	1,415	$0.18	$7,379	$1,538	$5,840	79%
MI	3,841,148	3%	110,304	$0.17	$4,904	$1,445	$3,459	71%
MN	2,124,745	8%	167,806	$0.13	$2,073	$1,138	$935	45%
MS	2,364,688	16%	387,201	$0.11	$1,506	$604	$902	60%
MO	1,096,593	17%	191,242	$0.12	$877	$332	$545	62%
MT	409,394	7%	30,686	$0.11	$2,811	$1,129	$1,681	60%
NE	3,775,581	19%	723,710	$0.11	$929	$532	$397	43%
NV	299,638	19%	55,891	$0.09	$1,440	$938	$502	35%
NH	736,613	13%	97,208	$0.10	$1,733	$705	$1,028	59%
NJ	520,251	0%	2,213	$0.21	$5,019	$1,441	$3,579	71%
NM	3,189,486	1%	41,519	$0.16	$2,668	$1,072	$1,596	60%
NY	763,603	7%	54,381	$0.13	$1,842	$532	$1,310	71%
NC	1,016,709	14%	143,791	$0.12	$1,129	$356	$774	69%
ND	7,262,279	1%	84,145	$0.20	$2,471	$1,354	$1,117	45%
OH	4,585,084	7%	343,411	$0.13	$2,338	$898	$1,440	62%
OK	1,455,321	24%	343,118	$0.11	$1,324	$479	$844	64%
OR	1,533,430	11%	167,065	$0.11	$1,389	$526	$863	62%
PA	4,958,859	2%	117,089	$0.14	$2,430	$1,071	$1,359	56%
RI	410,602	0%	1,997	$0.25	$3,792	$2,132	$1,660	44%
SC	1,815,094	22%	398,343	$0.13	$825	$449	$376	46%
SD	330,858	14%	45,762	$0.12	$1,945	$881	$1,064	55%
TN	2,504,556	19%	475,174	$0.12	$971	$644	$327	34%
TX	9,149,196	38%	3,452,560	$0.13	$557	$270	$287	52%
UT	906,292	4%	34,470	$0.10	$2,407	$578	$1,829	76%
VT	3,062,783	17%	508,522	$0.12	$1,335	$708	$627	47%
VA	257,167	0%	611	$0.20	$8,752	$1,685	$7,067	81%
WA	2,668,912	12%	320,395	$0.10	$1,086	$550	$536	49%
WV	2,299,107	5%	115,378	$0.14	$2,456	$1,123	$1,333	54%
WI	740,890	14%	101,078	$0.12	$2,141	$750	$1,390	65%
WY	226,865	8%	17,491	$0.11	$3,063	$1,199	$1,864	61%
Total			**15,564,329**		**$15,655,060,801**	**$7,019,733,897**	**$8,635,326,904**	
Average					**$1,006**	**$451**	**$555**	**55%**

State	Number of Households	% with Electric Res. and Central AC	Number of Elec. Res Ready for Hybrid Heat	Current Electric Res. Heating Energy Consumption (mmBtu)	Current Electric Res. CO_2 Emissions ($MtCO_2e$)	Effective Electrification (Reduction in Fossil Fuel. Energy Use)	CO_2 Emissions of Unconverted Electric Res. Heating ($MtCO_2e$)	CO_2 Emissions of Heat Pumps ($MtCO_2e$)	GHG Emissions Reductions ($MtCO_2e$)	GHG Emissions Reductions (%)
AL	1,848,325	20%	368,253	32,859,468	4.2	NA	2.9	0.5	0.8	20%
AZ	1,138,025	31%	348,616	16,608,717	1.9	NA	1.3	0.3	0.3	36%
AR	2,412,212	25%	614,376	22,218,715	2.8	NA	1.9	0.3	0.7	30%
CA	12,717,801	6%	735,883	59,326,881	3.6	NA	2.1	0.6	1.0	14%
CO	2,024,468	7%	143,978	17,965,323	3.0	NA	2.2	0.5	0.3	12%
CT	1,352,583	1%	10,799	11,081,809	0.7	NA	0.7	0.0	0.0	2%
DE	273,390	12%	32,457	2,347,463	0.2	NA	0.1	0.1	0.0	8%
DC	344,022	10%	34,731	4,295,409	0.4	NA	0.2	0.1	0.1	16%
FL	7,300,494	29%	2,113,524	31,868,994	3.7	NA	2.2	0.6	0.9	19%
GA	3,574,362	17%	594,256	50,300,012	6.5	NA	3.8	1.1	1.5	18%
ID	1,236,409	10%	119,968	15,662,823	2.3	NA	1.5	0.3	0.5	28%
IL	589,320	11%	66,859	13,436,748	1.3	NA	0.9	0.1	0.2	21%
IN	4,786,388	5%	240,316	44,670,781	7.7	NA	4.8	1.3	1.7	19%
IA	2,501,937	9%	234,268	41,690,644	6.0	NA	3.7	0.9	1.4	20%
KS	1,113,472	11%	121,013	13,512,063	1.9	NA	1.3	0.2	0.4	29%
KY	1,708,499	16%	275,599	35,130,054	4.5	NA	3.1	0.7	0.7	16%
LA	1,727,919	40%	684,426	17,247,453	2.0	NA	1.3	0.3	0.4	37%
ME	2,549,721	1%	19,225	17,919,467	1.2	NA	1.1	0.1	0.1	2%
MD	2,166,389	13%	271,807	29,705,117	3.1	NA	1.9	0.8	0.4	11%
MA	553,284	0%	1,415	3,870,744	0.3	NA	0.2	0.0	0.0	4%
MI	3,841,148	3%	110,304	32,244,008	5.1	NA	3.2	0.6	1.4	23%
MN	2,124,745	8%	167,806	19,463,388	2.9	NA	1.9	0.5	0.4	21%
MS	2,364,688	16%	387,201	39,316,610	7.3	NA	4.9	1.0	1.5	29%
MO	1,096,593	17%	191,242	15,090,178	1.8	NA	1.2	0.2	0.4	20%
MT	409,394	7%	30,686	7,750,942	0.8	NA	0.6	0.1	0.1	20%
NE	3,775,581	19%	723,710	64,779,435	5.9	NA	3.5	1.4	1.0	13%
NV	299,638	19%	55,891	6,161,463	0.9	NA	0.6	0.2	0.1	17%
NH	736,613	13%	97,208	11,803,952	1.7	NA	1.2	0.2	0.3	28%
NJ	520,251	0%	2,213	3,508,681	0.2	NA	0.2	0.0	0.0	4%
NM	3,189,486	1%	41,519	21,598,624	2.0	NA	1.9	0.0	0.1	7%
NY	763,603	7%	54,381	6,101,317	0.8	NA	0.5	0.1	0.2	30%
NC	1,016,709	14%	143,791	10,587,148	1.2	NA	0.8	0.1	0.3	30%
ND	7,262,279	1%	84,145	33,262,749	1.9	NA	1.8	0.0	0.0	5%
OH	4,585,084	7%	343,411	64,604,799	9.2	NA	5.7	1.3	2.2	20%
OK	1,455,321	24%	343,118	22,472,846	3.0	NA	2.1	0.3	0.6	41%
OR	1,533,430	11%	167,065	32,125,363	3.1	NA	1.8	0.5	0.8	14%
PA	4,958,859	2%	117,089	61,765,988	6.3	NA	6.0	0.1	0.2	6%
RI	410,602	0%	1,997	2,002,465	0.1	NA	0.1	0.0	0.0	2%
SC	1,815,094	22%	398,343	27,365,587	2.5	NA	1.5	0.6	0.5	14%
SD	330,858	14%	45,762	5,526,897	0.8	NA	0.6	0.1	0.1	26%
TN	2,504,556	19%	475,174	42,707,953	5.4	NA	3.7	1.1	0.6	11%
TX	9,149,196	38%	3,452,560	81,420,633	9.5	NA	6.5	1.5	1.6	33%
UT	906,292	4%	34,470	8,176,249	0.8	NA	0.6	0.1	0.2	26%
VT	3,062,783	17%	508,522	62,344,340	6.4	NA	3.8	1.4	1.2	15%
VA	257,167	0%	611	1,811,280	0.1	NA	0.1	0.0	0.0	4%
WA	2,668,912	12%	320,395	53,356,006	5.1	NA	2.9	1.1	1.1	11%
WV	2,299,107	5%	115,378	20,489,433	3.5	NA	2.2	0.6	0.7	18%
WI	740,890	14%	101,078	19,921,115	2.8	NA	1.7	0.4	0.8	20%
WY	226,865	8%	17,491	5,045,516	0.6	NA	0.5	0.1	0.1	21%
Total			**15,564,329**	**1,264,523,654**	**149**	**NA**	**97**	**23**	**29**	**20%**

Methane Gas

MODELING ASSUMPTIONS FOR METHANE GAS

- 85% efficient oil boiler or furnace[xxxiv]
- 1038 Btu per cubic foot US average heat content[xxxv, 68]
- 66 kg CO_2e per mmBtu emission factor[xxxvi, 69]
- Dec 2021 average retail prices[70]

MODELING RESULTS

Replacing one-way ACs with heat pumps in a hybrid system with methane gas heat would save consumers $77 in utility bills per household per year, and $2.6 billion across the nation (12% savings), while reducing GHG emissions from heating by 32 million metric tons (14% reduction).

The tables that follow first list the household cost impacts and then the statewide GHG impacts of electrifying methane gas heat with hybrid heat pumps.

xxxiv. Assumption for legacy stock in Steven Nadel, "Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps", ACEEE Report A1803, July 2018, p. 33.

xxxv. Varies by state.

xxxvi. Gas emission factor is listed as 53.06 $kgCO_2$/mmBtu in the EPA source, but this has been increased to 66 to account for methane leakage (per Source 9 in Waite & Modi, 2021), and could be higher still.

State	Number of Households	% with Methane Gas Heating and Central AC	Number of Methane Gas Households Ready for Hybrid Heat	Electric Rate ($/kWh)	Methane Gas Rate ($/mmBtu)	Ratio of Electric to Methane Gas Rates per Site Btu	Current Methane Gas Household Heating Annual Bill	Methane Gas Household Heating Annual Bill Under Program (HP + Methane Gas Backup)	Annual Heating Bill Savings ($)	Annual Heating Bill Savings (%)
AL	1,848,325	18%	330,698	$0.10	$14.83	2	$586	$400	$186	32%
AZ	1,138,025	31%	351,780	$0.11	$16.48	2	$761	$550	$211	28%
AR	2,412,212	23%	563,286	$0.13	$15.08	2	$385	$264	$121	31%
CA	12,717,801	32%	4,059,267	$0.23	$18.07	4	$581	$494	$87	15%
CO	2,024,468	41%	840,058	$0.14	$9.78	4	$788	$774	$14	2%
CT	1,352,583	11%	153,909	$0.21	$15.98	4	$1,386	$1,331	$55	4%
DE	273,390	37%	101,380	$0.13	$13.63	3	$910	$766	$144	16%
DC	344,022	26%	90,918	$0.13	$12.22	3	$750	$658	$92	12%
FL	7,300,494	3%	211,586	$0.12	$21.73	2	$250	$115	$134	54%
GA	3,574,362	26%	932,399	$0.12	$15.31	2	$784	$574	$210	27%
ID	1,236,409	45%	555,902	$0.12	$11.78	3	$810	$745	$65	8%
IL	589,320	30%	175,865	$0.10	$6.69	5	$504	$513	($9)	-2%
IN	4,786,388	55%	2,638,058	$0.14	$11.60	3	$1,002	$946	$56	6%
IA	2,501,937	42%	1,058,049	$0.14	$10.07	4	$766	$748	$18	2%
KS	1,113,472	48%	534,500	$0.13	$11.55	3	$758	$692	$66	9%
KY	1,708,499	24%	406,967	$0.12	$13.60	3	$862	$738	$125	14%
LA	1,727,919	27%	465,082	$0.12	$18.34	2	$543	$304	$239	44%
ME	2,549,721	17%	433,171	$0.24	$17.34	4	$1,458	$1,438	$20	1%
MD	2,166,389	29%	624,154	$0.14	$15.07	3	$1,094	$926	$168	15%
MA	553,284	2%	11,230	$0.18	$16.36	3	$1,087	$1,011	$76	7%
MI	3,841,148	54%	2,058,919	$0.17	$8.61	6	$723	$789	($66)	-9%
MN	2,124,745	48%	1,014,372	$0.13	$10.30	4	$713	$689	$23	3%
MS	2,364,688	37%	875,659	$0.11	$11.99	3	$707	$604	$103	15%
MO	1,096,593	19%	210,500	$0.12	$13.68	3	$554	$424	$130	23%
MT	409,394	32%	130,494	$0.11	$9.20	4	$821	$781	$40	5%
NE	3,775,581	16%	600,283	$0.11	$16.77	2	$959	$701	$258	27%
NV	299,638	30%	88,760	$0.09	$9.15	3	$708	$665	$43	6%
NH	736,613	44%	326,489	$0.10	$10.91	3	$703	$635	$68	10%
NJ	520,251	7%	34,777	$0.21	$19.54	3	$1,235	$1,143	$93	8%
NM	3,189,486	28%	879,108	$0.16	$10.53	4	$833	$844	($12)	-1%
NY	763,603	46%	350,416	$0.13	$13.11	3	$666	$572	$94	14%
NC	1,016,709	42%	428,839	$0.12	$9.41	4	$441	$415	$26	6%
ND	7,262,279	21%	1,527,415	$0.20	$14.18	4	$1,027	$1,004	$23	2%
OH	4,585,084	46%	2,126,015	$0.13	$9.58	4	$725	$704	$21	3%
OK	1,455,321	41%	596,973	$0.11	$12.09	3	$661	$539	$122	18%
OR	1,533,430	19%	288,213	$0.11	$11.26	3	$726	$565	$161	22%
PA	4,958,859	19%	937,946	$0.14	$11.79	4	$911	$858	$54	6%
RI	410,602	18%	72,102	$0.25	$16.24	5	$1,460	$1,489	($29)	-2%
SC	1,815,094	15%	268,466	$0.13	$11.33	3	$546	$475	$72	13%
SD	330,858	34%	113,993	$0.12	$12.00	3	$761	$703	$58	8%
TN	2,504,556	21%	516,805	$0.12	$12.03	3	$780	$664	$116	15%
TX	9,149,196	28%	2,594,379	$0.13	$16.06	2	$552	$376	$176	32%
UT	906,292	49%	447,703	$0.10	$9.71	3	$609	$553	$56	9%
VT	3,062,783	22%	665,628	$0.12	$13.52	3	$944	$777	$167	18%
VA	257,167	6%	14,387	$0.20	$12.75	5	$897	$908	($11)	-1%
WA	2,668,912	17%	458,098	$0.10	$10.36	3	$760	$584	$176	23%
WV	2,299,107	45%	1,045,330	$0.14	$9.12	5	$666	$675	($10)	-1%
WI	740,890	27%	197,825	$0.12	$10.09	3	$678	$630	$48	7%
WY	226,865	35%	78,727	$0.11	$10.70	3	$957	$881	$76	8%
Total			33,486,880				$25,209,291,481	$22,633,664,087	$2,575,627,394	
Average							$753	$676	$77	11%

State	Number of Households	% with Methane Gas Heating and Central AC	Number of Methane Gas Households Ready for Hybrid Heat	Current Methane Gas Heating Energy Consumption (mmBtu)	Current Methane Gas GHG Emissions ($MtCO_2e$)	Effective Electrification (Reduction in Methane Gas Energy Use)	CO_2 Emissions of Backup Methane Gas Heating ($MtCO_2e$)	GHG Emissions of Heat Pumps ($MtCO_2e$)	GHG Emissions Reductions ($MtCO_2e$)	GHG Emissions Reductions (%)
AL	1,848,325	18%	330,698	20,825,488	1.4	57%	0.9	0.2	0.3	20%
AZ	1,138,025	31%	351,780	21,092,604	1.4	50%	0.9	0.2	0.3	23%
AR	2,412,212	23%	563,286	20,898,321	1.4	71%	0.7	0.3	0.4	27%
CA	12,717,801	32%	4,059,267	265,696,801	17.5	89%	9.9	1.6	6.1	35%
CO	2,024,468	41%	840,058	115,885,554	7.6	29%	6.3	0.8	0.5	7%
CT	1,352,583	11%	153,909	39,380,732	2.6	36%	2.3	0.1	0.2	9%
DE	273,390	37%	101,380	10,457,050	0.7	48%	0.5	0.1	0.1	21%
DC	344,022	26%	90,918	8,620,605	0.6	41%	0.4	0.0	0.1	18%
FL	7,300,494	3%	211,586	3,757,993	0.2	85%	0.1	0.1	0.1	33%
GA	3,574,362	26%	932,399	73,794,790	4.9	58%	3.1	0.8	1.0	20%
ID	1,236,409	45%	555,902	53,277,109	3.5	24%	2.9	0.3	0.3	8%
IL	589,320	30%	175,865	22,704,026	1.5	36%	1.2	0.1	0.2	14%
IN	4,786,388	55%	2,638,058	326,827,318	21.6	27%	17.5	2.3	1.8	8%
IA	2,501,937	42%	1,058,049	115,506,927	7.6	29%	6.1	0.8	0.8	10%
KS	1,113,472	48%	534,500	48,858,393	3.2	34%	2.4	0.4	0.4	12%
KY	1,708,499	24%	406,967	41,092,461	2.7	37%	2.1	0.3	0.3	13%
LA	1,727,919	27%	465,082	17,891,046	1.2	76%	0.5	0.3	0.4	35%
ME	2,549,721	17%	433,171	107,446,878	7.1	33%	6.3	0.2	0.6	8%
MD	2,166,389	29%	624,154	70,000,088	4.6	42%	3.4	0.5	0.8	17%
MA	553,284	2%	11,230	2,201,462	0.1	28%	0.1	0.0	0.0	7%
MI	3,841,148	54%	2,058,919	247,915,222	16.4	25%	13.5	1.6	1.3	8%
MN	2,124,745	48%	1,014,372	97,772,979	6.5	20%	5.5	0.5	0.5	7%
MS	2,364,688	37%	875,659	71,986,015	4.8	36%	3.5	0.8	0.4	9%
MO	1,096,593	19%	210,500	13,569,946	0.9	57%	0.6	0.1	0.2	21%
MT	409,394	32%	130,494	19,928,409	1.3	28%	1.1	0.1	0.1	11%
NE	3,775,581	16%	600,283	53,024,285	3.5	49%	2.4	0.4	0.8	22%
NV	299,638	30%	88,760	9,580,976	0.6	20%	0.5	0.0	0.0	7%
NH	736,613	44%	326,489	29,310,011	1.9	26%	1.6	0.2	0.2	9%
NJ	520,251	7%	34,777	6,488,718	0.4	28%	0.4	0.0	0.0	7%
NM	3,189,486	28%	879,108	187,717,788	12.4	40%	10.6	0.6	1.2	10%
NY	763,603	46%	350,416	25,870,371	1.7	43%	1.2	0.2	0.3	16%
NC	1,016,709	42%	428,839	29,179,467	1.9	48%	1.3	0.3	0.4	20%
ND	7,262,279	21%	1,527,415	298,413,941	19.7	36%	17.1	0.6	2.0	10%
OH	4,585,084	46%	2,126,015	230,894,482	15.2	28%	12.2	1.5	1.5	10%
OK	1,455,321	41%	596,973	42,370,087	2.8	46%	1.8	0.5	0.5	19%
OR	1,533,430	19%	288,213	37,859,867	2.5	66%	1.7	0.3	0.5	22%
PA	4,958,859	19%	937,946	195,613,398	12.9	34%	11.3	0.6	1.0	8%
RI	410,602	18%	72,102	19,128,038	1.3	36%	1.1	0.0	0.1	9%
SC	1,815,094	15%	268,466	19,999,163	1.3	59%	0.8	0.2	0.3	26%
SD	330,858	34%	113,993	10,079,862	0.7	22%	0.6	0.1	0.0	7%
TN	2,504,556	21%	516,805	53,358,615	3.5	42%	2.6	0.4	0.5	15%
TX	9,149,196	28%	2,594,379	115,781,522	7.6	66%	3.7	1.6	2.3	30%
UT	906,292	49%	447,703	48,067,181	3.2	32%	2.6	0.2	0.4	12%
VT	3,062,783	22%	665,628	71,830,534	4.7	44%	3.4	0.4	0.9	19%
VA	257,167	6%	14,387	2,987,505	0.2	24%	0.2	0.0	0.0	6%
WA	2,668,912	17%	458,098	68,415,284	4.5	67%	3.0	0.5	1.0	22%
WV	2,299,107	45%	1,045,330	109,428,747	7.2	23%	6.1	0.7	0.5	7%
WI	740,890	27%	197,825	20,533,881	1.4	33%	1.1	0.1	0.1	11%
WY	226,865	35%	78,727	12,060,005	0.8	25%	0.7	0.1	0.1	8%
Total			33,486,880	3,535,381,943	233	36%	180	22	32	14%

End Notes

1. Anderson, M., LeBel, M., & Dupuy, M. (2021, May). Under pressure: Gas utility regulation for a time of transition. Regulatory Assistance Project.
2. Rachel Cluett, Jennifer Amann, Sodavy Ou, "Building Better Energy Efficiency Programs for Low-Income Households", ACEEE Report A1601, March 2016, p. 4.
3. Lazard, Levelized Cost of Energy Analysis, Version 14.0, October 19, 2020, https://www.lazard.com/perspective/lcoe2020.
4. Bloomberg New Energy Finance, "Sustainable Energy in America Factbook", 2021, p. 20, 23. https://bcse.org/wp-content/uploads/2021-Sustainable-Energy-in-America-Factbook.pdf
5. Justin Margolies and Kevin Gries, "The Best of Both Fuels: The Case for Dual Fuel Heating in the Upper Midwest", *ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA, 2020.
6. US Energy Information Administration, "2015 RECS Survey Data: Microdata", accessed April 18, 2022. Sum of total sample weight of homes with "Main space heating fuel" equal to "Electricity" and "Central air conditioner is a heat pump?" equal to "Yes".
7. Air-conditioning, Heating, & Refrigeration Institute (AHRI), "AHRI Releases December 2021 US Heating and Cooling Equipment Shipment Data", February 11, 2022, p. 4.
8. Stephen Pantano, Matt Malinowski, Alexander Gard-Murray, and Nate Adams, "3H 'Hybrid Heat Homes' An Incentive Program to Electrify Space Heating and Reduce Energy Bills in American Homes", CLASP, 2021.
9. AHRI.
10. Electric resistance and legacy, lower-efficiency heat pumps.
11. Energy Information Administration (EIA), "Table CE3.1Annual household site end-use consumption in the US—totals and averages", 2015 Residential End Use Survey.
12. US Department of Energy (DOE), "2015 Residential Buildings Energy End-Use Carbon Dioxide Emissions Splits, by Fuel Type (Million Metric Tons)", Buildings Energy Data Book, accessed May 3, 2022.
13. Previous space heating energy result divided by 2015 totals in EIA, "Table 2.1 Energy Consumption by Sector", *April 2022 Monthly Energy Review*, April 26, 2022.
14. Previous space heating CO_2 result divided by 2015 US CO_2 total in World Resources Institute, "Global Historical Emissions", Climate Watch (CAIT): Country Greenhouse Gas Emissions Data, accessed May 3, 2022.
15. Analysis of Main space heating fuel versus Main space heating equipment type; division between central and mini-split heat pump based on "Central air conditioner is a heat pump" ("Yes" interpreted as Ducted; "Not applicable" interpreted as Mini-split), from EIA, "Microdata", Residential Energy Consumption Survey 2015.
16. US Environmental Protection Agency, "Emission Factors for Greenhouse Gas Inventories", April 1, 2021.
17. "Secretary-General's statement on the IPCC Working Group 1 Report on the Physical Science Basis of the Sixth Assessment," August 9, 2021, https://www.un.org/sg/en/content/secretary-generals-statement-the-ipcc-working-group-1-report-the-physical-science-basis-of-the-sixth-assessment.
18. "IPCC, 2022: Summary for Policymakers" [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, at page 11..This Summary for Policymakers presents key findings of the Working Group IIcontribution to the Sixth Assessment Report of the IPCC Decision IPCC/XLVI-3, The assessment covers scientific literature accepted for publication by 1 September 2021.
19. Id.
20. Theresa Pistochini, Mitchal Dichter, Subhrajit Chakraborty, Nelson Dichter, and Aref Aboud. "Greenhouse gas emission forecasts for

electrification of space heating in residential homes in the US", Energy Policy, Volume 163, April 2022, p. 112813.

21. "What the war in Ukraine means for energy, climate and food," Jeff Tollefson, Nature.com, https://www.nature.com/articles/d41586-022-00969-9.

22. "LNG Project in Canada's East Could Be Sped Up to Supply Europe," Robert Tuttle, March 28, 2022, https://www.bloomberg.com/news/articles/2022-03-28/lng-project-in-canada-s-east-could-be-sped-up-to-supply-europe.

23. "Fact Sheet: United States and European Commission Announce Task Force to Reduce Europe's Dependence on Russian Fossil Fuels," MARCH 25, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/03/25/fact-sheet-united-states-and-european-commission-announce-task-force-to-reduce-europes-dependence-on-russian-fossil-fuels/.

24. EIA, "Natural Gas Weekly Update", Natural Gas, April 27, 2022.

25. EIA, "Heating Oil and Propane Update", Petroleum & Other Liquids, March 30, 2022.

26. Waite, M. and V. Modi (2020a), "Electricity Load Implications of Space Heating Decarbonization Pathways," Joule 4, 376–394, February 19, 2020.

27. US Energy Information Administration, "Short Term Outlook", March 8, 2022.

28. See, for example, Vaidyanathan, S. et. al (2013). "Overcoming Market Barriers and Using Market Forces to Advance Energy Efficiency". American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/publications/researchreports/e136.pdf

29. Shipley, J., Hopkins, A., Takahashi, K., & Farnsworth, D. (2021). Renovating regulation to electrify buildings: A guide for the handy regulator. Regulatory Assistance Project.

30. Berg, W., S. Vaidyanathan, B. Jennings, E. Cooper, C. Perry, M. DiMascio, and J. Singletary. 2020. *The 2020 State Energy Efficiency Scorecard*. Washington, DC: ACEEE. aceee.org/research-report/u2011 (hereinafter, "2020 Scorecard").

31. Gold, R., Gilleo, A., & Berg, W. (2019). Next-generation energy efficiency resource standards (Report U1905).American Council for an Energy-Efficient Economy. https://www.aceee.org/research-report/u1905

32. Molina, M., R. Gold, G. Calcagni, E. Belliveau, and S. Cowell. "Implementing Fuel-Neutral Goals: A Progress Report from Massachusetts and New York." Proceedings of the 2020 ACEEE Summer Study on Energy Efficiency in Buildings. Washington, DC: ACEEE.

33. 2020 Scorecard at page 29.

34. "State Policies and Rules to Enable Beneficial Electrification in Buildings through Fuel Switching," May 2020 https://www.aceee.org/policy-brief/2020/04/state-policies-and-rules-enable-beneficial-electrification-buildings-through.

35. Henner, N. (2020). "Energy Efficiency Program Financing: Size of the Markets". https://www.aceee.org/topic-brief/2020/12/energy-efficiency-program-financing-size-markets

36. National Standards, Appliance Standards Awareness Project, https://appliance-standards.org/national.

37. Federal and State Appliance Efficiency Standards, Northeast Energy Efficiency Partnerships, https://neep.org/smart-efficient-low-carbon-building-energy-solutions/appliance-efficiency-standards.

38. Revised Code of Washington Title 19, Chapter 19.260, Section 19.260.080. The Oregon Department of Energy submitted final rules to the Secretary of State on November 23, 2021 to amend program rules for appliances and other products. https://www.oregon.gov/energy/Get-Involved/Pages/EE-Standards-Rulemaking.aspx#2062.

39. Rule 1121 - Control of Nitrogen Oxides from Residential-Type, Natural Gas-Fired Water Heaters, South Coast Air Quality Management District, https://www.aqmd.gov/home/rules-compliance/rules/support-documents/rule-1121.

40. Renewable Portfolio Standards, NREL, https://www.nrel.gov/state-local-tribal/basics-portfolio-standards.html#:~:text=A%20renewable%20portfolio%20standard%20(RPS,as%20a%20renewable%20electricity%20standard.

41. Richard Cowart and Chris Neme, "The Vermont Clean Heat Standard" (December 2021), a Vermont Energy Action Network whitepaper, found at https://www.eanvt.org/chs-whitepaper/; Vermont General Assembly, H.715 (2022), "An act relating to the Clean Heat Standard" as passed by House and Senate, found at https://legislature.vermont.gov/. As H.715 was vetoed at the end of the 2022

legislative session, the CHS has not yet been enacted in Vermont. However, the bill provides an excellent overview of issues and structural elements for those considering a CHS.

42. Senate Bill 21-264, https://leg.colorado.gov/sites/default/files/2021a_264_signed.pdf.
43. Clean Heat Standard, Energy Action Network, https://www.eanvt.org/events-and-initiatives/clean-heatstandard/.
44. https://gettingtozeroforum.org/policy-resources/
45. New Buildings Institutes, https://newbuildings.org/code_policy/utility-programs-stretch-codes/stretch-codes/. Ambitious examples of code adoption in California, Massachusetts (Green Communities), New York City and Washington, DC.
46. https://www.cnbc.com/2021/11/04/ithaca-is-first-us-city-to-begin-100percent-decarbonization-of-buildings.html
47. https://www.wri.org/research/utilizing-city-utility-partnership-agreements-achieve-climate-and-energy-goals
48. https://www.sciencedirect.com/science/article/abs/pii/S0301421520303554
49. EIA, US Energy Information Administration, "2015 RECS Survey Data: Microdata", accessed April 18, 2022.
50. Ben Schoenbauer, Nicole Kessler, and Marty Kushler, "Cold Climate Air Source Heat Pump", Conservation Applied Research and Development (CARD) FINAL Report for Contract #86417, November 1, 2017, p. 36.
51. Margolies and Gries, p. 6.
52. Schoenbauer et al, p. 44.
53. David Thill, "Vermont gas utility has a new service: helping to electrify your home", Energy News Network, February 7, 2022.
54. Jake Marin, *Interview with Matt Malinowski and David Farnsworth*, January 25, 2022.
55. Mass Save, "Integrated Controls Qualified Product List", accessed May 17, 2022.
56. Goodman Air Conditioning & Heating, "GSZ14 Energy-Efficient Split System Heat Pump Up to 15 SEER & 9.0 HSPF 1½ to 5 Tons", data sheet, 8/20, p. 34.
57. Waite, M. and V. Modi (2020a), "Electricity Load Implications of Space Heating Decarbonization Pathways," Joule 4, 376–394, February 19, 2020.
58. US Census Bureau, "Table B25040 House Heating Fuel", 2015: *ACS 5-Year Estimates Detailed Tables*.
59. US Energy Information Administration, "2015 RECS Survey Data: Microdata", accessed April 18, 2022.
60. US EPA, "GHG Emission Factors", April 1, 2021.
61. Ibid.
62. US EIA, "Weekly Heating Oil and Propane Prices", *Petroleum & Other Liquids*.
63. US EPA, "GHG Emission Factors", April 1, 2021.
64. Ibid.
65. US EIA, "Weekly Heating Oil and Propane Prices", *Petroleum & Other Liquids*.
66. US EPA, "CO_2 total output emission rate (lb/MWh) by eGrid subregion, 2020", *eGrid Data Explorer*.
67. US EIA, "Average Retail Price of Electricity: Residential by State", *Electricity Data Browser*. December 2021.
68. US EIA, "Heat Content of Natural Gas Consumed", *Natural Gas*, data for December 2021, accessed May 18, 2022.
69. US EPA, "Emission Factors for Greenhouse Gas Inventories", April 1, 2021.
70. US EIA, "Natural Gas Prices", *Natural Gas*, data for Dec 2021 or latest month available before that, accessed May 18, 2022.

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