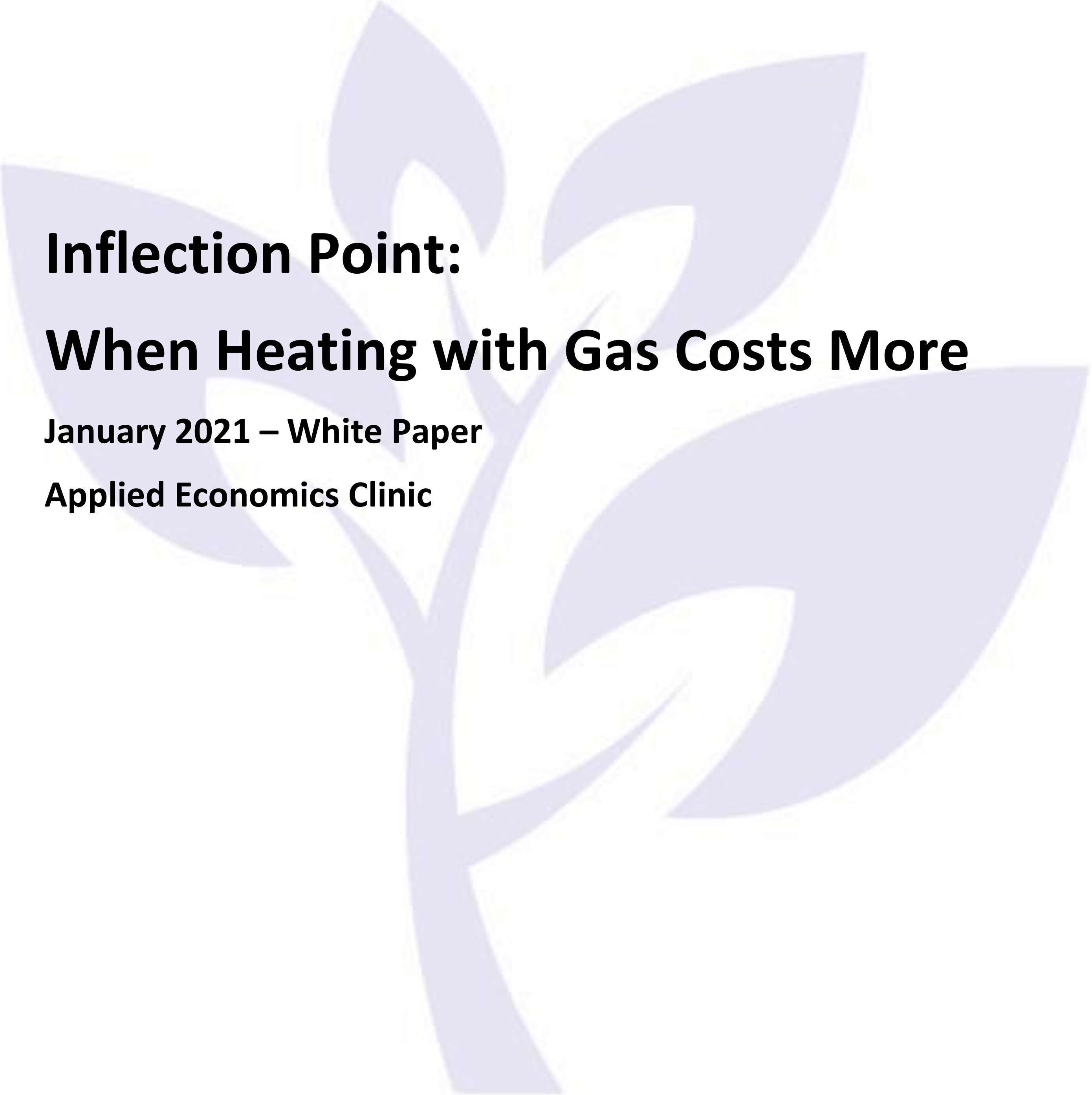

Inflection Point:
When Heating with Gas Costs More

January 2021 – White Paper

Applied Economics Clinic

Prepared for: HEET

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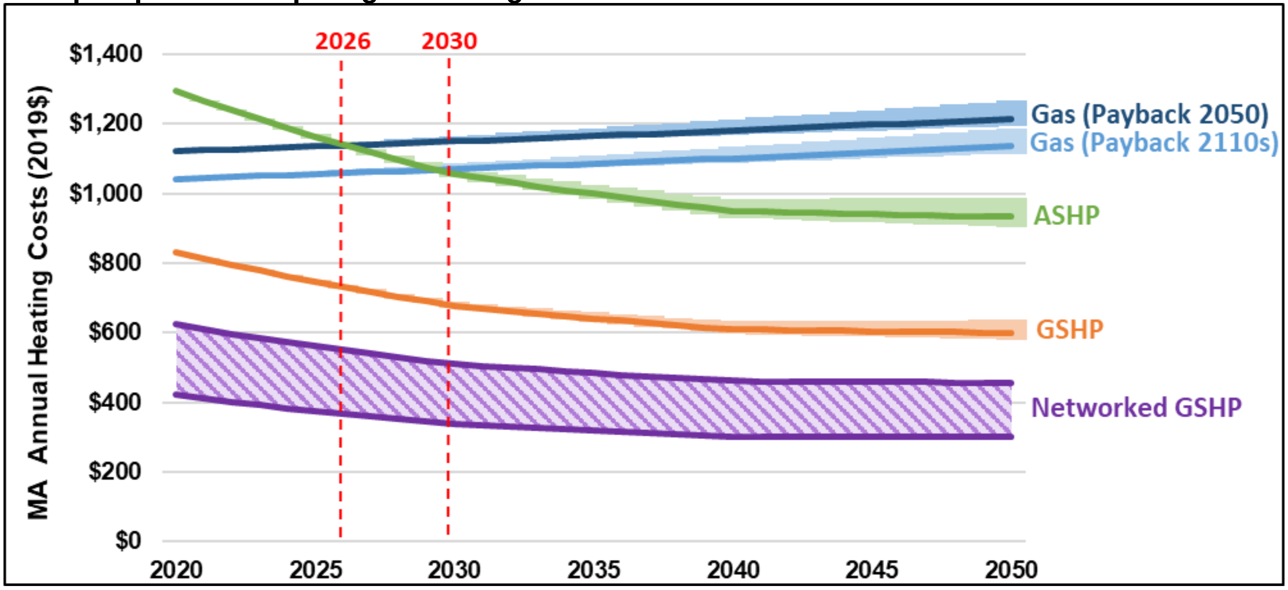
Executive Summary

Roughly half of Massachusetts households (1.4 million households) currently use piped gas to heat their homes. As Massachusetts moves towards its net-zero emissions mandate by 2050, households currently heating with fossil fuels like gas will need to transition to other energy sources with lower greenhouse gas emissions. The economic impact of this transition on Massachusetts households is a key factor for both household decision-making and state policy-making.

This Applied Economics Clinic white paper—prepared on behalf of HEET—compares the annual energy cost of heating the average-sized home in Massachusetts using either a gas furnace or electric heat pumps. This analysis focuses exclusively on a home's annual heating bill as it is the most relevant measure for Massachusetts households. The size of a household's energy bill can determine fuel choice and can be a large burden on families, particularly the low- and moderate-income families that spend a larger share of their income to pay their energy bills.

Today, gas heating bills are less expensive than the electricity needed to run an air-source heat pump (ASHP). Our analysis shows that this relationship will reverse. Heating with ASHPs will become less expensive than heating with gas, with an inflection point occurring at some point between 2026 and 2030 (see Figure ES-1). The time of the inflection point depends on how much is added to monthly gas bills to pay off current efforts to replace the Commonwealth's leaking pipelines.

Figure ES-1. Inflection points for an average-sized Massachusetts home: When do electric heat pumps out-compete gas heating?



Unlike ASHPs, ground-source heat pumps (GSHP) are already less expensive than heating with gas. Our analysis shows the expense of heating with GSHPs will continue to decrease over time and includes the newer networked type of GSHPs as this technology is predicted to lower heating bills for households even more.

Electrification—switching from burning fossil fuels to using electricity—is an essential strategy to achieve the Commonwealth's 2050 climate goals. This white paper finds that the electric heat pumps needed for this electrification will outcompete gas heating, in terms of annual heating bills, within the next decade. They are already the least expensive way to cool a home. Yet the necessary widespread modernization of home heating (and cooling) with heat pumps is obstructed by physical, economic, and informational barriers, including high upfront costs.

The following policy options can help meet state emissions mandates, while making clean energy and lower heating bills accessible to all:

- **Incentives for heat pump purchase.** These incentives need to be large enough to ensure that fewer households are negatively impacted by a rising cost of heating with gas. Heat pump adoption in the Commonwealth will lead to growing emission reduction benefits as the grid becomes more renewable each year, as mandated by state law.
- **Subsidies for low-income and rental housing heating and insulation upgrades.** Installing heat pumps in rental housing—and low- and moderate-income housing more generally—may require state subsidies that cover the entire cost of equipment and installation. In addition, for the Commonwealth to achieve net-zero greenhouse gas emissions by 2050, every household will need to improve their home's insulation through building shell upgrades. Inclusion of electric capacity and wiring upgrades may be necessary as there are substantial building infrastructure barriers in Massachusetts' housing stock. For many families, such retrofits will require an outside funding source.
- **Education and outreach to increase information availability and access.** Homeowners, renters, landlords, real estate agents, heating technicians and general contractors need more and better information regarding the many benefits of heat pumps, including inexpensive cooling, technological improvements, and the long-term economic impacts of heating with gas versus heat pumps. Additional benefits of heat pumps, not related to energy bills, include improved air quality and very low-cost cooling. These benefits add value not discussed in this analysis.

These types of state policies can encourage widespread heat pump adoption, including among renters and low- and moderate-income households, by making accurate information on the economic impacts of different heating systems more accessible to the public and by stepping in to shift these economics where and when necessary. Since gas furnaces have an average lifespan of 15 to 30 years, without such deliberate and intentional action, many households will buy gas heating systems now and end up paying rising energy costs over that lifespan.

Table of Contents

I. Introduction

As Massachusetts makes the changes needed to achieve net-zero emissions by 2050,[1] households will need affordable heating and cooling solutions with low or no greenhouse gas emissions. This Applied Economics Clinic white paper explores the costs of several home heating options for an average-sized home. While the cost of heating with piped gas rises over time, the cost to heat with a modern electric heat pump falls well below that of all other heating technologies in every future scenario. And there is a lot of room for Massachusetts heat pump ownership to grow: Heat pumps accounted for only 0.8 percent of all residential heating systems in Massachusetts in 2019.

AEC compared the cost to customers heating with a gas furnace in Massachusetts to those heating with old-fashioned electric baseboard heaters and modern electric heat pumps. This analysis focuses exclusively on energy bills, the cost measure that is most relevant to renters and many low- and moderate-income households. We do not include the costs of purchasing and installing a new heating system, a once-in-15-to-30-years investment for most homeowners.[2]

Nationally, the vast majority of low- and moderate-income households, minority households, and renting households pay more for their energy (as a share of their income) than the average household.[3] A recent American Council for an Energy-Efficient Economy (ACEEE) report notes that in Boston, the median low-income household spends about 10 percent of its income on energy, compared to the median household's spending of 3 percent.[4]

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[1] The Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs. April 22, 2020. "Determination of Statewide Emissions Limit for 2050". Available at: https://www.mass.gov/doc/final-signed-letter-of-determination-for-2050-emissions-limit/download

[2] (1) Consumer Reports. November 21, 2019. "Gas Furnace Buying Guide." Available at: https://www.consumerreports.org/cro/gas-furnaces/buying-guide/index.htm; (2) Griffith Energy Service, Inc. January 27, 2017. "The Average Age for Gas Furnaces." Available at: https://www.griffithenergyservices.com/articles/furnace-30-years-old-long-gas-furnaces-last; (3) Valley Service. May 19, 2020. "How long does a furnace last? - Average Lifespan Expectancy." Available at: https://valleyservice.net/blogs/how-long-does-a-furnace-last#:~:text=Average%20Furnace%20Lifespan,-Wondering%20what%20the&text=Although%20some%20furnaces%20can%20last,easily%20last%20over%2015%20years.

[3] American Council for an Energy-Efficient Economy (ACEEE). September 2020. "How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burdens across the U.S." Available at: https://www.aceee.org/research-report/u2006 p. 3.

[4] Ibid. p. 44.

Energy bills are especially relevant for the 38 percent of Massachusetts' households who rent their homes[5] and to homeowners (and landlords) who purchased their heating system recently (with many years of operational "life" left in it). Without significant assistance from the state, these types of heating customers will be stuck using the heating system that they already have. This white paper investigates whether a gas or electric heating system offers the lowest energy bill costs over the next three decades, with the goal of informing policy decisions regarding what types of heating systems should be subsidized.

Comparing heating fuels

We compare the cost of heating an average-sized household with a gas furnace or an electric heat pump. In our analysis we ask: In what year do electric heat pumps become the most economic choice? That's the inflection point.

Comparison of costs across different heating fuels can be complicated: Gas use is measured in therms; heating oil in barrels; electric use in kilowatt-hours. Regardless of the heating fuel, however, a particular building's needs the same amount of heat, which can be measured in "British thermal units (Btus)". (Technically, a Btu is the quantity of heat required to raise the temperature of one pound of water by 1 degree Fahrenheit.) In New England, an average-sized home requires 59 million Btus of heat each year. (A detailed explanation of Btus is provided in Appendix A: Measuring Energy Use in "Btu".)

This white paper estimates how much it would cost to heat an average-sized home in Massachusetts using different heating fuel options, and how those utility bill costs are expected to change in the future. Today, comparatively high electric prices in Massachusetts mean that, for the average-sized home, gas heating bills are lower than the cost of electricity needed to run a heat pump. In the future, this will change: Electric heat pumps will have lower utility bills than gas heating alternatives. Our analysis shows that electric heat pumps become the most economic heating option in 2030 (or sooner, if necessary gas-system pipe replacements are fully accounted for in customers' gas bills).

Section II addresses the state's current heating profile, electric heating options, and growth in heat pump adoption. Section III offers a brief overview of how this analysis was constructed. Section IV provides a detailed look at cost variation among heating options and identifies the least-cost option for customers. Section V discusses barriers to home electrification, and Section VI presents an overview of networked heat pump systems and their potential for lower customer costs. Section VII discusses potential policy options to promote heat pump adoption in Massachusetts and beyond.

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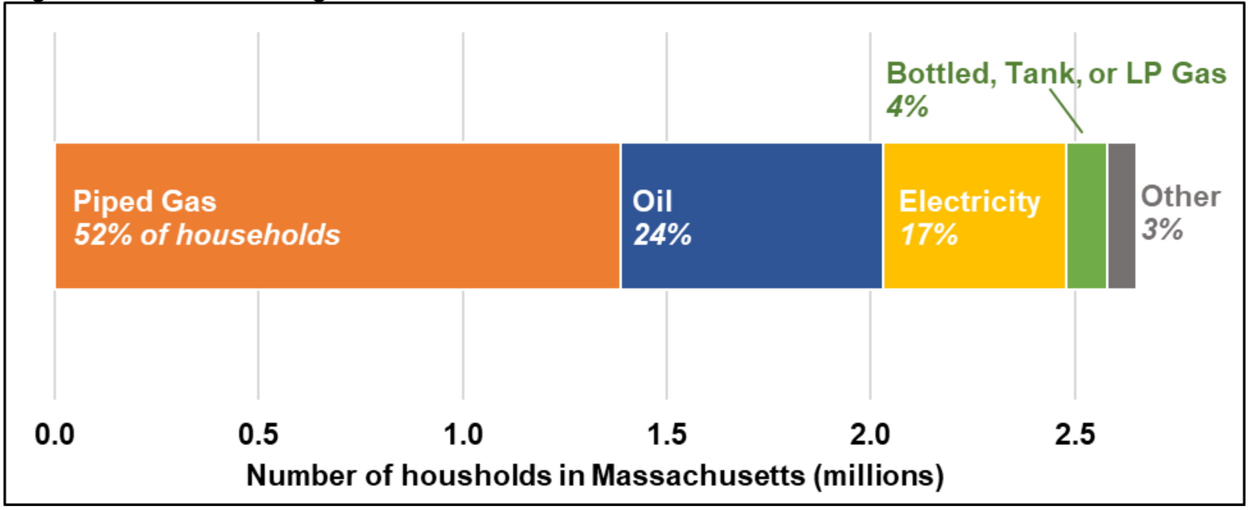
[5] U.S. Census Bureau. 2019. American Community Survey 1-Year Estimates [Table]. Demographic Characteristics for Occupied Housing Units (Table ID: S2502). Available at: https://data.census.gov/cedsci/table?q=renter&g=0400000US25&tid=ACSST1Y2019.S2502&hidePreview=true

II. Massachusetts Heating

Massachusetts has a relatively cold climate with average January temperatures around 26 degrees Fahrenheit. (The contiguous United States averages 33 degrees Fahrenheit in January).[6] With such cold winters, the Commonwealth requires a lot of space heating, which makes up the largest portion of energy use in homes (59 percent),[7] and households in Massachusetts spend 22 percent more on their energy bills than the U.S. average.[8]

Today, about half of Massachusetts households (52 percent or 1.4 million) use gas as the primary fuel to heat their homes (see Figure 1). Another 650,000 households use oil; 450,000 use electricity (mostly old-fashioned baseboard heating); and the remaining 170,000 rely on propane or other fuel sources such as wood.[9]

Figure 1. Home heating fuels used in Massachusetts households in 2019



Data source: U.S. Census Bureau. 2019. American Community Survey 1-Year Estimates [Table]. House Heating Fuel (Table ID: B25040). Available at: https://data.census.gov/cedsci/table?q=heating%20fuels&g=0100000US_0400000US25&tid=ACSDT1Y2019.B25040&hidePreview=true

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[6] NOAA National Centers for Environmental information, *Climate at a Glance*. Available at: https://www.ncdc.noaa.gov/cag/

[7] Commonwealth of Massachusetts. “Mass. Home Heating Profile Background.” Available at: https://www.mass.gov/service-details/mass-home-heating-profile-background

[8] Commonwealth of Massachusetts. “Mass. Home Heating Profile Background.” Available at: https://www.mass.gov/service-details/mass-home-heating-profile-background

[9] U.S. Census Bureau. 2018. American Community Survey 5-Year Estimates [Table]. House Heating Fuel (Table ID: B25040). Available at: https://data.census.gov/cedsci/table?q=heating%20fuels&g=0400000US25_0100000US&tid=ACSDT5Y2018.B25040&hidePreview=true

The main heating technologies used in Massachusetts are gas and oil furnaces or boilers, old-fashioned electric resistance heating, and modern electric air-source and ground-source heat pumps. (We exclude heating oil from our cost analysis because it is already more expensive to heat with oil than with gas or electric heat pumps.[10]) Both electric resistance and heat pumps utilize electricity to provide heat, but in different ways.

Electric heating technologies currently used in Massachusetts

Electric Resistance (efficiency 90%):[11] Electric resistance heaters create heat by passing electricity through wires, which shed some energy as heat. Electric baseboards are typically zoned heaters controlled by thermostats in each room.[12] These systems lose 10 percent of the electricity used: only 90 percent becomes heat (90% efficiency).

Air-source heat pumps (ASHP) (efficiency 300%): ASHPs heat and cool a building by using electricity to pump heat either inside or outside the building.[13] Temperature control comes from tweaking the difference between the outside and inside temperature—not from the electricity itself. In this way, ASHPs generate three units of heating energy for every one unit of electric energy used to run them (300% efficiency).

Ground-source heat pumps (GSHP) (efficiency 450%): GSHPs rely on the consistent underground temperature maintained just below the ground surface or in a body of water. Like other heat pumps, GSHPs operate by transferring heat either into or out of a building. GSHPs generate four and a half units of heating energy for every one unit of electric energy used to run them (450% efficiency).

Networked GSHPs (efficiency 600-800%): Interconnecting GSHPs in multiple buildings throughout a neighborhood using an underground shared loop of ambient-temperature water can further improve the efficiency of this technology. A networked GSHP system allows for excess energy not needed by one building to be moved to networked buildings that do need that energy. Networked GSHPs generate 6 to 8 units of heating energy for every one unit of electric energy used to run them (600-800% efficiency).

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[10] Commonwealth of Massachusetts. “Household Heating Costs.” Available at: https://www.mass.gov/info-details/household-heating-costs

[11] M.J. Bradley & Associates, LLC. 2019. *Life Cycle Analysis of the Northeast Supply Enhancement Project*. Available at: https://www.mjbradley.com/sites/default/files/MJBA_NESE_LCA_06112019.pdf

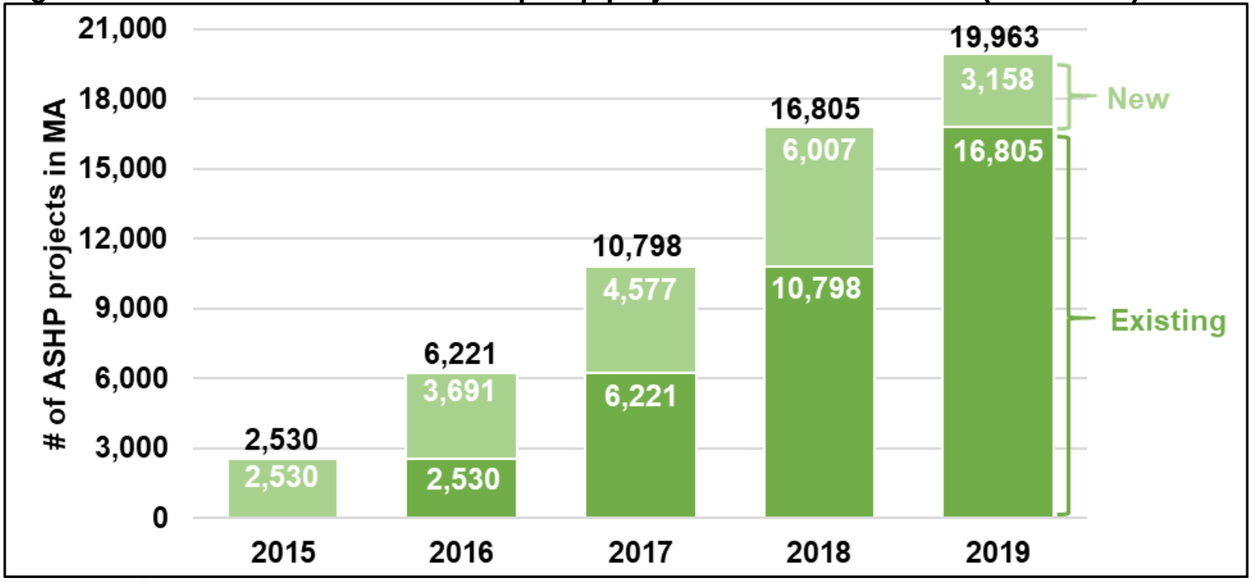
[12] U.S. Department of Energy (DOE). n.d. “Electric Resistance Heating.” Available at: https://www.energy.gov/energysaver/home-heating-systems/electric-resistance-heating

[13] Commonwealth of Massachusetts. “Air and Ground Source Heat Pumps.” Available at: https://www.mass.gov/service-details/air-and-ground-source-heat-pumps

Increasing popularity of heat pumps

From 2014 to 2019, the Massachusetts Clean Energy Center (MassCEC) offered rebates to promote residential ASHP installations. In mid-2019, this rebate program was replaced by the Whole-Home Air-Source Heat Pump pilot program.[14] MassCEC has also offered rebates to support residential and other small-scale GSHP installations since 2015. Between 2015 and 2019, ASHP installations increased by 68 percent per year on average (see Figure 2) while GSHP installations increased by 53 percent per year (see Figure 3).[15,16] This rapid growth has brought total installed heat pumps to a minimum of 20,427 (the number of heat pumps installed before 2015 is unknown, but likely small). But even with this accelerating rate of growth, heat pumps only accounted for 0.8 percent of all residential heating systems in Massachusetts in 2019. There is a lot of room for Massachusetts heat pump ownership to grow, and state incentives—to date—have not provided the stimulus needed to achieve widespread adoption.

Figure 2. Residential air-source heat pump projects in Massachusetts (2015-2019)



Data source: MassCEC. 2020. Residential and Small-Scale Air-Source Heat Pumps Database. Available at: https://www.masscec.com/heat-pumps/

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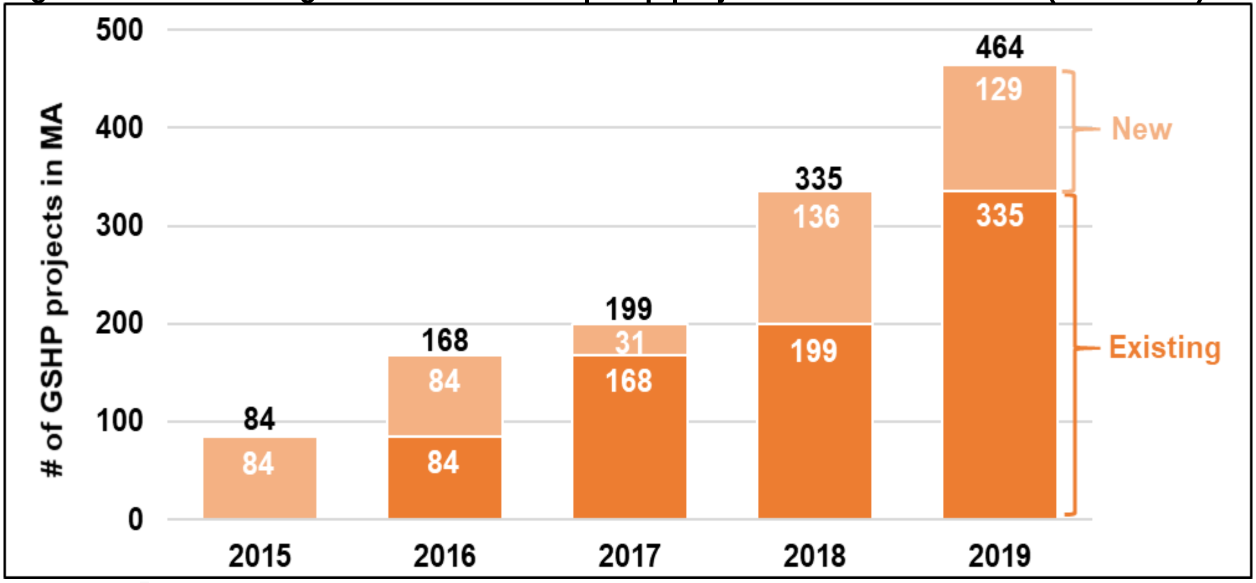
[14] MassCEC. "Air-Source Heat Pumps." Available at: https://www.masscec.com/air-source-heat-pumps-1

[15] MassCEC. 2020. Residential and Small-Scale Air-Source Heat Pumps Database. Available at: https://www.masscec.com/heat-pumps/

[16] MassCEC. 2020. Residential and Small-Scale Ground-Source Heat Pumps Database. Available at: https://www.masscec.com/ground-source-heat-pumps

Figure 3. Residential ground-source heat pump projects in Massachusetts (2015-2019)



Data source: MassCEC. 2020. Residential and Small-Scale Ground-Source Heat Pumps Database. Available at: https://www.masscec.com/ground-source-heat-pumps

III.Estimating Future Gas Bills

AEC compared the energy bill costs to customers of various residential heating options in Massachusetts and found important differences both between fuels and over time. We do not include the capital costs of purchasing and installing a new heating system in this analysis. (For a discussion of the complete customer costs of home heating see AEC's 2019 report entitled *Home Heat Pumps in Massachusetts*.)

Factoring in the cost of the upgrades to the gas distribution system

Massachusetts' leak-prone gas distribution system requires extensive repairs and infrastructure upgrades to improve safety. The current gas pipe replacement plan—to replace a quarter of all pipes in the state—is paid for by customers through an on-bill Gas System Enhancement Adjustment Factor (GSEAF) charge that amounts to about $49 per year for an average-sized home. As we explain in detail in our December 2020 policy brief, *Fixing Massachusetts' Leaky Pipes: When Will It Be Paid Off?*, at the current GSEAF rate, it would take until the 2110s to fully pay back these pipe replacement expenditures. However, these pipes will no longer be in use after Massachusetts reaches its net-zero greenhouse gas emissions target in 2050. To pay these costs off completely by 2050 (and avoid "stranded assets") would require that the GSEAF charge be increased from $49 to $128 per year for the average-sized home.

Factoring in the cost of the upgrades to the electric distribution system

Our analysis includes forecasts of future gas and electric prices for Massachusetts, and other normal elements of customer bills. (We present estimates for a range of future energy prices: Low, Reference, and High.) We do not, however, include any extraordinary upgrade charges for the electric distribution system in that way that we include GSEAF charges. The gas system's GSEAF charges are meant to correct a distribution system that is aging and riddled with leaks. While the Commonwealth's electric system needs normal annual maintenance and upgrades, we are not aware of any evidence of a need for widespread replacement of poles and wires in Massachusetts. For this reason, there is no parallel customer charge for electric system upgrades in our analysis.

Factoring in future energy costs and efficiencies

According to performance projections released by the National Renewable Energy Laboratory (NREL), air-source heat pump efficiency is expected to grow from an average of 300 percent in 2020 to between 440 and 530 percent by 2050, depending on the scenario of technological growth.[17] Our model accounts for these technological advancements by applying the trend of NREL's performance projections to the efficiency of air-source and ground-source heat pumps (see Appendix C: Sensitivity Analyses for a comparison of our results under different technological growth scenarios). Gas furnaces (currently 95% efficient) are not expected to increase in efficiency since they are already at their theoretical peak.

IV. Which Heating Option Will Cost the Least in the Future?

Figure 4 compares the costs of electric resistance heating, ASHPs, GSHPs, and the two scenarios for gas heating costs: *Gas* (*Payback 2110s)*, which uses the current GSEAF rate, and *Gas* (*Payback 2050)*, in which GSEAF is increased to pay off gas pipe replacement by 2050. By 2050, Massachusetts must achieve net zero emissions[18], rendering gas heating and its related infrastructure obsolete.

Throughout our 2020 to 2050 analysis period, GSHPs have the lowest energy bills and electric resistance heating has, by far, the highest. ASHPs bills are slightly more expensive than gas heating today (a difference of $260 per year for an average home). By the mid-2020s to early 2030s, however, ASHPs become less expensive than gas heating. Heat pumps also provide efficient, lower-cost air conditioning in the summer: an important source of potential savings not included in this heating-focused analysis.

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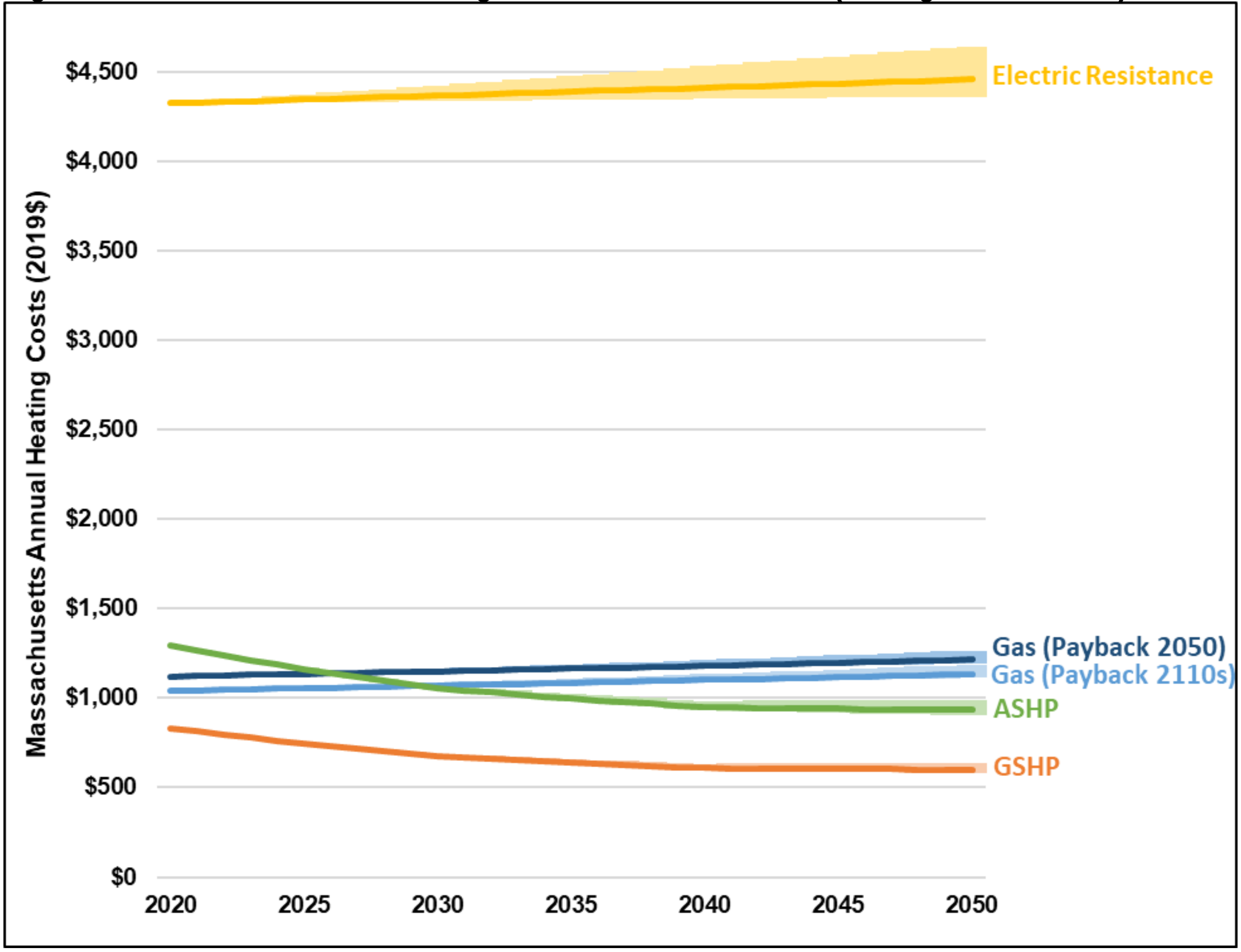
[17] Jadun, P. et al. 2017. Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70485. Available at: https://www.nrel.gov/docs/fy18osti/70485.pdf.

[18] The Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs. April 22, 2020. "Determination of Statewide Emissions Limit for 2050". Available at: https://www.mass.gov/doc/final-signed-letter-of-determination-for-2050-emissions-limit/download

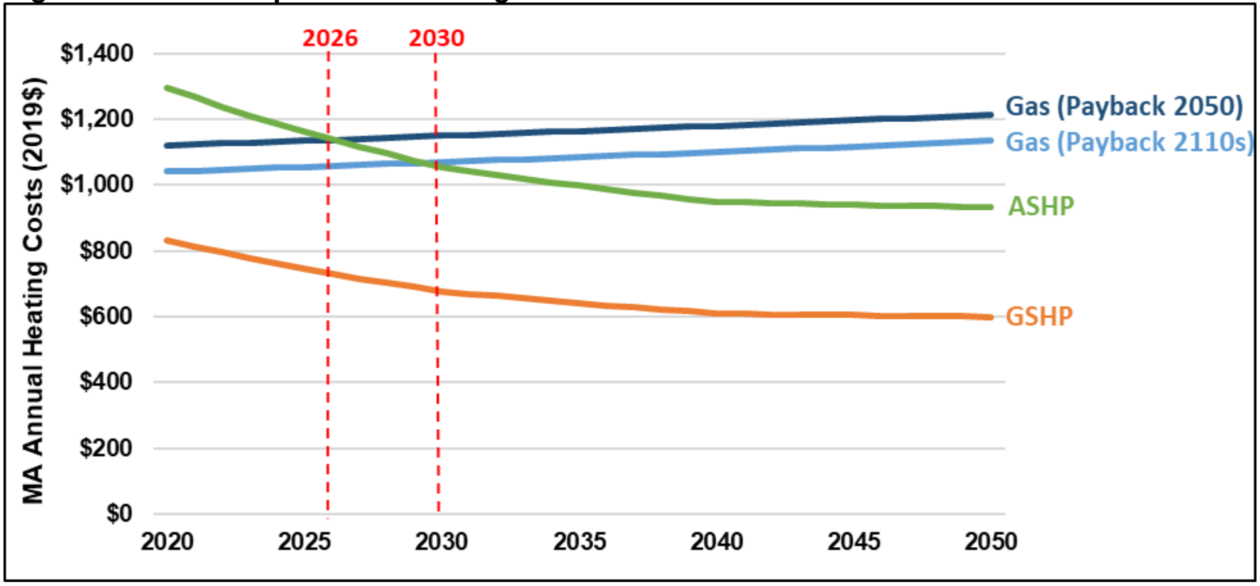
Figure 4. Annual residential heating costs in Massachusetts (average-sized home)



Note: The solid line represents the Reference Case for gas and electricity price projections. The shaded areas represent the uncertainty associated with forecasted energy prices. In this figure, the upper and lower limits of the shaded areas represent High and Low Case gas and electricity prices. See Appendix B: Methodology and Assumptions.

ASHPs will be cheaper to operate than gas heating by 2026 for the Gas (*Payback 2050*) scenario and by 2030 for the Gas (*Payback 2110s*) scenario (see Figure 5).

Figure 5. Inflection points for average-sized home



Annual heating costs differ depending (among other things) on the size of the home. In our analysis, we assumed an "average-sized" home of about 1,900 square feet. Table 1 presents analysis heating costs for two other home-sizes: a small apartment (750 square feet) and a large home (5,000 square feet).

Table 1. Annual heating costs by home size

Home Size	Heating Technologies	Annual Heating Costs (2019$)			
		2020	2025	2030	2035
Small Apartment (750 sq ft)	Gas (Payback 2110s)	$420	$430	$430	$440
	Gas (Payback 2050)	$460	$460	$470	$470
	ASHP	$520	$470	$430	$400
	GSHP	$340	$300	$270	$260
	Electric Resistance	$1,740	$1,750	$1,760	$1,770
Average Home (1,900 sq ft)	Gas (Payback 2110s)	$1,040	$1,060	$1,070	$1,090
	Gas (Payback 2050)	$1,130	$1,140	$1,160	$1,170
	ASHP	$1,300	$1,160	$1,060	$1,000
	GSHP	$830	$750	$680	$640
	Electric Resistance	$4,320	$4,340	$4,370	$4,390
Large Home (5,000 sq ft)	Gas (Payback 2110s)	$2,800	$2,840	$2,880	$2,920
	Gas (Payback 2050)	$3,030	$3,070	$3,110	$3,150
	ASHP	$3,480	$3,120	$2,840	$2,680
	GSHP	$2,240	$2,000	$1,820	$1,720
	Electric Resistance	$11,610	$11,670	$11,730	$11,790

Even though small homes have lower energy bills, families with lower incomes pay more for energy as a share of their income. Research from ACEEE found that the median Boston household pays just over 3 percent of its income in energy bills, while the median low-income family pays 10 percent, and a quarter of low-income households pay closer to 19 percent.[19]

Appendix C: Sensitivity Analyses reviews several additional uncertainties in these main findings, including:

- Less optimistic efficiency improvements for heat pumps, which delay ASHPs surpassing gas in cost effectiveness by one year;
- Biogas as a replacement for fossil-based "natural" gas in piped distribution systems. Biogas is costly and improves heat pumps' cost advantage over gas; and
- Networked geothermal heating systems (discussed in detail in Section VI), which outcompete even GSHPs.

V. Barriers to Heat Pump Installations

Physical, economic, and informational barriers all play a role in preventing or delaying the installation of residential heat pumps in Massachusetts (see Table 2). Low- and moderate-income households (defined as those with income at or below 80 percent of regional median income) are disproportionately affected by these obstacles because high upfront costs (to purchase and install the heat pump equipment) and unequal access to credit (to obtain low to no-interest loans) pose a greater burden to families with less income and savings.

Table 2. Potential barriers for heat pump installations

Barriers	Descriptions
Physical	Obstacles that hinder the retrofit of existing heating systems, such as: • substandard electrical systems, • incompatible infrastructure, and • limited workforce capacity.
Economic	Financial restraints that impede widespread adoption of heat pumps, particularly for low- and moderate-income households, such as: • high upfront costs, and • limited access to credit.
Informational	The perceptions of available heating options can limit heat pump installs due to: • inadequate information/misinformation, • status quo bias, and • slow stock turnover.

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[19] American Council for an Energy-Efficient Economy (ACEEE). September 2020. "How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burdens across the U.S." Available at: https://www.aceee.org/research-report/u2006 pp. 44-47

Physical barriers, such as substandard wiring or incompatible infrastructure, make it difficult to retrofit existing heating systems. In 2019, the National Resources Defense Council found that the retrofitting process needed for existing heating systems to meet heat pump requirements varies based on site-specific concerns like the building's age, heating requirements, and existing heat distribution and electric wiring systems[20] that need to be addressed prior to retrofitting—especially when introducing heat pump systems to mixed-use buildings.[21] In addition, a lack of trained technicians can impede the growth of heat pump installations. In 2020, Efficiency Maine Trust found that in some parts of New England, it is not unusual to wait several months for a heat pump consultation because the local workforce is unable to keep up with demand, particularly in summer and fall months.[22]

Economic barriers impede the widespread adoption of heat pumps, especially for low- and moderate-income households. Efficiency Maine Trust found that even with financial assistance from state rebate programs or grant awards, heat pump installations are often prohibitively expensive for many low-income customers due to high upfront costs and imperfect access to credit.[23] Loans can help cover the upfront costs of heat pump purchase and installation, since payments can be spread out over a longer period of time. However, many loan options are not available to customers with poor or no credit—a significant barrier for low- and moderate-income families. These economic barriers disproportionately affect low- and moderate-income customers who already spend a larger share of their income on energy than customers with higher incomes. See Figure 6 for median energy burdens throughout different regions in the United States. The median energy burden for the low-income families in New England is the highest in the United States by over 1 percentage point.[24] The potential energy savings from a new heat pump system could play and important role in lowering this burden.[25]

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[20] Steven Winter Associates. April 2019. *Heat Pump Retrofit Strategies for Multifamily Buildings. Natural Resources Defense Council*. Available at: https://www.nrdc.org/sites/default/files/heat-pump-retrofit-strategies-report-05082019.pdf. p. 2

[21] Ibid. p. 23

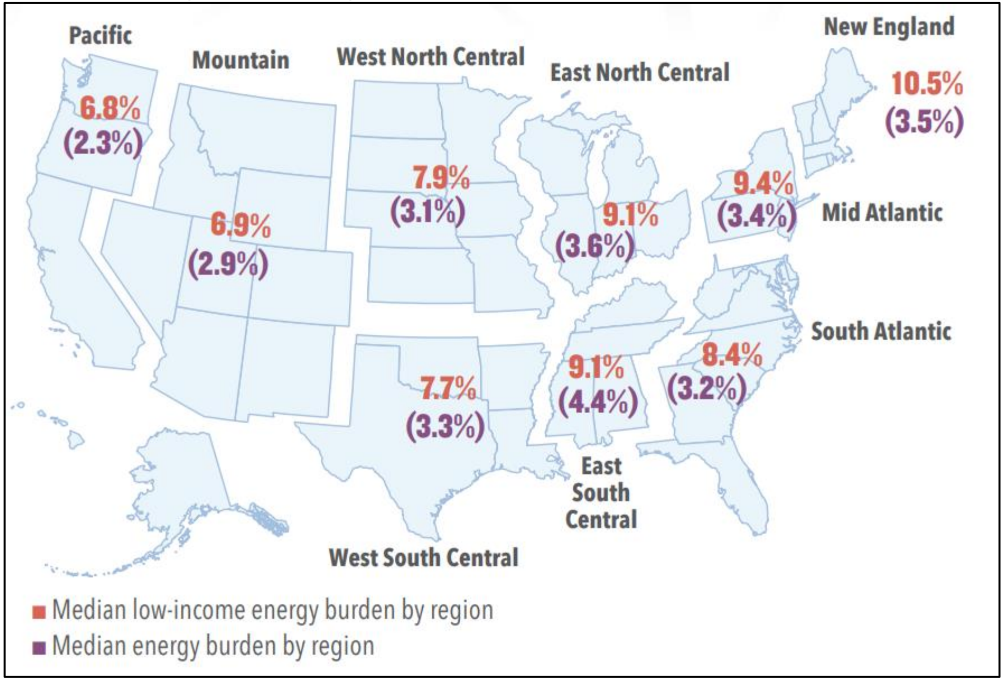
[22] Ibid. p. 35

[23] The Efficiency Maine Trust. January 31, 2020. *Beneficial Electrification: Barriers and Opportunities in Maine*. Available at: https://www.efficiencymaine.com/docs/EMT_Beneficial-Electrification-Study_2020_1_31.pdf p. 25

[24] American Council for an Energy-Efficient Economy (ACEEE). September 2020. "How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burdens across the U.S." Available at: https://www.aceee.org/research-report/u2006 p. 14

[25] The Efficiency Maine Trust. January 31, 2020. *Beneficial Electrification: Barriers and Opportunities in Maine*. Available at: https://www.efficiencymaine.com/docs/EMT_Beneficial-Electrification-Study_2020_1_31.pdf p. 31

Figure 6. Median low-income energy burdens (red) compared to median energy burdens (purple) in regions throughout the United States



Reproduced from: American Council for an Energy-Efficient Economy (ACEEE). September 2020. "How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burdens across the U.S." Available at: https://www.aceee.org/research-report/u2006. p. 14

A lack of certain kinds of information—as well as an abundance of misinformation—are also obstacles for heat pump adoption. Potential customers may be unaware of the latest heat pump technology advancements including extremely high efficiency and technologies that allow for operation in colder climates, causing them to pass over heat pumps as a viable heating option.[26] Recent analysis conducted at Columbia University's Center on Global Energy Policy found that "status quo bias" and "stock turnover" also add to the prevention or delay of residential heat pump installations.[27] Status quo bias refers to the likelihood that consumers will keep their existing equipment or decide to purchase the same equipment in the future. Stock turnover is a similar obstacle that impacts heat pump deployment. Slow stock turnover occurs when gas- and oil-fired heating systems are built to last for decades and are not replaced before the end of their physically useful lives.[28] Since most heating systems are replaced only after failure, homeowners are left with little time to purchase a replacement and forced to select the most readily available or highly recommended system. Due to status quo bias, these replacement systems will likely be the same technology as the existing equipment.

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[26] Ibid. p. 34

[27] Kaufman, N. et al. December 2019. "Decarbonizing Space Heating with Air Source Heat Pumps." Columbia University Center on Global Energy Policy. Available at: https://energypolicy.columbia.edu/sites/default/files/file-uploads/HeatPump-CGEP_Report_010220.pdf. p. 15-16.

[28] Ibid.

Widespread heat pump adoption faces challenges from physical, economic, and informational barriers, especially for low- to moderate-income households. Even as heat pumps are becoming more and more competitive with gas heating, these obstacles continue to place heat pumps just out of reach for many of the households that would benefit the most from a transition away from gas.

VI. Networked Ground Source Heat Pump (GSHP) Technology[29]

An individual GSHP installed in a single building is one of the most efficient ways of providing heating and cooling (able to provide an average of 4.5 units of energy for 1 unit of energy used). A GSHP system pumps water through boreholes, allowing the water to absorb the temperature of the ground. The heat pump in the building then extracts from the water the heating or cooling needed. GSHPs achieve higher efficiencies than ASHPs because the temperature of the ground, unlike the air, stays year-round in the 50s, an optimum temperature for heat pump efficiency.

That efficiency can be improved on by interconnecting GSHPs in multiple buildings throughout a neighborhood using an underground shared loop of ambient-temperature water (see Figure 7). This networked GSHP system (also known as networked geothermal or a GeoMicroDistrict[30]), allows for excess energy rejected by one building to be moved to other buildings in the network that need that energy. If not needed now, the energy can be stored in the ground until needed, even across seasons.

There are a few dozen networked geothermal systems in the world, including a few systems in the United States.[31,32] Networked GSHP systems can achieve the highest energy efficiency in neighborhoods with heating and cooling use that is equal, or balanced, annually.[33] The most efficient systems combine decentralized thermal energy sources (such as boreholes) with central energy management, including centralized pumping.

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[29] Acknowledgement: Section VI. research contribution by Ajinkya S. Kamat, Ph.D, Home Energy Efficiency Team.

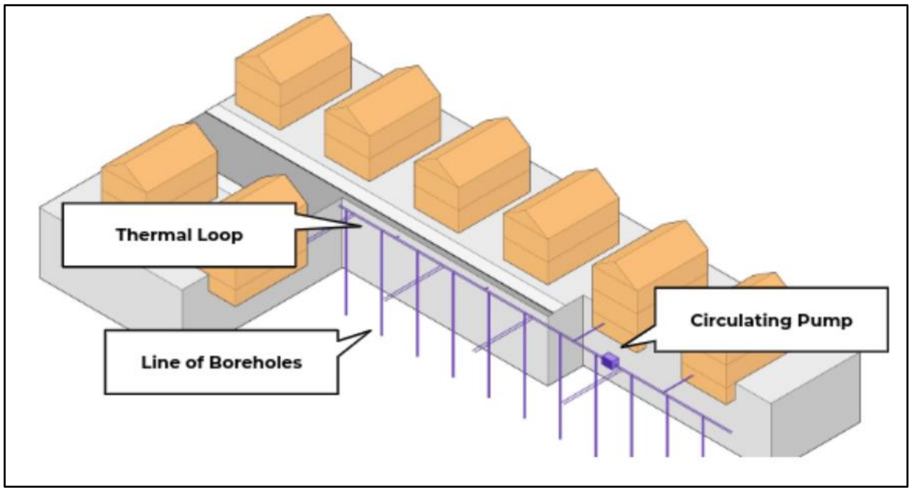
[30] BuroHappold Engineering. 2019. *GeoMicroDistrict Feasibility Study*. Prepared for HEET. Available at: https://heetma.org/energy-shift/geomicrodistrict-feasibility-study/.

[31] Ibid.

[32] The GreyEdge Group designed, built, and currently operate the networked GSHP system at Colorado Mesa University.

[33] BuroHappold Engineering. 2019. *GeoMicroDistrict Feasibility Study.* Prepared for HEET. Available at: https://heetma.org/energy-shift/geomicrodistrict-feasibility-study/.

Figure 7. Illustration of an example networked GSHP system



Reproduced from: HEET. "The GeoMicroDistrict." Available at: https://heetma.org/geomicrodistrict/

A “GeoMicroDistrict” is a scalable configuration of such a system. Each GeoMicroDistrict is a networked geothermal system serving a single street segment. Multiple GeoMicroDistricts can be interconnected, thus increasing the diversity of loads and in turn providing greater energy efficiency and resilience. Such expansion can create a “GeoGrid” built to the scale of a city.

The largest gas utility companies in Massachusetts are moving forward with pilot networked GSHP systems.[34] If installed by the gas utilities, the cost of this infrastructure could be spread across all customers and paid back over decades. As Massachusetts works to achieve net zero emissions by 2050[35], the opportunity to build and maintain networked GSHP systems in utilities’ existing gas rights of way in the street could provide a fossil-free business evolution for these companies while lowering heating bills.[36]

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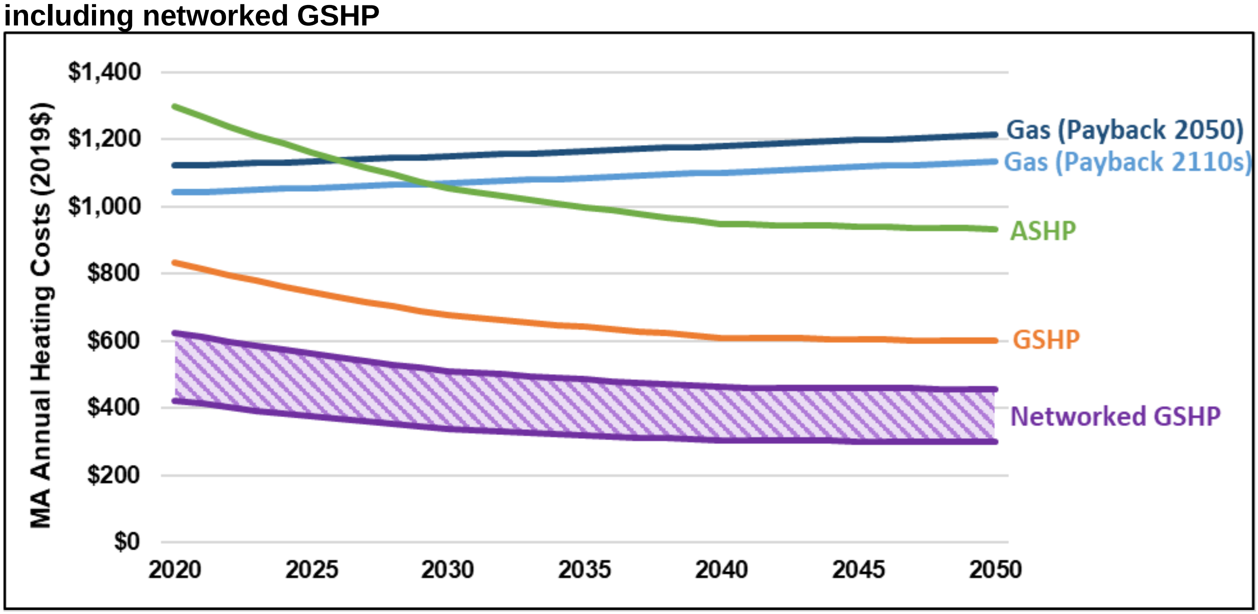
[34] Massachusetts Department of Public Utilities (MA DPU). 2020. D.P.U. 20-59/D.P.U. 19-140/D.P.U. 19-141. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12751142.

[35] The Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs. April 22, 2020. “Determination of Statewide Emissions Limit for 2050”. Available at: https://www.mass.gov/doc/final-signed-letter-of-determination-for-2050-emissions-limit/download.

[36] BuroHappold Engineering. 2019. *GeoMicroDistrict Feasibility Study.* Prepared for HEET. Available at: https://heetma.org/energy-shift/geomicrodistrict-feasibility-study/.

Figure 8 shows a projection of operational costs of networked geothermal systems for Massachusetts in comparison with other technologies discussed in Section III of this paper. We forecast the operational costs of a GeoMicroDistrict system in Massachusetts using the most comparable systems' efficiency estimates available for the U.S. context. Installations at Colorado Mesa University and Weber State University inform an efficiency estimate of 600 percent and up to 800 percent for networked GSHP systems with very high waste energy recovery.[37] Due to their greater efficiency, networked GSHPs are by far the least expensive heating option for customers, costing just $420-$620 per year for an average-sized home.

Figure 8. Annual residential heating costs in Massachusetts (average-sized home) including networked GSHP



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[37] Based on personal communication with The GreyEdge Group. The installations this estimate is based on are composed of arrays of boreholes and GSHPs serving individual buildings, interconnected through a shared ambient-temperature water loop with centralized pumping. It is of note that a comparison between a single ASHP or GSHP efficiency and a system efficiency of networked GSHPs is not exactly comparable given different boundaries for energy in and energy out.

VII. Policy Recommendations

GSHPs are already less expensive (in terms of customer energy bills) than gas. By 2030 (or sooner if gas system repairs are fully accounted for in gas bills). ASHPs will also be less expensive than heating with gas. Heat pumps run on electricity, and Massachusetts' electric supply grows cleaner every year due to state renewable energy mandates. The typical gas heating system operates for 15 to 30 years, meaning that a system installed today may last until 2050, affecting the Commonwealth's greenhouse gas emissions for decades to come. The installation of any heating system is a big, costly, long-term commitment. Careful, proactive policy design is needed to make the clean energy transition affordable for every household. In contrast, heat pump incentive policies that disproportionately benefit wealthier families cannot succeed in bringing low emissions heating into every home in the Commonwealth.

Heat pumps have lower greenhouse gas emissions than gas heating and, soon, both types of heat pumps (ASHPs and GSHPs) will outcompete gas in terms of annual energy costs. Our 2019 report on the economics of lifetime heat pumps costs (including equipment purchase, installation, and use in air conditioning) found that the least expensive heating choice for consumers depends on the design of state subsidies for heating system purchases.[38] When gas system purchases are subsidized (as they currently are in Massachusetts), gas heating equipment and operation (together) cost less over the lifetime of the system than electric heat pumps. However, if those subsidies were instead awarded to heat pumps, then heat pumps would have lower lifetime costs than gas. The Commonwealth's heating system subsidies are the determining factor for customers comparing costs and making decisions regarding which heating fuel to choose today to heat their home for the next 15 to 30 years.

Without state intervention, residents living in buildings with a heating system that still has years of operational "life" left, will be stuck with the heating system they have. For the vast majority of households, these heating systems are gas-fired and will become increasingly uneconomic to operate every year. States have the opportunity to affect consumer choices by making accurate information on the economic impacts of different heating systems more accessible to the public and by providing subsidies, especially to low- and middle-class families.

In order to decarbonize heating for Massachusetts households, state policy possibilities include:

- **Incentives for heat pump purchase.** These incentives need to be large enough to ensure that fewer households are negatively impacted by a rising cost of heating with gas. Heat pump adoption in the Commonwealth will lead to growing emission reduction benefits as the grid becomes more renewable each year, as mandated by state law.

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[38] Lopez, R., T. Comings, E.A. Stanton, and E. Tavares. 2019. Home Heat Pumps in Massachusetts. Applied Economics Clinic. Prepared for Green Energy Consumers Alliance. Available at: https://aeclinic.org/publicationpages/2019/5/29/home-heat-pumps-in-massachusetts

- **Subsidies for low-income and rental housing heating and insulation upgrades.** Installing heat pumps in rental housing—and low- and moderate-income housing more generally—may require state subsidies that cover the entire cost of equipment and installation. In addition, for the Commonwealth to achieve net-zero greenhouse gas emissions by 2050, every household will need to improve their home's insulation through building shell upgrades. Inclusion of electric capacity and wiring upgrades may be necessary as there are substantial building infrastructure barriers in Massachusetts' housing stock. For many families, such retrofits will require an outside funding source.
- **Education and outreach to increase information availability and access.** Homeowners, renters, landlords, real estate agents, heating technicians and general contractors need more and better information regarding the many benefits of heat pumps, including inexpensive cooling, technological improvements, and the long-term economic impacts of heating with gas versus heat pumps. Additional benefits of heat pumps, not related to energy bills, include improved air quality and very low-cost cooling. These benefits add value not discussed in this analysis.

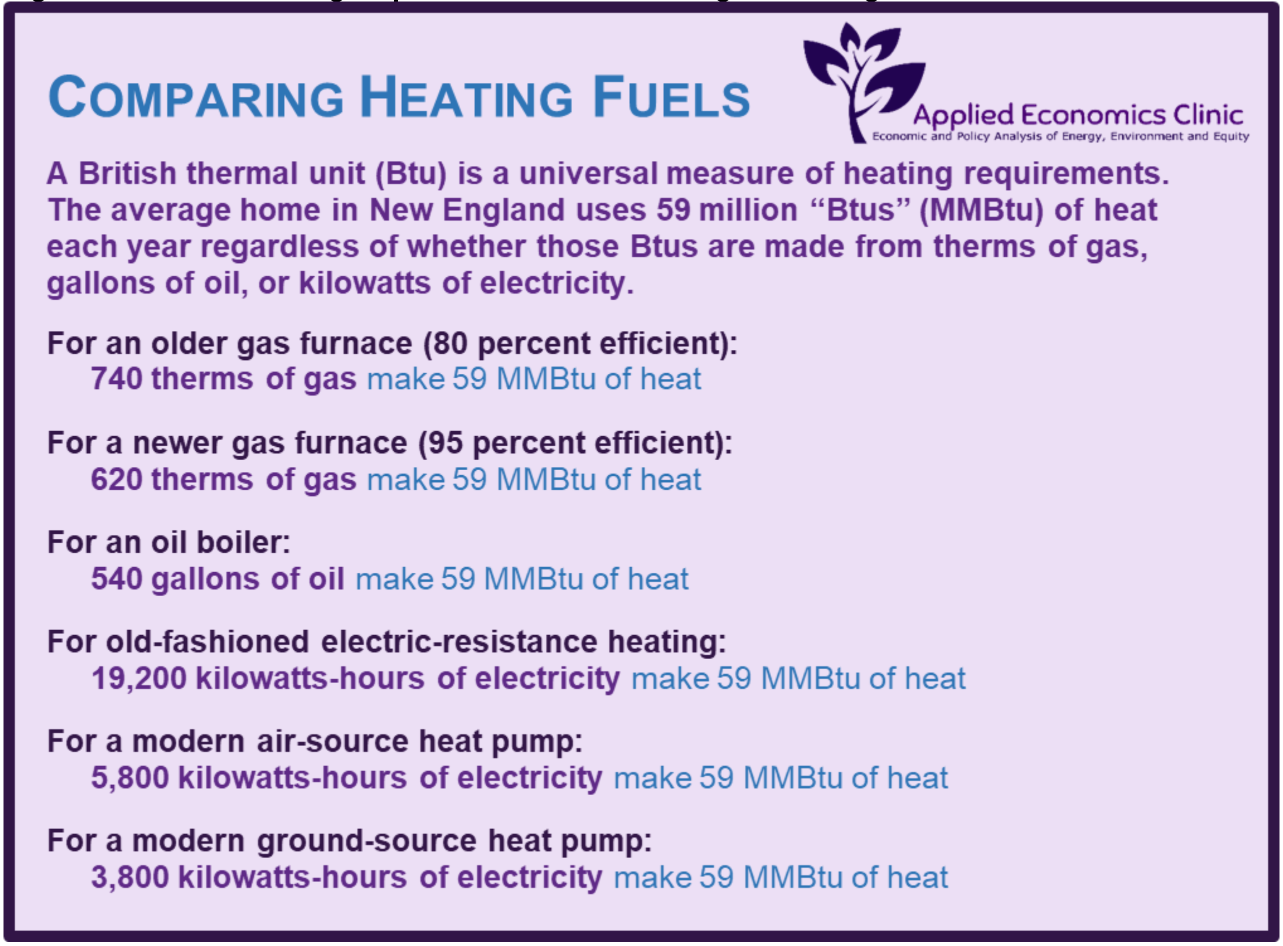
This white paper demonstrates benefits to both the Commonwealth and to consumers of a more rapid shift to heating with heat pumps. Given the lifespan of heating equipment and the time needed for the market and workforce to expand, it is critical to design policies and provide incentives well ahead of the predicted inflection point. Such action can benefit all, helping the state meet its emissions mandate and helping households lower their energy bills.

Appendix A: Measuring Energy Use in "Btu"

Energy used for heating is often measured in the physical units in which it is delivered to homes and businesses (e.g., therms of gas, gallons of oil, kilowatt-hours of electricity)—a practice that makes it difficult to directly compare how much energy is used by different kinds of heating systems. The British thermal unit (Btu) serves as a universal measure of heating requirements (i.e., how much "heat" is needed to warm a building), allowing easy comparison across various fuel options. (Technically, a Btu is the quantity of heat required to raise the temperature of one pound of water by 1 degree Fahrenheit.) In New England, an average-sized home requires 59 million Btus (abbreviated "MMBtu") of heat each year, regardless of the energy source that produces the heat.

Energy consumption varies widely among heating technologies: a new gas furnace requires 620 therms of gas to make 59 MMBtu of heat, while electric baseboards or space heaters require 19,200 kilowatt-hours (kWh) of electricity (see Figure 9). Note that some of these therms and kilowatt-hours are used to make Btus of actual heat, while some energy is lost to inefficiencies and leaks.

Figure 9. Annual heating requirements for an average New England home



COMPARING HEATING FUELS

Applied Economics Clinic
Economic and Policy Analysis of Energy, Environment and Equity

A British thermal unit (Btu) is a universal measure of heating requirements. The average home in New England uses 59 million "Btus" (MMBtu) of heat each year regardless of whether those Btus are made from therms of gas, gallons of oil, or kilowatts of electricity.

For an older gas furnace (80 percent efficient):
740 therms of gas make 59 MMBtu of heat

For a newer gas furnace (95 percent efficient):
620 therms of gas make 59 MMBtu of heat

For an oil boiler:
540 gallons of oil make 59 MMBtu of heat

For old-fashioned electric-resistance heating:
19,200 kilowatts-hours of electricity make 59 MMBtu of heat

For a modern air-source heat pump:
5,800 kilowatts-hours of electricity make 59 MMBtu of heat

For a modern ground-source heat pump:
3,800 kilowatts-hours of electricity make 59 MMBtu of heat

Measuring heating requirements in Btus also makes it possible to see differences in efficiency among electric heating options. Compared to the 19,200 kWh of electricity required by electric resistance to provide 59 MMBtu of heat, air-source and ground-source heat pumps only require 5,800 and 3,800 kWh of electricity, respectively. Electric resistance heating is 90 percent efficient (that is, 10 percent of energy is lost), while heat pumps are 300 to 450 percent efficient—they create more heating energy than is directly supplied by electricity. Perfect efficiency—without any loss—would be 100 percent efficient. By drawing energy from ambient temperature differences in the ground or air, heat pumps yield three to four times (300 to 450 percent) more energy than what is contained in the electricity used to run them (see Table 3).

Table 3. Heating requirements and conversions by technology type

	a	*b*	*c*	*d*
Heating Technology	**Energy Consumed**	**Efficiency (%)**	**Unit Conversion**	**Heating Requirement (MMBtu)** $d = (a * b) / c$
Gas Furnace (Old)	740 therms	80%	10 therms per MMBtu	59 MMBtu
Gas Furnace (New)	620 therms	95%	10 therms per MMBtu	59 MMBtu
Oil Boiler	540 gallons	80%	7 gallons per MMBtu	59 MMBtu
Electric Resistance	19,200 kWh	90%	293 kWh per MMBtu	59 MMBtu
Air-Source Heat Pump	5,800 kWh	300%	293 kWh per MMBtu	59 MMBtu
Ground-Source Heat Pump	3,800 kWh	450%	293 kWh per MMBtu	59 MMBtu

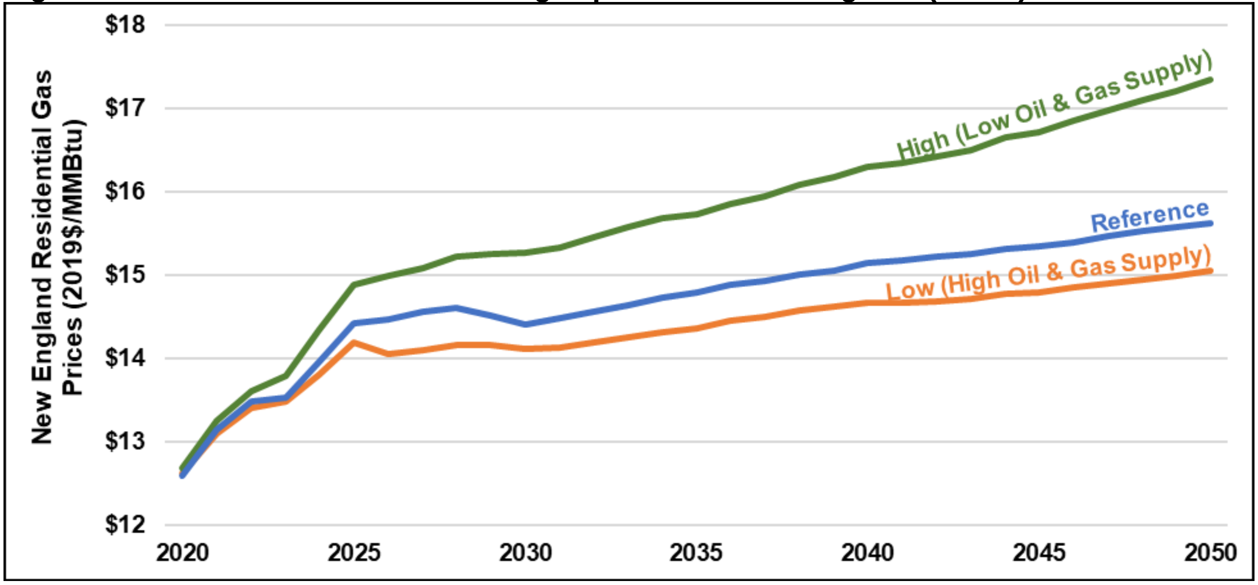
Appendix B: Methodology and Assumptions

To determine the associated utility bills, or cost to customers, for various residential heating options in Massachusetts, AEC compared heating costs on a $ per MMBtu basis (which were then scaled up to the annual heating costs for an average-sized home with a heating requirement of 59 MMBtu). The cost to customers includes all fixed and variable costs that residential customers would pay on their monthly gas or electric bill. The baseline year for this analysis is 2020.

Gas and Electric Prices

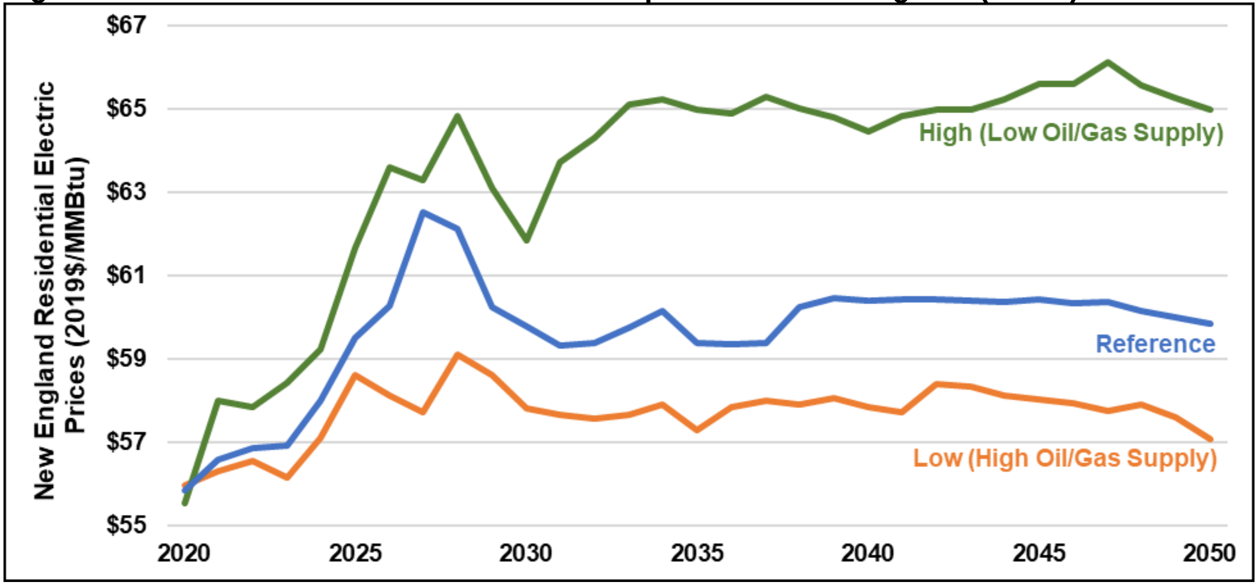
Annual growth rates in residential gas and electric prices are calculated using price forecasts from the U.S. Energy Information Administration's (U.S. EIA) *2020 Annual Energy Outlook (*AEO) for the Reference, High ("low oil and gas supply"), and Low ("high oil and gas supply") cases (see Figure 10 and Figure 11).

Figure 10. AEO forecasted residential gas prices for New England (2019$)



Reproduced from: U.S. EIA. 2020. Annual Energy Outlook 2020 [Table 3. Energy Prices by Sector and Source]. Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2020&region=1-1&cases=ref2020~highogs~lowogs&start=2018&end=2050&f=A&linechart=&map=highogs-d112619a.3-3-AEO2020.1-1&sourcekey=0

Figure 11. AEO forecasted residential electric prices for New England (2019$)



Reproduced from: U.S. EIA. 2020. Annual Energy Outlook 2020 [Table 3. Energy Prices by Sector and Source]. Available at: *https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2020&region=1-1&cases=ref2020~highogs~lowogs&start=2018&end=2050&f=A&linechart=&map=highogs-d112619a.3-3-AEO2020.1-1&sourcekey=0*

Table 4 reports the annual growth rate in residential gas and electric prices for each price forecast scenario.

Table 4. Average Annual growth rates for AEO price forecasts

2020 Annual Energy Outlook	Case/Scenario	Annual Growth Rate (2020-2050)
New England Residential Gas Price	Reference Case	0.7%
	Low Case (High Oil & Gas Supply)	0.6%
	High Case (Low Oil & Gas Supply)	1.1%
New England Residential Electricity Price	Reference Case	0.2%
	Low Case (High Oil & Gas Supply)	0.1%
	High Case (Low Oil & Gas Supply)	0.5%

Gas Rates

Gas rates for 2020 are based on the most recent service and delivery rates for each Massachusetts' gas utility and include the following charges and adjustment factors:[39]

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[39] Charges and adjustment factors are sourced from utility-specific documentation. See Appendix D: Utility-specific resources for gas and electric rates for a full list of utility-specific resources.

- Fixed Monthly Customer Charge (converted from a fixed monthly charge to an inferred $ per therm charge by dividing the equivalent annual customer charge by the U.S. EIA's 2018 annual residential gas sales[40] in therms for each utility)
- Distribution Charge ($ per therm)
- Revenue Decoupling Adjustment Factor (RDAF, $ per therm)
- Local Distribution Adjustment Factor (LDAF, $ per therm)
- Gas System Enhancement Adjustment Factor (GSEAF, $ per therm)
- Gas Adjustment Factor (GAF, $ per therm)

Using the appropriate efficiency rate for a new gas furnace (95 percent)[41] and the U.S. EIA's conversion factor (10 therms per MMBtu)[42], these utility-specific gas charges and adjustment factors were then converted from $ per therm to the more universal measure of $ per MMBtu.

The cost of electricity used in residential gas furnace operations was also included in total customer charges. This cost was calculated by multiplying by the U.S. EIA's typical electric consumption for a gas furnace (322 kWh per year) by the weighted average[43] of variable residential electric charges ($0.21 per kWh) and then dividing that product by the U.S. EIA's 2018 annual residential gas sales in MMBtu for each utility.

In Massachusetts gas rates, the GSEAF is the charge on a customer's monthly bill used to recover the costs associated with leak-prone gas infrastructure replacement under the Gas System Enhancement Program (GSEP). In this analysis, we considered two gas rate scenarios to evaluate various GSEP cost recovery mechanisms:

- **Gas (Payback 2110s):** GSEAF values are equal to those reported in the 2020 GSEP filings, adjusted for inflation. This scenario results in the complete recovery of costs for replacing leak-prone infrastructure by the 2110s.

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[40] U.S. EIA. 2018. *EIA Natural Gas Annual Respondent Query System*. Available at: https://www.eia.gov/naturalgas/ngqs/#?year1=2018&year2=2018&company=Name

[41] M.J. Bradley & Associates, LLC. 2019. *Life Cycle Analysis of the Northeast Supply Enhancement Project*. Available at: https://www.mjbradley.com/sites/default/files/MJBA_NESE_LCA_06112019.pdf

[42] U.S. EIA. Last Updated June 3, 2020. "Units and calculators explained". Available at: https://www.eia.gov/energyexplained/units-and-calculators/energy-conversion-calculators.php

[43] U.S. EIA. 2018. Technology Forecast Updates - Residential and Commercial Building Technologies - Reference Case. p. 8. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf. *See* Electric Rates for further details. The weighted average of variable residential electric charges is calculated based on the relative annual residential electric sales for 2018 as reported by each utility to the U.S. Energy Information Administration.

- **Gas (Payback 2050):** GSEAF values from the 2020 GSEP filings are multiplied by 2.63. This factor represents the required increase in customer charges to completely recover the costs associated with leak-prone infrastructure replacement by 2050. (For a discussion of our methodology in calculating leak-prone gas infrastructure replacement costs see AEC's December 2020 policy brief entitled *Fixing Massachusetts' Leaky Pipes: When Will It Be Paid Off?*)

The total residential customer charge for each gas utility is the sum of all utility-specific gas charges and adjustment factors and the cost of electricity needed to run gas furnaces. A residential customer charge for Massachusetts was then calculated by averaging the utility-specific gas rates weighted by each utility's annual residential gas sales for 2018 as reported to the U.S. EIA.

To project residential customer charges into the future, the Gas Adjustment Factor (GAF) and cost of electricity for gas furnaces were escalated based on the annual growth rates for gas and electric prices projections from the U.S. EIA's 2020 AEO. All other components of gas customer charges were assumed to be unchanged (in real, inflation-adjusted terms) in future years.

Electric Rates

Electric rates for 2020 are based on the most recent service and delivery rates for each of Massachusetts' electric utilities, which include the following charges and adjustment factors:[44]

- Fixed Monthly Customer Charge (converted from a fixed monthly charge to an inferred $ per kWh charge by dividing the equivalent annual customer charge by the U.S. EIA's annual residential electric sales[45] in kWh for 2018 for each utility)
- Basic Service Charge ($ per kWh)
- Distribution Charge ($ per kWh)
- Transition Charge ($ per kWh)
- Transmission Charge ($ per kWh)
- Energy Efficiency Charge ($ per kWh)
- Renewable Resource Charge ($ per kWh)
- Distributed Solar Charge ($ per kWh)
- Among other charges and adjustment factors

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[44] Charges and adjustment factors are sourced from utility-specific documentation. See Appendix D: Utility-specific resources for gas and electric rates for a full list of utility-specific resources.

[45] U.S. EIA. 2018. *EIA-861 Annual Survey Data*. Available at: https://www.eia.gov/electricity/data/eia861/

Using the appropriate efficiency rate (see below) and the U.S. EIA's conversion factor (293.1 kWh per MMBtu)[46], these utility-specific electric charges were then converted from $ per kWh to the more universal measure of $ per MMBtu.

The total residential customer charge for each electric utility is the sum of all utility-specific electric charges. An average residential electric rate for Massachusetts was then calculated by averaging the utility-specific electric rates weighted by each utility's annual residential electric sales for 2018 as reported to the U.S. EIA.[47]

The unit conversion from $ per kWh to $ per MMBtu differs by technology:

- Electric resistance heating (90 percent efficiency)[48]
- Air-source heat pumps [97.7 kwh per MMBtu]
- Ground-source heat pumps [65.1 kwh per MMBtu]

Instead of having an efficiency rate, heat pump technologies have what is known as a coefficient of performance (COP):

- **Efficiency rate:** the net energy output for a given amount of consumed energy (i.e., some energy is lost in the conversion)
- **Coefficient of performance (COP):** the required amount of energy that is needed to yield the desired output.

Air-source and ground source heat pumps have COPs of 3.0 and 4.5, respectively, which translate to efficiency conversion factors of 97.7 and 65.1 kWh per MMBtu.[49]

To project residential customer charges into the future, the Basic Service Charge was escalated based on the annual growth rate for electric price projection from the U.S. EIA's 2020 Annual Energy Outlook (AEO). All other components of electric customer charges were assumed to be unchanged (in real, inflation-adjusted terms) in future years. To project the residential customer charges for heat pump technologies, the efficiency rate is also adjusted to increase over time based on the National Renewable Energy Laboratory's (NREL) performance projections (see Figure 12).

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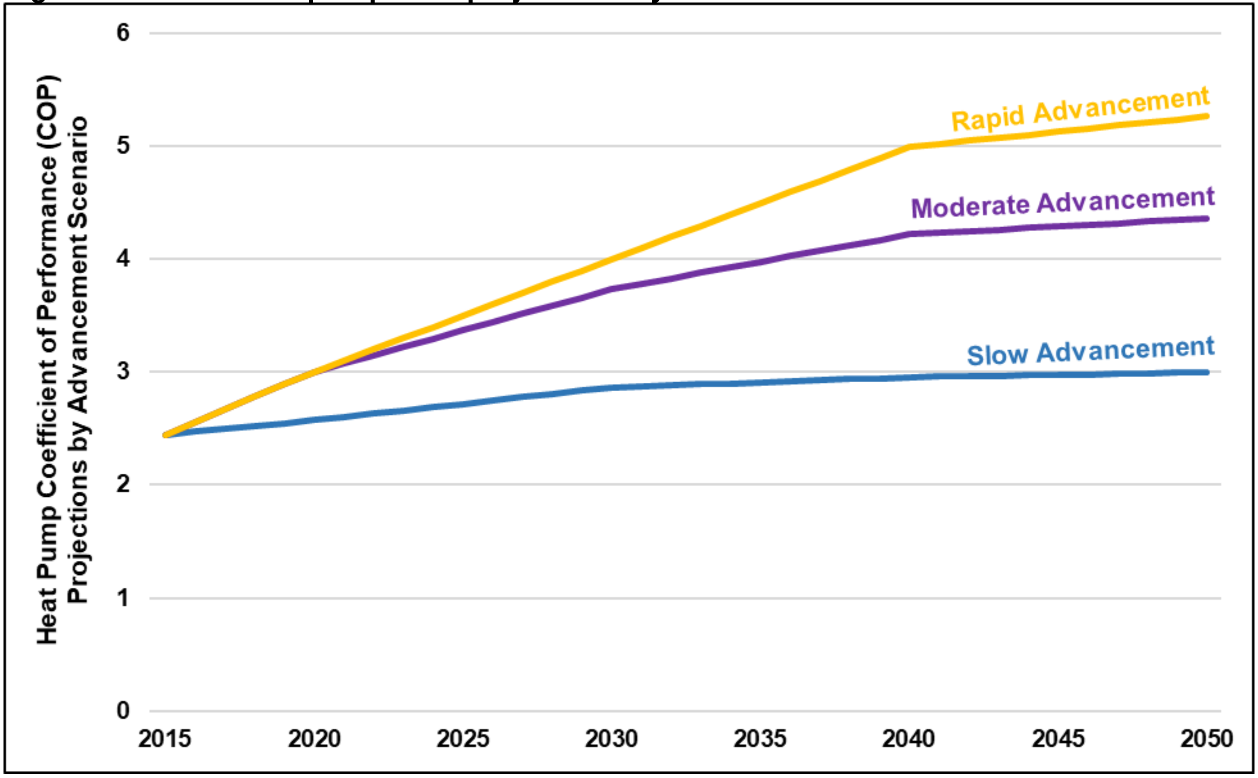
[46] U.S. EIA. Last Updated June 3, 2020. "Units and calculators explained". Available at: https://www.eia.gov/energyexplained/units-and-calculators/energy-conversion-calculators.php

[47] U.S. EIA. 2018. *EIA-861 Annual Survey Data*. Available at: https://www.eia.gov/electricity/data/eia861/

[48] M.J. Bradley & Associates, LLC. 2019. *Life Cycle Analysis of the Northeast Supply Enhancement Project*. Available at: https://www.mjbradley.com/sites/default/files/MJBA_NESE_LCA_06112019.pdf

[49] M.J. Bradley & Associates, LLC. 2019. *Life Cycle Analysis of the Northeast Supply Enhancement Project*. Available at: https://www.mjbradley.com/sites/default/files/MJBA_NESE_LCA_06112019.pdf

Figure 12. NREL heat pump COP projections by advancement scenario



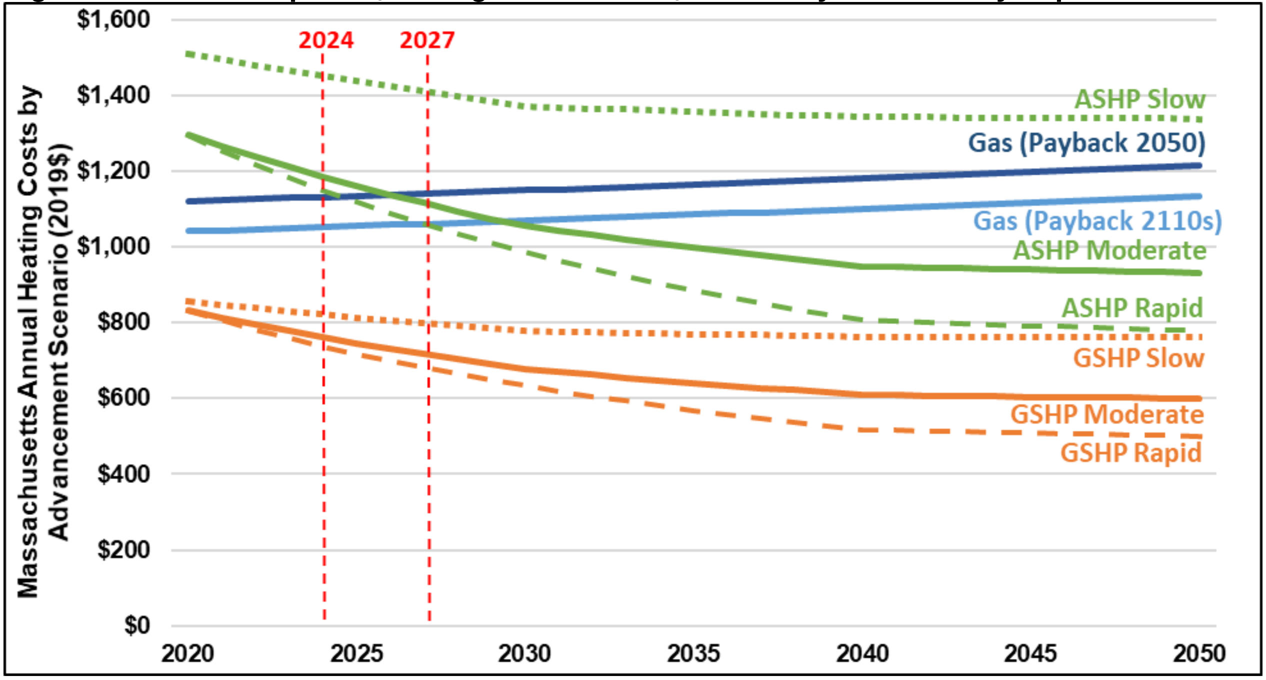
Reproduced from: Jadun, P. et al. 2017. Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70485. Available at: https://www.nrel.gov/docs/fy18osti/70485.pdf.

Appendix C: Sensitivity Analyses

Improvements to efficiency over time

The heating costs shown above assume only a very moderate pace of technological development. A quicker pace of efficiency increase in ASHPs would mean that ASHPs out compete gas heating in 2024 (versus 2026) for the Gas (Payback 2050) scenario and 2027 (versus 2030) for the Gas (Payback 2110s) scenario (see Figure 13). Even in the least optimistic case for improvements to heat pump efficiency, slower advancement delays ASHPs by just a year or two in out-competing gas heating.

Figure 13. Inflection points, average-sized home, sensitivity to efficiency improvements

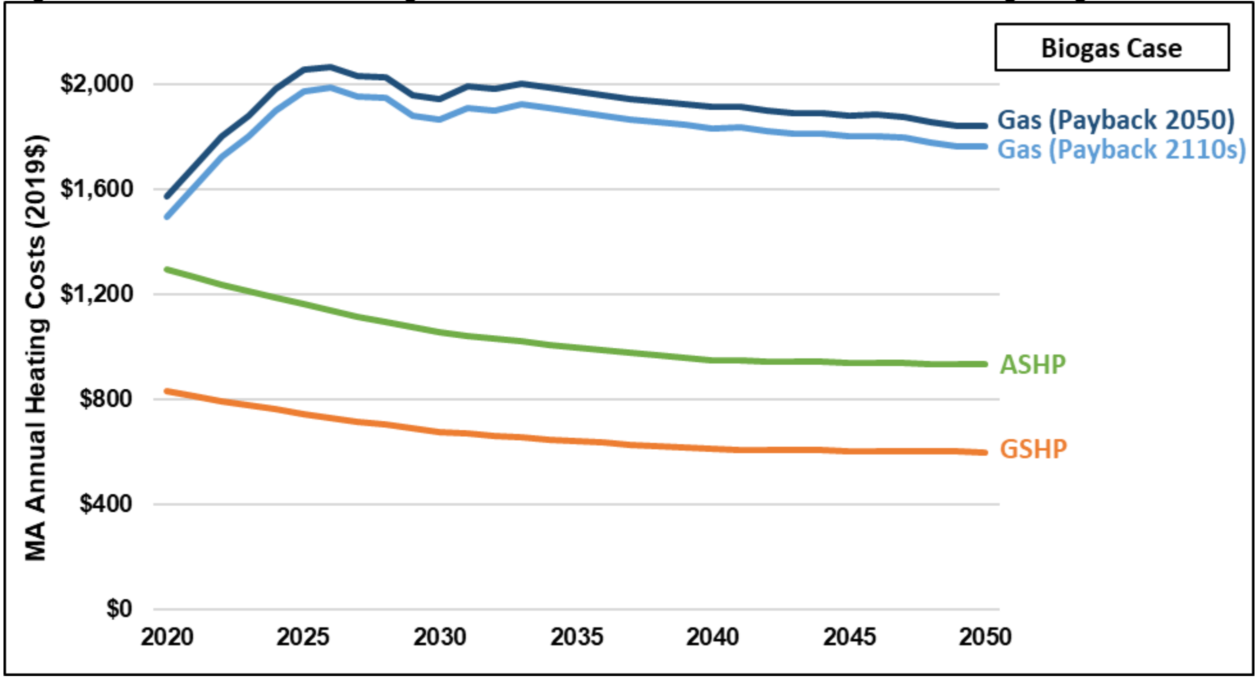


Biogas

Biogas (sometimes called “renewable” natural gas) is derived from biomass feedstocks (such as agricultural waste, forestry residues, or energy crops) through processes that include anaerobic digestion and thermal gasification. While biogas has the potential to be fully interchangeable with conventional gas in local distribution systems, it is not currently available at a scale necessary to replace fossil gas. In addition, the price and availability of biogas make it less cost-effective than conventional piped gas.

Massachusetts' gas utilities currently charge a Gas Adjustment Factor (GAF) to recover the costs associated with the supply of gas. Today the gas utilities charge a GAF that is approximately equal to $6 per MMBtu. According to ICF International's 2020 technical study report, *Opportunities for Evolving the Natural Gas Distribution Business to Support the District of Columbia's Climate Goals,* the marginal cost of biogas is estimated to be $14 per MMBtu today—more than twice the current expense for conventional gas supply.[50] Switching to biogas, raises the customer costs of both gas scenarios modeled in this report making gas heating even less competitive with heat pumps (see Figure 14). In 2020, gas heating with biogas would cost $1,500-1,580 per year (including all gas distribution charges), while ASHPs cost $1,300 per year. This cost difference continues to grow into the future with gas heating with biogas growing to $1,760-1,840 per year and ASHPs costs fall to $930 per year by 2050.

Figure 14. Residential heating cost to customers in Massachusetts using biogas



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[50] ICF. 2020. *Technical Study Report: Opportunities for Evolving the Natural Gas Distribution Business to Support the District of Columbia's Climate Goals*. Prepared for AltaGas. Available at: https://washingtongasdcclimatebusinessplan.com/wp-content/uploads/2020/04/Technical-Study-Report-Opportunities-for-Evolving-the-Natural-Gas-Distribution-Business-to-Support-DCs-Climate-Goals-April-2.pdf. p. 14

Appendix D: Utility-specific resources for gas and electric rates

Gas Rates and Information

Base Rate Charges and Adjustment Factors

- The Berkshire Gas Company. 2020. *Residential Rate – Heating*. Residential Heating Rate Classification No. R-3. Available at: https://www.berkshiregas.com/wps/wcm/connect/www.berkshiregas.com16325/d537b847-1695-438e-b0ce-b4f5e76f5b50/Regular-Delivery-Tariffs-MDPU-537-Rate-R-3-05-20.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE.Z18_J092I2G0NODI40A73GVBIB3C13-d537b847-1695-438e-b0ce-b4f5e76f5b50-n7g4DLn
- Boston Gas Company. 2019. *Base Rate Tariffs*. Residential Heating Rate Classification No. R-3. Available at: http://gasrates.nationalgridus.com/ne/Web%20Boston%201119%20v3.pdf
- Colonial Gas Company. 2019. *Base Rate Tariffs*. Residential Heating Rate Classification No. R-3. Available at: http://gasrates.nationalgridus.com/ne/Web%20Colonial%201119.pdf
- Columbia Gas of Massachusetts. 2020. *Tariffs, Rate Schedules and Agreements*. Residential Heating Rate Classification No. R-3. Available at: https://www.columbiagasma.com/docs/librariesprovider15/rates-and-tariffs/massachusetts-tariff.pdf?sfvrsn=3
- Eversource Energy. 2020. *2020 Summary of Eastern Massachusetts Gas Rates*. Residential Heating Rate Classification No. R-3. Available at: https://www.eversource.com/content/docs/default-source/rates-tariffs/summary-rates-gas.pdf
- Liberty Utilities. 2019. *Sales Service Rates – Peak.* Residential Heating Rate Classification No. R-3. Available at: https://massachusetts.libertyutilities.com/uploads/LUC%20Peak%20Rates%20-%201119%20-%20Peak%20Rates.pdf
- Unitil. 2020. *Energy for Residents: Gas Information*. Residential Heating Rate Classification No. R-3. Available at: https://unitil.com/energy-for-residents/gas-information/rates
- Massachusetts Department of Public Utilities (MA DPU). December 2019. 2019-2020 Peak Gas Adjustment Factors. Available at: https://www.mass.gov/doc/gaf-historical-data-workbook-1999-2019/download

Gas System Enhancement Adjustment Factors (GSEAFs)

- MA DPU Docket No. 19-GSEP-01. *2020 Gas System Enhancement Plan, Exhibit Unitil-AFCG-3 (Determination of the GSEAF).* Filed by Unitil (Gas Division). Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12029500

- MA DPU Docket No. 19-GSEP-02. *2020 Gas System Enhancement Plan, Exhibit BGC-JB/RG-3 (Calculation of GSEAF).* Filed by The Berkshire Gas Company. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/11385561
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