Home Heating in Massachusetts: What Influences Future Costs?

March 2024 – White Paper

Applied Economics Clinic

Prepared for: The Home Energy Efficiency Team (HEET)

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

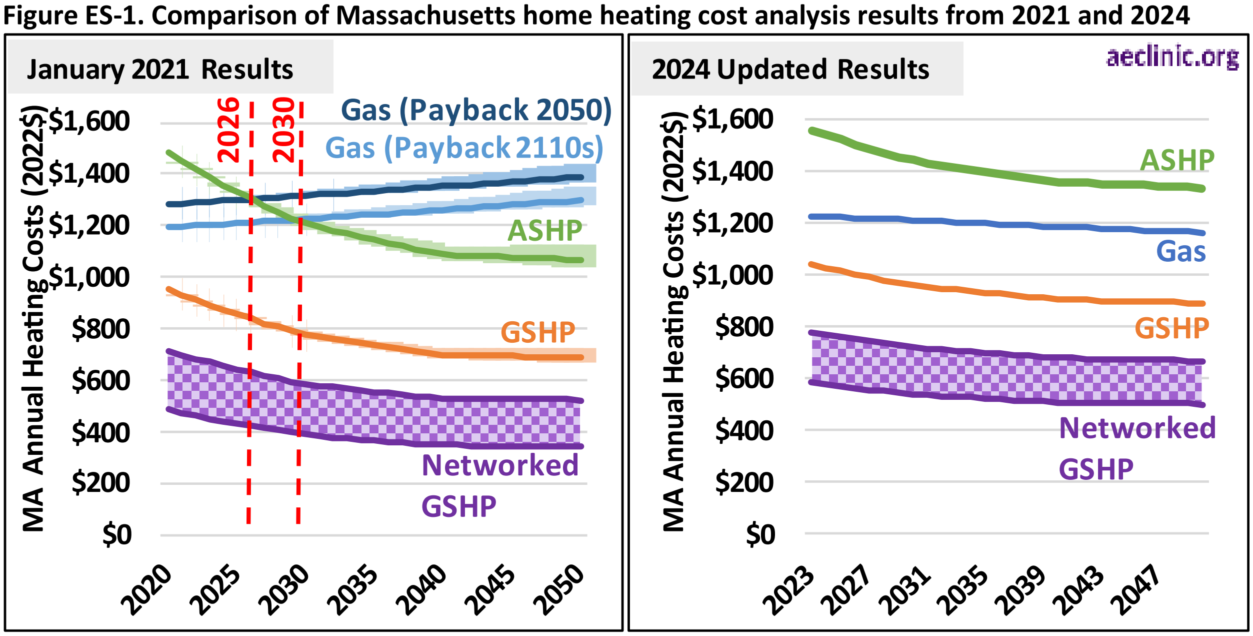
Executive Summary

Massachusetts' building sector accounts for over one-third of statewide greenhouse gas emissions. In 2022 Massachusetts adopted greenhouse gas emission limits for 2025 and 2030 for the buildings sector in line with *An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy*. To meet these building sector emissions limits, households and businesses that use gas and other fossil fuels for heating will need to transition to other energy sources with far lower greenhouse gas emissions.

A successful transition from fossil-fuel-based heating will require a clear understanding of anticipated home heating costs under different technology and fuel choices. Applied Economics Clinic's (AEC) January 2021 white paper, *Inflection Point: When Heating with Gas Costs More*, compared the annual energy cost of heating the average-sized home in Massachusetts using either a high-efficiency gas furnace or electric heat pumps—which found that heating with networked geothermal (also called networked ground-source heat pumps) or individual ground-source heat pumps (GSHPs) is less expensive than heating with gas-fired furnaces, and the cost of heating with air-source heat pumps (ASHPs) would fall below that of heating with gas sometime between 2026 and 2030 (see Figure ES-1 on the left).

This March 2024 AEC white paper, prepared on behalf of the Home Energy Efficiency Team (HEET), updates the home heating cost analysis conducted in AEC's January 2021 white paper; both analyses present operating costs only, excluding the costs of purchasing or maintaining heating equipment. Updated analysis, based on the most recent data and cost projections, finds that heating with networked geothermal and GSHPs is less expensive than heating with gas-fired furnaces today and can be expected to remain so through 2050 (see Figure ES-1 on the right). Our findings regarding ASHPs, however, point to more questions than answers: Changes in gas and electric prices over the past few years reversed our earlier findings, suggesting that notoriously uncertain forecasts of future fuel prices are of paramount importance in understanding the likely impacts of ASHP adoption on household finances.

Figure ES-1. Comparison of Massachusetts home heating cost analysis results from 2021 and 2024



Data source: (1) Castigliego, J.R., Alisalad, S., Stasio, T., and Stanton, E.A. Inflection Point: When Heating with Gas Costs More; (2) AEC calculation. See Appendix A: Methodology and Assumptions for information on how these costs were calculated.

Fuel and electric price forecasts have changed dramatically over the past three years, but any review of past price forecasts and real-world outcomes will show that energy market projections are inherently, and consistently, unreliable. Future gas and electric prices cannot be predicted with accuracy. For household heating equipment investment decisions—and policy-makers decisions regarding how to support households while achieving climate goals—uncertain energy prices pose a serious problem. Networked geothermal and GSHPs are one solution: Their operating costs are consistently below that of gas heating across widely different energy price forecasts. Policy support for ASHPs should consider household cost impacts across a wide range of potential future energy prices.

While residential customers can apply for rebates for ASHP purchases through Mass Save, most households may not be able to take on a commitment to paying higher annual heating costs associated with the switch from gas-fired furnaces to ASHPs. Therefore, the transformation in heating practices expected in the Massachusetts *2050 Decarbonization Roadmap* and *Clean Energy and Climate Plan* will require solutions that address the high cost of electric heating technologies, such as new incentives to stimulate adoption of networked geothermal systems, lower upfront costs of GSHPs, and a re-design of electric rates to better reflect the Commonwealth's plans for widespread heat pump adoption. Without addressing the significant cost barrier faced by Massachusetts residents, customers will continue to rely on existing gas- and oil-fired heating systems to heat their homes, and Massachusetts will fall short of meeting its residential heating and cooling sector emission reduction targets.

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About the Applied Economics Clinic

Based in Boston, Massachusetts, the Applied Economics Clinic (AEC, www.aeclinic.org) is a mission-based non-profit consulting group that offers expert services in the areas of energy, environment, consumer protection, and equity from seasoned professionals while providing on-the-job training to the next generation of technical experts.

AEC's non-profit status allows us to provide lower-cost services than most consultancies, and when we receive foundation grants, AEC also offers services on a pro bono basis to environmental justice-focused community-based organizations. AEC's clients are primarily public interest organizations—non-profits, government agencies, and green business associations—who work on issues related to AEC's areas of expertise. Our work products include expert testimony, analysis, modeling, policy briefs, and reports, on topics including energy and emissions forecasting, economic assessment of proposed infrastructure plans, and research on cutting-edge, flexible energy system resources.

AEC works proactively to support and promote diversity in our areas of work by providing applied, on-the-job learning experiences to graduate students—and occasionally highly qualified undergraduates—in related fields such as economics, environmental engineering, and political science. Over the years, AEC has hosted research assistants from Boston University, Brandeis University, Clark University, Tufts University, University of Massachusetts-Amherst, University of Massachusetts-Boston, University of Southern Maine, and University of Tennessee. AEC is committed to a just workplace that is diverse, pays a living wage, and is responsive to the needs of our staff.

Founded in 2017 by Director and Senior Economist Elizabeth A. Stanton, PhD, AEC's talented researchers and analysts provide a unique service-minded consulting experience. Dr. Stanton has had more than two decades of professional experience as a political and environmental economist leading numerous studies on environmental regulation, alternatives to fossil fuel infrastructure, and local and upstream emissions analysis. AEC professional staff includes experts in electric, multi-sector and economic systems modeling, climate and emissions analysis, green technologies, and translating technical information for a general audience. AEC's staff are committed to addressing climate change and environmental injustice in all its forms through diligent, transparent, and comprehensible research and analysis.

I. Introduction

Home heating costs and anticipated energy burdens are influenced by household heating fuel choices. A clear understanding of anticipated home heating costs under different heating technologies is especially important to Massachusetts' continued decarbonization under the Global Warming Solutions Act (GWSA) of 2008,[1] and the 2050 net-zero greenhouse gas emissions target established by former Massachusetts Governor Baker in April 2020.[2] In October 2020, the Massachusetts Department of Public Utilities (DPU) opened Docket No. 20-80, to investigate the role of gas utilities in the Commonwealth's clean energy transition.[3] In December 2023, the DPU filed an order under Docket No. 20-80, rejecting gas decarbonization strategies that rely on renewable natural gas and supporting those that rely on electric heating technologies and renewable hydrogen.[4]

Massachusetts successfully met its 2020 emission reduction target, reducing statewide emissions 30 percent below 1990 levels.[5] In 2021, the GWSA was amended by *An Act Creating A Next-Generation Roadmap for Massachusetts Climate Policy* to establish interim greenhouse gas emission reduction targets for 2025, 2030, 2035, 2040, and 2045, and to increase the 2050 emission reduction target to net-zero statewide emissions with an 85 percent reduction in greenhouse gas emissions below 1990 levels by 2050.[6] In addition to amendments to the GWSA, the Act also required sector-based greenhouse gas limits, not included in the Commonwealth's previous climate laws. For the first time, starting in 2025, Massachusetts will need to achieve a specific greenhouse gas emissions reduction in its residential heating and cooling sector.[7]

Greenhouse gas emissions from buildings made up 30 percent of Massachusetts' 2020 statewide greenhouse gas emissions, or 19.5 million metric tons (MMT) of carbon dioxide equivalents (CO_2e).[8] Most building sector emissions are attributed to residential buildings (12.2 $MMTCO_2e$ in 2020).[9] In June 2022, in line with *An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy*,[10] Former Massachusetts Governor Baker adopted interim statewide and sector-based greenhouse gas emission limits for 2025 and 2030 for the residential heating and cooling sector: 29 percent reduction from 1990

[1] Massachusetts Executive Office of Energy and Environmental Affairs. n.d. "Global Warming Solutions Act Background." Available at: https://www.mass.gov/info-details/global-warming-solutions-act-background

[2] 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

[3] Massachusetts Department of Public Utilities (DPU) Docket No. 20-80. *Investigation by the Department of Public Utilities on its own Motion into the role of gas local distribution companies as the Commonwealth achieves its target 2050 climate goals.* Available at: https://eeaonline.eea.state.ma.us/DPU/Fileroom/dockets/bynumber/20-80

[4] Massachusetts DPU Docket No. 20-80. December 6, 2023. *Order on Regulatory Principles and Framework*. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/18297602

[5] Massachusetts Executive Office of Energy and Environmental Affairs. June 30, 2022. *Statement of Compliance with 2020 Greenhouse Gas Emissions Limit*. Available at: https://www.mass.gov/doc/statement-of-compliance-with-2020-greenhouse-gas-emissions-limit/download

[6] Massachusetts General Laws Chapter 8 (2021). *An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy*. Available at: https://malegislature.gov/Laws/SessionLaws/Acts/2021/Chapter8

[7] Ibid.

[8] Ibid. p. xiv

[9] Ibid. [Table ES-2].

[10] Ibid.

levels by 2025 and 49 percent by 2030.[11] To meet these building sector targets, Massachusetts needs to move away from fossil fuel-based heating systems like gas- and oil-fired furnaces and boilers towards efficient electric heating systems like air- and ground-source heat pumps.[12] According to the *2050 Decarbonization Roadmap*'s Buildings Sector Report, Massachusetts would need to deploy electric heat pumps in nearly 100,000 homes each year to achieve the emission reductions required in the residential buildings sector.[13] This pace of deployment would add up to 1.5 million new heat pump installations (or 50 percent of the current housing stock[14]) in Massachusetts by 2035; and 3.0 million by 2050 (which is nearly all of Massachusetts current housing stock).

Massachusetts home heating is cheapest with networked geothermal and ground-source heat pumps

This Applied Economics Clinic (AEC) white paper, prepared on behalf of the Home Energy Efficiency Team (HEET), serves as an update to AEC's January 2021 white paper, *Inflection Point: When Heating with Gas Costs More*,[15] in which AEC found that heating with networked geothermal (also called networked ground-source heat pumps) or individual ground-source heat pumps (GSHPs) is less expensive than heating with gas-fired furnaces, and the cost of heating with air-source heat pumps (ASHPs) would fall below that of heating with gas sometime between 2026 and 2030.[16] Updated analysis, based on the most recent data and cost projections, finds that heating with networked geothermal and GSHPs will continue to be less expensive than heating with gas-fired furnaces through 2050. Our findings regarding ASHPs, however, point to more questions than answers: Changes in gas and electric prices over the past two years reversed our earlier findings, suggesting that notoriously uncertain forecasts of future fuel prices are of paramount importance in understanding the likely impacts of ASHP adoption on household finances.

Notoriously uncertain forecasts of future fuel prices are of paramount importance in understanding the likely impacts of ASHP adoption on household finances.

Estimated average household utility bills (shown in Figure 1 below) vary based on heating technology, year, and critically—as shown in the difference between AEC's 2021 and updated 2024 results—the 30-year forecast used for future gas and electric prices. In both analyses, networked geothermal and GSHPs are the least-cost heating option for Massachusetts households today and through 2050 (see Figure 1 below). However, AEC's earlier 2021 results suggest an inflection point in the cost of heating the average Massachusetts home using gas versus ASHPS in 2026 or 2030; there is no such inflection point in the updated 2024 results.

[11] Massachusetts Executive Office of Energy and Environmental Affairs. June 30, 2022. *Determination of Statewide Greenhouse Gas Emissions Limits and Sector-Specific Sublimits for 2025 and 2030*. Available at: https://www.mass.gov/doc/2025-and-2030-ghg-emissions-limit-letter-of-determination/download

[12] Massachusetts Executive Office of Energy and Environmental Affairs. December 2020. *Massachusetts 2050 Decarbonization Roadmap*. Available at: https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download

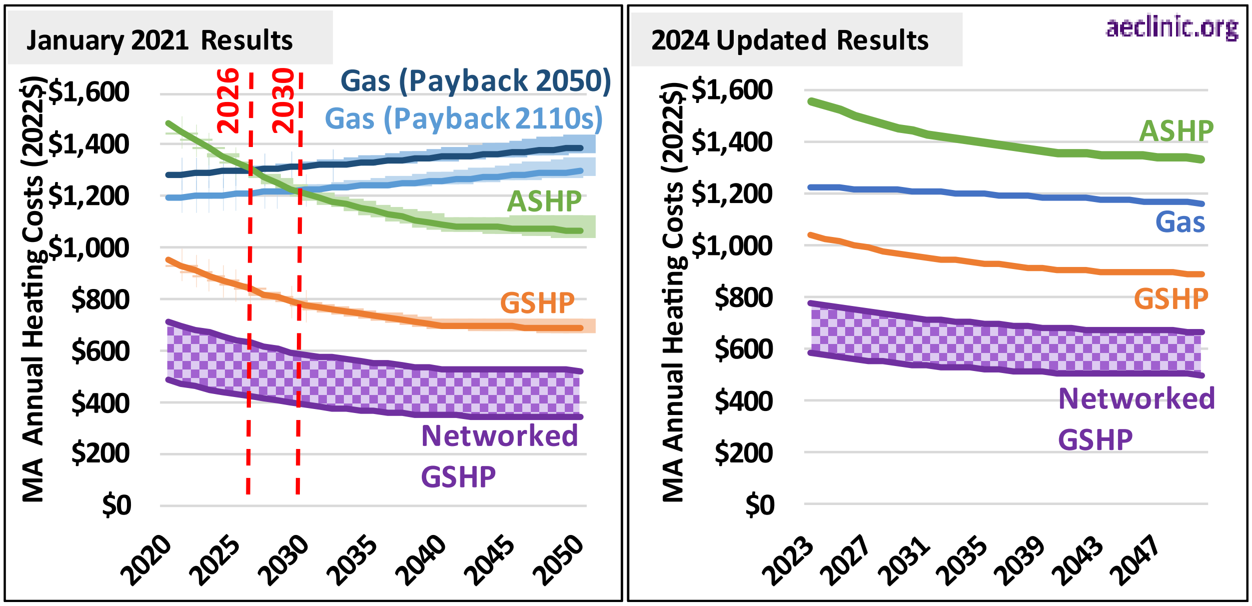
[13] Commonwealth of Massachusetts. 2020. *Buildings Sector Report*. Prepared by The Cadmus Group, Arup, VEIC, Energy Futures Group, and Evolved Energy Research. Available at: https://www.mass.gov/doc/buildings-sector-technical-report/download, p. 7.

[14] U.S. Census Bureau. "National, State, and County Housing Unit Totals: 2020-2022." Available at: https://www.census.gov/data/tables/time-series/demo/popest/2020s-total-housing-units.html

[15] Castigliego, J.R., Alisalad, S., Stasio, T., and Stanton, E.A. *Inflection Point: When Heating with Gas Costs More.* Prepared on behalf of HEET. Applied Economics Clinic. Available at: https://aeclinic.org/publicationpages/2021/01/13/inflection-point-when-heating-with-gas-costs-more

[16] Ibid.

Figure 1. Comparison of Massachusetts home heating cost analysis results from 2021 and 2024



Data source: (1) Castigliego, J.R., Alisalad, S., Stasio, T., and Stanton, E.A. Inflection Point: When Heating with Gas Costs More; (2) AEC calculation. See Appendix A: Methodology and Assumptions for information on how these costs were calculated.

Customer bills include all costs of producing and delivering energy but do not include the upfront or installation costs associated with a household's heating system. This analysis assumes the same home heating requirement each year, regardless of the energy source, and uses gas and electric rate data from Massachusetts' investor-owned utilities (e.g., National Grid, Eversource). Our findings do not represent rates and bills in communities participating in community choice aggregation[17] or in those served by municipal light plants.[18]

Section 0 offers a brief overview of Massachusetts heating fuels and technologies. Section III discusses the results of AEC's customer bill analysis, identifies the least cost heating fuel option, and discusses key takeaways. Finally, Appendix A: Methodology and Assumptions describes the main energy concepts and methodology used in this white paper.

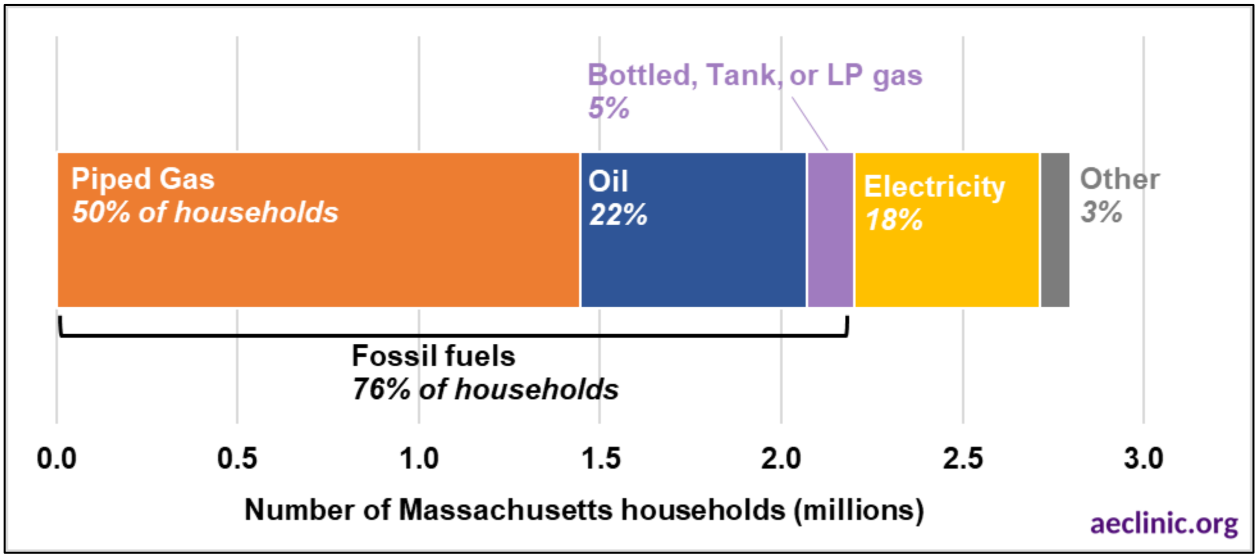
[17] Community choice aggregation is a program that allows a city or town to purchase electric supply on behalf of its residents in order to give residents more control over their energy supply and the ability to choose their electric supplier. For more information, see: Massachusetts Climate Action Network. n.d. "Community Choice Aggregation." Available at: https://www.massclimateaction.org/community_aggregation

[18] There are 50 towns in Massachusetts served by municipal light plants. See: Massachusetts Office of Energy and Environmental Affairs. n.d. "Massachusetts municipally owned electric companies." Available at: https://mass.gov/info-details/massachusetts-municipally-owned-electric-companies

II. Massachusetts Home Heating

Three-quarters (76 percent) of Massachusetts households heat their homes with fossil fuels,[19] down from 83 percent in 2010,[20] two years after the GWSA was enacted. In 2022, half of Massachusetts households heated their homes using piped gas, 22 percent using oil, and 5 percent using bottled, tank, or LP gas (see Figure 2). Just 18 percent of Massachusetts households heat their homes using electricity.[21]

Figure 2. Massachusetts home heating fuels



Data source: U.S. Census Bureau. 2022. ACS 1-Year Detailed Estimates [Table: B25040].

In New England, households heating with electricity are more likely to use old-fashioned electric resistance heating or central warm-air furnaces rather than an air-source heat pump (ASHP) or ground-source heat pump (GSHP); according to the U.S. Energy Information Administration's (EIA) 2020 Residential Energy Consumption Survey, of the 910,000 households in New England that heat their homes using electricity, only 180,000 (or 20 percent) heat their homes using heat pumps (including ductless mini-split systems). Half a million New England households—representing over half (i.e., 55 percent) of all New England households heating with electricity—rely on built-in electric resistance heating, while the remaining 25 percent utilize central warm-air furnaces, portable electric heaters, or some other electric equipment.[22]

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[19] U.S. Census Bureau. 2022. American Community Survey (ACS) 1-Year Detailed Estimates [Table: B25040]. Available at: https://data.census.gov/table/ACSDT1Y2022.B25040?q=B25040:+House+Heating+Fuel&g=040XX00US25

[20] U.S. Census Bureau. 2010. ACS 5-Year Detailed Estimates [Table: B25040]. Available at: https://data.census.gov/table/ACSDT5Y2010.B25040?q=B25040:+House+Heating+Fuel&g=040XX00US25

[21] U.S. Census Bureau. 2022. ACS 1-Year Detailed Estimates [Table: B25040]

[22] U.S. EIA. 2020. Residential Energy Consumption Survey (RECS) [Table HC6.7]. Available at: https://www.eia.gov/consumption/residential/data/2020/hc/pdf/HC%206.7.pdf

Across all net zero-compliant pathways in the *Massachusetts 2050 Decarbonization Roadmap*[23], electrification of building heating technology, or the replacement of gas- and oil-fired furnaces and boilers with heat pumps, is identified as a necessary and cost-effective strategy for decarbonization.[24] The Massachusetts Commission on Clean Heat's 2022 report identifies upfront cost of building electrification as one of the main barriers to widespread heat pump adoption in Massachusetts;[25] these costs vary with the size and energy-intensity of buildings.

A recent *Multifamily Heat Pump Barriers Study* commissioned by the Massachusetts' electric and gas providers found more generally that a lack of sufficient financial incentives and experienced contractors were important barriers to heat pump adoption in multifamily homes. Landlords are often unfamiliar with the different heating technology options offered and lack the incentive to electrify their rental properties.[26] A 2023 bill put forward by Massachusetts Senator Michael J. Barrett aims to reduce the cost of switching to heat pump technology by increasing customer incentives provided to gas and electric utilities.[27]

Home heating price forecasts can only be as good as the uncertain energy price predictions on which they are based. The results of home heating cost analyses are dependent on uncertain projections of fuel prices in the future; many factors influence the cost of gas, electricity, and other heating fuels, and the accuracy of their price forecasts.

Home heating price forecasts can only be good as the uncertain energy price predictions on which they are based.

Today's energy price forecasts differ substantially from those used in the January 2021 analysis (as is discussed in more detail below in Section III). While the results presented in this white paper no longer show an inflection point between the heating costs for ASHPs and gas-fired heating systems (that is, ASHP operating costs remain higher than gas furnaces through 2050), the comparison of our 2021 and 2024 modeling suggests two key findings for Massachusetts' decarbonization policy:

- First, despite large swings in important underlying forecasts, the superior economics of networked and GSHPs remains a constant: These geothermal heating technologies are less expensive than heating with gas today and throughout the foreseeable future.
- Second, ASHP economics are far less certain. Actual customer savings will depend on gas and electric prices in the future. And predicted customer savings—a critical touchstone for today's decarbonization planning and household heating equipment investments—depend on deeply uncertain forecasts of volatile energy products impacted by both global and domestic market forces. Households unable to afford the switch from fossil gas heating to ASHPs could be left paying higher and higher energy bills as the gas system's customer base shrinks.

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23 Massachusetts Executive Office of Energy and Environmental Affairs. December 2020. *Massachusetts 2050 Decarbonization Roadmap*. Available at: https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download

24 Ibid. p. 45

25 Massachusetts Executive Office of Energy and Environmental Affairs. November 2022. *Final Report: Massachusetts Commission on Clean Heat*. Available at: https://www.mass.gov/doc/massachusetts-commission-on-clean-heat-final-report-november-30-2022/download. p.24.

26 Guidehouse, Inc. March 25, 2022. *Multifamily Heat Pump Barriers Study*. Provided to the Electric and Gas Program Administrators of Massachusetts. MA21R35-E-MFHPB. Available at: https://ma-eeac.org/wp-content/uploads/MA21R35-MF-HP-Barrier-Study_Report_FINAL_25MAR2022.pdf.

27 Massachusetts Senate Bill 2748. 2023. *An Act Reducing the Financial Penalty Imposed on Customers Who Shift to Heat Pumps, Electric Appliances, and Electric Vehicles*. Available at: https://malegislature.gov/Bills/193/SD2748

III. The Cost of Future Heating

Comparison of costs across different heating fuels can be complicated; gas use is measured in therms, heating oil in gallons, and electric use in kilowatt-hours. Regardless of the heating fuel, however, a particular building needs the same amount of heat energy to achieve a given temperature; building heating requirements 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 50.4 million Btus (abbreviated "MMBtu") of heat each year, regardless of the energy source that produces the heat.[28]

The analysis presented in this white paper relies on EIA Annual Energy Outlook (AEO) gas and electric price forecasts from 2023; in comparison, our January 2021 white paper, *Inflection Point: When Heating with Gas Costs More*, used AEO energy price forecasts published in 2020. AEC's cost estimates for heating an average-sized Massachusetts home using different heating technologies—gas, ASHPs, GSHPs, and networked geothermal[29]—are based on the most recent residential gas and electric rates[30] in Massachusetts and projections[31] of residential gas and electric prices for the New England region. This analysis does not consider equipment costs or the retrofit and/or installation costs associated with each heating system type.

AEC's updated average customer energy bill analysis shows that from 2023 to 2050, heating with individual or networked GSHPs costs the least across all heating technologies reviewed (see Figure 3 below). On average, households heating with GSHPs save $260 per year compared to those heating with gas from 2023 to 2050. Households heating with ASHPs, however, appear to be at a disadvantage to those remaining on gas heating.

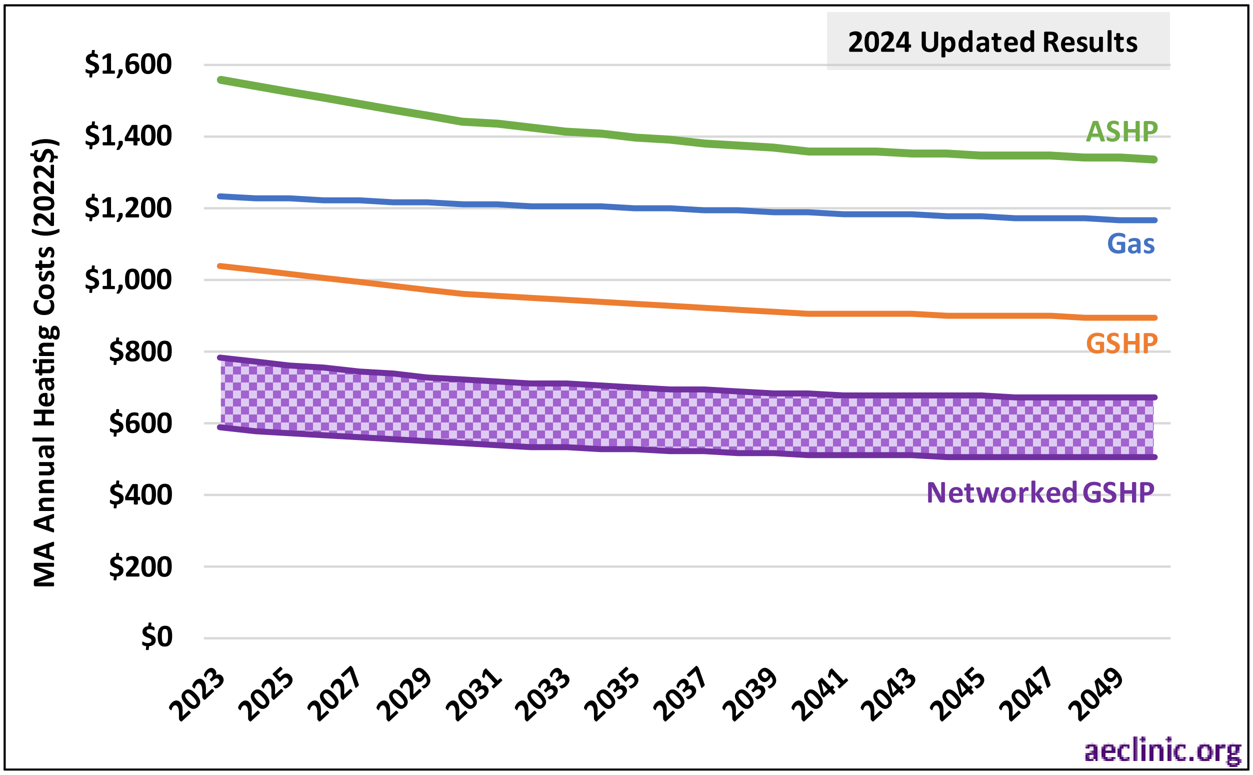
[28] U.S. EIA. 2020. RECS [Table CE3.2]. Available at: https://www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce3.2.pdf

[29] Networked geothermal heating systems are a set of interconnected ground-source heat pumps; Two Massachusetts utilities National Grid and Eversource are working on geothermal pilot projects. See: HEET. n.d. "Networked Geothermal." Available at: https://heet.org/geo/

[30] This white paper uses residential gas and electric rate data from Massachusetts' investor-owned utilities only. Residential rates for customers served by municipal light plants, co-operatives, and/or community choice communities are not represented in this analysis.

[31] U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3]. *Annual Energy Outlook 2023*. Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2023&region=1-1&cases=ref2023~highogs~lowogs&start=2021&end=2050&f=A&sourcekey=0

Figure 3. 2024 update to forecasted heating costs for average Massachusetts home

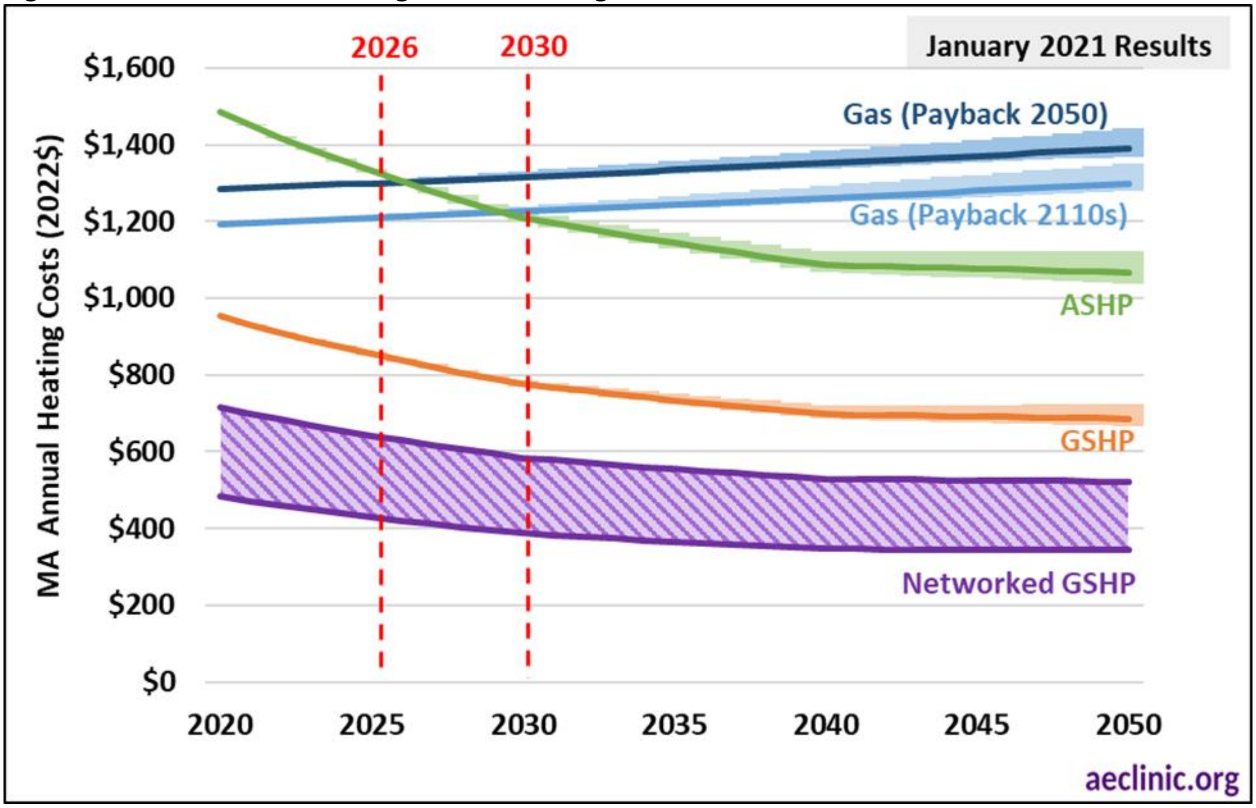


Data source: AEC calculation. See Appendix A: Methodology and Assumptions for information on how these costs were calculated.

Networked geothermal and GSHPs cost less than gas heating to run today and will continue to cost less through 2050.

These updated results are consistent with the finding in AEC's January 2021 white paper that networked geothermal and GSHPs cost less than gas heating to run today and will continue to cost less through 2050. New in this 2024 update is the lack of an inflection point between the cost of heating with ASHPs versus gas. Our earlier findings showed the annual cost of heating with ASHP falling below that of gas sometime between 2026 and 2030 (see Figure 4 below) whereas the more recent findings show heating with gas as less costly than heating with ASHPs through 2050 (see Figure 3 above). While all gas and electric price and rate data, have been updated in this latest analysis, the assumptions that drive the dramatic difference in 2021 and 2024 results are the fuel price forecasts from the EIA's AEO modeling. (See Appendix A: Methodology and Assumptions for more information on the methodology used in this white paper.)

Figure 4. 2021 forecasted heating costs for average Massachusetts home



Data source: Castigliego, J.R., Alisalad, S., Stasio, T., and Stanton, E.A. Inflection Point: When Heating with Gas Costs More.

Expected heating costs depend on uncertain projections of fuel prices in the future

Both state decarbonization policies and households' decisions on heating equipment investments—when to replace an old boiler or furnace and with what—are strongly influenced by expected future costs of heating for different technologies. Expected future heating costs, in turn, depend on the accuracy of uncertain projections of fuel prices in the future. Of course, no one expects a crystal ball, predicting exact future prices. But the deep uncertainty of future fuel prices, and the controlling influence that analysts' fuel price projections have on current-day decisions may be misunderstood or underappreciated. Well-intended guesses about future fuel prices—especially the omnipresent AEO forecasts published each year by EIA—dominate the results of modeling exercises used to inform both public and household decision-making. Several factors can introduce uncertainty in fuel price forecasts, such as: real world politics and market dynamics. The cost of energy products is influenced by many factors, including:

- global events (e.g., the Ukraine-Russia War[32])
- extreme weather (e.g., cold snaps[33])

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[32] U.S. EIA. October 11, 2023. "Winter Fuels Outlook 2023 -2024." Short-term Energy Outlook. Available at: https://www.eia.gov/outlooks/steo/report/perspectives/2023/10-winterfuels/article.php

[33] (1) Ladislaw, S., and Melton, M. February 15, 2014. "Polar Vortex, Propane Shortages, and Power Price Spikes: Perfect Storm or Signal for Broader Debate." Available at: https://www.csis.org/analysis/polar-vortex-propane-shortages-and-power-price-spikes-perfect-storm-or-signal-broader. (2) DiSavino, S., & Kelly, S. February 18, 2021. "Texas power consumers to pay the price of winter storm." *Reuters*. Available at: https://www.reuters.com/business/energy/texas-power-consumers-pay-price-winter-storm-2021-02-18/.

- market conditions (e.g., Inflation[34])
- changes in energy demand (e.g., higher demand from residential customers as households stay home during the COVID-19 pandemic[35])
- changes in fuel supply (e.g., increased supply from technological advancements like gas fracking[36])
- investment in fuel infrastructure (e.g., additional pipelines and/or import/export facilities[37])

In 2022, U.S. gas prices experienced two major shocks, a large winter storm that affected much of the United States and the Ukraine-Russia crisis—both of which caused a jump in the Henry Hub[38] spot price. Both events caused a spike in heating fuel prices, making it more expensive for customers to heat their homes.[39] In Massachusetts, heating fuel prices in recent years have been at their highest across all heating fuel types due to the Ukraine-Russia war and inflation;[40] between winter 2021/2022 and winter 2022/2023, for example, the average residential electric rate in Massachusetts rose from $0.27 per kilowatt-hour to $0.43 per kWh, a 60 percent increase (see Figure 5 below). In fact, according to analysis by the Massachusetts Department of Energy Resources, the cost of heating in Massachusetts has fluctuated significantly over the past decade. In Winter 2018/2019, the average residential gas rate was $1.40 per therm compared to an expected $2.04 per therm for Winter 2023/2024 (see Figure 5 below). Likewise, the average residential electric rate was $0.24 per kWh for the Winter 2018/2019 season compared to an expected $0.33 per kWh for Winter 2023/24.

[34] Associated Press. October 13, 2021. "Heating bills set to soar as inflation hits energy prices." *PBS Newshour*. Available at: https://www.pbs.org/newshour/economy/heating-bills-set-to-soar-as-inflation-hits-energy-prices.

[35] U.S. EIA. June 15, 2023. "Space heating consumed the most energy of any end use in homes, according to latest data." Available at: https://www.eia.gov/pressroom/releases/press535.php

[36] Stocker, M., Baffes, J. & Vorisek, D. "What triggered the oil price plunge of 2014-2016 and why it failed to deliver an economic impetus in eight charts" [Blog Post]. *World Bank*. Available at: https://blogs.worldbank.org/developmenttalk/what-triggered-oil-price-plunge-2014-2016-and-why-it-failed-deliver-economic-impetus-eight-charts.

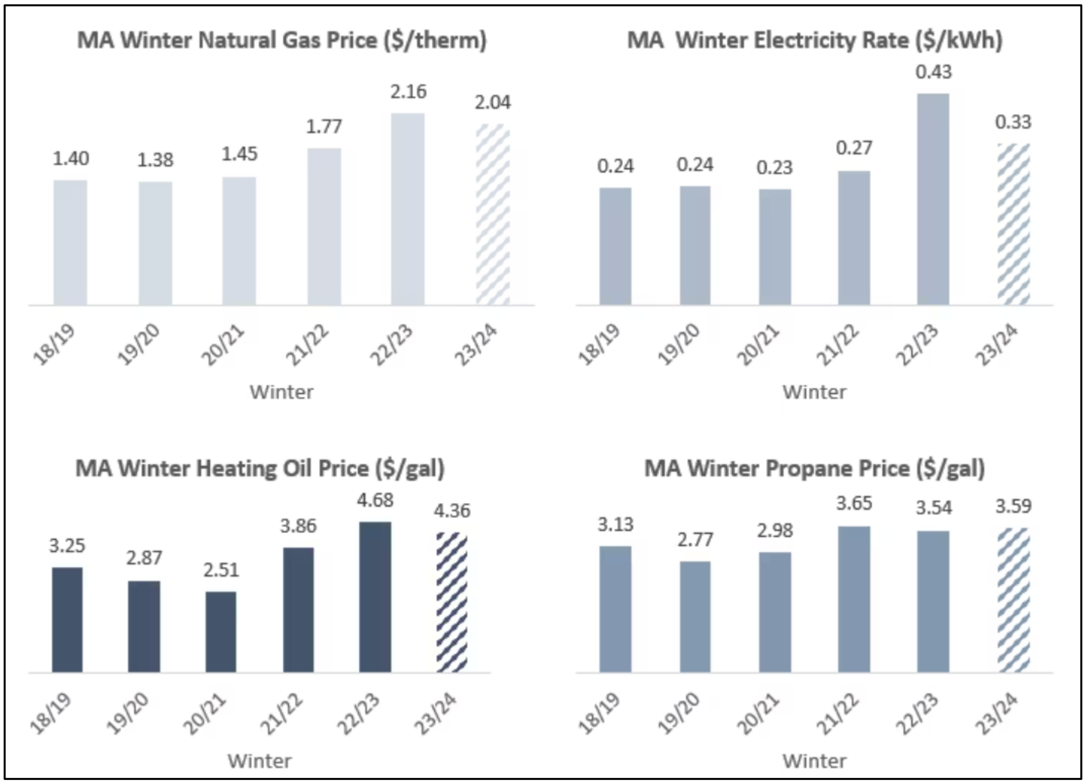
[37] Williams-Derry, C. June 15, 2023. "Rio Grande LNG project could raise U.S. gas prices—and add to a looming global glut." *Institute for Energy Economics and Financial Analysis (IEEFA).* Available at: https://ieefa.org/resources/rio-grande-lng-project-could-raise-us-gas-prices-and-add-looming-global-glut.

[38] The Henry Hub is located in Louisiana, where several natural gas interconnections meet. These pipelines serve markets all over the United States. Due to its central location, local markets typically price their natural gas in relation to the Henry Hub price. For more information, see: CME Group. n.d. "Understanding Henry Hub." Available at: https://www.cmegroup.com/education/courses/introduction-to-energy/introduction-to-natural-gas/understanding-henry-hub.html

[39] (1) SDGE. 2023. "Your Energy Bill and Why Rates are Higher." Available at: https://www.sdge.com/rates/rates-what-goes-sdge-bill-and-why-are-rates-higher; (2) Massachusetts Department of Resources (MA DOER). 2023. "Massachusetts Household Heating Costs." Available at: https://www.mass.gov/info-details/massachusetts-household-heating-costs

[40] Jordan, K. 2023. "Massachusetts Energy Prices Increases and Relief" [Blog]. Available at: https://majorenergy.com/massachusetts-energy-prices-increases-and-relief/#:~:text=National%20Grid%20electric%20rates%20increased,are%20estimated%20to%20increase%2038%25.

Figure 5. Massachusetts historical winter heating fuel prices



Source: Reproduced from: Massachusetts Department of Energy Resources. 2023. "Winter Season Average Residential Heating Fuel Prices" [Figure]. Available at: https://www.mass.gov/info-details/massachusetts-household-heating-costs#factors-impacting-heating-prices-this-

Forecasts of residential gas and electric prices in New England

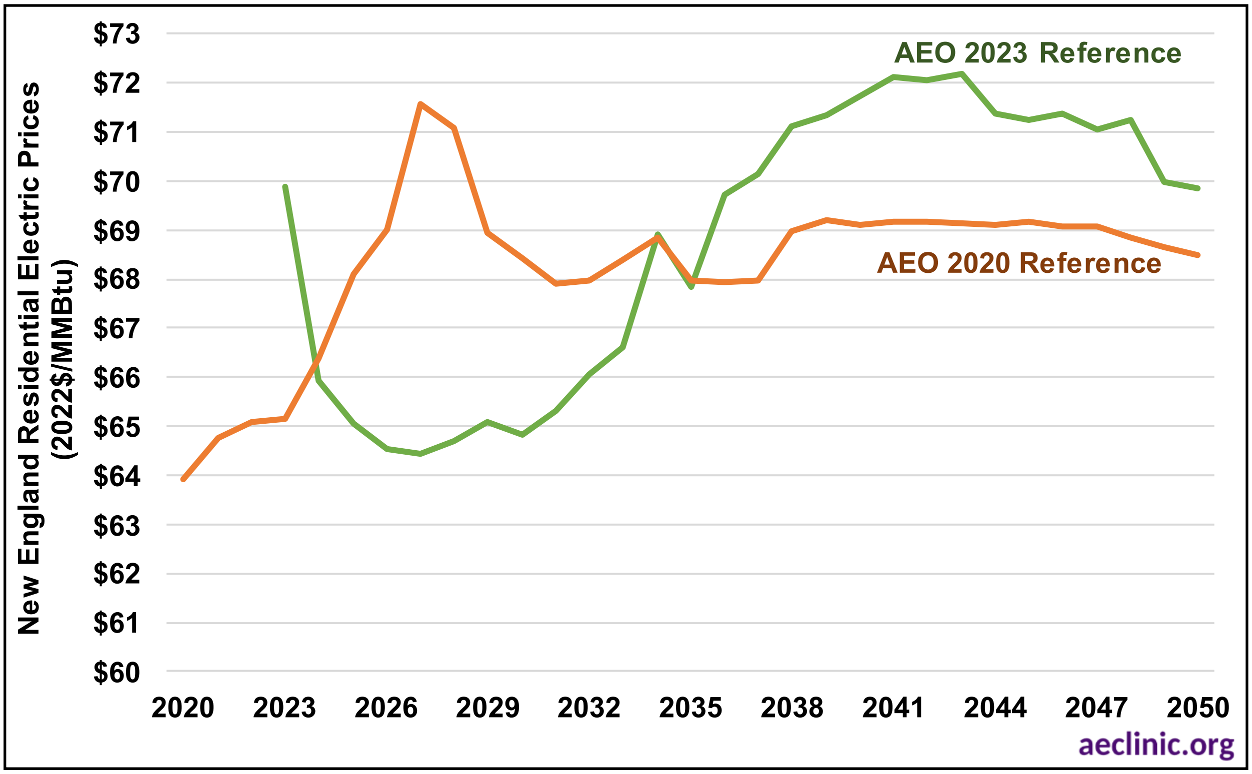
EIA's 2020 and 2023 AEO gas and electric price projections are entirely dissimilar (see Figure 6 below):

- The **2020 AEO** New England Reference case projection expected residential electric prices to grow an average 0.2 percent annually from 2023 to 2050.
- The **2023 AEO** New England Reference case projection predicts residential electric prices will rise and fall in comparable proportions from 2023 to 2050 so that the annual growth rate is close to zero (-0.002 percent).[41]

In the 2020s, the 2020 AEO projection rises; using the 2023 AEO projection, it falls.

[41] U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3]. *Annual Energy Outlook 2023*.

Figure 6. Comparison of 2020 and 2023 AEO forecasted New England residential electric prices



Data source: (1) U.S. EIA. 2020. "Energy Prices by Sector and Source" [Table 3]; (2) U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3].

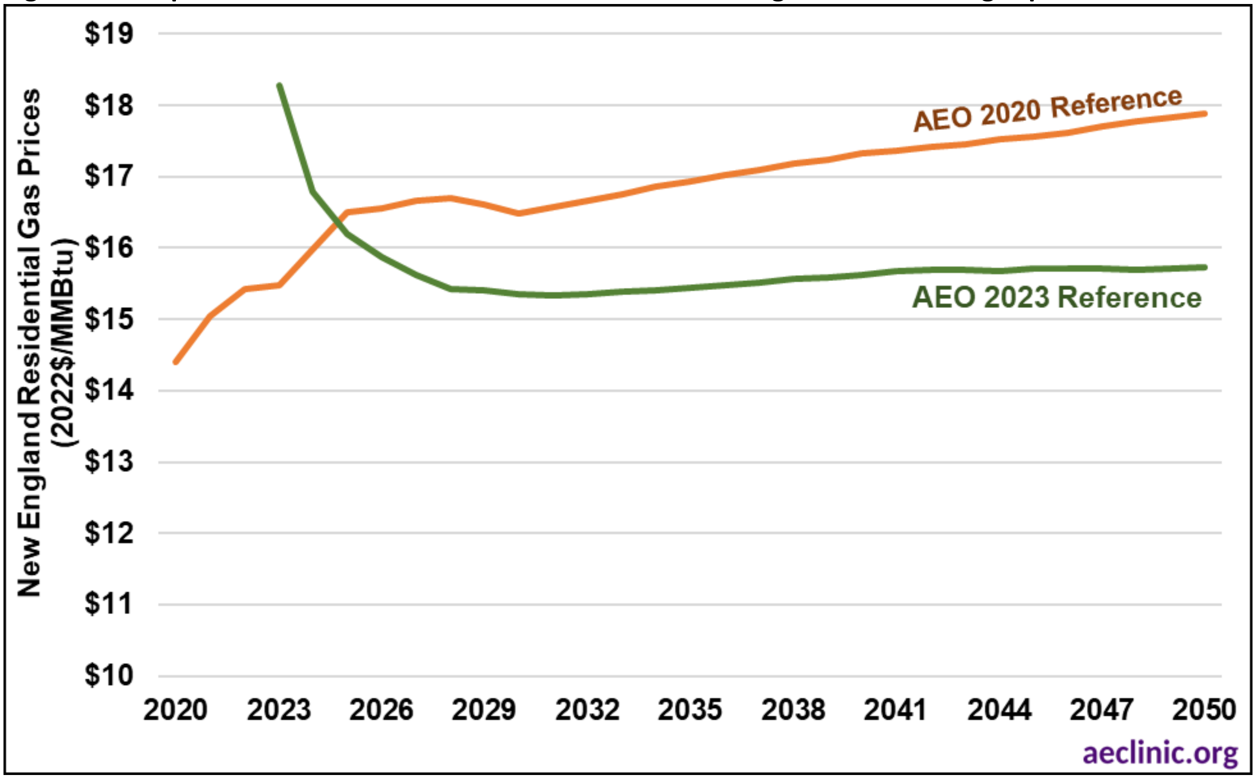
Similarly, EIA's 2020 and 2023 AEO gas price projections follow opposite trends (see Figure 7):

- The **2020 AEO** New England Reference case projection expected residential gas prices to grow an average of 0.5 percent annually from 2023 to 2050.
- The **2023 AEO** New England Reference case projection predicts residential gas prices will fall 0.6 percent annually from 2023 to 2050.[42]

These changes in AEO's forecasts make the difference between a predicted inflection point for the cost of heating the average Massachusetts home and a prediction that the operation of ASHPs will remain more costly than that of gas-fired furnaces through 2050.

[42] Ibid.

Figure 7. Comparison of 2020 and 2023 AEO forecasted New England residential gas prices



Data source: (1) U.S. EIA. 2020. "Energy Prices by Sector and Source" [Table 3]; (2) U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3].

Forecasts of the relative costs of future home heating operations are simply not robust to the substantial year to year differences in energy price forecasts. In the 2020 AEO forecast, New England residential gas prices were expected to increase at a higher rate than electric prices, lowering the cost to heat the average home with ASHPs below that of gas-fired heating systems. Compared to the 2020 AEO forecast, the latest 2023 AEO forecasts higher electric prices relative to gas prices calling into question the affordability of heating the average building using electric systems like ASHPs. Moreover, in the 2020 AEO forecast, expected electric prices from 2023 to 2050 were lower on average compared to the 2023 AEO forecast, making electric heating more expensive.

Each new energy price forecast means new findings: Which heating technology is least expensive?

> *As each new year's energy price forecasts change so too will the findings of which heating technology is least expensive.*

Individual or networked GSHPs are the least expensive heating option for Massachusetts households today, and they will continue to be the most economic choice in the future: Ground-source heating pumps are cheaper than heating with gas. The future economics of ASHPs, however, are far from certain. The EIA's most recent energy price forecasts suggest that gas heating will continue to cost households less through the 2050s. Our previous analysis in 2021 gave a very different result, showing ASHP's cost of operations falling below that of gas furnaces by 2030. This change in outcome has everything to do with uncertain expectations regarding future energy prices. Our conclusion is that the finding of which will be cheaper, ASHP or gas heating, is not robust. As each new year's energy price forecasts change so too will the findings of which heating technology is least expensive.

Households—and policy-makers—cannot count on ASHPs being less expensive in the future. And today's energy price projections suggest that without new rate design and/or tariff schedules gas heating will be cheaper. Moreover, installation of GSHPs is more costly than ASHPs and requires particular siting conditions, making GSHPs less accessible to most households compared to ASHPs which are installed above ground.[43] The transformation in heating practices expected in the Massachusetts *2050 Decarbonization Roadmap*[44] and *Clean Energy and Climate Plan*[45] to meet the Commonwealth's net-zero emissions target (i.e., installing a heat pump in nearly every Massachusetts home) will require a solution to this problem: Why should households shift to heat pumps when gas heating may very well cost less?

Solutions to this problem include:

- **Investment in networked geothermal:** Networked geothermal systems are the most affordable heating option but have the highest upfront costs and require neighborhood-wide decisions and investments. Gas utility investment in networked geothermal systems presents an opportunity to preserve jobs lost as utilities transition away from gas, meet Massachusetts's climate targets, and provide cheaper energy for buildings and homes.[46]
- **Increase incentives to reduce the cost of GSHPs:** Like ASHPs, GSHPs are more efficient than conventional heating systems but have high upfront costs. GSHP installations can cost anywhere from $10,000 to $30,000, several thousand more than an ASHP which can cost between $4,000 and $10,000.[47] Existing programs to reduce the cost of GSHPs (e.g., the federal Residential Renewable Energy Tax Credit[48]) allow some households to receive rebates for the installation of GSHPs, but not all households are able to cover the high upfront costs of GSHPs.[49]
- **Special electric tariffs for heat pump customers:** Alternative rate designs, such as demand charges or time-of-use pricing, have the potential to close the operating cost gap[50] between heating technologies and make ASHPs a cost-effective heating option relative to fossil-fuel heating systems like gas-fired furnaces.[51]

While residential customers can apply for rebates for ASHP purchases through Mass Save, most

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[43] Marsh, J. 2022. "Geothermal heat pump cost breakdown." *EnergySage*. Available at: https://www.energysage.com/heat-pumps/costs-benefits-geothermal-heat-pumps/

[44] Massachusetts Executive Office of Energy and Environmental Affairs. December 2020. *Massachusetts 2050 Decarbonization Roadmap*. Available at: https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download

[45] Massachusetts Executive Office of Energy and Environmental Affairs. June 30, 2022. *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*. Available at: https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download

[46] HEET. n.d. "Networked Geothermal." Available at: https://heet.org/geo/

[47] (1) Marsh, J. 2022. "Geothermal heat pump cost breakdown." *EnergySgge*; (2) McCabe, L. May 10, 2023. "How much does a heat pump cost in 2023?" *EnergySage*. Available at: https://www.energysage.com/heat-pumps/costs-and-benefits-air-source-heat-pumps/

[48] U.S. Internal Revenue Service. 2023. "Residential Clean Energy Credit." Available at: https://www.irs.gov/credits-deductions/residential-clean-energy-credit

[49] Marsh, J. 2022. "Geothermal heat pump cost breakdown." *EnergySage*.

[50] An "operating cost gap" is a measure that can be used to determine whether switching from one heating system to another would be a cost-effective choice for a given household. The "cost gap" is the difference between current and expected future operating costs and can be used to compare different heating systems.

[51] See AEC's recent white paper: Castigliego, J.R., E. Seliga, and E.A. Stanton. December 2023. *Space Heating with Heat Pumps: The Need for Alternative Rate Designs in Massachusetts*. Applied Economics Clinic White Paper, AEC-2023-12-WP-01. Prepared for the Green Energy Consumers Alliance (GECA). Available at: https://aeclinic.org/publicationpages/12/2023/space-heating-with-heat-pumps-the-need-for-alternative-rate-designs-in-massachusetts

households may not be able to take on a commitment to paying higher annual heating costs associated with the switch from gas-fired furnaces to ASHPs. Without new incentives to stimulate adoption of networked geothermal systems, further lower upfront costs of GSHPs, and re-design electric rates to better reflect the Commonwealth's plans for widespread heat pump adoption, customers will continue to rely on existing gas- and oil-fired heating systems to heat their homes, and Massachusetts will fall short of meeting its residential heating and cooling sector emission reduction targets.

Appendix A: Methodology and Assumptions

To estimate customer utility bills 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 50.4 MMBtu[52]). 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 2023. (Note: This analysis focuses exclusively on the operating costs of heating systems and does not consider equipment costs or the retrofit and/or installation costs associated with each heating system type. Rather, costs to heat the average home using electric heating technologies (ASHP, GSHP, or networked geothermal) compared to gas heating include: Massachusetts gas and electric rates projected into the future, and assumptions regarding changes to heating technology efficiency over time.)

Gas and electric prices

Annual growth rates in residential gas and electric prices are calculated using price forecasts from the U.S. EIA 2023 AEO for the Reference, High ("low oil and gas supply"), and Low ("high oil and gas supply") cases (see Figure 8 and Figure 9 below). Table 1 below reports the annual growth rate in residential gas and electric prices for each price forecast scenario. Although the findings provided in this white paper are based on AEO's reference case forecasts for residential gas and electric prices in New England, AEC also conducted a sensitivity analysis using the high and low case forecasts (see Figure 8 and Figure 9 below)—neither sensitivity had a substantive impact on the results of the analysis.

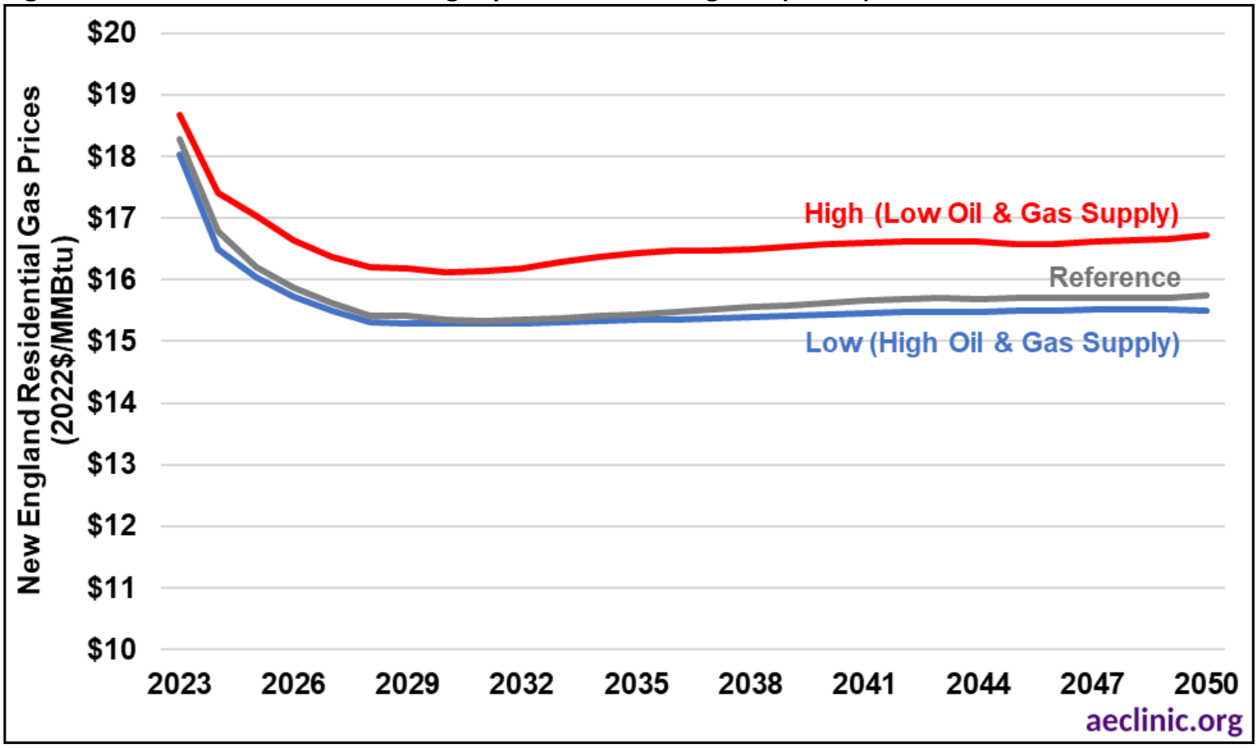
Table 1. Average annual growth rates for AEO price forecasts

2023 Annual Energy Outlook	Case/Scenario	Annual Growth Rate (2023-2050)
New England Residential Gas Price ($/MMBtu)	Reference Case	-0.6%
	Low Case (Low Oil and Gas Supply)	-0.6%
	High Case (High Oil and Gas Supply)	-0.4%
New England Residential Electric Price ($/MMBtu)	Reference	-0.002%
	Low Case (Low Oil and Gas Supply)	-0.2%
	High Case (High Oil and Gas Supply)	0.5%

Data source: U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3].

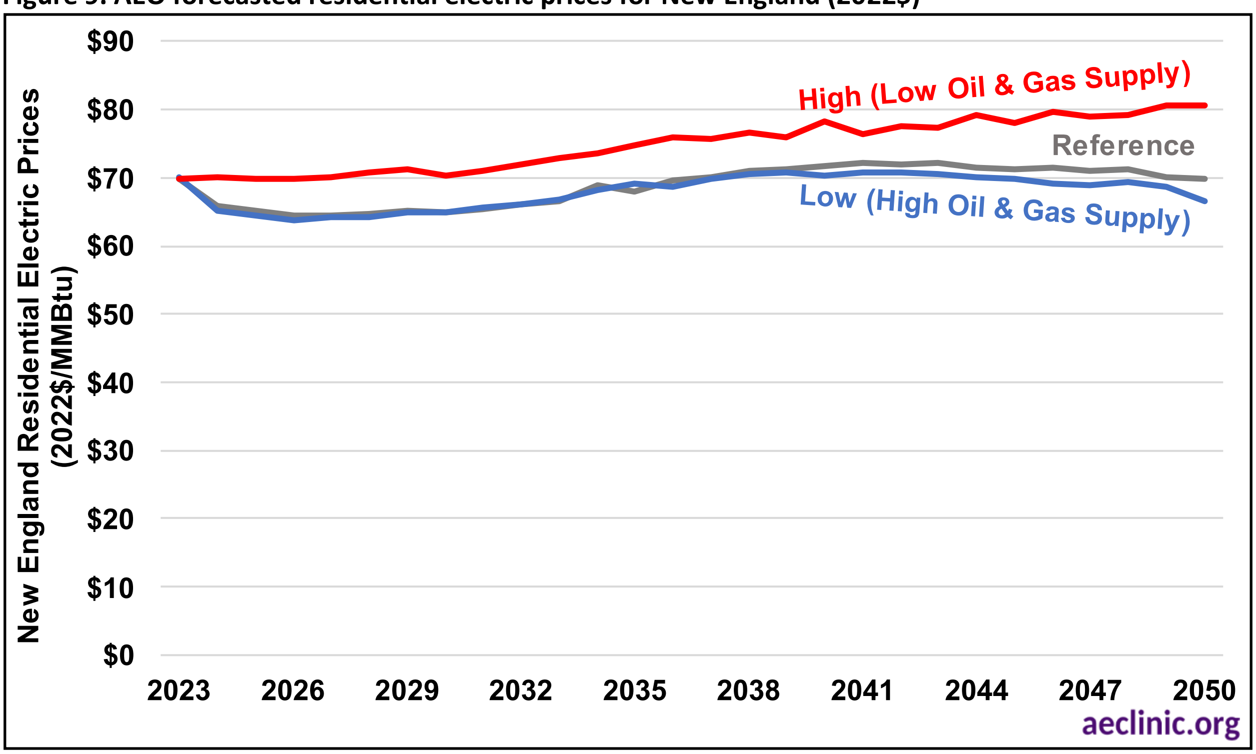
[52] U.S. EIA. 2020. Residential Energy Consumption Survey (RECS) [Table CE3.2]. Available at: https://www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce3.2.pdf

Figure 8. AEO forecasted residential gas prices for New England (2022$)



Data source: U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3].

Figure 9. AEO forecasted residential electric prices for New England (2022$)



Data source: U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3].

Gas rates in Massachusetts

Gas rates for 2023 are based on the most recent supply and delivery rates for each Massachusetts' gas utility and include the following charges and adjustment factors:

- **Supply Charges:**
  - Gas Adjustment Factor (GAF, $ per therm)
- **Delivery Charges:**
  - Fixed Monthly Customer Charge ($ per month; converted to an inferred $ per therm charge by dividing the equivalent annual customer charge by the EIA's 2022 annual residential gas sales[53] in therms for each utility)
  - Distribution Charge ($ per therm)
  - Revenue Decoupling Adjustment Factor (RDAF, $ per therm)
  - Local Distribution Adjustment Factor (LDAF, $ per therm)

A weighted[54] average of Massachusetts gas utilities' supply and delivery charges is calculated from these values (see Table 2).

Table 2. Summary of 2023 residential gas rates in Massachusetts by local distribution company

Local Distribution Company	Supply	Delivery	
	Cost of Gas Adjustment Factor ($ per therm)	Customer Charge ($ per month)	Total Delivery Charges ($ per therm)
National Grid	$0.882	$12.00	$1.277
Eversource	$0.899	$11.20	$1.134
Unitil	$0.362	$10.00	$1.924
Berkshire Gas Company	$0.974	$11.42	$0.954
Liberty Utilities	$1.017	$11.80	$0.808
Weighted Average	**$0.890**	**$11.69**	**$1.209**

Notes: The rates provided in this table correspond to the average rates of R-3 residential gas heating customers across all service territories by each distribution company.
Data sources: (1) Massachusetts DPU Docket No. 23-PGAF-GRID. August 2023. Local Distribution Adjustment Clause Filing for

[53] U.S. EIA. 2022. *EIA Natural Gas Annual Respondent Query System*. Available at: https://www.eia.gov/naturalgas/ngqs/#?year1=2021&year2=2021&company=Name

[54] Utility rates are weighted by their share of total Massachusetts gas sales as reported by U.S. EIA. See: U.S. EIA. 2022. "EIA Natural Gas Annual Respondent Query System." Available at: https://www.eia.gov/naturalgas/ngqs/#?year1=2022&year2=2022&company=Name

November 1, 2023 through October 31, 2024. Attachment B. Submitted by Boston Gas Company d/b/a National Grid. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17790614%20 pp.6-7; (2) Massachusetts DPU Docket No. 23-PGAF-NSTAR. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Section IV. Submitted by NSTAR Gas Company d/b/a Eversource Energy. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17793237%20 p.3; (3) Massachusetts DPU Docket No. 23-PGAF-EGMA. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Section 7. Exhibit EGMA-MQ-2. Submitted by Eversource Gas Company of Massachusetts d/b/a Eversource Energy. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17793081 p.3; (4) Massachusetts DPU Docket No. 23-PGAF-FGE. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Attachment A. Submitted by Fitchburg Gas and Electric Light Company d/b/a Unitil. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17790510 p.3; (5) Massachusetts DPU Docket No. 23-PGAF-BERK. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Form II. Submitted by The Berkshire Gas Company. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17811435 p.17; and (6) Massachusetts DPU Docket No. 23-PGAF-LIB. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Form II. Submitted by Liberty Utilities (New England Natural Gas Company) Corp. d/b/a Liberty. Attachment 2. Schedule 1. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17791574

Using the efficiency rate for a new gas furnace (95 percent)[55] and the conversion factor (10 therms per MMBtu)[56], these utility-specific gas charges and adjustment factors were then converted from $ per therm to the more universally comparable 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 EIA's typical electric consumption for a gas furnace (631 kWh per year[57]) by the weighted average[58] of variable residential electric charges in Massachusetts ($0.32 per kWh) and then dividing that product by the U.S. EIA's 2022 annual residential gas sales in MMBtu for each utility.[59] See below for more details on Massachusetts electric rates.

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 2022 as reported to the U.S. EIA.[60] See below for more details on Massachusetts gas rates.

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 2023 AEO.[61] All other components of gas customer charges were assumed

[55] U.S. EIA. March 2023. Technology Forecast Updates - Residential and Commercial Building Technologies - Reference Case. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf.

[56] 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

[57] U.S. EIA. March 2023. Technology Forecast Updates - Residential and Commercial Building Technologies - Reference Case. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf. p.10

[58] See
Electric for further details. The weighted average of variable residential electric charges is calculated based on the relative annual residential electric sales for 2022 as reported by each utility to the U.S. EIA.

[59] U.S. EIA. 2022. "EIA Natural Gas Annual Respondent Query System." Available at: https://www.eia.gov/naturalgas/ngqs/#?year1=2022&year2=2022&company=Name

[60] U.S. EIA. 2022. "EIA Natural Gas Annual Respondent Query System." Available at: https://www.eia.gov/naturalgas/ngqs/#?year1=2022&year2=2022&company=Name

[61] U.S. EIA. 2023. "Energy Prices by Sector and Source" [Table 3].

to remain unchanged (in real, inflation-adjusted terms) in future years.

Electric rates in Massachusetts

The cost to customers includes all fixed and variable costs that residential customers would pay on their monthly gas or electric bill. Electric rates include the following charges and adjustment factors (see Table 3):

- **Supply Charges:**
  - Basic Service Charge ($ per kWh)
- **Delivery Charges:**
  - Fixed Monthly Customer Charge ($ per month; 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[62] in kWh for 2022 for each utility)
  - Distribution Charge ($ per kWh)
  - Transmission Charge ($ per kWh)
  - Transition Charge ($ per kWh)
  - Energy Efficiency Charge ($ per kWh)
  - Renewable Energy Charge ($ per kWh)
  - Distributed Solar Charge ($ per kWh)
  - Among other charges and adjustment factors

A weighted[63] average of Massachusetts gas utilities' supply and delivery charges is calculated from these values (see Table 3).

Table 3. Summary of 2023 residential electric rates in Massachusetts by electric distribution company

Electric Distribution Company	Supply	Delivery	
	Basic Service Charge ($ per kWh)	Customer Charge ($ per month)	Total Delivery Charges ($ per kWh)
National Grid	$0.141	$7.00	$0.156
Eversource	$0.157	$10.00	$0.144
Unitil	$0.212	$7.00	$0.206
Weighted Average	**$0.149**	**$8.22**	**$0.152**

[62] U.S. EIA. 2021. *EIA-861 Annual Survey Data*. Available at: https://www.eia.gov/electricity/data/eia861/

[63] Utility rates are weighted by their share of total Massachusetts electric sales as reported by U.S. EIA. See: U.S. EIA. 2022. Form EIA-861. Available at: https://www.eia.gov/electricity/data/eia861/

Notes: The rates provided in this table correspond to the average rates of R-1 residential electric customers across all service territories by each distribution company. Eversource also provides service to residential space heating customers in its R-3 rate class; these rates are identical to Eversource's R-1 rates except for the total delivery charges of $0.144 per kWh on average.
Data sources: Supply Charges: Massachusetts Department of Public Utilities. Accessed August 31, 2023. "Basic service information and rates." Available at: https://www.mass.gov/info-details/basic-service-information-and-rates. Delivery Charges: (1) National Grid. 2023. "Tariff Provisions: Summary of Electric Delivery Service Rates." M.D.P.U. No. 1-23-F. Available at: https://www.nationalgridus.com/MA-Home/Rates/Tariff-Provisions; (2) Eversource. 2023. "Tariff Provisions: Summary of Electric Delivery Service Rates." M.D.P.U. No. 1-23-D. Available at: https://www.eversource.com/content/docs/default-source/rates-tariffs/ma-electric/1-tariff-ma.pdf?sfvrsn=2c5b9f03_7; and (3) Unitil. 2023. "Massachusetts Residential Electric Rates." Available at: https://www.unitil.com/sites/default/files/2023-08/MA_Elect_Residential_Rates_0823.pdf

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 2022 as reported to the U.S. EIA.[64]

The efficiency rate for heat pump technologies is sometimes called 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.

The unit conversion from $ per kWh to $ per MMBtu differs by technology. According to the 2022 *Cadmus Residential ccASHP Building Electrification Study*,[65] the average COP during the heating season ranges from a low of 1.1 to a high of 3.23, with an average COP of 2.34.[66] The analysis in this white paper assumes that ASHPs installed into the future are highly efficient, with a COP of 3.0,[67] or 97.7 kWh per MMBtu. In addition, this analysis assumes that GSHPs have a COP of 4.5,[68] or 65.1 kWh per MMBtu, and that networked geothermal has a COP between 6 and 8, or 36.6 kWh to 48.8 kWh per MMBtu.[69] Using the efficiency rate and the EIA's conversion factor (293.1 kWh per MMBtu)[70], these utility-specific electric charges were then converted from $ per kWh to the more universal measure of $ per MMBtu.

To project residential customer charges into the future, the Basic Service Charge was escalated using the annual growth rate for electric price projection from the U.S. EIA's 2023 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 COP is also adjusted to increase over time based on the growth rate of the seasonal coefficient of performance projections derived from National Renewable Energy Laboratory's (NREL) performance projections for ASHPs under

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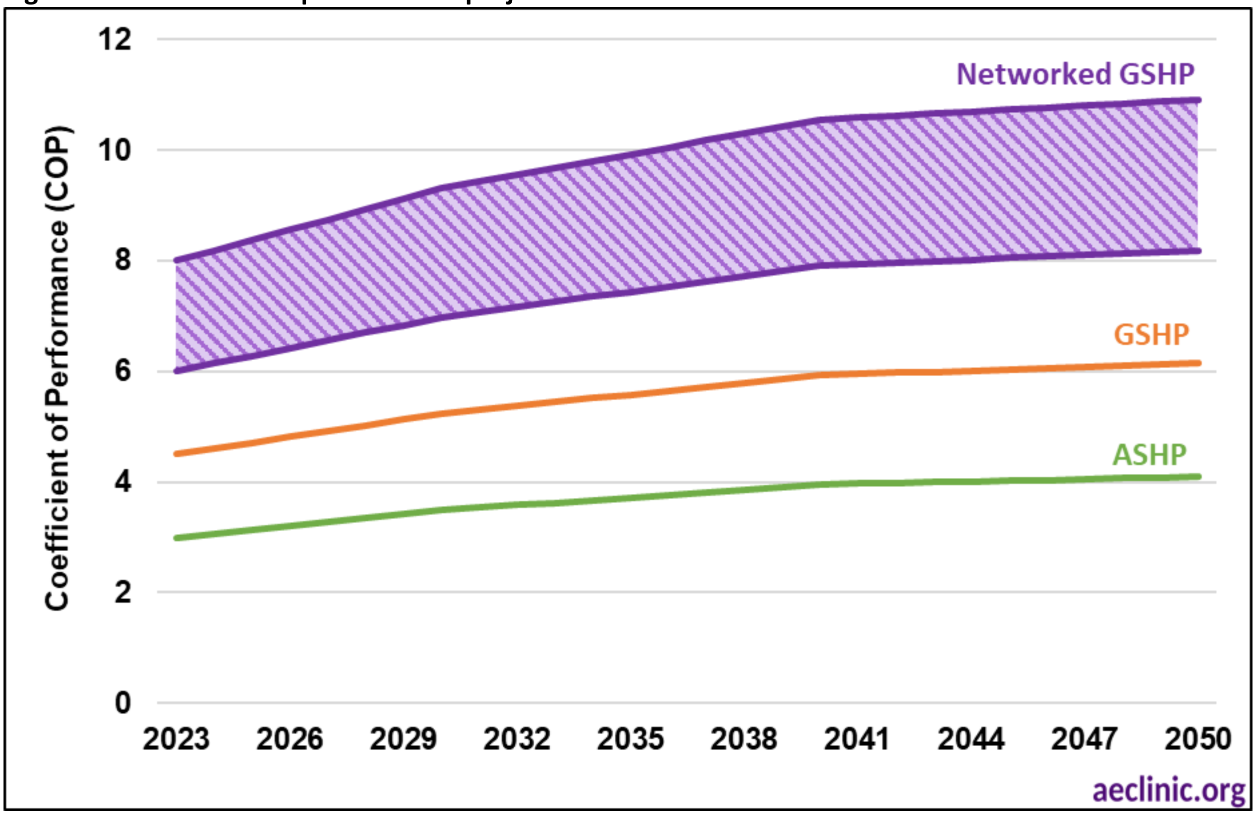
[64] U.S. EIA. 2018. *EIA-861 Annual Survey Data*. Available at: https://www.eia.gov/electricity/data/eia861/
[65] CADMUS. June 2022. Residential ccASHP Building Electrification Study. Available at: https://cadmusgroup.com/wp-content/uploads/2022/06/Residential-ccASHP-Building-Electrification-Study_Cadmus_Final_060322_Public.pdf
[66] Ibid. p. 22
[67] Ibid.
[68] U.S. EIA. March 2023. Technology Forecast Updates - Residential and Commercial Building Technologies - Reference Case. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf. p.11
[69] Oh, H., and Beckers, H. July 2023. Cost and performance analysis for five existing geothermal heat pump-based district energy systems in the United States. National Renewable Energy Laboratory. Available at: https://www.nrel.gov/docs/fy23osti/86678.pdf
[70] 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

the moderate advancement scenario (see Figure 10 below).[71]

Although the findings provided in this white paper are based on the moderate advancement scenario for heat pumps, AEC also conducted a sensitivity analysis using the slow and rapid advancement forecasts from NREL's performance projections for ASHPs[72]—neither sensitivity had a substantive impact on the results of the analysis.

Figure 10. Coefficient of performance projections under moderate advancement scenario



Data source: AEC calculation.

[71] Jadun, P., McMillan, C., Steinberg, D., Muratori, M., Vimmerstedt, L., and Mai, T. 2017. "Electrification Futures Study Technology Data." National Renewable Energy Laboratory. Last updated: September 16, 2022. doi: 10.7799/1414279.
[72] Ibid.