Memorandum

TO: MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION (DEP)

FROM: SUSTAINABLE ENERGY ADVANTAGE AND SYNAPSE ENERGY ECONOMICS

DATE: MAY 8, 2023

RE: DATA FOR USE IN ECONOMIC ANALYSIS OF A CLEAN HEAT STANDARD

Purpose

The purpose of this memo is to document assumptions and inputs that could be used in economic analysis a Massachusetts Clean Heat Standard. The data draws from existing sources such as the Mass Save program, including estimated capital and operating costs of different non-fossil heat technologies, the costs of fuels, and existing program costs that indicate potential costs associated with changing consumer purchasing behavior. Resource potential and emission reductions estimates are also included to provide context and inform economic comparisons between technologies and fuels.

The memo is organized by clean heat technology or fuel.

Electrification

The following section describes the costs and emissions reductions potential associated with heat pumps used for space and water heating.

Capital Costs

Mass Save presents total resource costs for each measure by sector. For the residential and commercial sectors, total resource cost (TRC) based costs represent the entire upfront system cost difference between the baseline and the low-carbon option. For income-eligible measures, TRC-based costs generally represent the full upfront cost of the measure, instead of the difference between the measure and the baseline option. (That is, the income-eligible measures assume that the replacement simply would not happen without programmatic intervention, not that it is happening and is shaped by the program.) The following table summarizes the range of TRC costs for the various electrification measures that the Mass Save Program Administrators (PAs) are offering in their 2022-2024 Energy Efficiency Plans. The Gas PAs did not plan to offer any electrification measures for the income-eligible sector, which is why some values are populated with N/As. The TRC ranges reflect the range of TRCs for different measures within each type. These include differentiation between single- and multi-family buildings, or between furnaces and boilers, for example.

Table 1. Mass Save TRC ranges by sector and measure type

Sector	Measure Type	Delivered Fuels	Gas
Residential	HVAC, Full Replacement, ASHP	$13,000-$19,000	$16,000-$22,000
Residential	HVAC, Full Replacement, GSHP	$20,000-$39,000	$20,000-$32,000
Residential	HVAC, Partial Replacement	$2,000-$13,000	$2,000-$13,000
Residential	Heat Pump Water Heater	$64-$1,000	$450
Income-Eligible	HVAC, Full Replacement, ASHP	$30,000-$35,000	N/A
Income-Eligible	HVAC, Partial Replacement	$13,000-$18,000	N/A
Income-Eligible	Heat Pump Water Heater	$2,700-$6,000	N/A
Commercial	HVAC, Full Replacement*	$20,000-$335,000	$20,000-$292,000
Commercial	HVAC, Partial Replacement	$17,000-$24,000	$17,000-$21,000

**Note: Commercial HVAC full replacement costs include custom project cost estimates, which set the high end of the cost range.*

The Massachusetts Clean Energy Center (MassCEC) also maintains a database of actual system costs for heat pump systems installed in the state. These costs vary depending on the type of heat pump technology installed. The costs ranged from roughly $16,000-$36,000 on average per home. There is not sufficient data to draw any robust conclusions from MassCEC data regarding different costs based on the existing heating fuel.

Table 2. Total installed system costs for residential heat pumps in Massachusetts.

System Type	Average Costs ($/ton)	Average tonnage	Average System Cost
Air to water	$8,621	4	$34,665
Centrally Ducted	$8,853	3	$23,839
Mixed of single- and multi-head minisplits	$9,231	4	$36,657
Multi-head minisplit	$8,398	3	$28,294
Single-head mini-split	$6,415	2	$15,934
Total	$8,353	3	$26,402

Source: Massachusetts Clean Energy Center. 2021. "Whole-home ASHP projects database." Available at: https://files-cdn.masscec.com/uploads/attachments/WholeHomePilotProjectDatabase_08.11.2021.xlsx.

Our installed cost estimates for commercial heat pumps for Massachusetts are based on two major sources as shown in Figure 3. As the original cost estimates are national estimates or for another state, we converted these values to Massachusetts values based on regional cost factors. The total installed costs range from $1,730 to $3,400 per ton of heating capacity, depending on the system type. We then estimated the average statewide cost per ton across all system types, based on the system-type saturation rates that we derived from Energy Information Administration's Commercial Building Energy Consumption Survey (CBECS). The resulting average installed cost is $2,246 per ton.

Table 3. Total installed system costs for commercial heat pumps

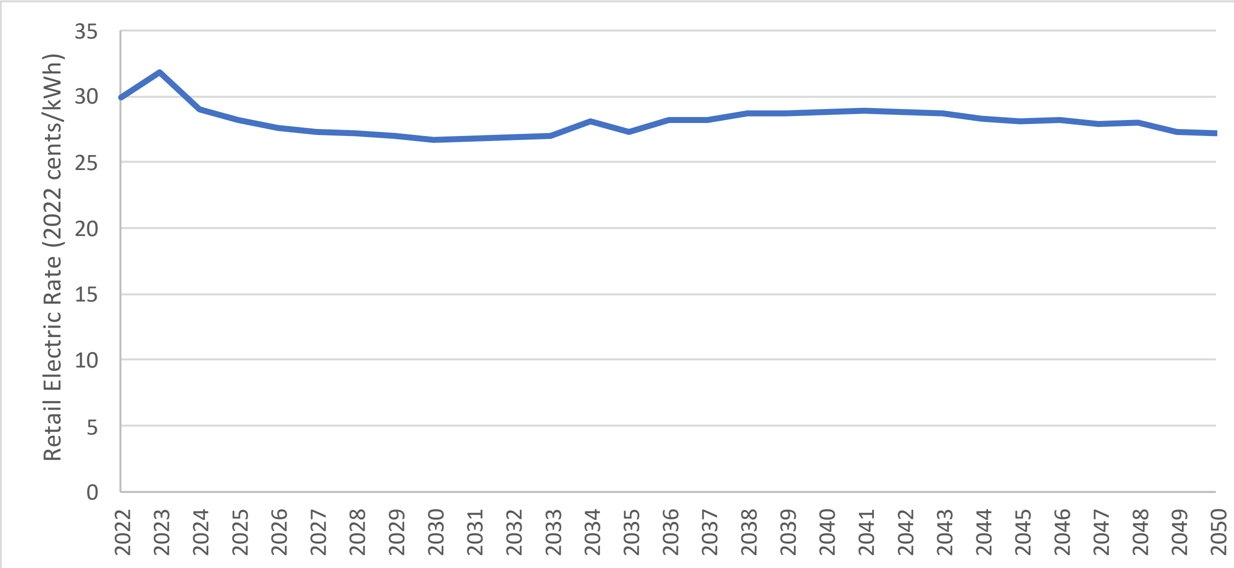
System Type	Average Costs (2022$/ton)	System type saturation based on CBECS
Packaged rooftop	$1,732	36%
Split system	$2,049	5%
Ductless mini splits	$2,055	18%
Variable refrigerant flow (VRF)	$3,401	20%
Air to water and water to water	$2,247	20%
Total	$2,246	N/A

Source: California Technical Forum. "California Electronic Technical Reference Manual." Available at: https://www.caetrm.com/login/?next=/; Nadel, S., C. Perry 2020. Electrifying Space Heating in Existing Commercial Buildings. Available at: https://www.aceee.org/sites/default/files/pdfs/b2004.pdf.
**Note: the cost estimates are converted to Massachusetts based on RSMeans and also adjusted for inflation.*

Operating Costs

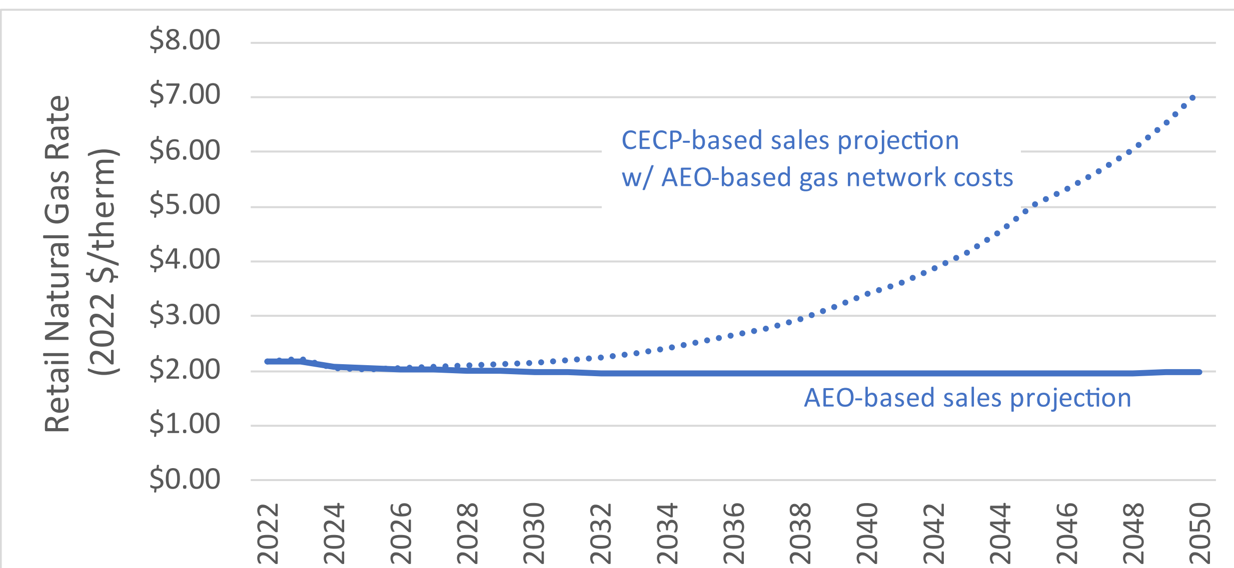
The operating costs of a heat pump system consist of the fuel costs associated with system operation. Since heat pumps require electricity, the operating costs will be based on the customer's retail electric rates. The current retail delivery price for Massachusetts residential customers is roughly 13.5 cents per kWh, while generation costs about 16.5 cents per kWh. While the future price of energy is uncertain, there are a number of ways to estimate future electric rates. For the purposes of this analysis, we have separated the all-in electric rate into generation, transmission, distribution, and other costs. We have projected generation, transmission, and distribution by scaling the 2022 actual prices (averaged across Eversource and National Grid) based on the New England projections from the 2023 EIA Annual Energy Outlook (AEO 2023). While we have only presented residential rates here, a similar method can be applied to commercial rates. We note that AEO 2023's reference case for New England does not comply with Massachusetts's clean energy requirements in the electric sector, nor does it include an electrification pathway in end uses that reflects the state's roadmap. Therefore, these rate projections are highly approximate more than a few years into the future.

Figure 1. Residential retail electric prices



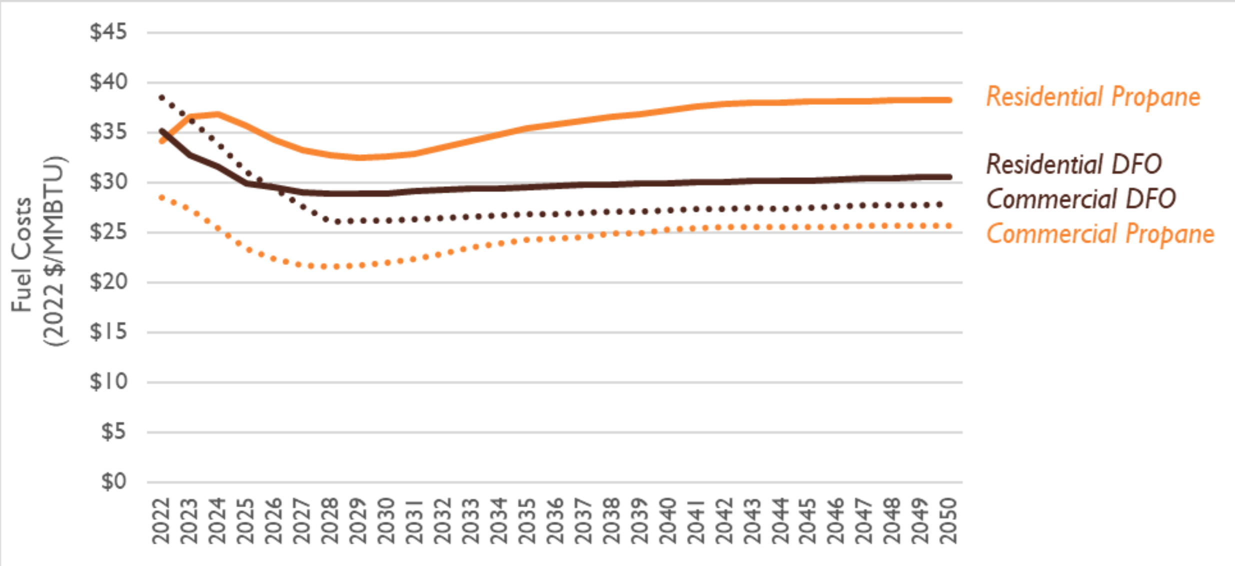
For heating systems relying on natural gas, retail gas rates drive the operating costs. To estimate future gas rates, we took a similar approach to the electric retail rates. We began by dividing the gas rate into delivery and supply components, then scaled both current rate components based on AEO 2023 projections. We then prepared an alternate case in which we used the same fixed delivery costs of the gas network but divided these costs among fewer therms of gas delivered, along the "phased" gas use trajectory from the analysis presented in the Clean Energy and Climate Plan for 2050 (CECP). This provides a rough estimate of the high end of plausible gas retail delivery rates. While we have only presented residential rates here, a similar method could be applied to commercial rates.

Figure 2. Residential retail natural gas prices



For delivered fuels such as propane and oil, AEO 2023 projects that residential oil, commercial propane, and commercial oil costs will decrease through 2030 and then flatten out through 2050. For residential propane costs, AEO projects costs will decrease through 2030 and then increase again to levels higher than the present day (see Figure 3).

Figure 3. AEO 2023 projected fuel costs for New England

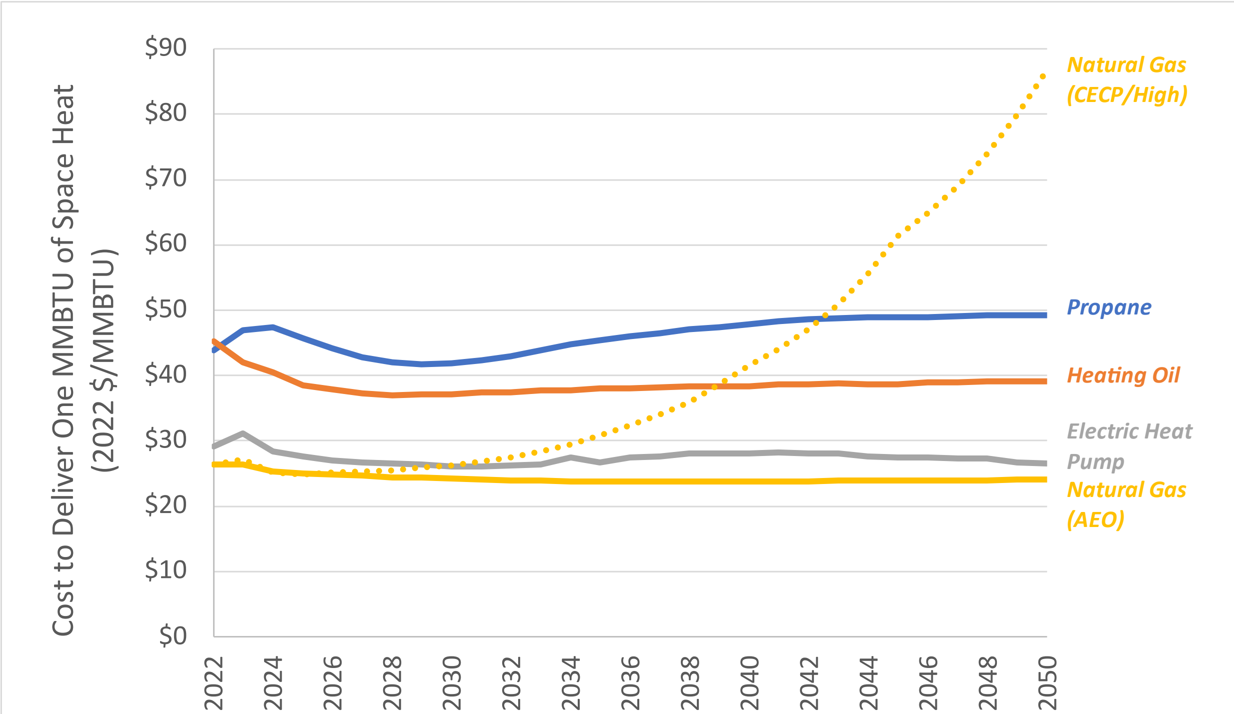


Fuel comparison

Figure 4 places the retail price projections presented above onto a common framework to allow comparison of space heating costs. This analysis uses the assumed efficiencies used by the Department of Energy Resources[1] to convert the fuel costs into the cost to deliver space heat into a residential building. One MMBTU of heat is about as much heat as a large home in Massachusetts requires on the coldest day of the winter.

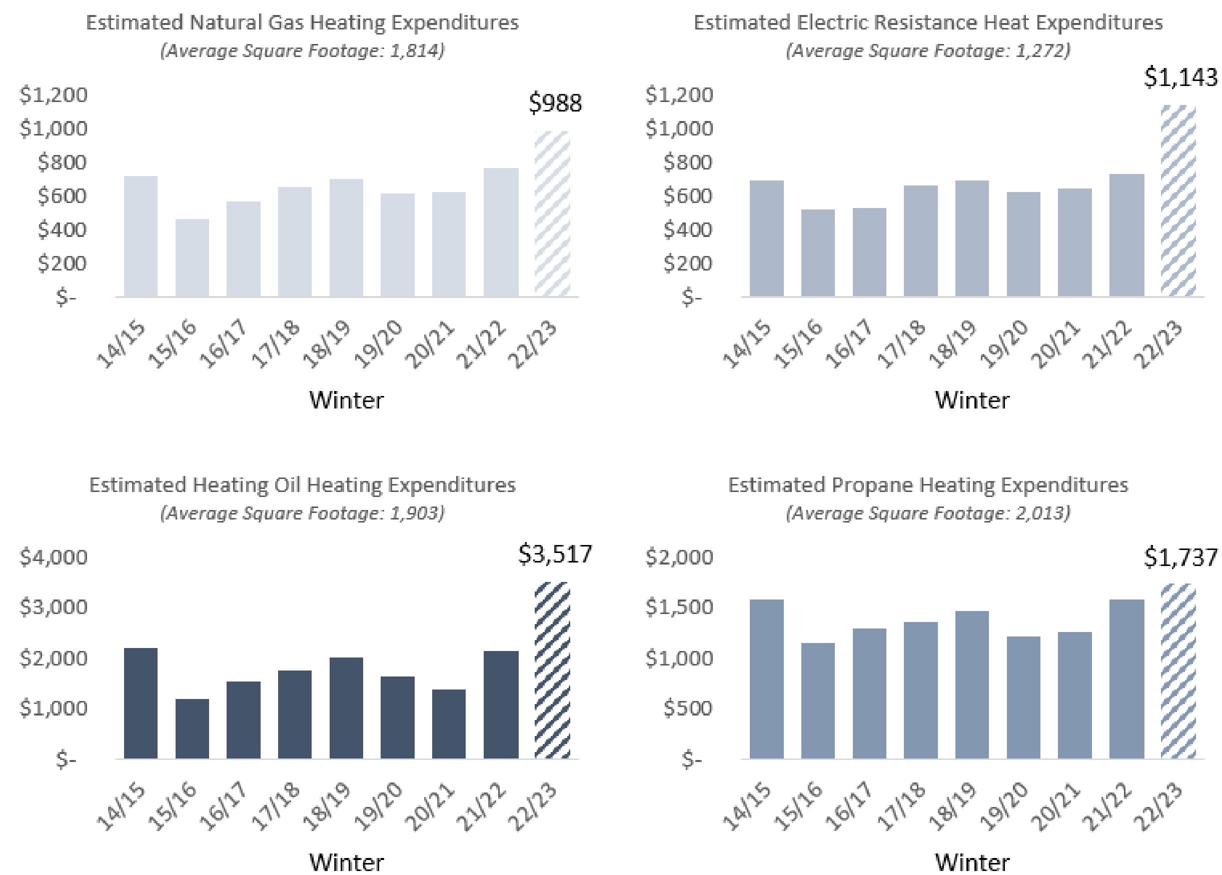
[1] MA Department of Energy Resources. Massachusetts Household Heating Costs. Available at: https://www.mass.gov/info-details/massachusetts-household-heating-costs.; Note: We used the ratio between fuel cost and heat cost presented in Figure 2.

Figure 4. Residential delivered heat cost comparison, using AEO 2023-based fuel price projections



These cost projections reflect projections of the average price for different fuels over a multi-decade period. However, fuel prices and annual heating costs are volatile, driven by the weather, economy, technological advancement, and geopolitical factors. Figure 5 shows the variation in annual heating costs for households using each of four different fuels over the last nine winters. These calculations reflect only changes in fuel cost; space heating costs also vary based on the severity of any given winter.

Figure 5. Winter Season Average Residential Household Space Heating Expenditures



Reproduced from MA DOER Massachusetts Household Heating Costs; https://www.mass.gov/info-details/massachusetts-household-heating-costs

Program Costs

Below, we present three different cost categories for measures that Mass Save is currently incentivizing. We calculated the costs using a weighted-average approach based on the portfolio of measures that the PAs proposed in their most recent EE Plan. We note that different PAs rely on different TRC and incentive cost assumptions for numerous measures in the plan, which impact the calculated statewide weighted average program costs.

For the residential and commercial TRC-based costs, these represent the entire upfront cost difference between the baseline and the low-carbon option. For income-eligible TRC-based costs, these are the full equipment costs. The planned range of measures included within each average varies between residential and income-eligible, so these averages are not directly comparable even after accounting for the difference between cost-differential and full-cost approaches. The "incentive cost" represents the amount required to achieve emissions reductions at the same rate as Mass Save if the program were to exit these measures. The customer cost is equal to the difference between the Mass Save cost and the

TRC. In general, the commercial sector costs are much higher than the other sectors due to larger project sizes and higher amounts of custom projects.

Table 4. Weighted-Average Mass Save TRC, Incentive, and Customer Costs for electrification measures in the 2022-2024 Plan.

Sector	Base fuel	End use	TRC-cost ($)	Incentive cost ($)	Customer cost ($)
Residential	Oil	HVAC, Full Replacement	$16,167	$10,848	$5,319
Residential	Oil	HVAC, Partial Replacement	$11,665	$4,044	$7,620
Residential	Oil	Hot Water	$753	$710	$43
Residential	Propane	HVAC, Full Replacement	$16,747	$10,993	$5,755
Residential	Propane	HVAC, Partial Replacement	$11,637	$4,077	$7,560
Residential	Propane	Hot Water	$1,049	$543	$506
Income Eligible	Oil	HVAC, Full Replacement	$30,000	$30,000	$0
Income Eligible	Oil	HVAC, Partial Replacement	$15,969	$15,969	$0
Income Eligible	Oil	Hot Water	$3,732	$3,732	$0
Income Eligible	Propane	HVAC, Full Replacement	$30,000	$30,000	$0
Income Eligible	Propane	HVAC, Partial Replacement	$15,529	$15,529	$0
Income Eligible	Propane	Hot Water	$4,661	$4,661	$0
Commercial	Oil	HVAC, Full Replacement*	$233,224	$170,195	$63,029
Commercial	Oil	HVAC, Partial Replacement	$20,596	$14,417	$6,179
Commercial	Propane	HVAC, Full Replacement*	$236,647	$172,703	$63,944
Commercial	Propane	HVAC, Partial Replacement	$22,928	$16,050	$6,878
Residential	Gas	HVAC, Full Replacement	$16,393	$7,859	$8,533

Sector	Base fuel	End use	TRC-cost ($)	Incentive cost ($)	Customer cost ($)
Residential	Gas	HVAC, Partial Replacement	$11,693	$3,961	$7,732
Residential	Gas	Hot Water	$457	$200	$257
Commercial	Gas	HVAC, Full Replacement*	$227,406	$136,953	$90,453
Commercial	Gas	HVAC, Partial Replacement	$17,143	$12,000	$5,143

**Note: Commercial HVAC full replacement costs include custom project cost estimates.*

Emissions Reductions

Mass Save uses a net emissions approach to estimate the emissions reduction potential of electrification measures such that the reduction in emissions from on-site fuel combustion is netted with the emissions from the electricity used to operate the measure. We present emissions impact assumptions using Mass Save's approach, with the on-site contribution separated out for clarity.

New England relies on fossil fuel generators to produce electricity, along with clean energy sources such as nuclear and renewable generation. Many states in New England, including Massachusetts, have policies that will increase the amount of generation from clean energy over time. This means that, under a netting approach, an electrification measure installed in the future, when the grid is cleaner, will displace more CO_2 emissions over its lifetime than an electrification measure installed today, because the emissions associated with its electricity use will be lower.

Table 4 presents the average net lifetime avoided CO_2e emissions associated with installing a full HVAC replacement, partial HVAC replacement, and water heater heat pump system in 2023, on an on-site-only basis and using Mass Save's assumptions. These values were calculated based on the Mass Save Program Administrators' 2022-2024 Energy Efficiency Plan.

Table 4. Mass Save average net lifetime avoided CO2e emissions for measures installed this year, metric tons

		Existing Fuel					
		Onsite avoided CO2e emissions			Net avoided CO2e emissions		
Sector	Measure Type	Oil	Propane	Gas	Oil	Propane	Gas
Residential	HVAC, Full Replacement	145	114	79	131	101	62
Residential	HVAC, Partial Replacement	50	44	27	43	36	20
Residential	Heat Pump Water Heater	20	13	10	18	12	8
Commercial	HVAC, Full Replacement	120	96	62	101	77	43
Commercial	HVAC, Partial Replacement	72	57	47	63	49	39

Building Envelope Improvements

Building envelope measures such as air sealing and insulation have consistently provided cost-effective savings for energy efficiency programs. The following sections describe the costs and emissions reductions potential of these measures.

Capital Costs

According to Mass Save, air-sealing measures cost around $800-$900 per residential dwelling unit to install. Insulation is a more costly building envelope improvement at $2,000-$4,000 per dwelling unit. Capital costs for commercial projects vary widely depending on the building. Mass Save estimates that commercial air-sealing is comparable in price to residential installations, while insulation can cost between $1,500 and $20,000 per project.

Program Costs

Using these capital cost estimates along with Mass Save incentive offerings, we developed the same three categories of costs for building envelope measures as we did for the electrification measures above. See Table 5 for a summary of measure costs by category. In general, the commercial sector costs are much higher due to the larger project sizes and higher amounts of custom projects.

Table 5. Weighted-Average MassSave TRC, Incentive, and Customer Costs for the 2022-2024 Plan.

Sector	Base fuel	End use	TRC-cost ($)	Incentive cost ($)	Customer cost ($)
Residential	Oil	Envelope	$1,938	$1,560	$378
Residential	Propane	Envelope	$1,265	$1,012	$253
Income Eligible	Oil	Envelope	$3,678	$3,678	$0
Income Eligible	Propane	Envelope	$1,275	$1,275	$0
Commercial	Oil	Envelope	$13,108	$9,548	$3,559
Commercial	Propane	Envelope	$15,405	$11,216	$4,190
Residential	Gas	Envelope	$1,669	$1,418	$251
Income Eligible	Gas	Envelope	$1,858	$1,858	$0
Commercial	Gas	Envelope	$7,732	$4,222	$3,510

Emissions Reductions

The magnitude of GHG reductions per building envelope measure installed is relatively small compared to space-heating electrification measures. As with electrification measures, building envelope emissions reductions are dependent on the fuel-type used to heat the building. Insulation measures also tend to have higher savings impacts than other envelope improvements such as air sealing and window replacements. Table 6 below summarizes the range of emissions impacts that building envelope measures are assumed to have, according to the *Mass Save 2022-2024 Plan*.[2]

Table 6. Mass Save net lifetime avoided CO2e emissions ranges for measures installed this year, metric tons

		Existing Fuel		
Sector	Measure Type	Oil	Propane	Gas
Residential	Envelope	1-34	1-21	1-20
Income-Eligible	Envelope	6-45	10-34	2-29
Commercial	Envelope*	7-40	1-40	2-5,600

**Note: Commercial envelope emissions include custom project estimates, which set the high end of the emissions reduction range.*

[2] Plan and supporting documents are available from Massachusetts Energy Efficiency Advisory Council. "Plans and Updates: Three-Year Electric & Gas Energy Efficiency Plans." Available at: https://ma-eeac.org/plans-updates/.

Biomethane

Potential

Renewable natural gas (RNG or "biomethane"), can be produced via two pathways: anaerobic digestion and thermal gasification. In the near term, biomethane will likely be mainly produced from landfills and anaerobic digestion of other organic materials (e.g., animal manure), as thermal gasification of feedstocks is still a nascent technology. The availability of renewable natural gas (RNG) for use in heating-sector decarbonization is limited by both availability of feedstocks for RNG production and demand for RNG in other sectors that use natural gas (such as the electric generation, transportation, and industrial sectors). ICF International reported high and low resource potential estimates for biomethane by 2040 in a report for the American Gas Foundation.[3] Table 7 below presents the resource potential estimates for biomethane produced annually by 2040 in Massachusetts and the greater New England region. Most of the Massachusetts-sourced biomethane would be available from landfills and municipal solid waste, followed by waste-water recovery, food waste, and forest residues. The availability of RNG for use in Massachusetts is not necessarily limited to what can be produced in-state; RNG could be imported from other regions. However, just as Massachusetts will be looking for ways to decarbonize, so will other states. Thus, the extent to which Massachusetts can import RNG is in part limited by competing demand from other states.

It should be noted that these production potential estimates are meant to demonstrate the potential for RNG production that could occur in 2040, given the right set of factors. Current RNG production is relatively limited and is mainly used for on-site power generation or for vehicle fuel.

[3] ICF International. 2019. Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment. Prepared for the American Gas Foundation. Available at https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf.

Table 7. Biomethane resource potential in 2040

	Feedstock	Massachusetts (tBtu / year)		New England (tBtu / year)	
		Low	High	Low	High
Anaerobic Digestion	Landfill Gas	5.7	9.3	13.3	21.7
	Animal Manure [a]	0.10	0.21	8.0	16.0
	Water Resource Recovery Facilities	0.62	0.86	1.1	1.6
	Food Waste	0.81	1.4	1.8	3.1
	Subtotal	7.2	11.8	24.2	42.4
Thermal Gasification	Agricultural Residues	0.01	0.03	0.0	0.1
	Forestry and Forest Residues	0.61	1.2	3.6	7.3
	Energy Crops	0.04	0.08	0.2	0.5
	Municipal Solid Waste	6.6	14.8	14.4	32.4
	Subtotal	7.2	16.1	18.2	40.3
Total		**14.4**	**27.9**	**42.4**	**82.7**

a. Animal manure sources include dairy, swine, and poultry. In New England, all potential is from dairy.
Source: Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment, American Gas Foundation

Emissions reductions

Table 8 shows the lifecycle emissions of biomethane produced from different feedstocks. Emissions values are based on the California Low Carbon Fuel Standard (LCFS) values. Landfill gas has the lowest emission reduction potential compared to conventional natural gas, whereas animal manure offers the greatest emissions reductions (9.7 versus 241.8 of kg of CO_2 equivalent per MMBtu, respectively).

Table 8. Biomethane emissions

	Feedstock	Emissions (gCO_2e/MJ) [a]	Avoided Emissions ($kgCO_2e/MMBtu$) [b]
Anaerobic Digestion	Landfill Gas	55.7	9.7
	Animal Manure	-164.2	241.8
	Water Resource Recovery Facilities	55.8	9.7
	Food Waste	30.8	36.1
Thermal Gasification	Agricultural Residues	30.8	36.1
	Forestry and Forest Residues	30.8	36.1
	Energy Crops	30.8	36.1
	Municipal Solid Waste	30.8	36.1

a. Emissions based on LCFS lifecycle estimates, adjusted for pipeline compression. Source: California Air Resources Board. "Table 8. Temporary Pathways for Fuels with Indeterminate Cis". Available at https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/temp.pdf?_ga=2.263661061.848824970.1680539020-2094476347.1680539020.

b. Avoided emissions are compared to emissions from pipeline natural gas.

Fuel costs

Table 9 shows the cost of production, incremental cost of production compared to natural gas, and the cost of production per ton of emissions reductions. Biomethane produced from animal manure offers the greatest emissions reductions per dollar, but availability in Massachusetts is limited relative to other feedstocks. There is a greater regional potential for animal manure, although, historically, lack of pipeline access and the number of small farms have been significant barriers to accessing this resource. In contrast, biomethane produced from landfill gas may be available at a lower cost per emissions reductions compared to other feedstocks.

Table 9. Biomethane production cost and emissions reduction cost

	Feedstock	Production Cost ($/MMBtu)	Incremental Cost ($/MMBtu) [a]	Cost per Emissions Reductions ($/avoided metric ton CO2e)
Anaerobic Digestion	Landfill Gas	$7.10-$19.00	$3.60-$15.50	$370-$1,595
	Animal Manure	$18.40-$32.60	$14.90-$29.10	$62-$120
	Water Resource Recovery Facilities	$7.40-$26.10	$3.90-$22.60	$401-$2,325
	Food Waste	$19.40-$28.30	$15.90-$24.80	$440-$687
Thermal Gasification	Agricultural Residues	$18.30-$27.40	$14.80-$23.90	$410-$662
	Forestry and Forest Residues	$17.30-$29.20	$13.80-$25.70	$382-$712
	Energy Crops	$18.30-$31.20	$14.80-$27.70	$410-$767
	Municipal Solid Waste	$17.30-$44.20	$13.80-$40.70	$382-$1,128

a. Incremental cost of biomethane compared to average forecasted natural gas cost. Source: EIA. 2022 Annual Energy Outlook. https://www.eia.gov/outlooks/aeo/.

The price of RNG is uncertain and will likely be impacted by multiple factors that may have opposite price effects, such as the cost and availability of feedstocks, demand for RNG, and pace of technological development. While the cost of biomethane can be as low as $7.10 per MMBtu, the availability of these low-cost feedstocks is likely limited. Further, because the RNG market is still relatively undeveloped, we expect that the marginal cost of RNG will be closer to the high value of feedstock cost ranges. As the RNG market develops and demand for biomethane increases, higher cost feedstocks such as animal manure and thermal gasification feedstocks, which ICF estimates are available starting at approximately $17 per MMBtu, or higher-cost landfill gas, will likely set the marginal cost of RNG.

Hydrogen

Potential

Green hydrogen is hydrogen produced through the electrolysis of water: electricity from zero-carbon sources is run through water to separate hydrogen from oxygen. Green hydrogen is a potentially unlimited resource, limited only by the availability of cost-effective zero-carbon electricity. Practical limitations to its potential come from the necessary infrastructure, rather than the fuel itself. Hydrogen causes embrittlement of steel, so pipelines to carry it must be coated or made of another material. It also burns at a much higher temperature than natural gas. The combined impact of these two characteristics is that hydrogen either requires its own standalone pipeline infrastructure serving hydrogen-ready equipment, or is limited to blending with natural gas at relatively low levels. Many analyses assume a 20 percent blend limit by volume, which is about a 7 percent limit by energy.

However, an analysis on behalf of the California Public Utilities Commission showed that the practical limit may be closer to 5 percent by volume (less than 2 percent by energy) until all equipment connected to the gas system can be shown to be safe with a hydrogen blend.[4]

Emissions reductions

Hydrogen can be a zero-net-carbon resource if produced using zero-carbon electricity, such as renewable or nuclear energy. A 7 percent blend of zero-carbon hydrogen with natural gas (by energy) could lower the emissions per unit of energy delivered as much as 7 percent if there are no emissions from hydrogen leaks.

However, Hydrogen itself is a moderately potent greenhouse gas, once indirect atmospheric chemistry effects are accounted for, with a global warming potential of approximately 25 to 45 times that of CO_2 over a 20-year timeframe,[5] so leak management is an issue. Hydrogen has a lower GWP than methane, but is also a smaller molecule so small leaks can be a greater concern.

Fuel costs

Zero-carbon hydrogen is not produced at large volumes today, so cost estimates generally focus on point values in 10 to 20 years. The cost of zero-carbon hydrogen production via electrolysis of water depends on three primary factors: the cost of the input electricity; the cost and performance of the electrolyzer; and the capacity factor of the electrolyzer. Lazard calculated the cost of hydrogen produced using renewable energy across a range of these parameters, with and without public subsidies. Lazard finds that using a 20-100 MW electrolyzer, costs for hydrogen production could range between $0.83 (low end for subsidized, alkaline electrolyzer) and $7.37 per kg (high end for unsubsidized, PEM electrolyzer);[6] about $6 to $55 per MMBTU. This spans the same general range as biomethane. However, these costs are for fuel production only do not include the cost of infrastructure upgrades, which could increase these costs substantially.

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[4] California Public Utilities Commission. July 21, 2022. "CPUC Issues Independent Study on Injecting Hydrogen Into Natural Gas Systems." Available at: https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-issues-independent-study-on-injecting-hydrogen-into-natural-gas-systems

[5] Ocko, I. B. and Hamburg, S. P. 2022. *Climate consequences of hydrogen emissions*, Atmospheric Chemistry and Physics, 22, 14, 9349–9368. Available at: https://doi.org/10.5194/acp-22-9349-2022.

[6] Lazard. April 2023. *Lazard's Levelized Cost of Energy+*. Page 27. Available at: https://www.lazard.com/media/ruwg1jol/lazards-lcoeplus-april-2023.pdf.

Bioheating Oil

Potential

Approximately 21 percent of Massachusetts residential homes heat their homes with a fuel oil furnace or boiler, and four percent have a fuel oil water heater.[7] In 2020, according to the EIA, 512.4 million gallons of residential and 55.2 million gallons of commercial distillate fuel oil were sold in Massachusetts.[8]

We assume a current heating fuel oil blend of B5 (i.e., five percent biodiesel). Biodiesel blends above 20 percent (e.g., B100) require changes to customer equipment, which we expect would be a significant barrier to adoption of those blends. (The barriers relate to warranty coverage: most oil boilers are warranteed only up to a B20 blend. While some customers may be willing to violate their warranty, or their warranty has expired, we expect that this threshold will dampen retail interest to supply the fuel.) While renewable diesel does not require blending, renewable diesel is less widely available than biodiesel. The U.S. EIA projects domestic production capacity will more than double by the end of 2025, primarily driven by demand in the West Coast market.[9]

Emissions reductions

Based on California Low Carbon Fuel Standard emissions values, B20 offers an emission reduction of six to ten percent compared to a B5 baseline blend. Renewable diesel offers an emission reduction of approximately 63 percent compared to baseline. The emissions reductions of bioheating fuel can vary significantly and are in part dependent on the availability of low-carbon feedstocks.

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[7] Guidehouse. Massachusetts Residential Baseline Study. March 2020. Prepared for the Electric and Gas Program Administrators of Massachusetts. Available at: https://ma-eeac.org/wp-content/uploads/RES-1-Residential-Baseline-Study-Ph4-Comprehensive-Report-2020-04-02.pdf

[8] U.S. EIA. "Adjusted Sales of Distillate Fuel Oil by End Use." Available at: https://www.eia.gov/dnav/pet/pet_cons_821dsta_dcu_SMA_a.htm

[9] U.S. EIA. 2023. Today in Energy. "Domestic renewable diesel capacity could more than double through 2025." Available at: https://www.eia.gov/todayinenergy/detail.php?id=55399.

Table 10. Bioheating oil emissions

Fuel	Emissions ($kgCO_2e/MMBtu$) [a]	Avoided Emissions ($kgCO_2e/MMBtu$)
B5	102.2–103.6	N/A
B20	91.9–97.1	6.49–10.3
B100	29.8–58.0	45.6–72.4 [b]
Renewable Diesel	38.6	63.6–65.0

a. Synapse calculated based on LCFS emissions estimates for biodiesel and renewable diesel.
b. Low estimate reflects the average carbon intensity of biodiesel produced from fats, oils, and grease residues (Source: California Air Resources Board. "Table 8. Temporary Pathways for Fuels with Indeterminate Cis". Available at https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/temp.pdf?_ga=2.263661061.848824970.1680539020-2094476347.1680539020). High estimate reflects 2020 LCFS data (Source: California Air Resources Board. 2023. "Substitute Pathways and Default Blend Levels for LCFS Reporting for Specific Fuel Transaction Types." Available at: https://ww2.arb.ca.gov/resources/documents/substitute-pathways-and-default-blend-levels-lcfs-reporting-specific-fuel#footnote3_1cgif2z).

The maximum annual emissions reduction potential associated with replacing all heating oil with B20 produced from fats, oils, and grease residues ranges between 506 and 804 million $kgCO_2e$.

Table 11. Bioheating oil emissions reduction potential

	Units	Value
Statewide Annual Heating Oil Consumption	Million Gallons	568
Statewide Annual Heating Oil Consumption	tBtu	78
B20 Avoided Emissions	$kgCO_2e/MMBtu$	6.49–10.3
Emissions Reduction Potential	Million $kgCO_2e$	506 – 804

Fuel costs

As shown in Figure 6, the national average retail price of B20 generally tracks with diesel prices at a price at or slightly below diesel, due to federal subsidies. In contrast, the price of B100 sells at a premium compared to B20 and diesel. However, these prices may not be representative of fuels produced from the fats, oils, and waste greases that yield the largest emission reductions under the California scoring system cited above.

Figure 6. Average Retail Fuel Prices of Diesel and Biodiesel Blends in the United States

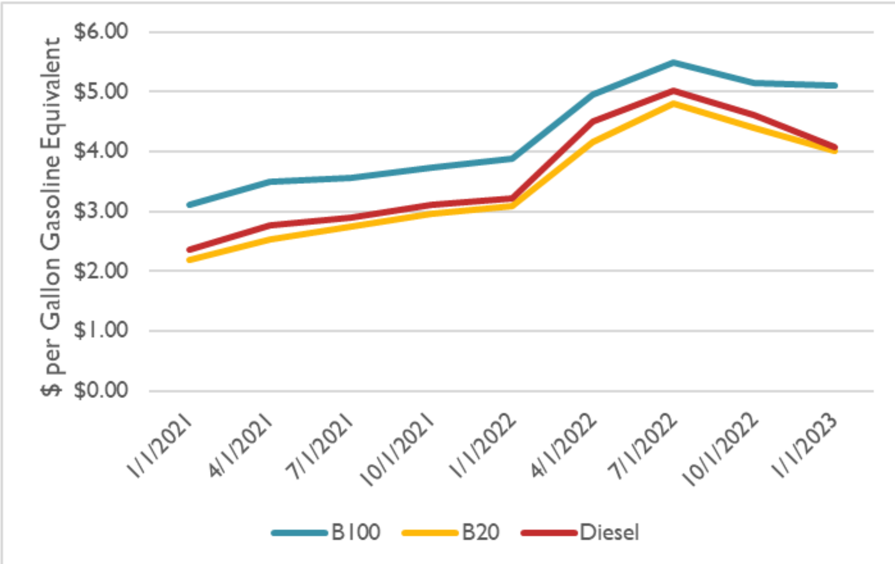

Figure data source: Alternative Fuels Data Center. Average Retail Fuel Prices in the United States. Available at: https://afdc.energy.gov/data/10326.

Clean Cities produces quarterly reports on retail fuel prices in the United States (without any specification of the fuel feedstock). In the most recent report, published in January 2023, the national average price of B100 was $0.063 per gallon higher than diesel, while B20 was $0.12 lower.[10] Notably, in New England, both B100 and B20 were cheaper than diesel. Table 12 displays retail prices of Diesel, B20, and B100 in January 2023. We display prices both in terms of dollars per gallon and dollars per diesel gallon equivalent.[11]

Table 12. January 2023 retail fuel prices

Region	Diesel Prices	B99/B100 Prices		B20	
	($/gal)	($/gal)	($/DGE)	($/gal)	($/DGE)
New England	$5.17	$4.50	**$4.95**	$4.37	**$4.46**

[10] U.S. DOE. 2023. *Clean Cities Alternative Fuel Price Report*. Available at: https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_january_2023.pdf?5f9051bfbf.

[11] Biodiesel has a lower energy content compared to diesel. We multiplied B100 $/gal prices by 1.1 and B20 prices by 1.02 to get $/DGE.

National Average	$4.58	$5.22	**$5.74**	$4.46	**$4.55**

Clean Cities also reports renewable diesel prices, although all prices are from California and are not differentiated by feedstock. The average of 86 renewable diesel prices reported in January 2023 was $5.57 per gallon, compared to the average retail diesel price in California of $5.53 per gallon.[12] This price includes any state or federal subsidies.

In the future, additional state or federal policies supporting the use of low-carbon fuels in the transportation and heating sectors could influence demand for B20 and renewable fuels, thus resulting in an increased incremental cost and cost of emissions reductions. This may already be true for fuels derived from derived from fats, oils, and grease residues, which have the lowest emissions on a lifecycle basis.

[12] U.S. DOE. 2023. Clean Cities Alternative Fuel Price Report. Available at: https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_january_2023.pdf?5f9051bfbf.

Appendix: Costs per Ton of Emissions Reduction

The following table presents the estimated TRC, incentive, and customer costs per avoided metric ton of CO_2 for energy efficiency (i.e., envelope) and electrification (i.e., HVAC and hot water) measures currently offered by Mass Save program administrators' plan for 2022-2024. All calculations were done using the benefit-cost models that the PAs filed with the DPU for their 2022-2024 Three-Year-Plan.

These values reflect the weighted average across the specific measures within each group, weighted by the PAs' planned quantities. The values presented here are for 2025 in $2022. The costs per ton fall slightly for later years for electrification measures due to the fall in grid emissions.

Appendix Table 1: Cost per MT of avoided onsite emissions ($2022/MT)

Sector	Fuel	End Use	TRC-based cost ($/metric ton)	Mass Save-based cost ($/metric ton)	Customer cost-based cost ($/metric ton)
Residential	Oil	HVAC	$177	$70	$107
Residential	Oil	Envelope	$208	$155	$53
Residential	Oil	Hot Water	$1	$16	-$15
Residential	Propane	HVAC	$202	$90	$112
Residential	Propane	Envelope	$240	$166	$74
Residential	Propane	Hot Water	$6	$1	$4
Income Eligible	Oil	HVAC	$250	$250	$0
Income Eligible	Oil	Envelope	$108	$108	$0
Income Eligible	Oil	Hot Water	$140	$140	$0
Income Eligible	Propane	HVAC	$285	$285	$0
Income Eligible	Propane	Envelope	$58	$58	$0
Income Eligible	Propane	Hot Water	$225	$225	$0
Commercial	Oil	HVAC	$443	$314	$128
Commercial	Propane	HVAC	$473	$337	$136
Residential	Gas	HVAC	$328	$125	$203
Residential	Gas	Envelope	$195	$160	$36
Residential	Gas	Hot Water	$46	$20	$26
Income Eligible	Gas	Envelope	$153	$153	$0
Commercial	Gas	HVAC	$551	$340	$211
Commercial	Gas	Envelope	$448	$236	$212

Appendix Table 2: Cost per MT of avoided net emissions ($2022/MT)

Sector	Fuel	End Use	TRC-based cost ($/metric ton)	Mass Save-based cost ($/metric ton)	Customer cost-based cost ($/metric ton)
Residential	Oil	HVAC	$203	$80	$123
Residential	Oil	Envelope	$206	$154	$52
Residential	Oil	Hot Water	$1	$17	-$16
Residential	Propane	HVAC	$243	$108	$134
Residential	Propane	Envelope	$236	$163	$72
Residential	Propane	Hot Water	$6	$1	$5
Income Eligible	Oil	HVAC	$281	$281	$0
Income Eligible	Oil	Envelope	$106	$106	$0
Income Eligible	Oil	Hot Water	$156	$156	$0
Income Eligible	Propane	HVAC	$331	$331	$0
Income Eligible	Propane	Envelope	$57	$57	$0
Income Eligible	Propane	Hot Water	$250	$250	$0
Commercial	Oil	HVAC	$517	$367	$150
Commercial	Propane	HVAC	$556	$395	$160
Residential	Gas	HVAC	$443	$170	$273
Residential	Gas	Envelope	$194	$159	$35
Residential	Gas	Hot Water	$54	$23	$30
Income Eligible	Gas	Envelope	$150	$150	$0
Commercial	Gas	HVAC	$744	$459	$285
Commercial	Gas	Envelope	$448	$236	$212