Appendices to the Massachusetts Clean Energy and Climate Plan for 2025 and 2030

Executive Office of Energy and Environmental Affairs

Massachusetts Global Warming Solutions

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The following Appendices include modeling and analysis performed pursuant to section 5 of chapter 21N of the General Laws. These Appendices do not necessarily reflect the policy positions of the Commonwealth. Policy positions of the Commonwealth are contained in the body of the 2025/2030 Clean Energy and Climate Plan.

APPENDIX A: TECHNICAL PATHWAYS MODELING

This Appendix is prepared by Evolved Energy Research (EER), the contract consulting team that has been conducting the analyses in support of the Massachusetts Clean Energy and Climate Plan ("2025/2030 CECP" or "Plan")

A.1 OVERVIEW

To create emissions target sublimits for this 2025/2030 CECP, the Executive Office of Energy and Environmental Affairs (EEA) conducted a follow-on analysis to the Massachusetts 2050 Decarbonization Roadmap (2050 Roadmap Study). The 2050 Roadmap Study highlighted that electrification is a key pillar of the Commonwealth's decarbonization strategy. This follow-on analysis focused on investigating different strategies for building heating on the path to meeting the CECP requirements. This document provides details of the follow-on clean heat analysis and results behind the study's insights used to set sublimits.

Different strategies for decarbonizing heat raise essential questions about technology deployment, the timing and costs of investments in energy system delivery upgrades (for both the electric grid and natural gas systems), and impacts to customers' energy bills. The 2050 Roadmap Study identifies electric heat pumps as a leading strategy for reducing Massachusetts' buildings emissions, but the timing and scale of their deployment drive different outcomes for all of these questions. This analysis used a range of scenarios, described in the Scenario Assumptions section, to help address these questions. Scenarios are assessed using the same methodology as the 2050 Roadmap Study with targeted updates and refinements, described in the Methodology section. Finally, results from the analysis are presented in the Results section.

A.2 SCENARIO ASSUMPTIONS

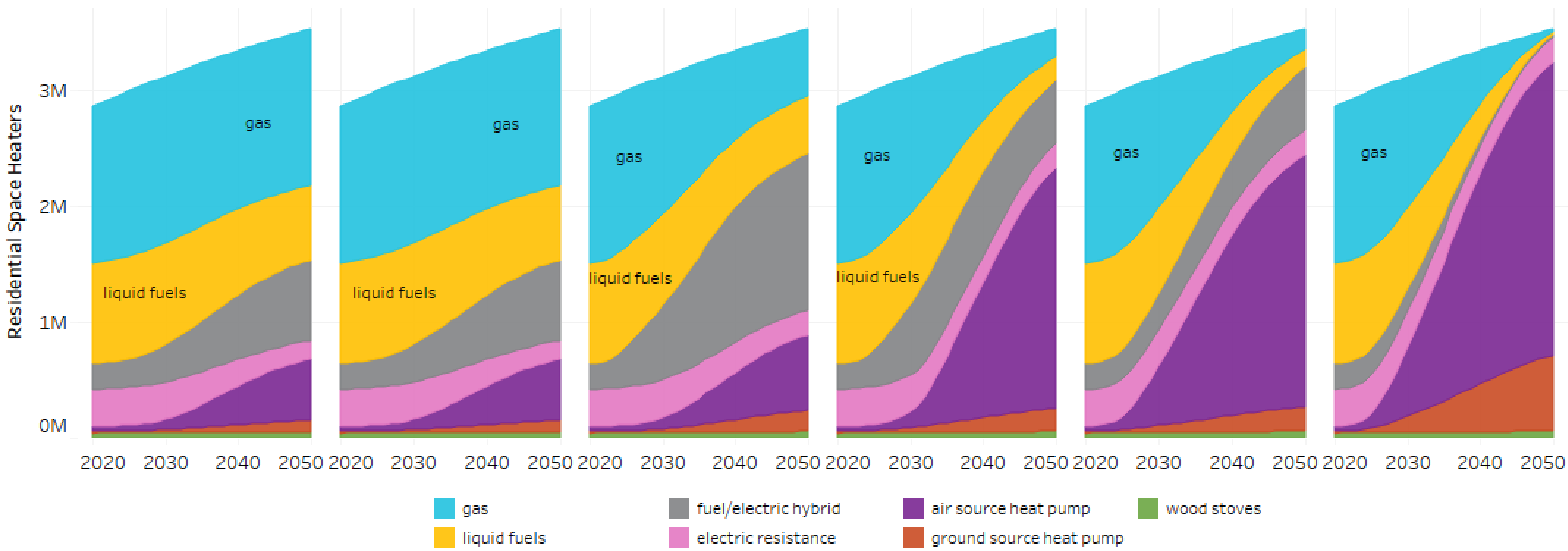
This analysis builds on the 2050 Roadmap Study, updating key inputs and refining scenarios to focus on a range of pathways specifically designed to evaluate decarbonizing heat. This study evaluates five scenarios to represent the spectrum of decarbonized heat strategies, ranging from heavy reliance on clean fuels to full building electrification. Each scenario relies to a different degree on a suite of available clean heating technologies: traditional furnaces and boilers operating with clean fuels; all-electric ground-source and air-source heat pumps; and hybrid heat pumps which use natural gas backup heat during the coldest weather events. Outside of the differences in decarbonizing heating, the scenarios share key assumptions about policies, fuel prices, and price trajectories.

A.3 SCENARIO DEFINITIONS

The following table describes each scenario and provides an overview of differences in residential heating technologies through 2050 to illustrate the differences in the scenarios. The evolution of residential space heating stock is included in Figure A.1 to show the difference across scenarios.

Figure A.1. Scenario Definitions for Clean Heat Pathways with Illustrations of Residential Space Heating Stock Composition

Reference	Clean Fuels	Hybrid	Phased	High Electrification	Full Electrification
Today's trend of residential customers switching from oil and liquid propane to gas heating continues. Only scenario which does not achieve GWSA emissions limits.	Same heating technology adoption as Reference scenario but includes extensive reliance on carbon neutral gas and liquids to meet GHG targets.	Rapid adoption of fuel-electric hybrid pumps by 2030. Combustion backup remain common at low temperatures, resulting in moderate demand for RNG and biofuel in 2050.	Rapid adoption of both partial-home and whole-home heat pump systems but with an emphasis on partial-home systems in the 2020s and then whole home thereafter. Some use of clean fuels in 2050.	Rapid adoption whole-home heat pumps. Some use of clean fuels in 2050. Most similar to the "All Options" pathway from the Roadmap Study.	Maximum adoption of whole-home air-source and ground-source heat-pumps at the rates required to no longer use fuels in buildings in 2050.



As in the 2050 Roadmap Study, each scenario extends its assumptions beyond Massachusetts to not only the rest of New England, but the entire United States. Evaluating the Commonwealth's decarbonization strategies within U.S. emissions reductions ensures that the resulting scenarios are sustainable, i.e., Massachusetts does not consume more than its fair share of available renewable and zero-carbon energy sources.

A.4 COMMON ASSUMPTIONS ACROSS SCENARIOS

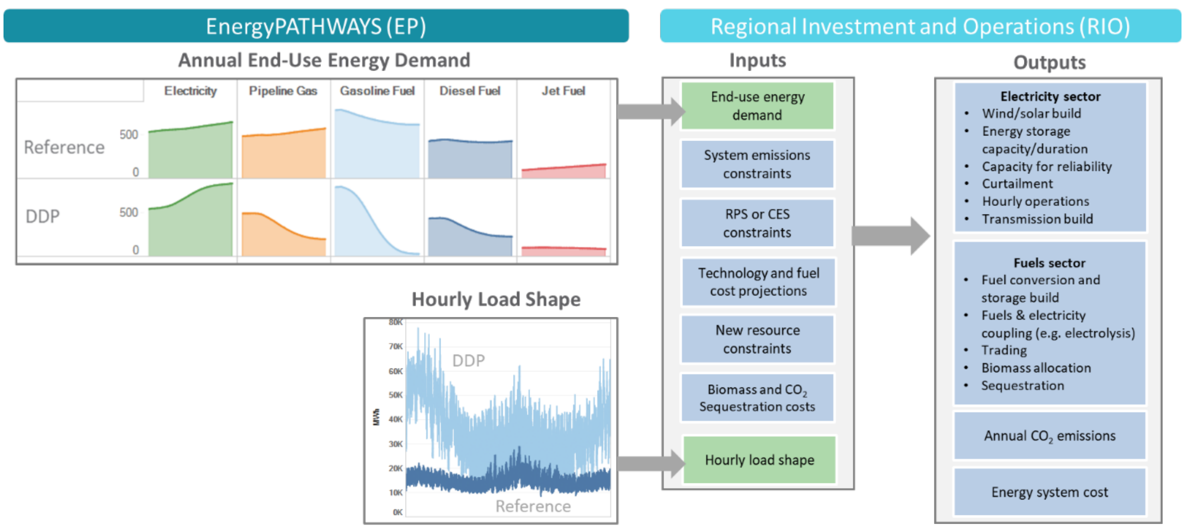
Outside of the key differences in how emissions from building space heating are reduced, the scenarios align on assumptions about other critical elements of decarbonization for the region. These shared assumptions include:

- ***Emissions***
  - Based on the draft Clean Energy and Climate Plan, a 50% reduction in 1990-level emissions by 2030.
  - A 90% reduction in emissions by 2050.
- ***Buildings***
  - Include 5% renewable natural gas and 20% biofuel in 2030 even though there are no policies requiring such levels of clean fuels; drop-in alternatives are variable thereafter.
- ***Electricity***
  - Renewable Portfolio Standard 40% in 2030.
  - Clean Energy Standard to 60% in 2030.
  - Municipal Light Plant (MLP) Greenhouse Gas Emissions Standard set to 50% in 2030.
  - Offshore wind construction schedule fixed based on planned procurements through 2030.
  - New England Clean Energy Connect transmission line completed.
- ***Transportation***
  - Updates to emissions inventories to align aviation emissions accounting.
  - Assume California zero-emission vehicle (ZEV) standards are adopted nationally, and biodiesel allowed.
  - ZEV sales reaching 100% of sales by 2035 for light-duty vehicle types and larger vehicles soon thereafter.
  - Utilize mid-range vehicle miles traveled trajectory from the U.S. Energy Information Administration's (EIA's) Annual Energy Outlook (2021).
- ***Non-Energy***
  - Includes new hydrofluorocarbon (HFC) regulations, along with non-energy emissions trajectories modeled by the Massachusetts Department of Environmental Protection (MassDEP), including Solid Waste Master Plan and Kain regulations.

A.5 METHODOLOGY

This analysis utilized the same pathway analysis approach and modeling tools as the2050 Roadmap Study, Regional Investment and Operations (RIO) and EnergyPATHWAYS (EP), with updates to select modeling inputs. Both platforms are numerical models with high temporal, sectoral, and spatial resolution developed by Evolved Energy Research to study energy system transformation. EP is a bottom-up stock accounting model that creates final energy demand across more than sixty demand subsectors and twenty-five final energy types. This final energy demand for fuels and time-varying (8,760 hour) electricity demand profiles are used as inputs to RIO, a linear programming model that combines capacity expansion and sequential hourly operations to find least-cost supply-side pathways. This pair of models produce energy, cost, and emissions data over a 30-year study period, running through 2050. Interactions between EP and RIO are illustrated in Figure A.2.

Figure A.2. EnergyPATHWAYS and RIO Modeling Flowchart Using Illustrative Data (study results are not pictured)



RIO has unique capabilities for this analysis because it models detailed interactions among electricity generation, fuel production, and carbon capture with high temporal granularity, allowing accurate evaluation of coupling between these sectors in the context of economy-wide emissions constraints. Additionally, RIO tracks fuels and energy storage state of charge over an entire year, making it possible to access electricity balancing in high variable generation systems. RIO solves for all infrastructure decisions on a five-year time-step to optimize the energy system transition, not only the endpoint of the period.

For complete documentation of both RIO and EP, see the methodology section of the Energy Pathways to Deep Decarbonization Technical Report of the 2050 Roadmap Study. The following sections provide key methodological differences for this analysis and the work completed for the Decarbonization Roadmap for the study's demand-side and supply-side components. Overarching data updates for this analysis over the 2050 Roadmap Study include:

- Migrated from AEO2019 forecasts of total energy consumption to AEO2021, reflecting forecasted impacts of the COVID-19 pandemic.

- Incorporated new planned electricity procurements in the region for offshore wind.
- Assumed compliance with the new proposed California ZEV standards.
- Incorporated recent changes to Massachusetts' GHG emissions inventories accounting procedures as they apply to aviation fuels and non-energy emissions.

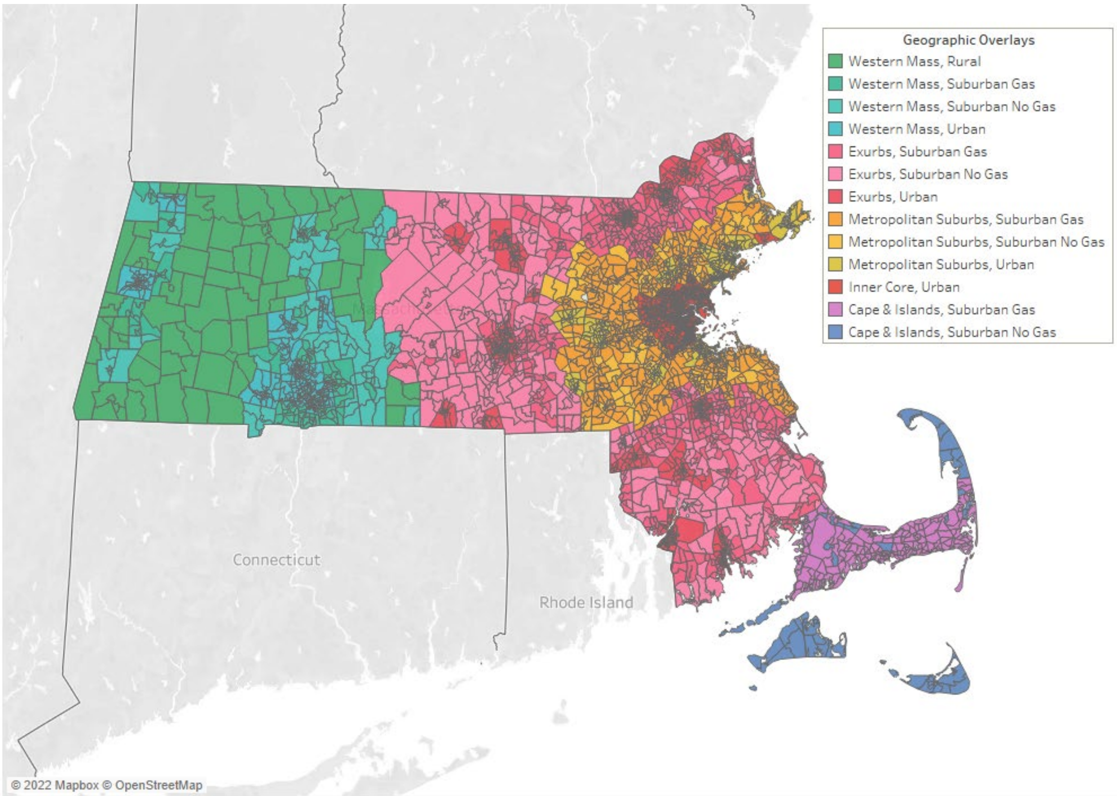
DEMAND-SIDE UPDATES

Updates to the demand-side modeling of energy-related equipment focused on targeted refinements over the 2050 Roadmap Study. This analysis has implemented methodology updates for the demand-side to focus on crucial elements of decarbonization pathways for Massachusetts, which builds on the Roadmap findings. The updates for this analysis include: revisions to the geographic representation of the Commonwealth of Massachusetts; the introduction of fuel-electric partial-home approaches to electrification, the incorporation of separate tracking of new and used vehicle stocks; and, methodological improvements to load-shape generation, including shifting to a 2011 weather year. More detail on these updates is provided in the following sub-sections.

Updated Geographic Representation of Massachusetts

Revisions were made to the geographic representation of the Commonwealth for the demand-side analysis to support more insights around geography, density, the presence of gas infrastructure, and environmental justice group status. A cohort analysis resulted in 26 distinct geographic zones, which became the new representation of Massachusetts for the EnergyPATHWAYS modeling. The following Figure A.3 shows three of the four dimensions in the cohort analysis that drove the updates to the new modeling geography. An additional dimension of environmental justice group status was used for the final geographic representation.

Figure A.3. Cohort Analysis Results for Geography, Density, and the Existence of Gas Infrastructure.



Fuel-Electric Partial-Home Heating Approach

The key driver of differences for the clean heat scenarios is what technology replaces existing building furnace and boiler stock as it retires. In some scenarios, this analysis includes a broader set of electric heating technologies for replacing or adding cooling when a home turns over its air-conditioning or had previously did not have air-conditioning. This analysis also replaces the retired furnaces and boilers in the residential, commercial, and industrial sectors. The following heating technologies were incorporated into the demand-side modeling:

- Electric Hybrid Natural Gas Boiler/Radiator
- Air-source heat pump (ASHP) Hybrid with Natural Gas Furnace – Heating
- Electric Hybrid Distillate Boiler/Radiator
- ASHP Hybrid w Distillate Furnace – Heating
- ASHP Hybrid w liquefied petroleum gas (LPG) Furnace – Heating

When the combined heating technologies are used, half of the buildings' heating systems would be served by fuel and the other half with electricity based on analysis of a cut-out temperature of 32 degrees Fahrenheit with electricity consumption shapes to match this behavior. The heat pumps used for our modeled heating systems are less costly than cold-weather heat pumps, with only a $300 incremental cost over a standard air conditioner, but they operate at lower efficiency than cold-weather heat pumps and rely on natural gas (rather than electric) fuel below 32 degrees Fahrenheit.

Including these joint technologies makes it possible for the scenarios to explore strategies that allow for a simulation of a roll-out of clean heat strategies when air conditioning needs replacing or being added. This enables more time for necessary electricity investments in clean supply and grid upgrades, and such assumption may present the possibility of some cost savings in the near and medium-term. However, any partial-home adoption of heat pumps will be replaced with whole-home heat electrification later.

Differentiating New and Used Vehicles

Another update over the 2050 Roadmap Study is added specificity to the vehicle stock by distinguishing between 'new' and 'old' vehicle fleets. This update was made to capture the variation in vehicle age across cohorts in Massachusetts. The average age of vehicles varies significantly by cohort—for example, for urban populations in Western Massachusetts, used vehicles make up 35% of vehicle stocks for non-environmental justice (EJ) populations vs. 71% for EJ populations.

Within the modeling framework, 'new' vehicles become 'old' vehicles after five years, and vehicle capital costs are assumed to depreciate by 60% over the first five years. A used vehicle has a range of remaining useful life, lasting 5–20 years before retirement (averaging ten years). The flow from new to used vehicles helps us to track electric vehicle share of in the "new" versus "old" fleet of vehicles. Tracking them provides us information about how many EVs may be available to the used market.

Load-Shape Updates

This analysis revisited the load shapes used in the 2050 Roadmap Study to make refinements, with a particular focus on how decarbonization of heating influences pathways to 2050. This analysis migrated to using 2011 as the weather year instead of 2012, which better represents typical winter conditions in Massachusetts for long-term planning.

SUPPLY-SIDE UPDATES

Updates to supply-side modeling incorporated a range of changes relative to the Roadmap:

- Updates to policy constraints, including modeling a 50% emissions reduction relative to 1990 levels by 2030, as put forth in the Interim CECP.
- Updates to the fleet of existing generators to capture new electricity procurement since the 2050 Roadmap Study.
- Incorporated physical inter-state transmission networks for both hydrogen and carbon dioxide (CO_2), enabling new investment decisions.
- Enabled inter-state trading of zero-carbon fuels.
- Improved consumption-based emissions tracking for electricity across New England
- Updated technology cost and performance assumptions, reflecting updates to cost trajectories for key technologies from the National Renewable Energy Laboratory's (NREL) Annual Technology Baseline.

The supply-side analysis also included two additional sensitivities on the High Electrification scenario, one on New England transmission and the other on flexible loads. The transmission sensitivity evaluates a least-cost supply portfolio with the New England Clean Energy Connect transmission line not completed until after 2030. The other sensitivity explored the impacts of modest flexible loads for space heating and cooling systems, and electric vehicle charging. Flexible loads are modeled as shifting some percentage of load from peak hours to non-peak hours. This sensitivity quantifies cost savings from mitigating peak loads on the transmission and distribution system.

A.6 RESULTS

This section provides visualizations of key modeling results. Results are presented for each of the two major modeling efforts: demand-side results showing changes in final energy demand, along with the evolution of critical energy-consuming technology stocks and hourly electricity load; and supply-side results, which include emissions, energy system costs, and decarbonized electricity and fuel supply.

DEMAND-SIDE

Final energy demand by the type of energy carrier (e.g., electricity, gasoline, hydrogen) across all scenarios for both Massachusetts and New England is presented in Figure A.4. Results are through 2050 and reflect the historical energy demand levels affected by the COVID pandemic in 2020 and 2021. Pipeline gas represents all energy delivered through the natural gas transmission and distribution pipeline, which historically has exclusively been natural gas but in the future may be a blend of fossil natural gas, renewable natural gas, synthetically produced methane, or hydrogen.

Additional detail on the drivers of growth in electricity demand in the Commonwealth is provided in Figure A.5 showing annual electricity demand by category for each scenario through 2050.

Figure A.4. Final Energy Demand for Massachusetts and New England by Scenario

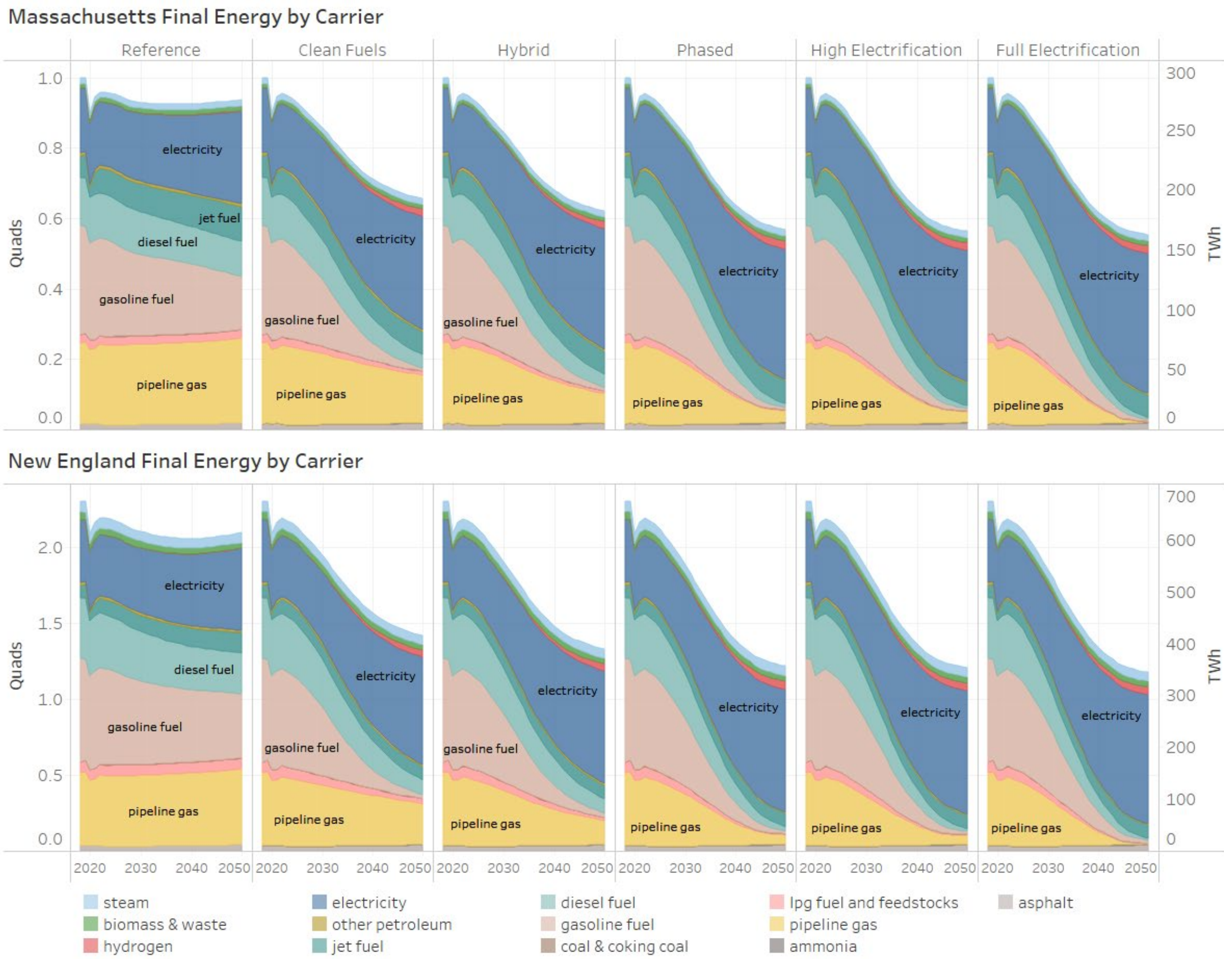
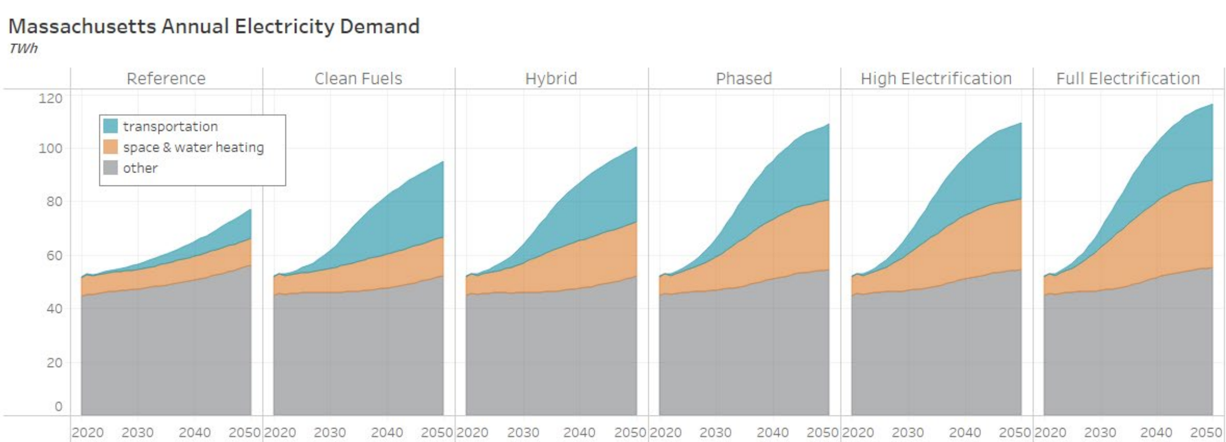


Figure A.5. Growth in Annual Electricity Demand for Massachusetts and New England by Scenario



Changes in space heating equipment are the key differentiator between scenarios for this analysis. Figure A.6 shows how changes in sales for residential space heating equipment alter the equipment stock over time, affecting final energy demand. Figure A.7 shows the same for commercial space heating.

Figure A.6. Sales Share, Equipment Stock, and Final Energy Demand for Residential Space Heating

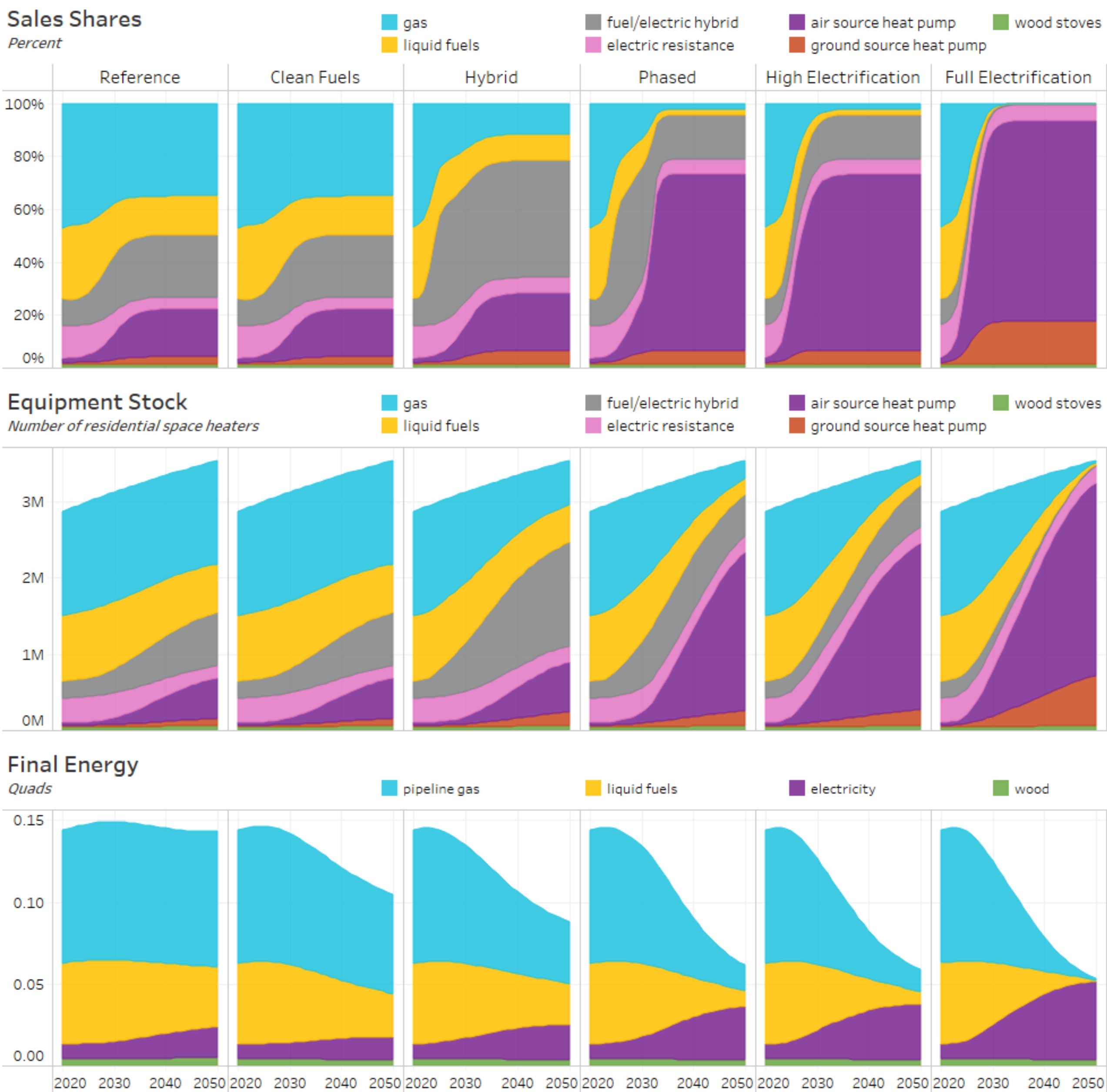
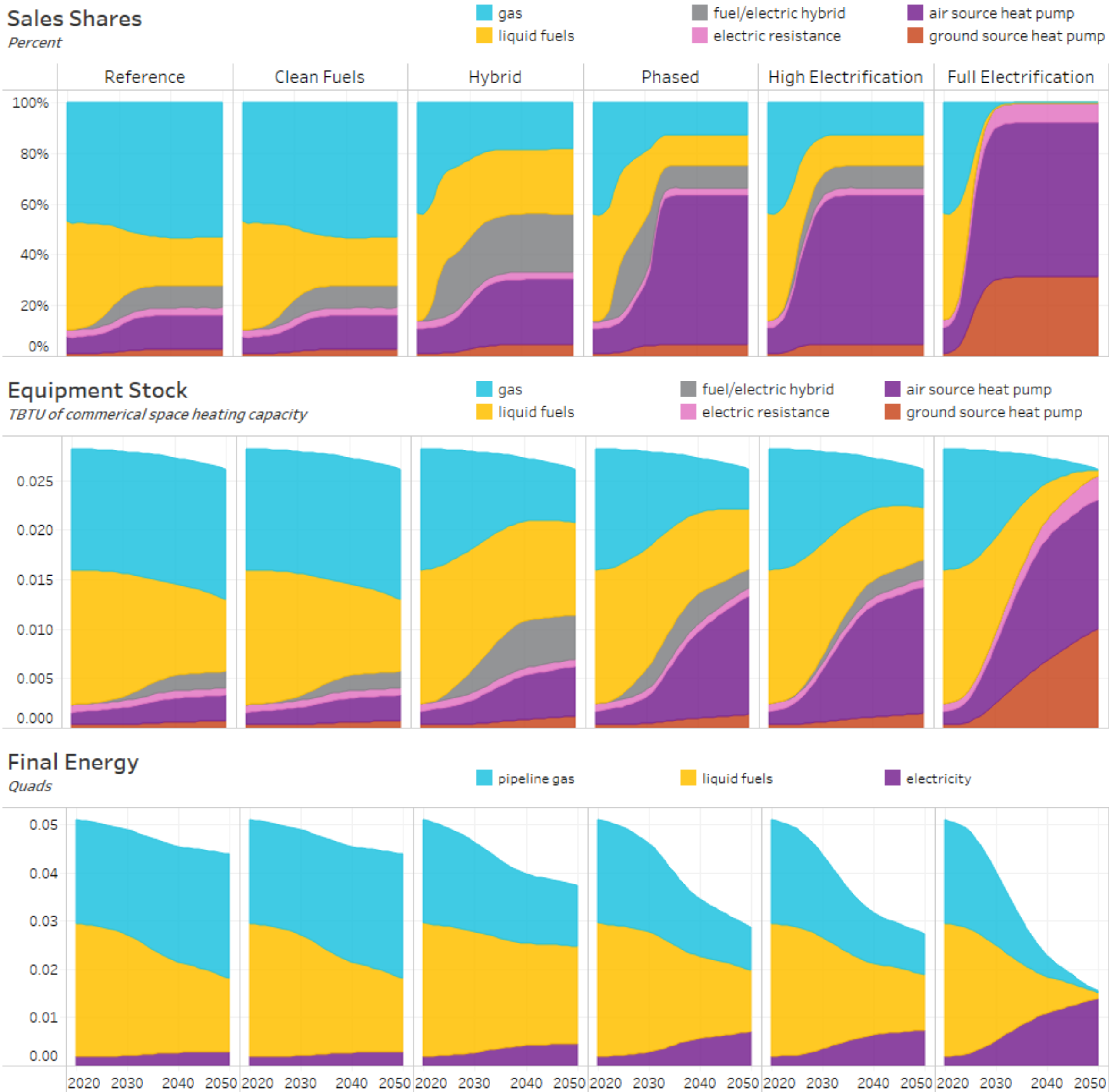
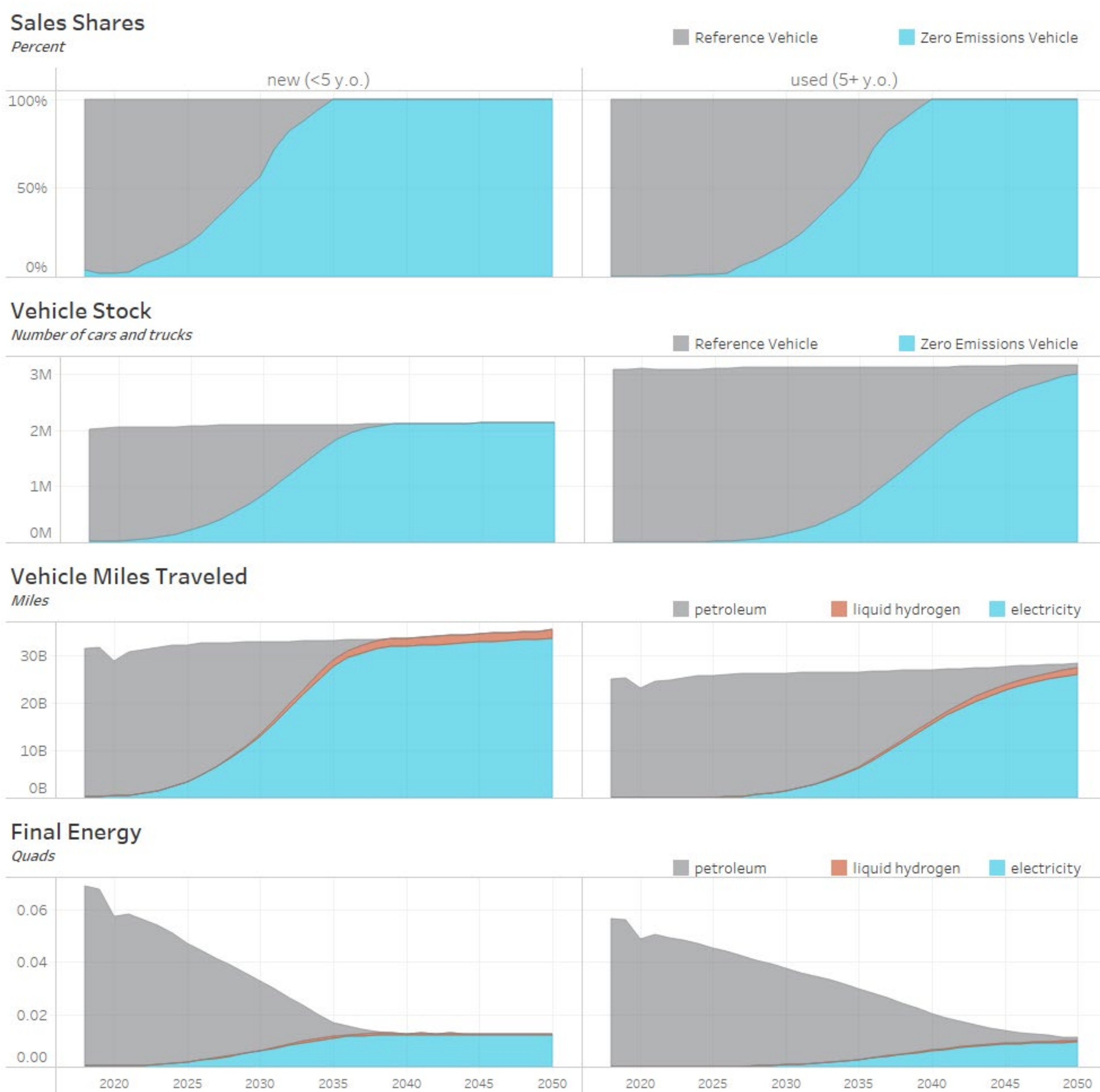


Figure A.7. Sales Share, Equipment Stock, and Final Energy Demand for Commercial Space Heating



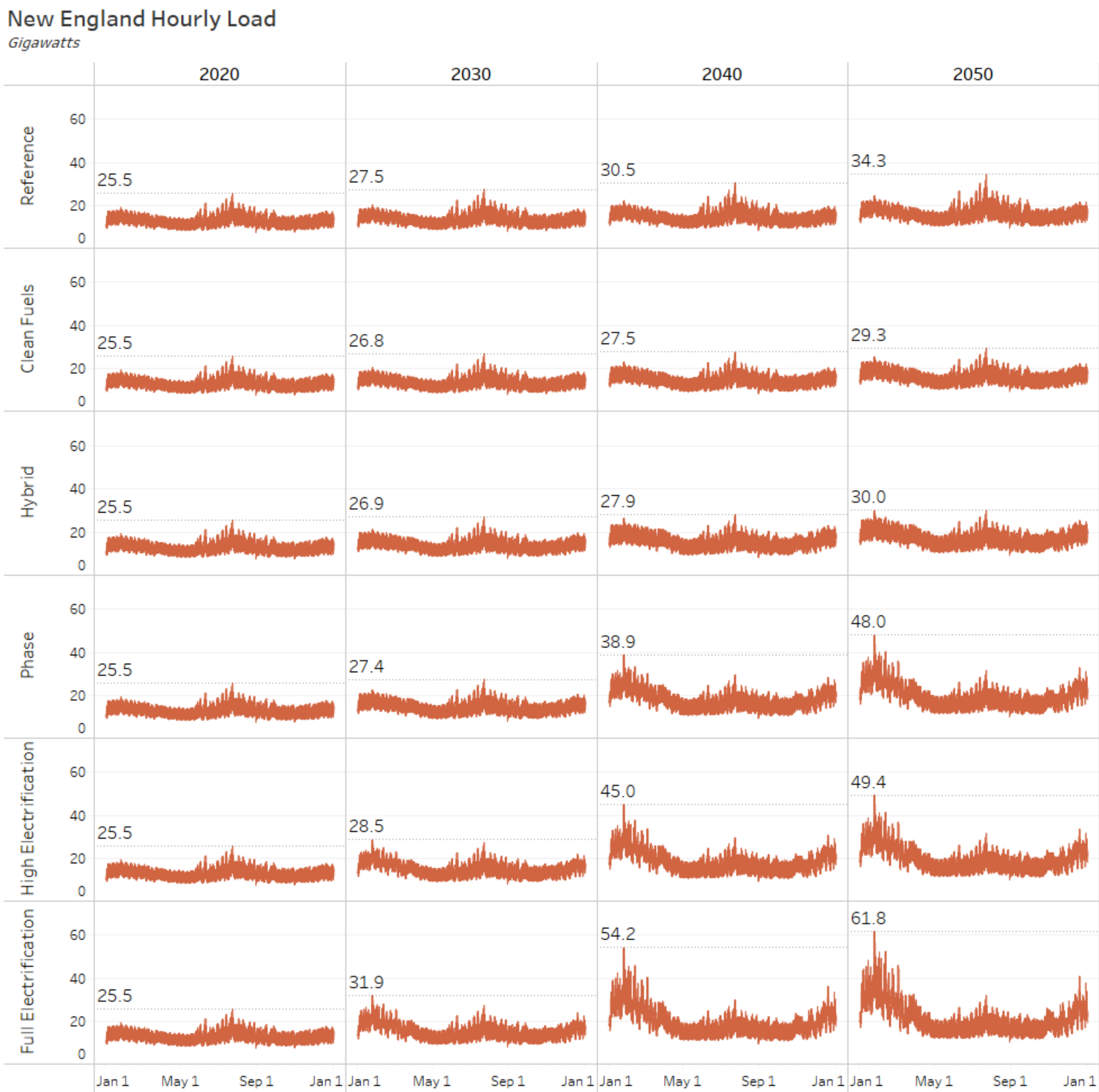
Transportation is also a critical factor in emissions for Massachusetts. Updates for this analysis separate light-duty vehicles into new (less than five years old) and used categories to better capture the dynamics of electric vehicle penetration in the used car fleet. Figure A.8 compares how changes in the new and used vehicle sales impact the vehicle stock, miles traveled by each vehicle type, and ultimately final energy demand. All clean heat scenarios share the same vehicle pathway, which is shown in the figure below.

Figure A.8. Sales Share, Vehicle Stock, VMT, and Final Energy by Scenario for Vehicle Type



Electrification of many end-uses increases electricity demand across New England, but heating electrification has a pronounced impact on peak load across the region. Figure A.9 shows the evolution of hourly electricity demand for New England, illustrating how higher levels of electrification of heat impact electricity loads over a year.

Figure A.9. Evolution Of Hourly Electricity Load, Excluding Transportation, Across New England



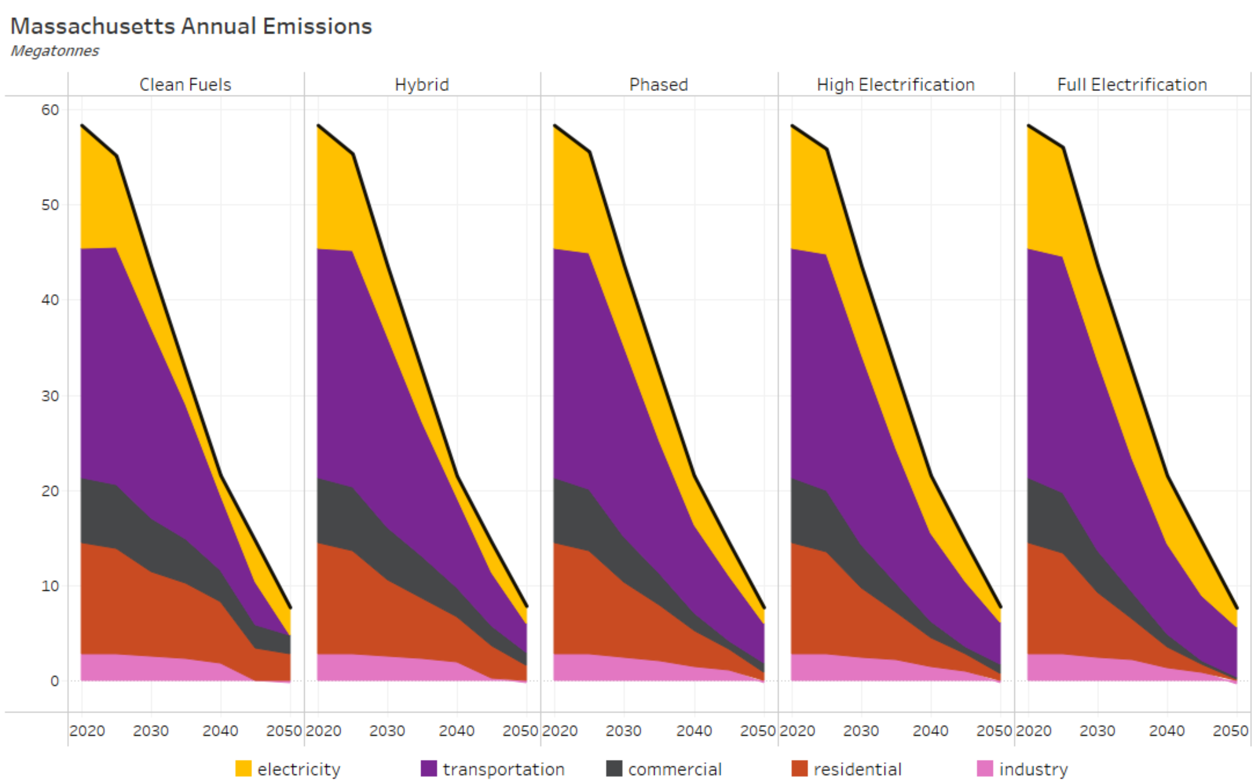
SUPPLY-SIDE

The supply-side modeling from RIO takes the demand-side results as an input and determines infrastructure investments and energy system operations needed to meet the demand profile in each modeled scenario. RIO then produces emissions and energy system cost outputs for each scenario. The results in this section address results for each of these portions of the RIO analysis, starting with emissions in Massachusetts.

Emissions

Figure A.10 shows annual CO_2 emissions by scenario for the Commonwealth. In this figure, emissions are shown by sectors, capturing all fuel combustion, non-energy CO_2, and any sequestration or negative emissions technologies. Emission accounting aligns with the Massachusetts GHG inventory methodology.

Figure A.10. Annual Emissions in Massachusetts by Sector



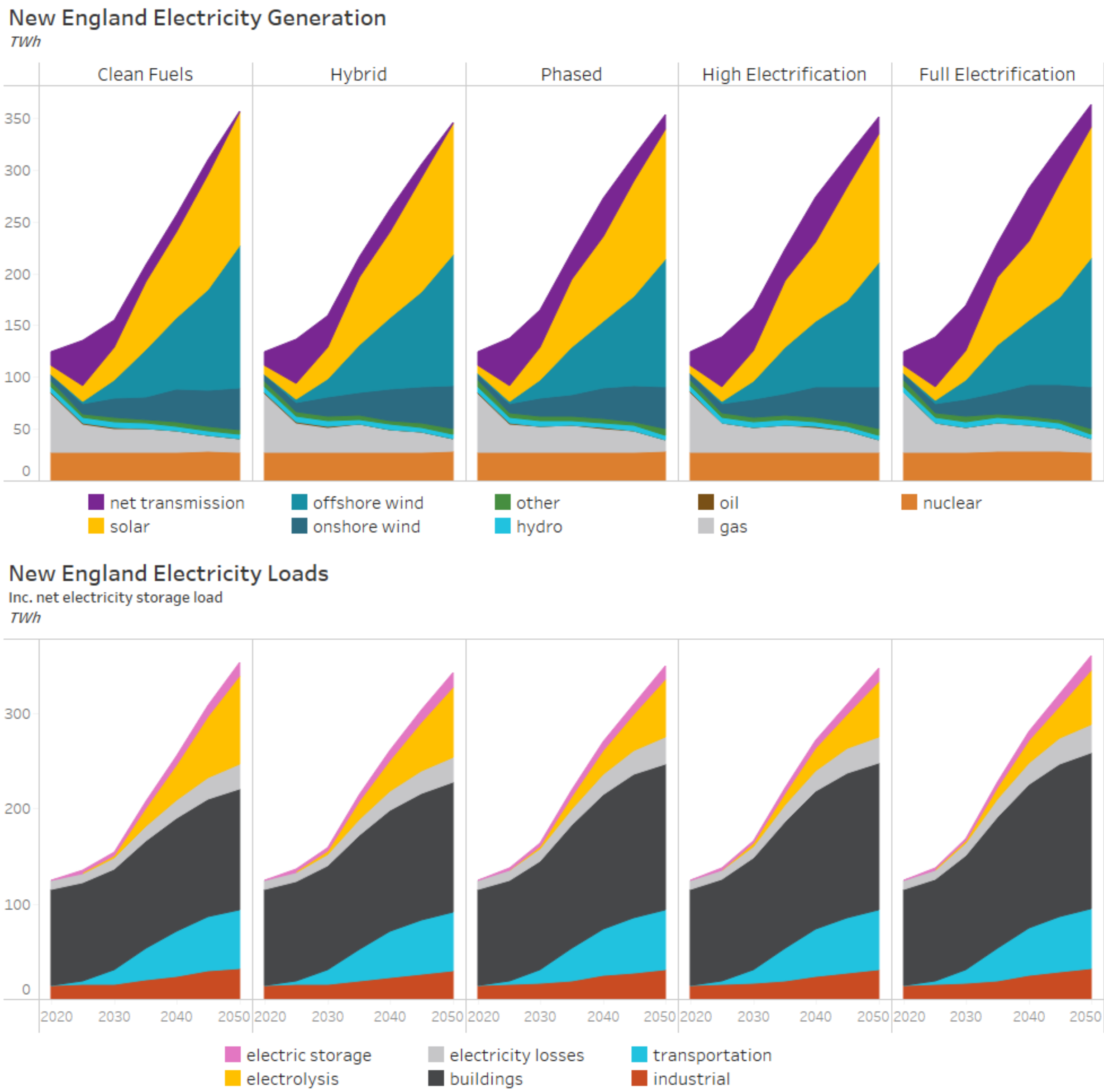
Energy Supply

Decarbonized electricity is critical element of achieving the emissions targets for Massachusetts. Figure A.11 shows installed electricity capacity for both Massachusetts and New England by year. Both the Commonwealth and New England dramatically expand deployment of renewable generation through 2050, particularly solar and offshore wind.

Figure A.11. Installed Nameplate Capacity of Generation and Storage for Massachusetts and New England

New England's annual electricity generation and electricity demand is shown in Figure A.12. Annual net electricity imports are shown as "net transmission" in the top graphs, reflecting New England being a net importer of electricity every year in all scenarios. Imports to the region increase significantly in all scenarios in 2025 as new, planned transmission is added, accessing low-cost hydro power from Canada. While New England is a net importer on an annual basis, the region also exports electricity to surrounding geographies in many hours of the year, helping to balance a cleaner electricity system.

Figure A.12. Annual New England Electricity Generation and Load



Expanded transmission capacity across New England supports a cleaner electricity system. Figure A.13 shows the total quantity of transmission capacity for each New England state and all of the geographic zones in the RIO analysis, beginning with existing capacity in 2020 and adding new capacity through 2050 where all scenarios assume NECEC and Champlain Power Express are online by 2025.

Figure A.13. Transmission Capacity by Year for New England States

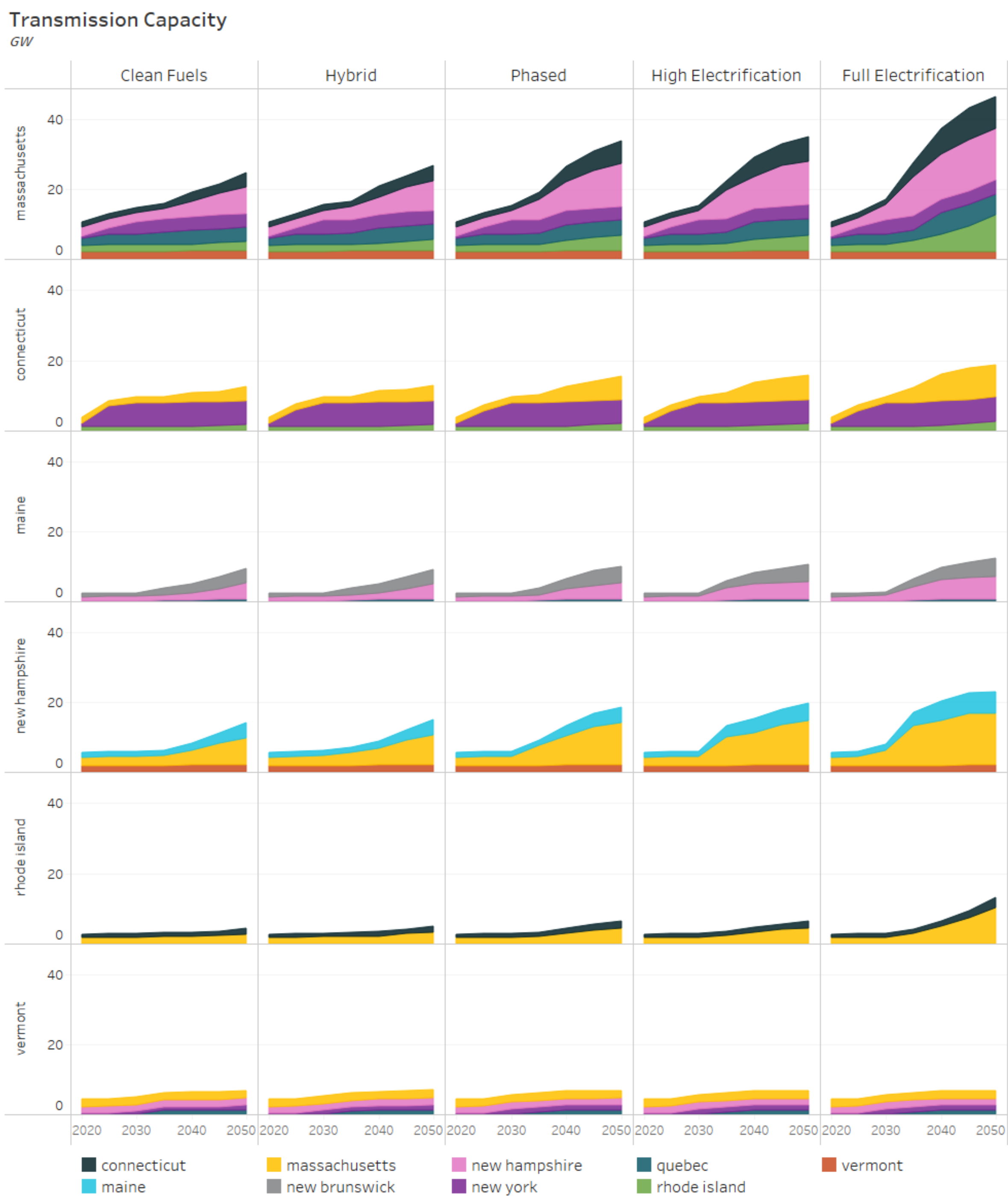
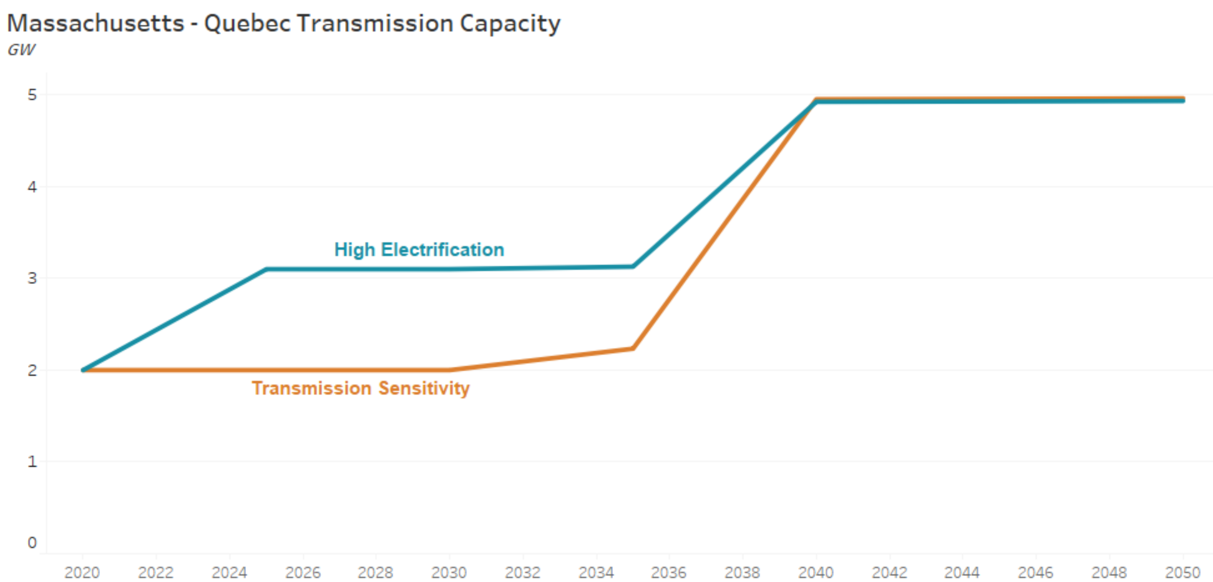


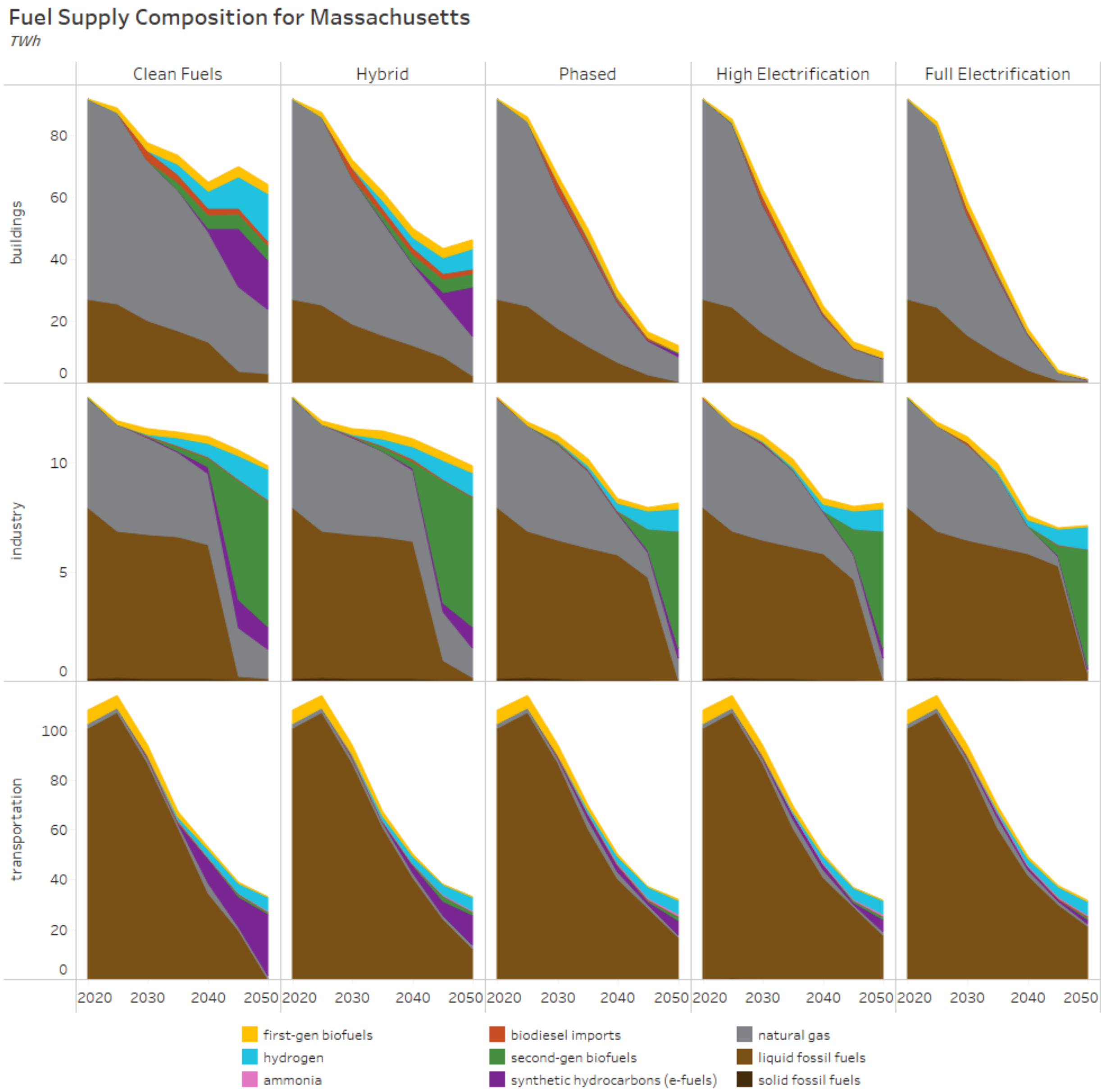
Figure A.14 compares transmission capacity between Massachusetts and Canada for the High Electrification scenario and a transmission sensitivity on that scenario, where the NECEC line does not come online until after 2030. This figure shows that by 2040 both scenarios see the same level of transmission expansion, indicating that additional capacity beyond what the NECEC enables is economical to support decarbonization.

Figure A.14. Transmission Capacity between Massachusetts and Québec for High Electrification with Transmission Sensitivity



Cleaner electricity and the level of final energy demand for fuels are critical factors that influence the level of decarbonization needed from fuels. Figure A.15 compares the mix of fuel supply, breaking out clean and zero-carbon fuels from fossil fuel supply, serving demand in Massachusetts buildings, industry, and transportation. First-generation biofuels include corn ethanol and anaerobic digestion, while second-generation biofuels include biomass gasification for methanation or Fischer-Tropsch fuels as well as pyrolysis technologies with carbon capture.

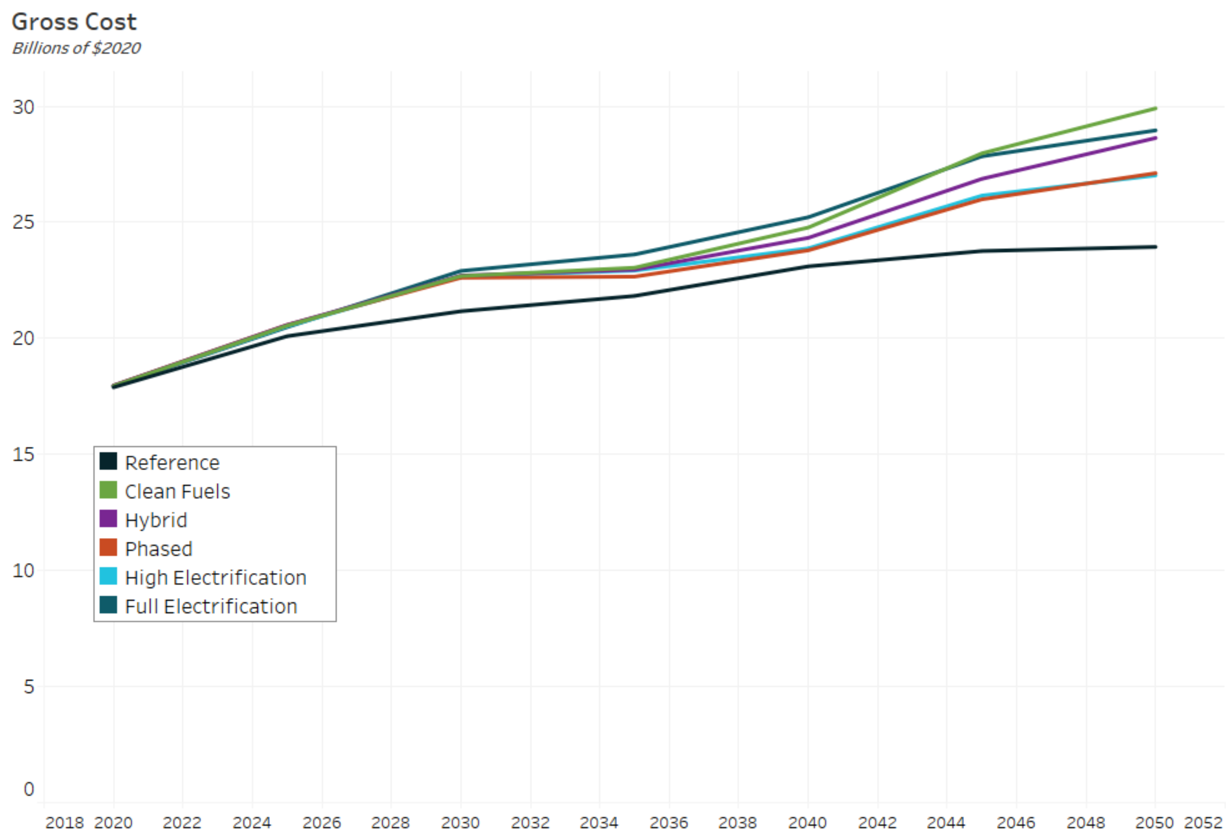
Figure A.15. The Composition of Fuels Serving Building, Industrial, and Transportation Demand in Massachusetts



Energy System Costs

Supply-side results also include energy system costs for all scenarios, which reflect the investment and operation costs for an energy supply portfolio that meets both the policy constraints and final energy demand from the demand-side analysis. Figure A.16 compares the total gross cost of Massachusetts' energy system for each scenario.

Figure A.16. Total Energy System Costs by Scenario



Comparing the net cost of scenarios, i.e., the incremental cost or savings relative to another scenario, often offers more insight than looking at gross costs alone. Figure A.17 compares net cost to the Phased scenario, breaking out cost into broad categories related to electricity production and delivery, pipeline gas production and delivery, demand-side equipment, and the production and delivery of other fuels. This figure also includes the net cost of the flexible load sensitivity on the High Electrification scenario. The sensitivity shows the additional flexible load provides savings starting in 2025 and increasing through 2050.

Figure A.17. Net Cost Compared to the Phased Scenario

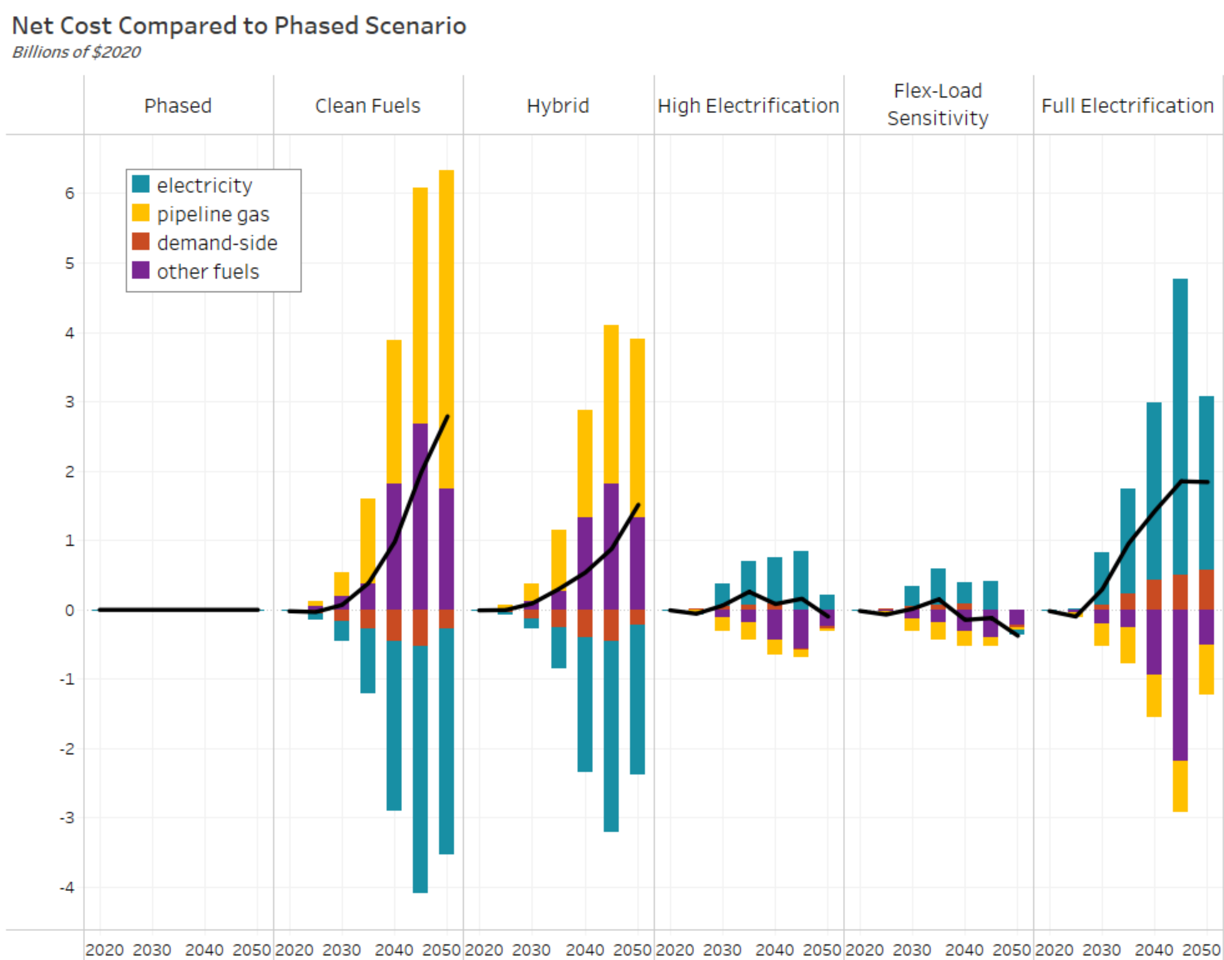
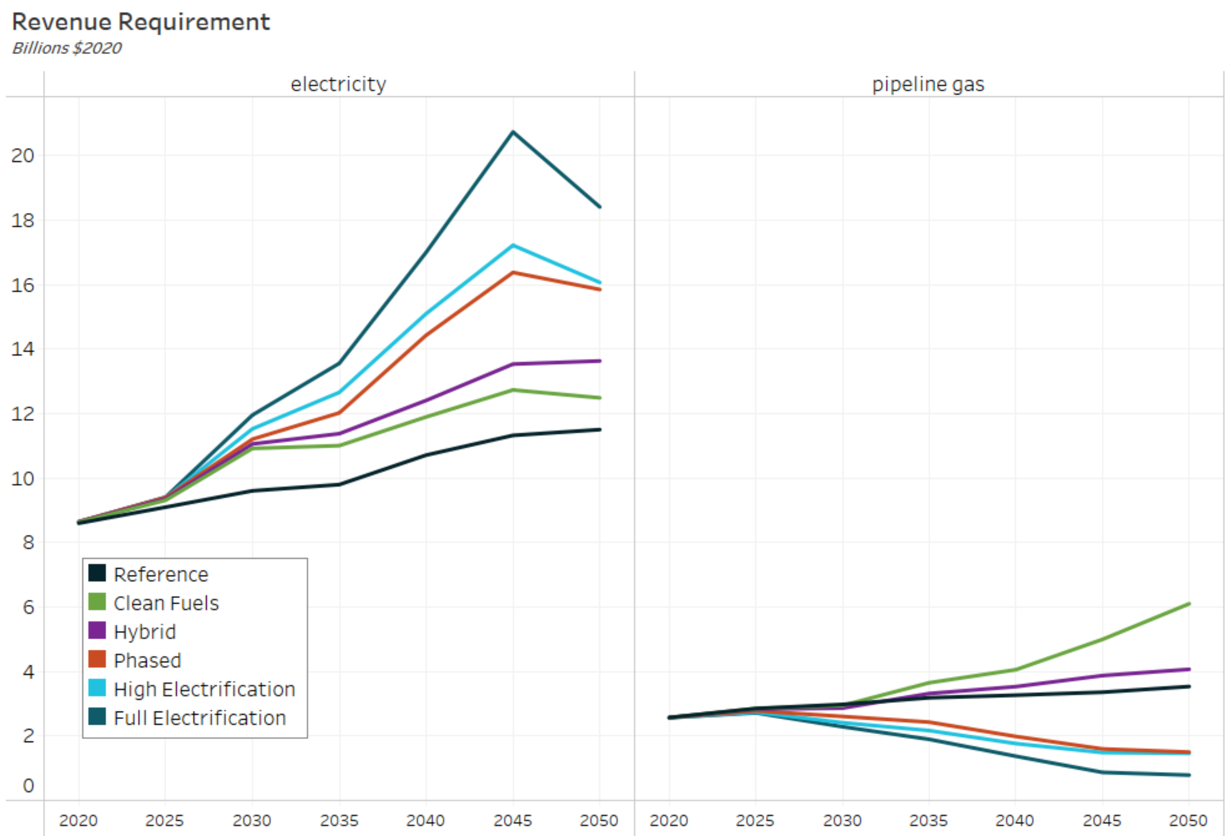


Figure A.18 translates cost results into estimated revenue requirements for Massachusetts. Costs are allocated separately to an electricity and a pipeline gas revenue requirement, where changes from year to year reflect changes in investments in the underlying assets. The electricity revenue requirements decline after 2045 because decarbonizing the electric sector is one of the first actions taken in the model to meet emissions targets, so much of the investment in the electric sector is made in the 2030–2040 timeframe.

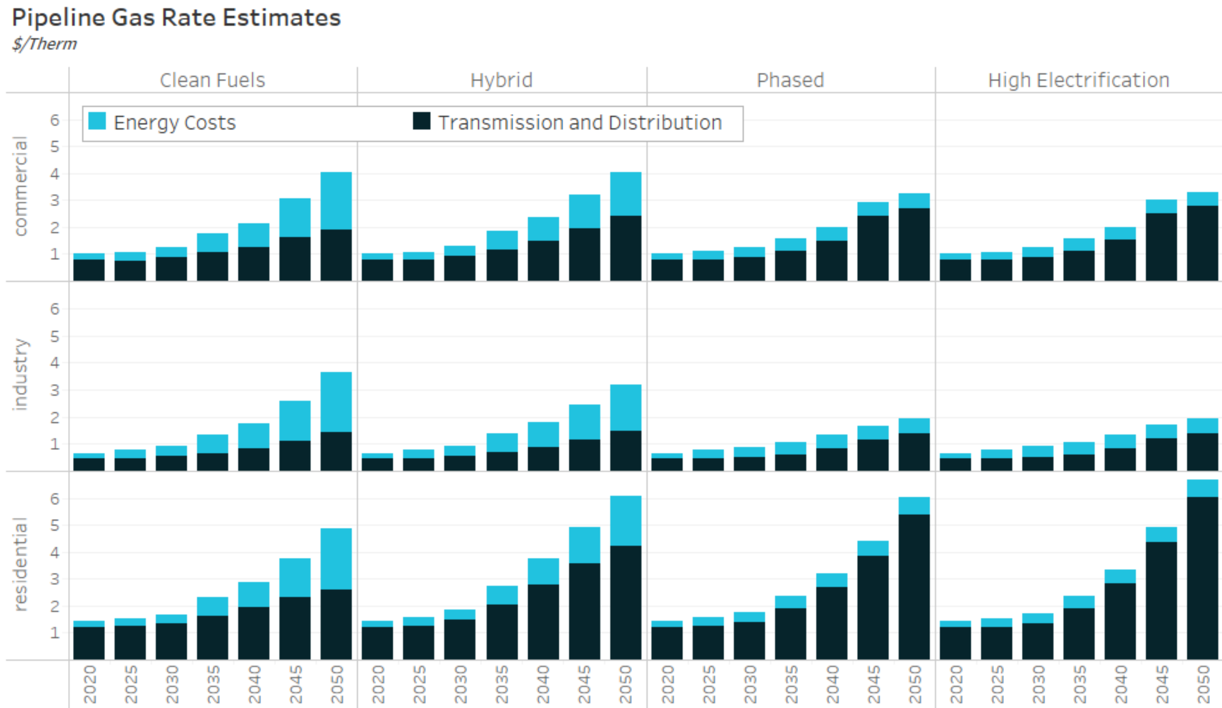
Figure A.18. Revenue Requirement for Electricity and Pipeline Gas by Scenario



Future average rates are estimated using the revenue requirement results combined with electricity sales and pipeline gas throughput results. Figure A.19 shows estimated average rates for pipeline gas. The contents of the pipeline are a mix of natural gas and zero-carbon drop-in fuels, varying by scenario. Differing energy and delivery costs result in varied rates across sectors. Figure A.20 shows estimated average rates for electricity. Electric rates are not broken out by sector because cost allocation for electric sector transformation is highly uncertain.

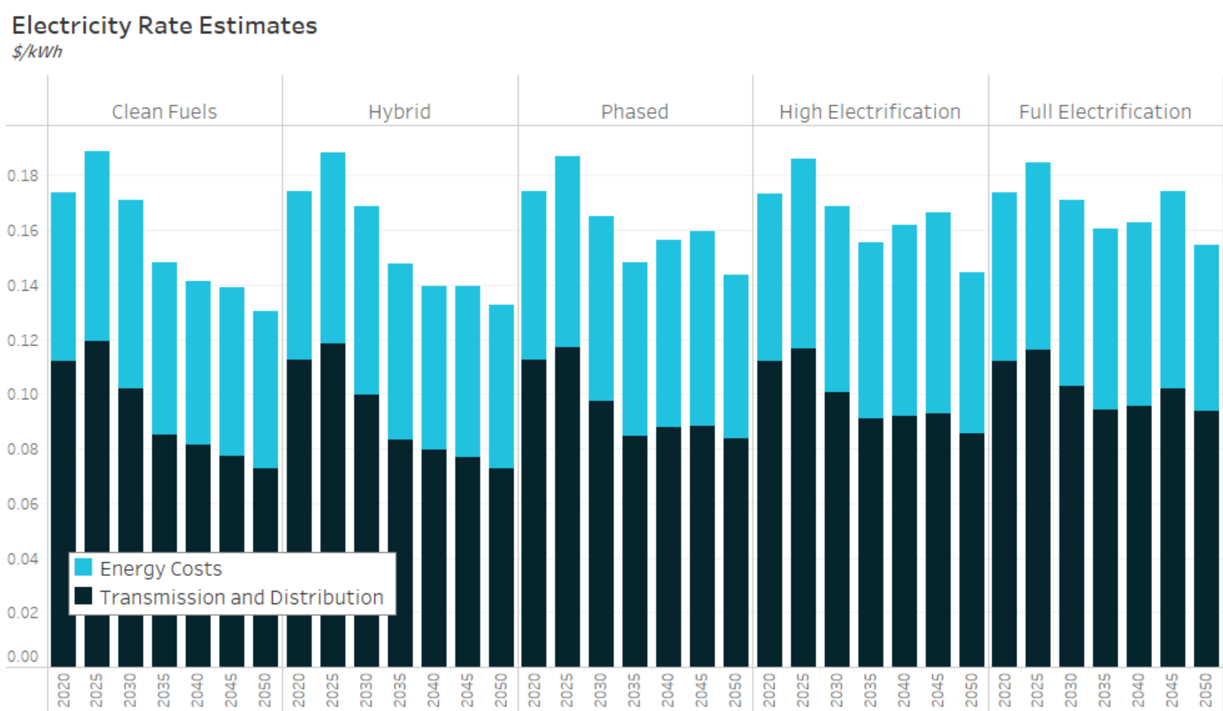
Electric rates decline over the study period, despite large infrastructure investments required to expand the grid to meet growing electric demand: rate declines are driven by increased throughput on the grid. Conversely, pipeline gas rates increase in most scenarios because throughput declines. The Clean Fuels scenario is the exception: throughput remains similar to the reference case, but high demand for zero-carbon pipeline gas requires some very high-cost supply (primarily synthetic natural gas), which drives up average rates.

Figure A.19. Estimated Average Rates for Pipeline Gas for Massachusetts Commercial, Industrial, and Residential Sectors*



**Note: Full Electrification is not included on account of a negligible volume of gas throughput by 2050.*

Figure A.20. Estimated Average Rates for Electricity in Massachusetts



APPENDIX B: A CLEAN HEAT STANDARD FOR MASSACHUSETTS

This Appendix is prepared by Richard Cowart, Nancy L. Seidman and Mark LeBel of the Regulatory Assistance Project (RAP)®

RAP®

JULY 2022

REGULATORY ASSISTANCE PROJECT

A Clean Heat Standard for Massachusetts

Prepared for the Massachusetts Executive Office of Energy and Environmental Affairs

Richard Cowart, Nancy L. Seidman and Mark LeBel

About This Appendix

This appendix includes analysis performed by the Regulatory Assistance Project (RAP)® pursuant to the development of this 2025/2030 Clean Energy and Climate Plan. The Commonwealth of Massachusetts commissioned this study to inform the development of policies and programs designed to achieve the 2025 and 2030 limits and sublimits for the sectors of residential heating and cooling and commercial and industrial heating and cooling. The contents of this Appendix B reflect the views and analysis of RAP rather than the policy positions of the Commonwealth. This appendix is being published with the plan because it contains analysis performed pursuant to Section 5 of Chapter 21N of the General Laws.

RAP is an independent global nongovernmental organization advancing policy innovation and thought leadership within the energy community.

This appendix addresses the problem of greenhouse gas emissions from space and water heating by discussing regulatory and other policy strategies that could be used to deploy clean heat solutions. RAP's firsthand knowledge of the constraints and challenges policymakers face suggests that a Clean Heat Standard may be a plausible approach. This appendix evaluates and discusses how the architecture and features of such a program <u>might</u> operate to drive the Commonwealth's ambitious decarbonization goals forward.

Authors and Acknowledgments

Richard Cowart is a principal, Nancy L. Seidman is a senior advisor and Mark LeBel is an associate at the Regulatory Assistance Project.

Ruth Hare and Donna Brutkoski of RAP provided editorial assistance.

The Clean Heat Standard concept and some information in this paper are repurposed, with gratitude and permission, from a 2021 white paper published by Energy Action Network and written by Richard Cowart of RAP and Chris Neme of the Energy Futures Group. That publication, titled *The Clean Heat Standard*, is available here: https://www.eanvt.org/chs-whitepaper/

That said, responsibility for the information and views set out in this RAP paper lies with the authors.

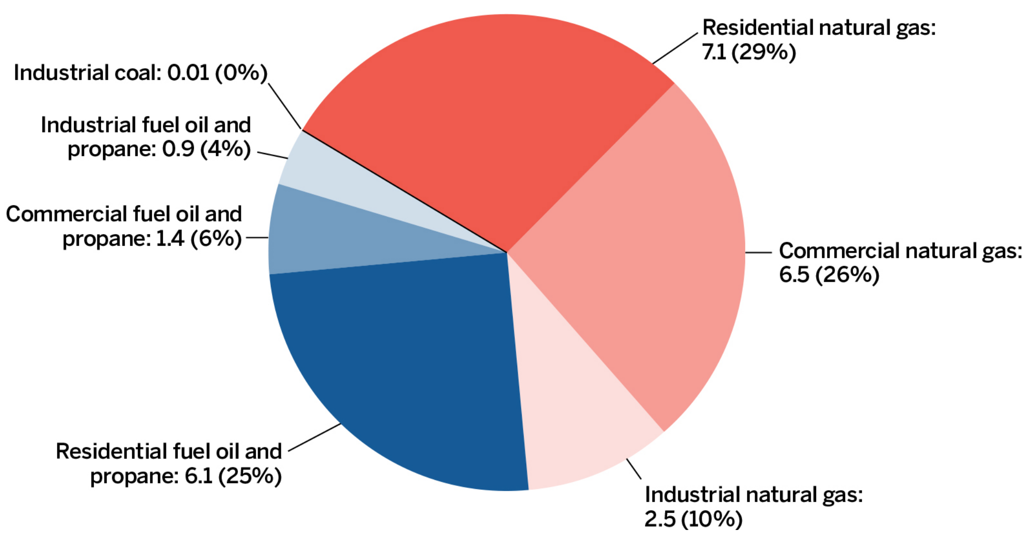
Contents

Introduction

This paper addresses the problem that RAP calls fossil heat. Fossil heating fuels include natural gas, fuel oil, liquid propane and smaller amounts of kerosene and coal. Although heating buildings (space heating) is the largest use of fossil heating fuels, it is not the only end use in this sector. Fossil fuels are also burned for water heating, clothes drying, cooking, municipal and commercial operations and important industrial processes. In recent years, families and businesses in Massachusetts spent nearly $6 billion annually[1] to purchase fossil heating fuels across these end uses, even before recent price spikes. These costs are a burden across the Commonwealth, particularly for low-income households, struggling small businesses and disadvantaged communities, and importing those fuels imposes a drain on the broader economy.

Furthermore, fossil heat accounted for 34% of Massachusetts' climate pollution in 2018[2] and was the second largest source of greenhouse gas (GHG) emissions, after transportation. Figure 1 provides a breakdown of greenhouse gas emissions from fossil fuels in Massachusetts' thermal sector in 2018.[3] Natural gas combustion emissions made up nearly two-thirds of those emissions, and residential oil and propane combustion emissions were approximately one-quarter. Oil and propane combustion in the commercial and industrial sectors made up the vast majority of the remaining 10%, with small amounts of industrial coal combustion.

Figure 1. Massachusetts 2018 thermal fossil fuel greenhouse gas emissions (million metric tons CO_2)



Data source: Massachusetts Department of Environmental Protection. (n.d.). *MassDEP Emissions Inventories.* Appendix C

[1] In 2019, the residential, commercial and industrial sectors in Massachusetts spent nearly $5.96 billion on thermal fossil fuels. Specifically, $1.69 billion on fuel oil, $417 million on propane and nearly $3.85 billion on natural gas. Averaged over the past decade, fossil thermal spending has been $5.76 billion per year. Data are from the U.S. Energy Information Agency State Energy Data System, as compiled by the Massachusetts Executive Office of Energy and Environmental Affairs.

[2] Percentage calculated using gross greenhouse gas emissions including agriculture, land use, industrial processes and waste. Massachusetts Department of Environmental Protection. (n.d.). *MassDEP emissions inventories.* Appendix C. https://www.mass.gov/lists/massdep-emissions-inventories#greenhouse-gas-baseline,-inventory-&-projection-

[3] Massachusetts Department of Environmental Protection, n.d.

State law requires the Commonwealth to reduce greenhouse gas emissions, including those from space heating and other thermal uses. In addition, cleaner heating systems can reduce local air pollution and improve indoor air quality. Of course, in our New England climate, heat will always be an essential service — for health, comfort and a viable economy. Similarly, thermal processes are essential to many commercial and industrial operations. As a result, we must find effective, affordable and equitable pathways to rapidly revamp the thermal sector in Massachusetts. In this paper, the authors describe the concept of a new requirement on heating energy providers, which RAP calls a **Clean Heat Standard**. There are several major design choices necessary to implement this concept, and numerous additional details that can affect the operation of the program.

At the highest level, a Clean Heat Standard is a credit-based performance standard that would be applied to suppliers of heating energy in Massachusetts, notably gas utilities and providers of heating oil and propane, and possibly electricity suppliers. These parties would be obligated to serve their customers with gradually increasing percentages of low- or zero-emissions heat, so that sales of fossil fuels are phased down over time. Just as a renewable portfolio standard (RPS) requires electricity providers to replace coal- and gas-fired generation with wind, solar and other clean electricity generation, the Clean Heat Standard would replace fuel oil, propane and fossil gas heat with weatherization improvements, energy efficiency improvements, heat pumps, clean district energy and other verified low-carbon options, potentially including renewable methane, clean hydrogen, biodiesel, renewable diesel and advanced wood heat.

As a performance standard, the Clean Heat Standard requires measured additions to the clean heat side of the ledger, replacing fossil heat with clean heat and drawing down emissions from actions by customers as well as heat providers. For some end uses, especially in the industrial sector, it will be more difficult to substitute low-emitting heat sources. However, because the design of the standard includes credit trading and other compliance flexibility measures, greenhouse gas reductions from various heat end uses can help with compliance. Importantly, a Clean Heat Standard can work alongside many other policies to reduce thermal emissions.

The Challenge and Opportunity of Decarbonizing Heat

In 2008, the Massachusetts General Court passed the Global Warming Solutions Act (GWSA), which included an overarching framework for reducing greenhouse gas emissions in the Commonwealth substantially over time.[4] In 2021, the General Court passed An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy, which Governor Charlie Baker signed on March 26, 2021.[5] The Climate Roadmap law

[4] Chapter 298 of the Session Laws of 2008.

[5] Chapter 8 of the Session Laws of 2021.

enhanced and updated the requirements of the GWSA. Those updated statutory requirements include:

- Economywide greenhouse gas emissions must be reduced, relative to 1990 levels, by at least 50% by 2030 and at least 75% by 2040.
- In 2050, statewide GHG emissions must be net zero, and gross GHG emissions levels must be at least 85% below 1990 levels.
- GHG emissions limits must also be set for 2025, 2035 and 2045.

Of particular relevance to this paper, the secretary of the Executive Office of Energy and Environmental Affairs (EEA) is now required to set sublimits for specific sectors, including commercial and industrial heating and cooling, residential heating and cooling, industrial processes, and natural gas distribution and service. These named sectors include, but are not strictly limited to, the thermal sector. The greenhouse gas emissions for all these sectors must be quite substantially reduced on an ambitious schedule to stay within the overall GHG emissions reduction mandates. The 2021 Climate Roadmap law also added a requirement to "set numerical benchmarks and track adoption within the commonwealth of … solar thermal technologies, [and] air-source and ground-source heat pumps" in addition to other nonthermal technologies.[6] In addition, the 2021 Climate Roadmap law added a new requirement that the relevant greenhouse gas regulations "shall achieve required emissions reduction equitably and in a manner that protects low- and moderate-income persons and environmental justice populations."[7]

At present, EEA modeling suggests that the emissions reduction percentages for heating and cooling buildings may be set just below the overall 2030 greenhouse gas emissions reduction requirement of 50% relative to 1990 levels, while emissions from industrial processes (which are only partly due to thermal applications) may rise. The relevant sectors ultimately covered, in whole or in part, by the Clean Heat Standard will likely be required to reduce their GHG emissions by around 49% from 1990 levels by 2030, which is approximately 40% below 2020 levels. Table 1 on the next page shows historic Massachusetts GHG emissions by sector with the corresponding limits for 2025 and 2030 set by the EEA.[8]

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[6] M.G.L. C. 21N, §5(xi).

[7] M.G.L. C. 21N, §6

[8] Massachusetts Executive Office of Energy and Environmental Affairs.

Table 1. Economywide greenhouse gas emissions limits and sector sublimits for 2025 and 2030

Sublimits	Gross emissions (million metric tons of CO_2 equivalent)			Reduction (increase) from 1990	
	1990	2025	2030	2025	2030
Residential heating and cooling	15.3	10.8	7.8	29%	49%
Commercial and industrial heating and cooling	14.2	9.3	7.2	35%	49%
Transportation	30.2	24.9	19.8	18%	34%
Electric power	28.0	13.2	8.4	53%	70%
Natural gas distribution and service	2.3	0.4	0.4	82%	82%
Industrial processes	0.7	3.6	2.5	(449%)	(281%)
All others	3.4	1.0	0.9	70%	73%
Total	**94.0**	**63.2**	**47.0**	**33%**	**50%**

Source: Massachusetts Executive Office of Energy and Environmental Affairs

Reducing emissions from thermal sectors presents some challenges. However, it also presents new opportunities because clean heating options give the Commonwealth the chance to:

- Improve public health with cleaner air indoors and outdoors.
- Stimulate the economy with reduced expenditures on fossil fuels imported from other regions and overseas.
- Create new local industries and jobs.
- Make homes and businesses more comfortable year-round.

In September 2021, Governor Baker issued Executive Order #596, establishing the Commission on Clean Heat to advise on a framework for achieving long-term greenhouse gas emissions reductions from the heating sector. The commission has developed principles that are useful in thinking about the relevant challenges and opportunities and in developing programs and regulations in this area, including the Clean Heat Standard. Those principles are:[9]

- **Impact**: The regulatory approach and incentives are bold and strong enough to transform the market, the workforce and consumer demand, achieving required emissions reductions without negative economic consequences overall.
- **Simplicity**: The regulatory approach is simple, easy to use and transparent and has clear and broadly understood compliance requirements that are uniform across the state, minimizing the burden on regulated entities.

[9] Massachusetts Commission on Clean Heat, in personal communication to the Regulatory Assistance Project, April 19, 2022.

- **Neutral accounting**: The regulatory approach scores emissions reductions in a fair and neutral manner, allowing the market to drive innovation and the most efficient and effective technologies to prevail.
- **Equity**: The regulatory approach is designed to avoid burdening low- and moderate-income residents and environmental justice communities, and it provides opportunities for them to lead.
- **Resourcing**: The regulatory approach is appropriately resourced to ensure it can be implemented effectively.
- **Revenue**: Revenue generated by the regulatory approach is directed in a fair and trusted manner to support compliance, promote equity and advance decarbonization efforts.
- **Timing**: The regulatory approach is implemented quickly, with compliance requirements coming online in a time frame that is realistic but sufficient to achieve emissions reduction mandates.
- **Public education**: The regulatory approach incorporates strong public and workforce education and transparency to obtain buy-in at scale and minimize the chances of backlash.

Technology Options for Clean Heat

As a priority, Massachusetts will need to deepen investments in weatherization and demand-side efficiency to reduce thermal needs regardless of the underlying heating technologies involved. Efficiency options include improved insulation, improved windows, air sealing and automated temperature controls. Demand-side management measures (such as controlling water heaters and air conditioning during peak demand) will be increasingly important as electrification of end uses expands in the Commonwealth, to better match thermal electric demands with the capacity and energy available from renewable electricity sources.

Typical fossil-fueled heating technologies have several elements in common. For space heating, the combustion process, regardless of whether the underlying fuel is natural gas, heating oil or propane, is utilized to heat air or water, and then that hot air or water is circulated throughout the building to heat individual rooms. If a fossil-fueled space heating unit circulates air, it is typically referred to as a furnace. If a space heating unit heats water, it is referred to as a boiler. For water heating, in many cases, the hot water is stored in an insulated tank, but tankless water heaters are increasingly common. For all these fossil-fueled heating technologies, more efficient versions have been developed over time, and these often require more complex controls and venting arrangements. Nearly every modern fossil-fueled heating unit requires electricity for some part of its operation, including ignition, control technologies, pumps to circulate water and fans to circulate air. As a result, losing electric service for any significant period will prevent the operation of the fossil-fueled heating system in most houses.

There are now a substantial number of heating technologies that are cleaner than fossil fuel technologies, with lower greenhouse gas emissions[10] and no on-site combustion that affects indoor air quality or local air pollution. Chief among those are electric heating technologies, including:

- Electric resistance — Running an electric current through metal can be used to heat air or water. This is a relatively inefficient technology for space heating but is a common water heating technology.
- Air-source heat pumps — Typically using an outdoor compressor and an indoor unit, an air-source heat pump uses the inherent energy in the outdoor air with a refrigerant to either heat or cool the indoor air. Ductless indoor units directly heat or cool the room where they are located, but indoor units can also be connected to air ducts to transport the conditioned air, like a traditional furnace. Both ductless and central air-source heat pumps also provide cooling in summer.
- Heat pump water heaters — This technology is similar to an air-source heat pump with a simpler, single-unit arrangement, but it directly heats water instead of air. There is no outdoor condenser, as these units take heat from the air in the space where they are located, often a basement or cool storage space.[11]
- Geothermal heat pumps — Also known as ground-source heat pumps, these use the consistent temperature of the earth (instead of ambient air) to provide very efficient heat or cooling to a building through a heat exchanger using loops of refrigerant-filled pipe buried in the ground.
- Geothermal district energy, using heat pumps within buildings — This uses a system of ground-source heat pumps to serve multiple homes or businesses at a time.

Other clean thermal supply alternatives:

- Solar thermal — Flat plates or evacuated tube collectors can be used to heat water, which can either be used for space heating or water heating.
- Clean district energy using zero-GHG inputs — This includes combined heat and power facilities that use renewable electricity sources to create steam, which can be distributed to heat one or more buildings.

There are a range of other heating fuels (solids, liquid and gases) that are not derived from fossil fuels and may have the potential to provide clean heat in the Commonwealth of Massachusetts. Importantly, there are many variations in how these fuels are created, collected or combusted, which leads to different kinds of upstream and downstream environmental impacts.

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[10] In a region dominated by high-emitting electric generation resources, such as coal, less efficient electric heating technologies (e.g., electric resistance space heating) can still be responsible for substantial greenhouse gas emissions. However, GHG emissions from the New England electricity grid have decreased significantly over the past two decades and are projected to continue decreasing in the coming decades.

[11] Although air-source heat pumps for domestic hot water are common, they are not often used in the United States for hydronic space heating systems (those relying on circulating fluids via radiators or baseboard pipes), which require higher-temperature fluids. This could change as heat pump technologies improve.

The primary alternatives for clean solid fuels are various forms of advanced wood heating, typically using wood pellets. Some sources of woody biomass could be considered to be zero- or low-GHG emitting when evaluated on a life cycle basis — for example, if pellets are made from sawmill residue or other waste products. Newer combustion technologies for wood fuels are much cleaner and more efficient than those of the past.

In addition, at least two different kinds of liquid fuels can substitute for fossil heating oil[12] as a blend or sometimes as a full replacement:

- Biodiesel — This can be derived from vegetable oils, soybeans or other food byproducts. Biodiesel can be used as a blend, but pure biodiesel is hard to store and may require modifications to typical heating equipment.
- Renewable diesel — Renewable diesel can be derived from the same feedstocks as biodiesel but is further refined into the same chemical form as fossil diesel fuel. As a result, renewable diesel can be used as a blend or a replacement for fossil heating oil.

Potentially cleaner forms of gaseous fuels are:

- Biomethane or renewable natural gas — There are several different collection sources for forms of methane that could be considered renewable. Potentially valuable sources include those that recapture methane that would otherwise be vented into the atmosphere. Those include collection at landfills, livestock operations, wastewater treatment plants and coal-mine mouths and anaerobic digestion, but not synthetic methane created from other fossil fuels. Most forms of biomethane contain contaminants that have health impacts and that interfere with combustion control technologies for reducing other pollutants, such as nitrogen oxides (NOx).
- Clean hydrogen — Today, nearly all hydrogen is created using steam-methane reforming, which typically has significant greenhouse gas emissions from the energy needed and the chemical process itself. This is known as gray hydrogen. However, green hydrogen, created from the electrolysis of a water molecule using zero-GHG electricity, has no GHG emissions associated directly with its production. Several other hydrogen creation methods are being explored across the globe, and each has its unique features. Although many analysts support the use of green hydrogen on a limited basis as a replacement for gray hydrogen and in high-temperature applications that are not easily electrified, a much wider use of hydrogen as a replacement for pipeline gas raises a number of issues. Hydrogen poses challenges for existing gas pipeline infrastructure because of its chemical and physical properties, and substantial investments to carry significant percentages of hydrogen would be needed. Combustion of hydrogen can also have significant nitrogen oxide emissions.

The Commonwealth of Massachusetts has some experience in making judgments about which of these fuels, and which specific versions of each, should be considered clean under the Alternative Energy Portfolio Standard run by the Department of Energy Resources. Under that program,[13] biomass, biogas and liquid biofuels are eligible only if they meet

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[12] Fossil heating oil is also known as distillate fuel oil and is chemically identical to stationary and mobile diesel fuel.

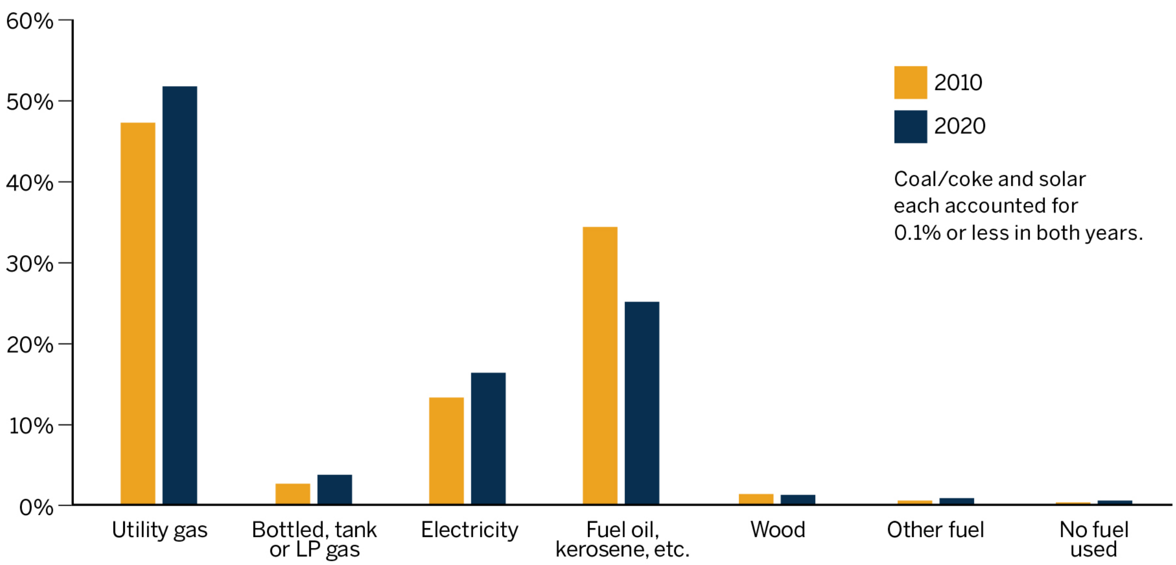
[13] M.G.L. C. 25A, §11F1/2(b).

strict standards for conventional air pollutants and the use of low-greenhouse gas feedstocks such as wastes and residues. Furthermore, any forest-derived biomass must meet sustainable forestry practices. Similar judgments regarding whether these alternative gases, liquid fuels and solid fuels are worthy of public policy support can be made in a Clean Heat Standard, as discussed further below in the section titled "The Architecture of a Clean Heat Standard."

The Current Thermal Sector in Massachusetts

There are approximately 2.7 million housing units in Massachusetts. As shown in Figure 2, roughly 85% of those homes were heated primarily by fossil fuels in 2010.[14] That fell to approximately 81% in 2020, but this still represents a large majority of the residential building stock. In this time, there was a significant decline in the number of homes heated primarily by fuel oil, from 35% to 25%, but that came with a 4-percentage-point increase in the number of homes heated by gas from utilities and a smaller increase in propane usage. Over this period, there was a 3-percentage-point increase in the proportion of homes that reported electricity as their primary heating fuel and a small uptick in the number of homes heated by solar energy. The "wood" category held roughly steady. This shows that fuel switching has been occurring in Massachusetts homes, and that nearly one-fifth of Massachusetts homes are already heated without on-site combustion of fossil fuels, primarily by electricity.

Figure 2. Residential housing units by primary heating types

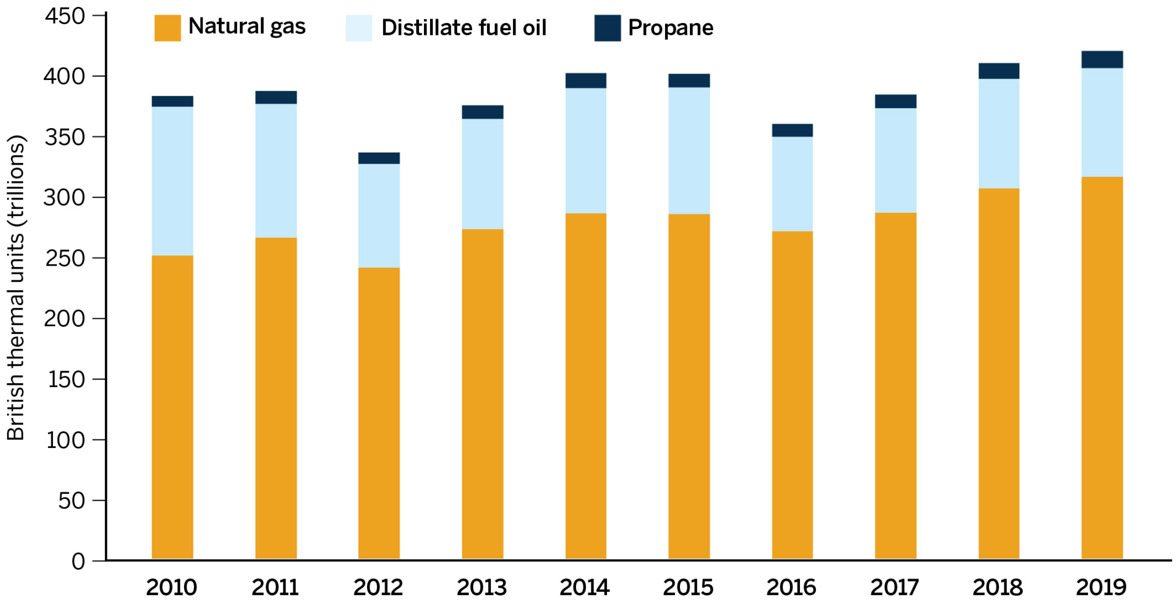


Data source: U.S. Census Bureau. (n.d.). *American Community Survey*

[14] U.S. Census Bureau. (n.d.). *American Community Survey*. Selected housing characteristics for 2010 and 2020. https://data.census.gov/cedsci/table?q=DP04&g=0400000US25&tid=ACSDP5Y2010.DP04

Figure 3 shows thermal fossil fuel consumption by fuel from 2010 to 2019 for the residential, commercial and industrial sectors.[15]

Figure 3. Thermal fossil fuel consumption in Massachusetts for the residential, commercial and industrial sectors



Data source: U.S. Energy Information Agency State Energy Data System

While overall fossil fuel consumption in these sectors increased modestly from 2010 to 2019, natural gas combustion increased 25%, propane usage increased 54% and fuel oil usage declined 27%. Another consideration is that consumption can vary quite a bit from year to year. Weather is a significant variable (cold winters require more energy for space heating), but there are other reasons for annual variations as well.

Pathways for the Necessary Transformation

In an analysis by Evolved Energy Research for the 2025/2030 Clean Energy and Climate Plan (CECP), there are five different compliance scenarios in addition to the baseline. The 2025/2030 CECP has designated the "phased" scenario as the primary compliance scenario, although it is appropriate to recognize the uncertainties across many dimensions. As an indicative matter, the "phased" scenario contains the following projected changes to residential heating systems from 2020 to 2030 to achieve the required reductions:

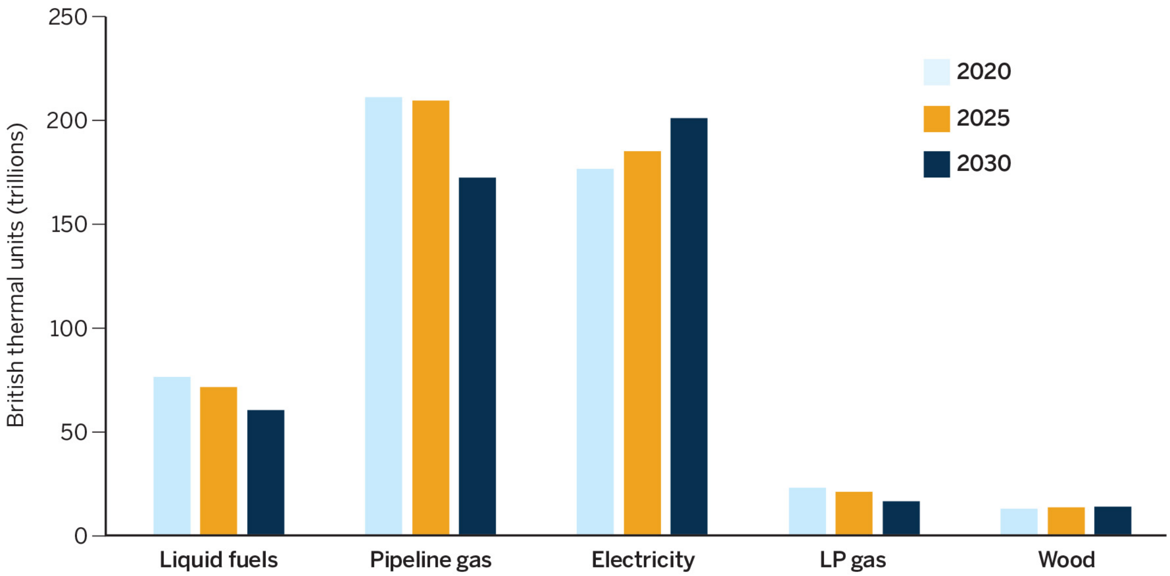
- Nearly 130,000 new whole-home air-source and ground-source heat pump systems.
- Over 380,000 air-source heat pumps added to fossil-fueled furnace systems in a partial building electrification setup.

[15] Data compiled by the Massachusetts Executive Office of Energy and Environmental Affairs from the U.S. Energy Information Agency State Energy Data System. https://www.eia.gov/state/seds/seds-data-complete.php

- Approximately 660,000 fossil-fueled water heaters replaced with electric water heaters, either traditional resistance technology or heat pump water heaters.
- Approximately 230,000 buildings fully weatherized.

These changes in heating systems and the building stock, along with corresponding changes in the commercial and industrial sectors, would lead to significant changes in the combustion of thermal fuels by 2030, as shown in Figure 4.[16]

Figure 4. Final energy demand by fuel for the residential, commercial and industrial sectors in phased policy scenario



Data source: Massachusetts Executive Office of Energy and Environmental Affairs modeling

From 2020 to 2030, the phased policy scenario sees an 18.5% decrease in pipeline gas consumption, a 21.2% decrease in liquid fuels and a 28.9% decrease in liquid propane gas for these three sectors. Additional greenhouse gas emissions are achieved by replacing 5% of pipeline natural gas with renewable natural gas and 20% of liquid fuels with biofuels by 2030. Achieving these changes requires substantial deployment of clean heating technologies over the next eight years. It will require coordination with and action by many individual building owners and residents to help them make this a reality.

Furthermore, Massachusetts will need to build local industries and train employees. Massachusetts needs locally focused businesses with customer relationships and, literally, boots on the ground to deliver new technologies and help customers understand their functions and limitations and methods to optimize their use. The Commonwealth's economy contains an array of pipeline gas companies, weatherization providers, electric utilities, fuel suppliers, renewable energy companies and heating contractors who could, if refocused and provided incentives, do much of the needed work.

16 Modeling by the Massachusetts Executive Office of Energy and Environmental Affairs.

The Commission on Clean Heat has identified that Massachusetts needs a set of policy options, including the possibility of a Clean Heat Standard, that will support customers and suppliers and will ensure delivery of heating solutions at the scale needed to meet the Commonwealth's ambitious climate, equity and economic goals. The remainder of this paper focuses on the principal design options for a Clean Heat Standard to deliver essential emissions reductions from the thermal sector in Massachusetts. But a Clean Heat Standard is by no means the only policy option available to reduce thermal greenhouse gas emissions. In this rapidly advancing field, a clean energy performance standard on heat providers is a relatively new idea. Massachusetts will need to consider the associated opportunities, challenges and alternatives before moving forward.

Other policies can contribute significantly to thermal decarbonization, including cap-and-invest programs, fuel blending requirements, thermal energy efficiency that could include efforts in gas efficiency, building codes, heating equipment appliance standards and reliance on electric sector mandates. Each of these other policy options has merit, and each could be adopted to work in tandem with a Clean Heat Standard. To the degree that any of these parallel strategies lowers demand for fossil heat or lowers the cost of delivering clean heat solutions, they make it easier to deliver cleaner fuels and heating conversions, speeding up the transition to clean heat in Massachusetts. A Clean Heat Standard is an overarching strategy that can work with and tie together an array of complementary policies. The collective impact of the broad suite of programs can ensure an adequate rate of progress over time, while simultaneously advancing other policy goals.

There are many ways to approach the thermal decarbonization challenge, so it is vital to keep in mind a few guiding principles to test decision-making on various aspects of the Clean Heat Standard program. A successful set of policies will:[17]

- **Meet Massachusetts' climate goals** — reduce local air pollution and global greenhouse gases and be expected to meet the thermal sector's share of emissions reductions called for in the Global Warming Solutions Act.
- **Enhance social equity** — build social equity into the architecture of the program and, particularly, minimize adverse impacts on low-income households and those most burdened by high energy bills.
- **Secure physical delivery in Massachusetts** — provide real and verified emissions reductions, delivered via cleaner heating services at end-use locations in the state.
- **Provide customer flexibility** — give individual homeowners, building owners and other consumers a range of low-emissions heating choices, as well as the ability to decide whether and when to make changes in response to market offerings.
- **Promote supplier flexibility** — offer multiple pathways for obligated entities to meet their obligations under the standard.
- **Minimize cost** — provide flexibility to enable emissions reductions to be achieved at the lowest possible cost.

[17] The principles developed by the Commission on Clean Heat overlap with a few of these but are different enough to merit including this list.

- **Maintain resource diversity** — retain Massachusetts' ability to provide affordable heating services despite changing global energy prices and supply conditions.
- **Minimize negative side effects**, including exported environmental harms from cleaner heating choices in Massachusetts.
- **Scale over time** — grow in scale gradually to provide opportunities to benefit from new technology, capture economies of scale and provide certainty to market participants that the market for clean heat solutions will continue and grow.
- **Be as simple as possible —** minimize complexity of administration while maintaining enough regulatory rigor to ensure that emissions reductions are real and are consistent with state requirements.
- **Work well with other policies** — work well with, and be mutually reinforcing with, Massachusetts' weatherization programs, utility efficiency and fossil fuel reduction programs and other greenhouse gas reduction initiatives. It should work with existing Massachusetts policies and institutions to boost progress, ensure consistency across policies and avoid re-creating the wheel.
- **Enhance economic development** — replace expensive and price-volatile fossil fuels with efficiency investments and cleaner and more affordable energy carriers. This conversion will support growth in the economy, including new jobs and job training opportunities, and fuel providers' ability to transition to new and economically sustainable business models.

Building Blocks for a Clean Heat Standard

No single policy is likely to meet all the critical goals set out in the GWSA or the 2021 Climate Roadmap law. However, as RAP will show below, a performance standard for the delivery of clean heat measures to heat customers across the Commonwealth can do much to close the gap between the Commonwealth's ambitions and the existing policy landscape. RAP calls this performance standard the Clean Heat Standard, requiring heating energy providers to deliver an increasing quantity of low-emissions heating services to Massachusetts customers.

This paper briefly describes the Clean Heat Standard and how it would work and shows how experience with existing policies can help policymakers and stakeholders understand and work through the design issues with this new idea. The paper then describes the initial decisions that must be made to set up a Clean Heat Standard and the major design elements, along with observations and options. Based on the analyses explained in subsequent sections, RAP draws two major conclusions:

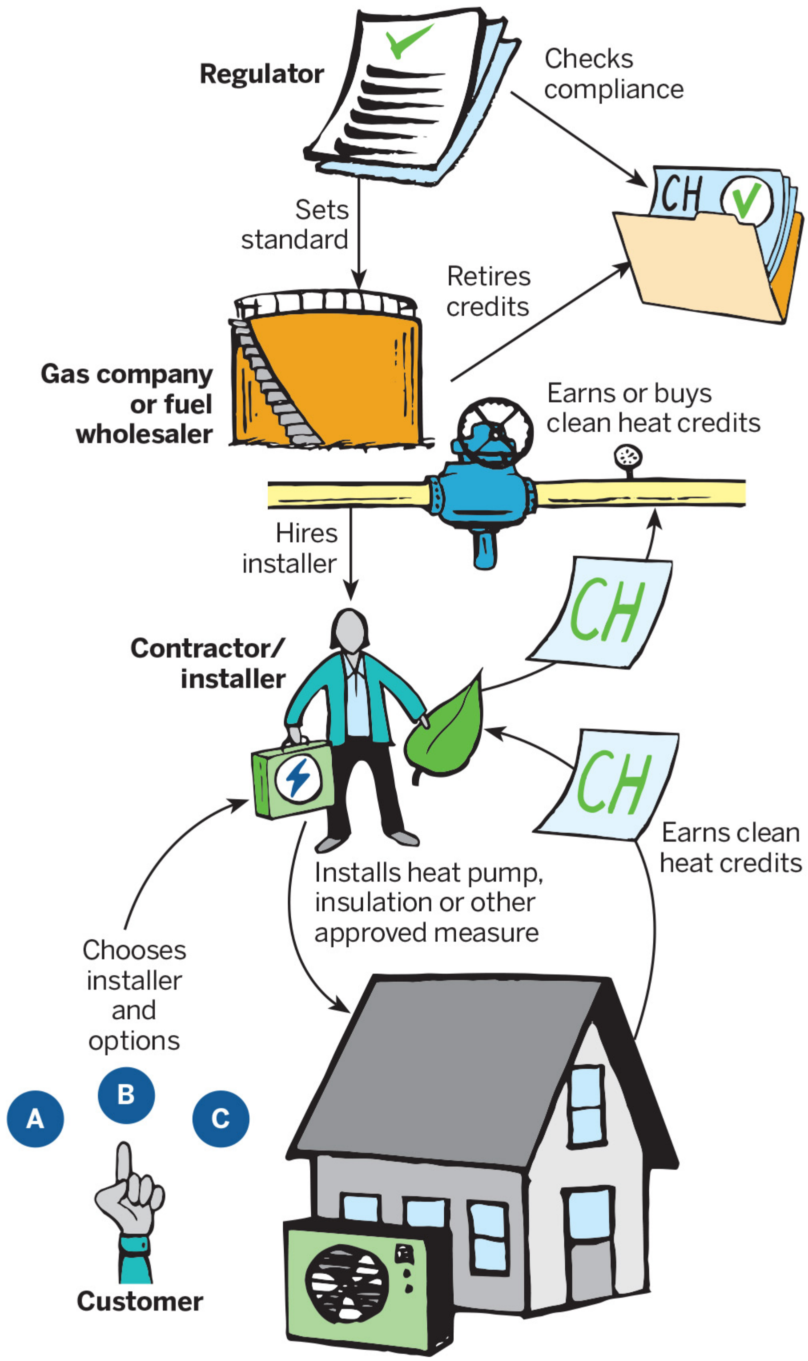
1. The Clean Heat Standard is a practical and cost-effective policy tool to meet emissions reduction goals for the thermal sector, and it could be implemented in a progressive, equitable manner consistent with the Commonwealth's objectives for a timely and equitable transition.
2. The standard can be implemented to work in concert with other policy tools, and this could lower the cost and improve the benefits of the clean heat transition.

Fossil heating fuels reach customers in the Commonwealth in a variety of ways. To ensure complete and evenhanded coverage of the Clean Heat Standard, the performance obligation could be applied to all major suppliers of fossil heating fuels, including the "delivered fuels" (fuel oil, propane, kerosene and coal) and gaseous fuels delivered by pipelines and distribution networks (termed natural gas, fossil gas or pipeline gas.) The standard would apply to all substantial fossil fuel sales from any of these sources. Here are the key features of the standard:

- The Clean Heat Standard is akin to a renewable portfolio standard and to the low-carbon fuel standard in California. The targets for program administrators in the Massachusetts three-year energy efficiency plans required since the 2008 Green Communities Act can also be considered performance standards in that the overall standard and major milestones are set by the Clean Energy and Climate Plan emissions limit for the residential and commercial/industrial heating sectors, and a regulatory agency is authorized to supervise implementation. Massachusetts' Clean Energy Standard is another example, notable for the fact that the percentage standard is established in a regulatory process, not legislation.
- Obligated fuel suppliers would be required to deliver clean heat solutions to Massachusetts customers on a percentage basis that rises over time. Although each year's clean heat additions could be modest (perhaps 4% of delivered heating energy), clean heat additions would add up over time to help meet the thermal sector's emissions reduction requirements.
- Obligated parties could meet their Clean Heat Standard obligation through a wide range of actions. Most importantly, working with families and businesses, they could help customers to improve the efficiency of their homes by installing low-emissions heating systems, such as cold-climate heat pumps, heat pump water heaters or advanced wood heating equipment, or by better insulating their buildings. Demonstrably cleaner fuels can be considered as well in the qualifying resources.
- Anyone delivering qualified clean heat solutions to Massachusetts homes and businesses could earn clean heat credits, which could then be sold to the obligated fossil fuel providers, who will need them to meet their annual performance obligations. Earning credits is not restricted to gas companies or obligated parties. RAP expects most of the customer-level work to be done in coordination with local enterprises, including obligated parties themselves, heating contractors, efficiency providers, existing weatherization programs and others.
- A critical feature of the Clean Heat Standard is customer choice. The standard does not require a homeowner or business customer to change their heating system or to choose any particular clean heat option. The program allows customers to choose from a range of options, or to take no action until the time is right for them. But it will provide incentives, information and support for clean heat options. Experience has shown that these measures can accelerate the transition to cleaner and more efficient buildings across the state, providing lower-cost and more price-stable clean heating options and helping to reduce dependence on fossil fuels.

Figure 5 shows the actors that could be involved with a Clean Heat Standard and their potential roles.[18]

Figure 5. Clean Heat Standard sample processes



Source: Adapted from Cowart, R., & Neme, C. (2021). *The Clean Heat Standard*

[18] Adapted from Cowart, R., & Neme, C. (2021). *The clean heat standard.* Energy Action Network. https://www.eanvt.org/chs-whitepaper/

Building on Experience: Performance Standards in Energy Sectors

The Clean Heat Standard would not be the first time that performance obligations have been placed on energy providers. In Massachusetts, across the United States and in many other countries there are decades of experience with clean energy performance standards applied to the electric power sector and, in some cases, to regulated pipeline gas companies and suppliers of liquid fuels. What's unique about the Clean Heat Standard is that it would apply a performance standard to energy providers across both regulated and non-utility energy companies in the same program. At least four types of programs set up across the country provide potential lessons for the design of a Clean Heat Standard: (1) renewable portfolio standards, (2) low-carbon fuel standards, (3) energy efficiency obligations and (4) other states' clean heat policies.

What's unique about the Clean Heat Standard is that it would apply a performance standard to energy providers across both regulated and non-utility energy companies in the same program.

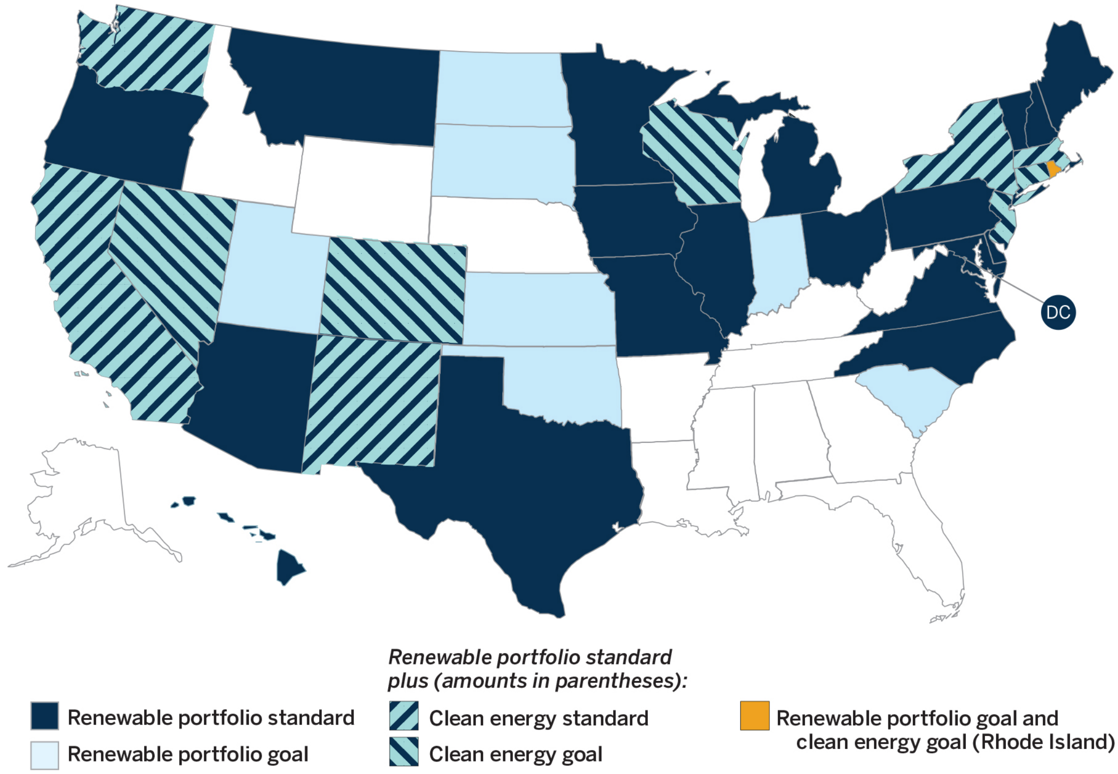
Renewable Portfolio Standards

The most widely known examples of clean energy performance standards are the electric renewable portfolio standards in place in many jurisdictions to mandate continuing increases in renewable energy generation as part of utilities' portfolios of electric power provided to end-use customers. At least 30 U.S. states have electric portfolio standards in place. Five states have clean energy standards that include a broader range of eligible generator types (e.g., large hydro is excluded from Massachusetts' RPS but included in its clean energy standard). Figure 6 on the next page shows which states have standards or goals in place for renewable and clean energy.[19]

[19] Based on North Carolina Clean Energy Technology Center. (2020, September). *Renewable & clean energy standards.* Database of State Incentives for Renewables & Efficiency. http://www.dsireusa.org/resources/detailed-summary-maps/

Figure 6. State renewable and clean energy standards

30 states and Washington, D.C., have a renewable portfolio standard. Five states have a clean energy standard. Eight states have renewable portfolio goals, and five states have clean energy goals.



Arizona: 15% by 2025*
California: 60% by 2030 *(100% by 2045)*
Colorado: 30% by 2020 (IOUs)*† *(100% by 2050)*
Connecticut: 40% by 2030 *(100% by 2040)*
Delaware: 25% by 2026*
Hawaii: 100% by 2045
Illinois: 25% by 2026
Indiana: 10% by 2025†
Iowa: 105 MW
Kansas: 20% by 2020
Maine: 100% by 2050
Maryland: 50% by 2030
Massachusetts: 35% by 2030 and 1% each year thereafter (new resources); 6.7% by 2020 (existing resources) *(80% by 2050)*
Michigan: 15% by 2021*†
Minnesota: 26.5% by 2025 (IOUs) 31.5% by 2020 (Xcel)
Missouri: 15% by 2021
Montana: 15% by 2015
Nevada: 50% by 2030 *(100% by 2050)*
New Hampshire: 25.2% by 2025
New Jersey: 50% by 2030 *(100% by 2050)*
New Mexico: 80% by 2040 (IOUs) *(100% by 2045 [IOUs])*
New York: 70% by 2030 *(100% by 2040)*
North Carolina: 12.5% by 2021 (IOUs)
North Dakota: 10% by 2015
Ohio: 8.5% by 2026
Oklahoma: 15% by 2015
Oregon: 50% by 2040* (large utilities)
Pennsylvania: 18% by 2021†
Rhode Island: 38.5% by 2035 *(100% by 2030 goal)*
South Carolina: 2% by 2021
South Dakota: 10% by 2015
Texas: 5,880 MW by 2015*
Utah: 20% by 2025*†
Vermont: 75% by 2032
Virginia: 100% by 2045/2050
Washington: 15% by 2020* *(100% by 2045)*
Washington, D.C.: 100% by 2032
Wisconsin: 10% by 2015 *(100% by 2050)*

U.S. territories
Puerto Rico: 100% by 2050
Guam: 25% by 2035
U.S. Virgin Islands: 30% by 2025
Northern Mariana Islands: 20% by 2016

IOUs = investor-owned utilities
* Extra credit for solar or customer-sited renewables
† Includes nonrenewable alternative resources

Source: Based on North Carolina Clean Energy Technology Center. (2020). *Renewable & Clean Energy Standards*

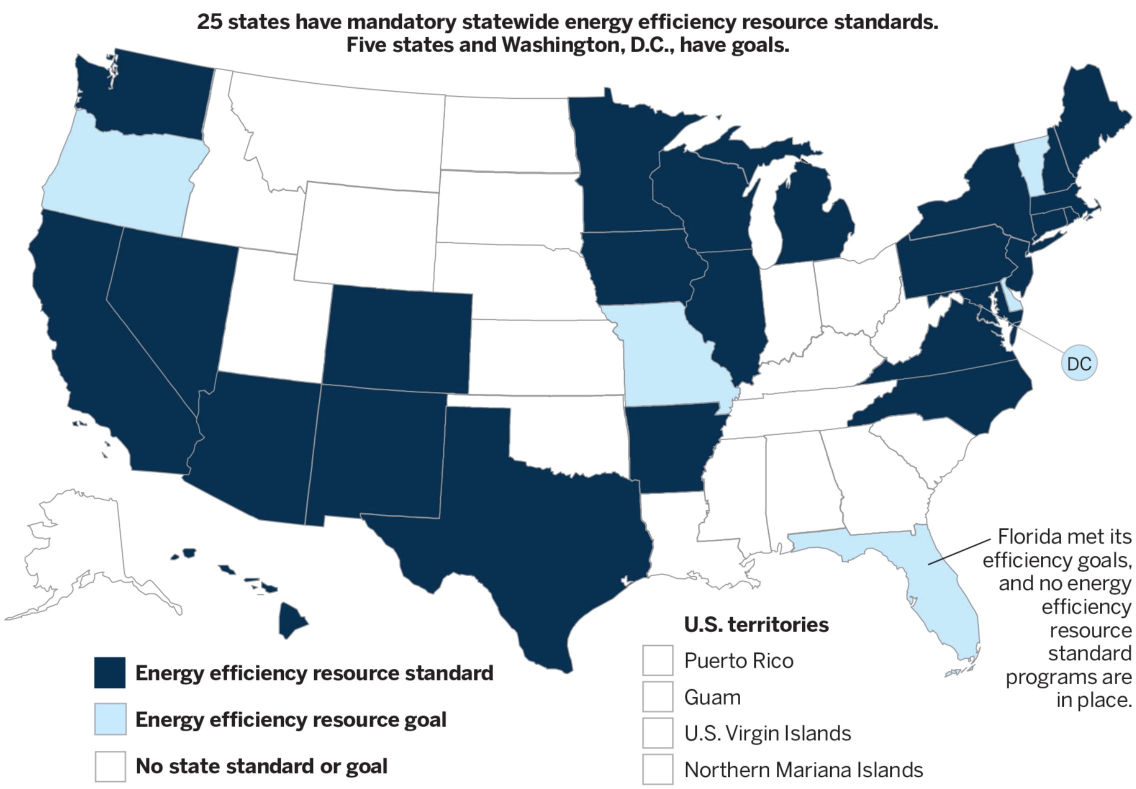
Low-Carbon Fuel Standards

The low-carbon fuel standards in California, Oregon, Washington and British Columbia are designed to decrease the carbon intensity of transportation fuels on a life cycle basis, using metric tons of greenhouse gas emissions. Although the transportation and thermal sectors are quite different, the California program has two aspects that could be useful in the design of a Clean Heat Standard. First, the low-carbon fuel standard includes electricity as a creditable resource in meeting the standard. Second, the program uses life cycle emissions across all eligible fuel types, providing good analytical examples that could be drawn on, or improved, for a Clean Heat Standard in Massachusetts.[20]

Energy Efficiency Obligations

At least 31 states have an energy efficiency resource standard or similar obligations in place, requiring regulated utilities or retail electricity suppliers to deliver energy efficiency savings to and with their end-use customers (see Figure 7[21]). These too rely on performance standards to reduce consumption, total energy costs and emissions.

Figure 7. State energy efficiency resource standards and goals



Source: North Carolina Clean Energy Technology Center. (2021). *Energy Efficiency Resource Standards (and Goals)*

[20] The California Air Resources Board relies primarily on the GREET model, developed by Argonne National Laboratory, to compare the life cycle emissions of different transportation fuels and substitutes. Purdue's Global Trade Analysis Project (GTAP) model is also used to evaluate life cycle emissions of biofuels. To the degree that Massachusetts chooses to evaluate and compare heating options on the basis of life cycle greenhouse gas emissions, it could choose to rely on these or similar models to compare resource options within a Clean Heat Standard.

[21] North Carolina Clean Energy Technology Center. (2021, September). *Energy efficiency resource standards (and goals).* Database of State Incentives for Renewables & Efficiency. http://www.dsireusa.org/resources/detailed-summary-maps/

Important lessons can be taken from the experience gained by Massachusetts and other states in the delivery of end-use energy efficiency measures. First, although it is challenging to overcome the consumer barriers to efficiency, good program design can succeed in enrolling customers in changing the technologies they use in their homes and businesses. Second, there has been a great deal of experience in measuring and verifying consumption savings from long-lived measures. As this paper discusses later, these two topics are quite important in the design of a Clean Heat Standard, which relies in large measure on enrolling customers to change their heating systems and on measuring and crediting greenhouse gas savings from those systems over multiyear periods.

Other States' Experience With Clean Heat Policies

Two other states, Colorado and Vermont, can offer ideas for Massachusetts. In 2021, Colorado adopted legislation requiring its pipeline gas utilities to create clean heat plans that would reduce emissions by 22% by 2030.[22] Gas distribution utilities can choose from a range of "clean heat resources" to meet the emissions reduction requirements, including electrification, efficiency, green hydrogen and a limited fraction of recovered methane and methane leakage reductions. In December 2021, the Vermont Climate Council recommended adopting a broader Clean Heat Standard for both pipeline and delivered fuels.[23] The General Assembly adopted detailed legislation to implement that recommendation, but the governor vetoed it at the end of the 2022 legislative session.[24] Decision-makers and stakeholders in Massachusetts will be able to learn from the legislative and regulatory processes in those states as they develop a Clean Heat Standard for the Commonwealth.

Threshold Issues for Implementing a Clean Heat Standard

Building in Equity

While equity and environmental justice have long been goals of Massachusetts energy and environmental policy, Massachusetts now has an explicit statutory requirement for greenhouse gas regulations to rigorously address these important issues. Equity has process and substance components.

As a matter of procedural equity, significant efforts must be undertaken in the initial program design stage to obtain input from low-income residents of the Commonwealth and from environmental justice communities. Input from housing agencies, weatherization and efficiency practitioners and finance experts should support this

[22] Senate Bill 21-264, codified at Colorado Revised Statutes 40-3.2-108 (2021). See also Henchen, M., & Overturf, E. (2021, August 11). *Policy win: Colorado's innovative Clean Heat Standard will force gas utilities to clean up their act*. Canary Media. https://www.canarymedia.com/articles/policy-regulation/policy-win-colorados-innovative-clean-heat-standard

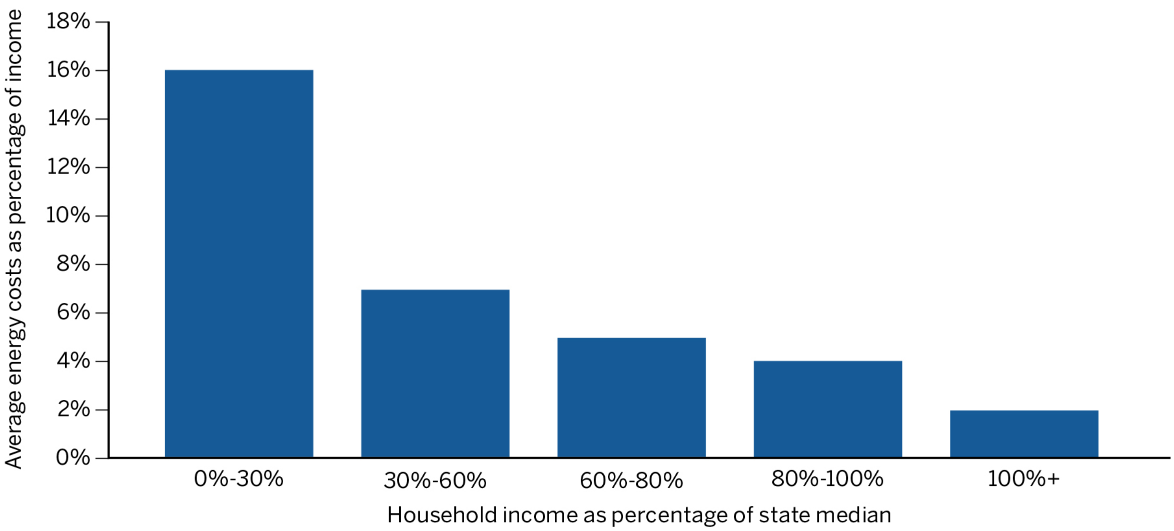
[23] Vermont Climate Council. (2021). *Initial Vermont Climate Action Plan*, pp. 97-101. https://climatechange.vermont.gov/sites/climatecouncilsandbox/files/2021-12/Initial%20Climate%20Action%20Plan%20-%20Final%20-%2012-1-21.pdf

[24] An Act Relating to the Clean Heat Standard. H.715, Vermont General Assembly. (2022). https://legislature.vermont.gov/Documents/2022/Docs/BILLS/H-0715/H-0715%20As%20Passed%20by%20Both%20House%20and%20Senate%20Official.pdf

engagement. The design process must be open to ideas from energy-burdened communities, housing providers and others with lived experience and professional expertise delivering weatherization and heating solutions. There are important roles for community organizations in this process.

Substantively, studies reveal that low-income populations spend a disproportionately high fraction of their income on household energy, despite consuming less energy overall. Figure 8 shows how energy burden is significantly higher for low-income residents of Massachusetts.[25]

Figure 8. Energy burden in Massachusetts by percentages of state median income



Source: U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. (n.d.). *Low-Income Energy Affordability Data (LEAD) Tool*

There are several design elements of the Clean Heat Standard that should be shaped with equity in mind. For example, the standard could be developed with an equity carve-out requiring that a progressive fraction of clean heat credits be acquired from measures in low- and moderate-income households. Alternatively, regulated parties could be awarded a credit bonus, reducing their overall obligation, if a certain equity threshold were reached. In addition, the standard could cooperate with equity-focused goals in other programs, such as community outreach programs, means-tested energy rate tiers, and Mass Save® rebates dedicated to low- and moderate-income consumers.

Low-income households and environmental justice communities often have the highest-emitting building stock. Decarbonizing this fraction of the housing stock will make the greatest proportional contribution to reducing energy burdens, improving health outcomes and ensuring transitional equity. Building-shell improvements and heating conversions will be necessary to improve this fraction of the housing stock; since the financial resources of occupants are by definition limited, public policies are needed

[25] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. (n.d.). *Low-Income Energy Affordability Data (LEAD) tool*. https://www.energy.gov/eere/slsc/maps/lead-tool

to make it happen. Those strategies should be built into the Clean Heat Standard program design from the beginning.[26] Some specific ideas are included in the next section, “The Architecture of a Clean Heat Standard.”

Interaction With Other Programs

Although a Clean Heat Standard is broadly compatible with a wide range of other policies, it is also important to consider more specific ways that these policies might interact, to understand the different impacts of this new policy.

First, the simplest way to construct a Clean Heat Standard is to allow any program-qualified action that reduces greenhouse gas emissions in the thermal sector to earn credits, whether or not the action was uniquely “caused” by the Clean Heat Standard program or by an obligated party (an “umbrella” approach). This allows greater competition among service providers and avoids requiring proof of specific attribution as a condition for earning clean heat credits. For example, installing clean electric heating and bringing insulation up to rigorous standards in existing housing should be able to generate credits regardless of who installed the measure or why. The Clean Heat Standard would just ask, “Is it a qualified clean heat measure?” and “How much will it reduce greenhouse gas emissions?” This way of constructing the program has financial implications, in most cases deliberately by design. Credits generated by upgrading buildings can be sold to obligated parties, thus defraying the cost to the builder or developer for meeting those requirements. In principle, it would be possible to develop a Clean Heat Standard that required direct attribution, but this is more administratively complex and would require a different approach for setting the standard.[27]

Second, as a starting point it makes sense to name the owner of the property or business equipment being upgraded as the default owner of clean heat credits generated from on-site projects. Although in principle property owners could mint credits under the program and sell them to an obligated party or a broker, it is more likely that individual property owners would need support to do so or that automatic credit creation and exchange could be facilitated by other programs. For example, energy efficiency programs that support clean heat can provide for automatic acquisition of the clean heat credit and provide incremental incentive value in exchange, along with processes that automatically mint credits.

[26] There is, on the surface, tension in program design between dedicating efficiency and heat-switching resources to consumers with the highest energy burdens and maximizing early pollution reductions by focusing on the quickest reductions from anywhere. RAP recognizes that a just transition requires both justice and an effective transition, so multiple objectives must be served. At this point, RAP judges that the balance should favor early action to improve heating systems for those who bear the greatest energy burdens. Ultimately, clean heat solutions will have to be delivered to most homes and businesses across Massachusetts, so almost everyone will ultimately be served. RAP believes it is equitable and ultimately cost-effective to provide clean heat solutions to the most energy-burdened households disproportionately earlier in the process than would be the case if the distribution of benefits were left to market forces alone.

[27] In an umbrella Clean Heat Standard, if the statewide emissions reduction target is 40%, the standard can be set at 40% and all qualified actions can earn credits. In an attribution-based system, regulators would need to estimate the reduction likely to result from other ongoing programs and market forces, (say 18%) and calculate the performance gap (in this example, 22%). The Clean Heat Standard could be set to deliver just the remaining "gap” amount of reduction (22%), but regulators would want to make sure that each clean heat credit claim was additional to what would have happened anyway. The umbrella Clean Heat Standard approach eliminates these administrative and measurement uncertainties.

In addition, other programs can be designed to be supportive of the Clean Heat Standard. Materials and websites for other programs should include the Clean Heat Standard as part of the menu of options for Massachusetts residents to consider.

These are simple examples of more specific ways that the Clean Heat Standard may interact with other energy and environmental policy efforts. Additional considerations may become clear during the regulatory process to develop the program specifics.

The Architecture of a Clean Heat Standard

Nature of the Obligation

The main advantage of the Clean Heat Standard is that it focuses on the delivery of concrete, delivered clean solutions to drive down consumption of fossil fuels. A key goal of the standard is to stimulate suppliers of clean heat alternatives to deliver clean heat solutions to their customers. However, a credit-based system must take care to measure the right accomplishments. For example, a Clean Heat Standard that requires installation of X number of heat pumps or weatherization of Y square feet of building space could be based on good estimates of the greenhouse gas results but would be measuring inputs rather than measuring the outputs (GHG reductions). A crediting system that focuses on counting tons of GHG reductions would ensure that emissions reductions are prioritized and quantified. Additional options include crediting based on heating energy provided (e.g., in therms).

Clean Heat Credits

The basic concept of a Clean Heat Standard is an earned-credit system, most analogous to the electric sector's RPS. Such a program would require obligated parties to deliver annually a gradually increasing quantity of heating services through approved clean heat measures and to retire the number of clean heat credits required in that year. As these measures replace fossil heat services, greenhouse gas emissions will decline in sync with the Commonwealth's climate mandates (see the following section on the pace of change). Like other performance standards, the Clean Heat Standard would provide a clear picture of the rate of change required. The program would create a commercial value for each heat pump installed, each customer served with an approved alternative, the square feet of homes weatherized and other complementary measures the Commonwealth wants to support.

That, in turn, could help fuel dealers, HVAC contractors, fuel producers and others to transition their businesses to selling such products and services.

The Common Denominator to Measure Credits Should Be CO_2e

In electricity performance standards, performance is normally counted in kWh. Since the principal goal of a Clean Heat Standard is to deliver the emissions reductions required by the GWSA and the 2021 Climate Roadmap law, credits could be measured in terms of CO_2 equivalents (CO_2e), which would give credit for the CO_2 emissions avoided by the addition of a variety of clean heat solutions. Using CO_2e also allows a variety of clean heat options, from weatherization and heat pumps to approved clean fuels, to be compared on a quantitative basis.

Because the Clean Heat Standard would award credits for actions taken in the form of CO_2e avoided, it would be critical to establish standards to quantify the performance of different types of clean heat measures over time. This type of problem has been addressed in other performance-based systems, including energy efficiency programs and low-carbon fuel standards.

Energy efficiency programs have well-established protocols for quantifying the energy, capacity and environmental benefits of different types of efficiency measures, such as light bulbs, weatherization and appliance replacements. So-called deemed savings rates are based on field measurements and are updated over time. A Clean Heat Standard would require a similar manual and a process to create it and update it.[28]

Size of the Annual Obligation

The size of the annual obligation for those covered by this program is a critical decision since it sets the pace and slope of the emissions reductions from a Clean Heat Standard. The regulating agency will need to determine (with public input) the glide path to a significant reduction in emissions, up to or beyond 85%. It must also set out the timeline for achieving that goal, including interim steps to be met in the CECP by 2025, 2030 and 2040.

The obligation for residential, commercial and industrial heating sectors would rise over time to meet the 2025/2030 CECP goals established by the Secretariat under the GWSA, along with other policies deemed appropriate, such as the three-year energy efficiency plans. These goals indicate a nearly 50% reduction from 1990 gross emissions in these sectors by 2030. As plans for 2040 and 2050 are developed, longer-term goals will be established.

Technology carve-outs are not necessarily needed but could be included in the Clean Heat Standard program, if desired for public policy reasons such as addressing the legislative requirement to track heat pump deployment. However, a key strength of the standard is that credits can be earned in multiple ways, allowing customer choices, provider choices and competition to deliver solutions. Therefore, RAP does not recommend including carve-outs for specific technologies, except where the public policy pathway is quite clear and barriers to that pathway may block progress. In such cases it may be important to promote certain clean solutions that are needed in the long term even where short-term solutions might otherwise prevail in the market. Giving extra credits for replacing fossil-fueled furnaces with heat pumps is one possible example. If the end goal is to reach net-zero emissions economywide and the pace of stock turnover presents only a few opportunities to replace heating systems in the next three decades, it may be important

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[28] Life cycle CO2e analysis would also be required if renewable fuels or biofuels were included in a Clean Heat Standard. There are scientifically determined values assessing the life cycle emissions of different types of fuel, differentiated by feedstock, location and other variables. Systems like the GREET and GTAP models used by the California Air Resources Board and the Environmental Protection Agency could help to assign life cycle emissions values for any fuels deemed creditable under a Clean Heat Standard in Massachusetts.

to encourage certain long-term solutions immediately even when lower cost near-term solutions are more readily available.

Ongoing and periodic program review will be necessary to consider potential regulatory amendments. For example, on evidence and after public hearings, it could be desirable to adjust the level of obligation on a forward-going basis: (a) upward, if credits are meaningfully oversupplied or (b) downward, subject to strict conditions, in response to serious, unavoidable technical problems, supply constraints and adverse market conditions.

The Obligation Rises Over Time in Sync With Climate Requirements

The essential idea of the Clean Heat Standard is to add clean heat resources to Massachusetts homes and businesses over time.

Heating, like electricity, is an essential service. Just as an RPS seeks to add clean resources to the power mix without imposing a cap on consumption, the Clean Heat Standard seeks to add clean heat services to the thermal sector without putting a limit on how much heat is delivered or consumed. However, continued investments in energy efficiency measures should help reduce the costs of clean heat solutions. Adding clean heat solutions in Massachusetts serves multiple purposes: lowering heating costs to residents, adding resilience to the heating sector,[29] supporting efficient cooling in low-income communities as the climate warms and extreme heat events become more common, promoting jobs in advanced heating technologies, improving indoor and outdoor air quality — and lowering greenhouse gas emissions. Lowering climate pollution is not the only reason to create a Clean Heat Standard.

That said, as the supply of clean heat services in Massachusetts grows over time, greenhouse gas emissions from the thermal sector will naturally decline. The standard should be designed to sync with the state's overall climate requirements, recognizing as well that the Clean Heat Standard is not the only tool called upon to reduce emissions from the thermal sector.

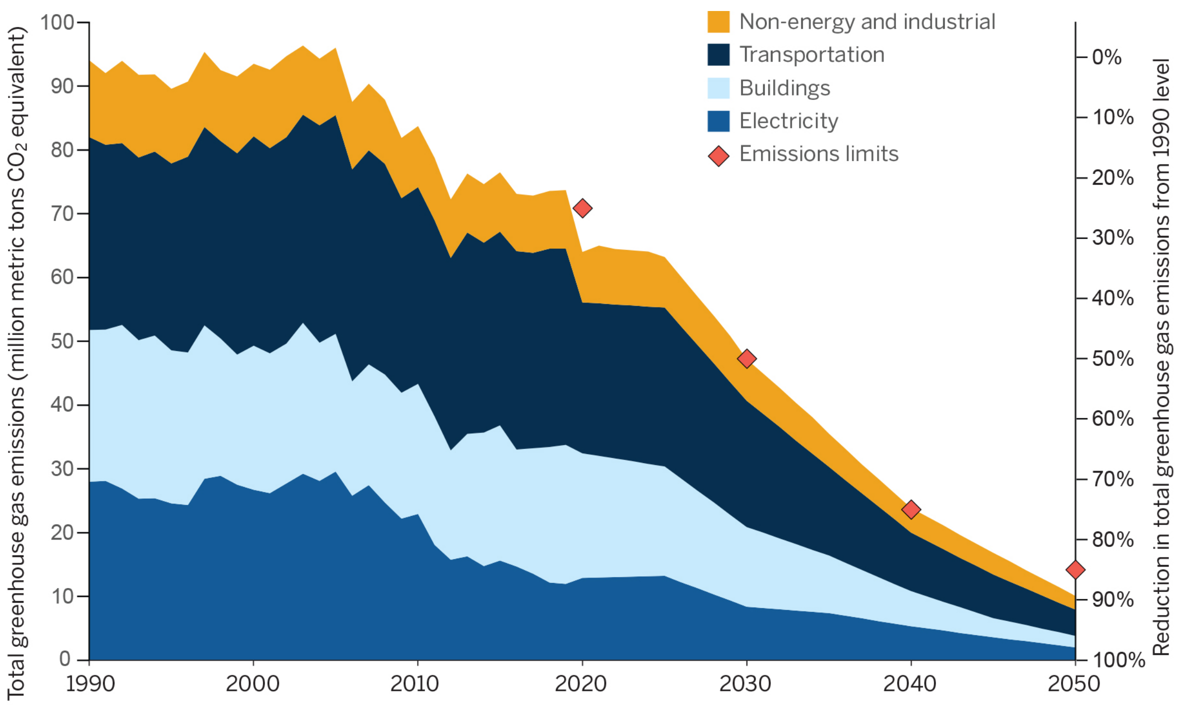
Figure 9 on the next page shows how emissions from the thermal sector should decline in keeping with the GWSA requirements.[30] In very general terms, the rate of improvement set out in the law is roughly 4% per year until 2025, rising to just under 5% per year between 2025 and 2030, and then settling to a reduction in emissions of about 3% per year from 2030 to 2050.[31]

[29] Adopting a Clean Heat Standard now protects Massachusetts against the risk of supply disruptions and abrupt policy shifts that are likely to come later, as the climate crisis worsens and future governments impose policies to rapidly shift away from fossil heating fuels.

[30] Massachusetts Executive Office of Energy and Environmental Affairs.

[31] Massachusetts measures greenhouse gas reductions from a 1990 baseline.

Figure 9. Sector greenhouse gas emissions as shares of Massachusetts economywide total



Note: 1990 through 2019 reflect full-year historical data.

Source: Massachusetts Executive Office of Energy and Environmental Affairs

The Standard Could Be Adjusted as Conditions Change

Decades of experience with energy policies, including utility integrated resource plans, renewable portfolio standards and efficiency programs, have taught providers and regulators that the costs of environmental improvement often come down more quickly than first projected. When renewable portfolio mandates created a growing market for wind and solar power, initial costs were relatively high. However, economies of scale, experience and competitive bidding for renewables drove down costs much more quickly than analysts expected. With the expected growth in Massachusetts for installed heat pumps, a similar decrease in costs may occur over time, potentially including the cost of installation.[32]

In addition, as equipment vendors, contractors and supply houses gain experience with these cleaner technologies, heating markets may gradually be transformed, as has happened with lighting technologies. This evolution could lead to two positive results. Most directly, lower costs for clean heat systems would yield a greater supply of clean heat credits, moderating the cost of the Clean Heat Standard program for providers and consumers. Beyond that, with higher uptake and lower costs for the standard, decision-

[32] The cost of delivering and installing clean heat solutions should drop with increased scale and experience in Massachusetts. If other states and nations adopt similar policies, the manufactured cost of clean heating equipment might decline, while equipment performance is likely to continue to improve. The cost of biofuels might rise due to potential supply limitations or might drop with technological improvement. Increased penetration of heat pumps could deliver positive benefits to the electric system if usage is managed over time through advanced rate designs, storage and demand management techniques.

makers might have the opportunity to increase the pace or ambition of the standard itself, which would deliver deeper greenhouse gas savings earlier in the program. This might be needed if climate progress in other sectors moves more slowly than expected or desired or if future CECPs require faster or deeper emissions reductions than currently outlined.

On the other hand, economic conditions might change dramatically to cause a shortage of clean heat opportunities, or supply chain disruptions could interfere with delivery of new equipment.[33] For all these reasons, the Clean Heat Standard program could build in an opportunity for state regulators to revise the obligation level on a forward-going basis. Any adjustments to slow down progress should be subject to strict limits to protect the essential purposes of the standard.

Obligated Parties

The obligation to lower the greenhouse gas emissions of fossil heating fuels could be applied on a competitively neutral basis across all fossil heating fuels, including gaseous fuels delivered by pipelines and distribution networks (termed natural gas, fossil gas or pipeline gas) and delivered fuels (fuel oil, propane, kerosene and coal). The standard would apply to all substantial fossil fuel sales from any of these sources.

Although coverage of the standard should be inclusive, the question remains: Who should be the "obligated parties" to ensure that this responsibility is carried out?

Massachusetts does not produce fossil fuels. The Commonwealth depends on imports of petroleum and diesel. Massachusetts residents and businesses spend about $6 billion each year to import fuels to heat buildings and water, to cook and to run industrial processes.

A variety of enterprises are involved in this large, critical sector. Fossil fuels are delivered into the state to terminals in Chelsea, Boston and Springfield, and fuel is delivered via truck or rail from other terminals such as Albany, New York; Providence, Rhode Island; Portland, Maine; and New Haven, Connecticut. Liquefied natural gas arrives infrequently at a terminal in Boston, and pipelines deliver a large quantity of fossil gas. There are wholesale fuel suppliers operating out of terminals in Chelsea and Springfield. Massachusetts wholesalers and retailers also operate bulk storage facilities for distillate products and propane in the Commonwealth.

At the retail level, Massachusetts is served by many retail providers of fuel oil and propane and regulated and competitive suppliers of pipeline gas. These entities range in size from very large corporations to local, family-owned fuel dealers.

RAP sees the following options for obligated parties in Massachusetts:

- Regulated investor-owned gas utilities.
- Providers of delivered fuels, with the point of regulation applying either at the wholesale level or at the retail level.

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33 If Massachusetts launches a Clean Heat Standard program designed to achieve reductions in the next 25 years, it's impossible to anticipate events like the COVID-19 pandemic or the supply chain issues that have resulted. The program will need provisions that allow for adjustments over those 25 years, such as a required periodic review.

- Fossil heat providers that are not any of the above-named parties, including competitive gas suppliers.
- Electricity suppliers, either on their own or together with other heating suppliers.

Other categories that may warrant consideration include:

- Large commercial properties above a set threshold of fuel usage (to prevent individual homeowners from an individual obligation).
- Municipalities or municipal gas companies as obligated parties, perhaps with municipal electric companies having the option of creating and selling credits.
- Landlords with real estate above a set threshold of square footage.
- Other options that could be raised through public input.

As the list above reveals, a Clean Heat Standard in Massachusetts could be applied in many ways. At a very practical level, reducing building heat emissions requires building owners to decide to deploy clean heat solutions, such as a cold-climate air source heat pump, when replacing or augmenting their HVAC systems. RAP does not envision enacting a mandate directly on end users that would require individuals to replace their heating systems, so how can they be supported to make those changes? The principal reason to place a clean heat obligation on energy providers is that they have commercial relationships with end-use customers and thus can work with their customers on choices for heating that reduce emissions. In addition, in the long run, clean heat services will be a business opportunity in Massachusetts, and the state's economic goals are served by developing expertise in-house and in-state, as has been done for energy efficiency and solar power. Placing an obligation on existing heating providers on a competitively neutral basis might well provide a needed boost in that direction.

Obligations on Pipeline Gas Providers

With respect to pipeline gas, the obligation should cover all deliveries in Massachusetts. This can be accomplished by imposing the obligation on all pipeline gas retailers, regulated and competitive,[34] or on the natural gas local distribution companies that deliver the fuel. Due to more direct regulatory oversight, and for ease of administration, it is easier to apply the obligation on the regulated local distribution companies, but either choice could work.[35]

Obligations on Delivered Fuel Providers

The discussion below touches on how the standard should be applied to delivered fuels, such as distillate heating oil and propane.

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[34] For information on competitive gas suppliers, see Massachusetts Department of Public Utilities. (n.d.). *Competitive supply for natural gas.* https://www.mass.gov/info-details/competitive-supply-for-natural-gas

[35] Fossil heating fuels are delivered in a variety of ways, including directly from interstate pipelines to larger industrial users. Municipalities also deliver fossil gas to end users through public systems. As a general matter, RAP suggests including all thermal sales in the Clean Heat Standard to achieve the Commonwealth's climate goals and to avoid creating bypass incentives. However, decisions on scope involve other statewide public policy choices that decision-makers will need to weigh.

A basic question to address is: Should the Clean Heat Standard obligation for delivered fuels be implemented "downstream," on retail delivery companies, or "upstream," on wholesale providers?

As noted above, a major reason to assign the clean heat obligation to retail fossil fuel companies is their direct relationship with end-use customers. These companies employ technicians and delivery staff members who could be trained to work with customers on heat pump options and other cleaner-heating solutions. These companies could develop new business models to succeed under a clean heat mandate.

On the other hand, upstream wholesalers have greater financial and management capacity and are less numerous, and they have the opportunity to acquire and blend renewable fuels into the system, which could quickly deliver at least some carbon savings without requiring actions by end users.[36] Wholesalers could also meet their clean heat obligations by purchasing credits from others or contracting with a range of delivery entities, including fuel dealers, heat pump contractors or statewide delivery organizations. Finally, wholesale providers might wish to use this opportunity to build up a clean heat line of business, akin to the work that many traditional power companies have been doing in transitioning to renewable electricity. An upstream obligation would still give retail fuel dealers the opportunity, but not the direct obligation, to deliver fuel-switching services to their customers. They could work with the wholesalers to identify customers who are good candidates for upgrades.

Legal research is required to determine the best way to apply an obligation at the wholesale level if some wholesale transactions occur outside of the Commonwealth (e.g., filling a tanker truck at a fuel storage depot in another state). At the wholesale level, the obligation to meet a Clean Heat Standard could be attached at the time a tanker truck is filled for sale, even if that happens out of state, if it is intended for sale in Massachusetts as per a bill of lading.[37]

One key advantage of placing the Clean Heat Standard obligation onto delivered fuel wholesalers is that it creates opportunities for multiple categories of actors to perform work and earn credits. However, since either upstream or retailer obligations could work, the ultimate choice might well come down to the practical preferences of the Commonwealth and stakeholders including energy service providers. Whichever way the standard is designed, it should provide ample opportunity for regional and state-based fuel dealers and energy companies to develop new lines of business and to thrive in a low-carbon energy environment.

[36] Fossil fuel wholesalers include in-state and out-of-state entities, and out-of-state entities with in-state facilities and operations. Intermediate shipment points are also commonly used, as in the numerous bulk storage tanks that store fuel for later loading onto local delivery trucks. If the Clean Heat Standard obligation is not imposed at the retail level, RAP suggests that it be imposed on the first jurisdictional provider of fossil heating fuels destined for consumption in Massachusetts.

[37] A variety of legal options have been developed to ensure regulatory coverage of interstate fossil fuel sales. If obligations are placed on multistate wholesale operators, Massachusetts would need to evaluate how those methods could be applied to a Clean Heat Standard and how reliable the reporting and compliance pathways would be.

Obligations on Electricity Providers

Massachusetts is among a handful of states that have gotten a start on thermal efficiency and cleaner heat by extending electric utility energy efficiency or renewable energy programs to at least some fossil fuel uses. Under the Alternative Energy Portfolio Standard (APS), retail electricity suppliers (both regulated distribution utilities and competitive suppliers) are obliged to purchase alternative energy credits equal to a certain percentage of their retail sales in a given year. That percentage requirement, 5.5% in 2022, has been rising at the rate of 0.25 percentage point each year. Initially the program was designed to promote combined heat and power (CHP) installations, and over the years the largest fraction of the alternative energy credits has come from fossil gas-fired CHP operations. Much smaller fractions have been delivered by renewable thermal measures, including heat pumps, and by liquid biofuels and fuel cells.

The APS has been revised several times, enlarging the categories of technologies that can earn credits. Studies of the APS and stakeholder reviews of its implementation have crystallized a set of conclusions and recommendations that are relevant to the design of a Clean Heat Standard:

- The size of the APS obligation and its current rate of increase are small in comparison to the scale of clean heat deployment needed to reach statutory emissions limits.
- The APS has helped to drive innovation and deployment of some alternative energy solutions in Massachusetts.
- It has helped to add resilience and reliability to the power grid, especially via the operation of CHP units in critical facilities like hospitals.
- It has reduced emissions, but not at a rate sufficient to meet the goals set in the GWSA and the 2021 Climate Roadmap law.
- It has contributed to lower energy costs and diversification in the energy sector of the economy.
- Finally, and perhaps most importantly, Massachusetts' experience with the APS shows that a performance standard that permits a range of technologies to compete in lowering emissions can deliver cost savings and emissions reductions — if the credit system is set to reward sustainable, low-emissions energy options.

Notwithstanding those positive experiences, a thorough review of the APS by Daymark Energy Advisors for the Department of Energy Resources[38] found some challenges with the existing program.

- A major problem with the APS program has been a growing mismatch between demand and supply. The standard was initially set at a low level and grows slowly. Because natural gas-fired CHP is a well-developed and relatively low-cost generating technology, its inclusion in the program has crowded out other solutions.

[38] Daymark Energy Advisors. (2020). *Alternative Energy Portfolio Standard review*. https://www.mass.gov/doc/alternative-energy-portfolio-standard-review/download

- Moreover, the program's energy-based credits are delivered on a MWh basis, much like an RPS, rather than measuring and rewarding greenhouse gas reductions. Renewable energy solutions that reduce emissions more than CHP has done are not rewarded in the alternative energy credit market sufficiently to truly provide the necessary incentives for broad adoption.

The Daymark report reveals that the APS program would require substantial modification if it were to be used as a vehicle to reduce emissions in the thermal sector. The report states that "in the cases modeled, CHP systems do not provide any emissions benefits." Meanwhile, "small renewable thermal systems," including heat pumps, biomass pellet boilers and solar thermal hot water, "achieve emissions reductions for the lowest cost compared to other renewable thermal and CHP systems." However, those small renewable thermal systems do not receive the incentives they need to be deployed and play only a very small role in the APS program.

The Massachusetts APS program could be modified to change the incentive structure, remove fossil generation from the list of creditable measures and promote alternative technologies based on emissions reductions. The Department of Energy Resources is planning to launch a rulemaking to address some of these issues. But should the Commonwealth make all those changes, while keeping the obligation to perform at a much higher level on retail electricity suppliers?

Massachusetts could substantially increase the existing thermal obligation on electric utilities, or it could place the requirements on fossil fuel suppliers or on both fossil and electricity providers. The merits of these choices are sketched out below.

First, a leading factor in this choice is that electric utilities and electric rates are already bearing most of the cost of addressing climate change in energy in Massachusetts and the region. Electric rates have supported renewables additions, grid upgrades and electric efficiency programs. Carbon costs are also reflected to some degree in power costs through the Regional Greenhouse Gas Initiative (RGGI). Yet, clean and affordable electricity will be needed to help transform the other sectors of the economy, including heating. In contrast, natural gas utilities and their rates bear less cost for energy efficiency: They face no renewable fuels mandates and have no carbon reduction requirements. Delivered fuel companies and their customers have even lower climate obligations.

As a result, progress has been relatively slow in the thermal sector, and we have created a situation in which the cleanest energy source (electricity) is paying extra costs to address climate change, while the higher-emitting fossil fuels are paying much less. The resulting relative prices are sending the wrong signals to consumers and making it that much harder to clean up our energy mix. Putting a clean heat obligation on the fossil fuel suppliers helps to rebalance the scales so that a greater share of emissions reduction costs is reflected on consumers' fossil heating fuel bills instead of their electric bills.[39]

If we assume that Massachusetts does not plan to implement a clean heat obligation directly on end-use consumers, consumers will need to make heating choices on an

[39] The Daymark report points out that switching the obligation from retail electricity suppliers to natural gas local distribution companies is one option to address the structural problems of the APS program. Daymark Energy Advisors, 2020, p. 3 and elsewhere.

individual basis. Consumers naturally compare the total cost of heating with one system against the total cost with another system when they are renovating a building or replacing a failed furnace or boiler. Incentive awards can make a big difference at that time, but comparative fuel costs matter as well. So even if "all customers will pay" one way or another, it matters how they pay.

Second, a diversity of solutions to reduce emissions from the heating sector will be important to consider. For instance, fuel suppliers, electricity suppliers and a natural gas utility are likely to take different approaches to the solutions offered to customers and how they will be marketed. Electric utilities, for example, could focus on heat pumps. However, particularly in the short run, Massachusetts may need a combination of thermal solutions to meet its climate goals. Fossil fuel providers have proposed options to deliver cleaner heat solutions, and some of them might be needed to deliver near-term solutions, particularly in a transition period. In the longer run, a broad conversion away from pipeline gas will require either phased decommissioning of parts of the gas grid or planned provision of hybrid electric/gas heating or both. If gas utilities are involved, they can help to deliver heating system changes to customers in geographically targeted areas to avoid customer confusion and minimize the total cost of the system conversion.[40] And, particularly in rural areas served by delivered fuels, choice is important to consumers due to personal preferences and the nature of the building stock.[41]

Finally, if the clean heat obligation is placed on fossil fuel providers in proportion to their annual sales of fossil fuels, this creates a continuous incentive for those providers to reduce their fossil fuel sales every year. When each year's clean heat obligations are keyed to current or recent fossil fuel sales, actions that reduce fossil fuel sales will both (a) earn clean heat credits in the present year and (b) reduce the size of the obligation in future years. This creates an incentive for continuous decarbonization by obligated fossil fuel providers.

To deliver the depth and pace of change required, it is at least useful, and probably necessary, to engage the existing fossil fuel industry in its own transition to a clean thermal sector. These factors counsel against placing the obligation entirely on electricity providers, particularly at the start of the program.

A Phased Approach

As the discussion above makes clear, there are several reasons to impose a Clean Heat Standard obligation on fossil fuel providers — and some potential to impose the obligation on electricity providers. A third option is to adopt a phased approach, including electricity suppliers as obligated entities in the standard over the longer term when Massachusetts

[40] Where parts of the gas grid are to be decommissioned, it will be essential to offer heat pumps, district heating services or other options to those customers on a geographically targeted basis. Gas utilities will have to be involved in this new type of planning process.

[41] For example, some rural buildings may be ready for conversion to heat pumps almost immediately, but many will require efficiency renovations first. Some customers may be ready, willing and financially able to do those renovations, while others will want or need to wait.

expects to have largely reduced the use of fossil fuels for heating. Reasons for taking this phased approach include:

- Over time, as electrification proceeds in powering heating and transportation needs, electricity suppliers' financial strength is likely to increase along with their capacity to purchase compliance credits and hedge risks associated with weather and fuel price variability.
- Massachusetts Pathways analysis and the text of recent climate legislation identify electrification as a necessary component of decarbonization, and electric utilities are likely to be more supportive of electrification than other potential compliance entities.
- Electricity customers include virtually all residences and businesses in Massachusetts; thus, placing the obligation on electricity customers would spread the costs of the transition more broadly, particularly in later years when there are fewer and fewer customers of gas companies and delivered fuel suppliers.

Considering these factors, it would be useful to study how the mix of obligated parties might evolve over time. One option would be to assign clean heat obligations across both fossil fuel providers and electric utilities *in proportion to their sales for heat*. In 2022, a relatively small fraction (under 15%) of the total obligation would fall on electricity providers. But as the pace of electrification picks up, that fraction would grow. Decision-makers should examine whether the Massachusetts clean heat obligation should be designed to shift the compliance obligation across different heating providers over time. If the obligation were only on fossil fuel providers, it would be placed on a declining number of users, whereas if it were on electricity providers as well, all heat customers would be contributing to the transition.[42] This design question will require substantial additional analysis and modeling before decisions can be made.

What Actions or Fuels Should Earn Clean Heat Credits?

The Program Is a Performance Standard, Not a Technology Mandate

One of the central ideas of the Clean Heat Standard is to enable a variety of pathways to decarbonize heating, instead of choosing winners by having regulators require certain heating choices rather than others. This is important for at least three reasons:

1. Ultimately, end-use customers need to install their own heating equipment and choose their energy suppliers. Buildings differ, consumer preferences differ, and even the same consumers will choose different heating systems as their budgets and preferences change over time.
2. A performance standard creates competitive pressure across technologies and fuels, which will lower the total costs of the heating transition and help to drive innovation, both in technology and in service delivery pathways.

[42] Putting the obligation on providers with a shrinking quantity of fossil sales is difficult but achievable. If the annual obligation is proportional to an obligated party's fossil sales, as those sales go down, so does the obligation in quantitative terms.

3. The fundamental purpose of the Clean Heat Standard is to reduce emissions, not to promote certain technologies for extrinsic reasons. The standard needs to include guardrails to ensure that unsustainable or clearly undesirable choices are not rewarded, but within a range of solutions it should allow customers, providers and markets to choose clean heat paths.

In short, the standard should permit a range of technologies and fuels to compete for the ability to earn clean heat credits. The standard could be met in multiple ways, combining different numbers of weatherization jobs, heat pumps, district heating or advanced wood heat systems, and/or different blends of renewable pipeline gas, perhaps green hydrogen and approved biofuels. The evolution of technologies, their relative costs and market dynamics would ultimately drive what the mix of resources should be or will be.

One thing we do know, whatever the future clean heat mix will turn out to be, is that Massachusetts will need substantial increases in clean heat investments and fuels through a variety of means. And climate science tells us that early actions to reduce emissions are particularly valuable. In general, diversity in creditable clean heat measures will promote a quicker and less expensive transition.

The discussion below addresses some of the major policy choices regarding eligible clean heat options for Massachusetts, and, where appropriate, RAP's views regarding them. In summary:

- Only those measures that directly reduce combustion of fossil fuels in Massachusetts homes and businesses would be eligible for clean heat credits.
- Biofuels and renewable gases could be eligible for clean heat credits on a limited basis and only if delivered and used in Massachusetts.
- Clean heat credits need to account for life cycle greenhouse gas emissions of the fuel(s) used.
- Exclusions: Certain measures, including pure offsets, fossil fuel fugitive emissions reductions and fuel switching from one fossil fuel to another will not earn clean heat credits.

Direct Reductions in Fossil Fuel Combustion in Massachusetts Homes and Businesses

Although it would be possible to create a clean heat performance standard that could be satisfied by emissions offsets in any sector, anywhere in the world, such a standard would not satisfy the requirements of Massachusetts law, nor would it help deliver the physical changes needed in Massachusetts to transition away from reliance on fossil fuels. The GWSA and the 2021 Climate Roadmap law clearly articulate a preference for direct reductions in Massachusetts' gross greenhouse gas emissions. In addition, to reduce the Commonwealth's reliance on expensive and price-volatile fossil fuels, we need to focus on the direct delivery of building upgrades and clean heat solutions in Massachusetts homes and businesses.

Direct reductions from in-state homes and businesses are also much easier to document as being real (i.e., actually occurring) and legitimate (e.g., relative to an appropriate baseline) and not being double-counted (e.g., relative to emissions reduction requirements in other sectors or in other jurisdictions).[43] For example, it would be very challenging to verify whether investments in tree planting, especially in another country, effectively achieved the level of greenhouse gas emissions reduction assumed. Similarly, it would be challenging to determine whether GHG emissions reductions at an industrial facility in another state were both (a) attributable to the actions or payment of an obligated party in Massachusetts[44] and (b) not also being counted toward other emissions reduction requirements in the host state or even a third state.

Deliverability Requirement for Biofuels

A requirement that any biofuels substituted for fossil fuels be "delivered" to Massachusetts homes and businesses is consistent with the principle of focusing on curbing emissions within the Commonwealth. For biodiesel or other biofuels displacing fuel oil, propane or kerosene, this requirement means that clean heat credits can be earned only for biofuel physically delivered and used in Massachusetts. Biogas (biomethane) that is trucked to an in-state home or business would also be an eligible measure. Giving credits simply for the *creation* of biofuels anywhere in the world — or even anywhere in North America or the United States — would overwhelm the Clean Heat Standard and undermine its fundamental goal to change the nature of heating in the Commonwealth. Put simply, the standard should be a clean heat program for Massachusetts, not an offsets support system.

The concept of deliverability is a little more complicated in the context of the pipeline delivery system for methane gas and hydrogen because it is not possible to trace which molecules of methane or hydrogen are burned in which homes and businesses. Thus, for pipeline biogas, deliverability could be satisfied by purchase and sale of what gas utilities call a bundled product. Specifically, the obligated gas supplier must purchase the biogas itself (including its greenhouse gas emissions reduction attributes) and have a contractual pathway for physical delivery of the biogas from the point at which it is injected into a pipeline all the way to a distribution system in Massachusetts.

This concept is also consistent with the way renewable energy credits are credited in the electric RPS, where renewable electric generation in Quebec, New York and other New England states is eligible to count when the power is delivered to the power grids and markets that directly serve Massachusetts. Renewable generation cannot earn RPS credits in Massachusetts when the generator is located on a remote power grid and sold in a remote power market (e.g., in California or Georgia) that does not deliver electricity in this region.

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[43] As discussed in the section below on credit creation, a concern about offsets is the need to ensure that reductions occurred, proper baseline reductions are measured and the reductions are not credited for multiple purposes (or in multiple jurisdictions). Some of these concerns are applicable to biofuels. However, when and if biofuels are used in Massachusetts, their life cycle greenhouse gas emissions can be assessed and measured against the life cycle GHG emissions of the fossil fuels they displace in Massachusetts homes and businesses.

[44] Although it is not necessary to document attribution for direct reductions in Massachusetts emissions, it would make no sense to allow counting of any emissions offsets, especially outside of the state's borders, without requiring a demonstration of attribution.

Life Cycle Accounting for Clean Heat Credits

Discussions about complex comparisons in the energy world invariably end up in a discussion of "compared to what?" The combustion of biofuels typically produces the same amount of CO_2 emissions at the burner tip as combustion of the fossil fuels they are displacing. The difference is that biofuels can provide other greenhouse gas emissions reduction benefits — either eliminating emissions of other greenhouse gases or removing CO_2 from the atmosphere before they are burned. Massachusetts' program should avoid giving excess credits for emissions impacts that are merely exported to another jurisdiction. Thus, clean heat credits for biofuels need to be based on their net effect on greenhouse gas emissions, including indirect effects. To estimate that net effect, one must compare the life cycle emissions of the fossil fuel avoided with the life cycle emissions of the cleaner fuel being used. The same logic can apply to the replacement of fossil fuel heat by electric heat pumps, using appropriate average emissions rates for the electricity that will be used to power the electric appliance. This logic applies to all creditable actions[45] but is most appropriate for measures based on fuel substitutions, such as biofuels, advanced wood heat and electricity-driven heat.

Exclusions

A comprehensive climate program will necessarily offer a world of opportunities to reduce emissions in different places and across many sectors. An economywide cap-and-trade program might try to cover them all. For reasons explained earlier in this paper, even though a Clean Heat Standard addresses a major portion of the Commonwealth's emissions, it focuses on a narrower goal: decarbonizing heating operations at the end-user level in the Commonwealth. Awarding credits for actions not closely linked to that goal would undermine its effectiveness and slow the pace of the thermal energy transition we need.

For this reason, measures that do not reduce thermal fossil fuel emissions at customer locations in Massachusetts would not be eligible to earn clean heat credits. Pure emissions offsets (e.g., tree planting or reductions in fossil fuel combustion outside of the Massachusetts thermal sector) would not earn credits under the Clean Heat Standard program. Reductions in fugitive emissions upstream from homes and businesses, fossil fuel storage systems, natural gas distribution systems and shared propane facilities would not be eligible.

In addition, giving clean heat credits to actions that merely substitute one fossil fuel for another would be problematic, even if emissions are temporarily reduced by the switch. For example, hooking up a building that currently heats with fuel oil to the pipeline gas grid might reduce emissions somewhat in the short run. However, the goal of the clean heat program is to reduce emissions altogether, and that new pipeline connection both adds to the fixed costs of the pipeline grid and delays the ultimate conversion of the building away from fossil fuels.

[45] Complex life cycle analyses are typically and appropriately moderated by establishing "boundaries of analysis" that allow decision-makers to focus on the most important impacts and to avoid ever-deeper assessments of the remote impacts of the actions in question. Protocols for life cycle assessments reflect judgments about the appropriate boundaries in particular cases.

Finally, the regulatory agencies could establish a process to consider whether eligibility to earn clean heat credits should be further restricted to protect against secondary undesirable environmental and social impacts of switching thermal heat sources from fossil sources to alternatives. Some biofuels have been shown to have serious negative impacts and should not be awarded credits under the Clean Heat Standard, regardless of the calculated greenhouse gas savings (if any).

In addition, a threshold percentage standard of improvement might also be employed to discourage fuel substitutions that may only marginally improve emissions.[46] Moreover, it would also be possible to design upper limits on the total contribution that could be credited from particular clean heat fuels or technologies — for example, an upper limit on the total quantity or fraction of biofuels that meet the threshold set for their life cycle greenhouse gas emissions. It is also important to consider the long-term goals of decarbonizing heating when assessing the potential short-term costs of switching to one technology or fuel versus another.

Obviously, a Clean Heat Standard can be designed in many ways, and particular resource choices can be included, limited or required to meet the Commonwealth's policy goals. These choices deserve careful attention, because limiting options will reduce the range of market-based consumer choice, may raise overall compliance costs, and could slow the pace of greenhouse gas reductions. These trade-offs are issues that need to be handled carefully, but the public and regulatory processes available in Massachusetts can address them.

Creation, Ownership and Transfer of Clean Heat Credits

Causation Is Not Required to Acquire Credits

One of the most attractive features of the Clean Heat Standard is that it can recognize credits for the delivery of clean heat solutions without needing to consider which program or entity (or combination thereof) "caused" the solution to be delivered. The 2021 Climate Roadmap law requires specific levels of emissions reduction at multiple points between today and 2050. A Clean Heat Standard is an overarching policy tool for ensuring that those reductions are achieved in the Commonwealth's thermal sector. Thus, what matters is whether emissions actually go down and the correct number of clean heat credits have been generated and retired.

It is important that programs and actors who deliver clean heat savings can be paid in credits for those actions. However, for the main purpose of the law, it does not matter who generates those credits or why they were generated. If many of the credits would have been generated through natural evolution of the market (e.g., customers buying heat pumps or weatherizing homes on their own, without any programmatic inducement), that would simply mean that the level of effort required by obligated parties to acquire the right number of credits — and the cost they would need to incur to do so — will be lower than if natural market forces would not produce much change on their own.

[46] For example, the APS statute requires at least a 50% improvement as a qualification condition for APS inclusion. Higher or lower thresholds could be set for different types of resources.

This is akin to how most electricity renewables mandates work. Electric utilities must show that a certain percentage of their electric portfolio each year comes from wind, solar and other renewable energy sources. It does not matter whether a customer would have put photovoltaic panels on their roof without a utility program or whether a wind turbine would have been built without any utility support. As long as the utility acquires the renewable attributes of such resources, it can use them to demonstrate compliance with its RPS obligation.

Customers Own Their Clean Heat Credits

It is important to note that as a starting provision, ownership of clean heat credits should begin with the end-use customer[47] whose fossil heat consumption has been reduced. That customer can decide whether to transfer the credits to the contractor, installer or fuel supplier who provided the clean heat services, sell them in the market or hold them for future use. In many, if not most, cases we can expect the provider of the service to contract with the customer for ownership of any credits and most likely offer an incentive payment or discount on the service provided. There is a great deal of experience in marketing energy efficiency and other energy services to demonstrate that the flexible use of discounts and incentives can spur customer uptake of the measures in question.

This customer flexibility will serve several purposes. It will broaden the range of options for obligated parties and create greater competition in the market, lowering the cost of compliance with the Clean Heat Standard. It should also make it easier for businesses selling clean heat products and services (e.g., HVAC contractors selling heat pumps, vendors of pellet stoves and weatherization contractors) to find markets and the best prices for the credits they could generate.

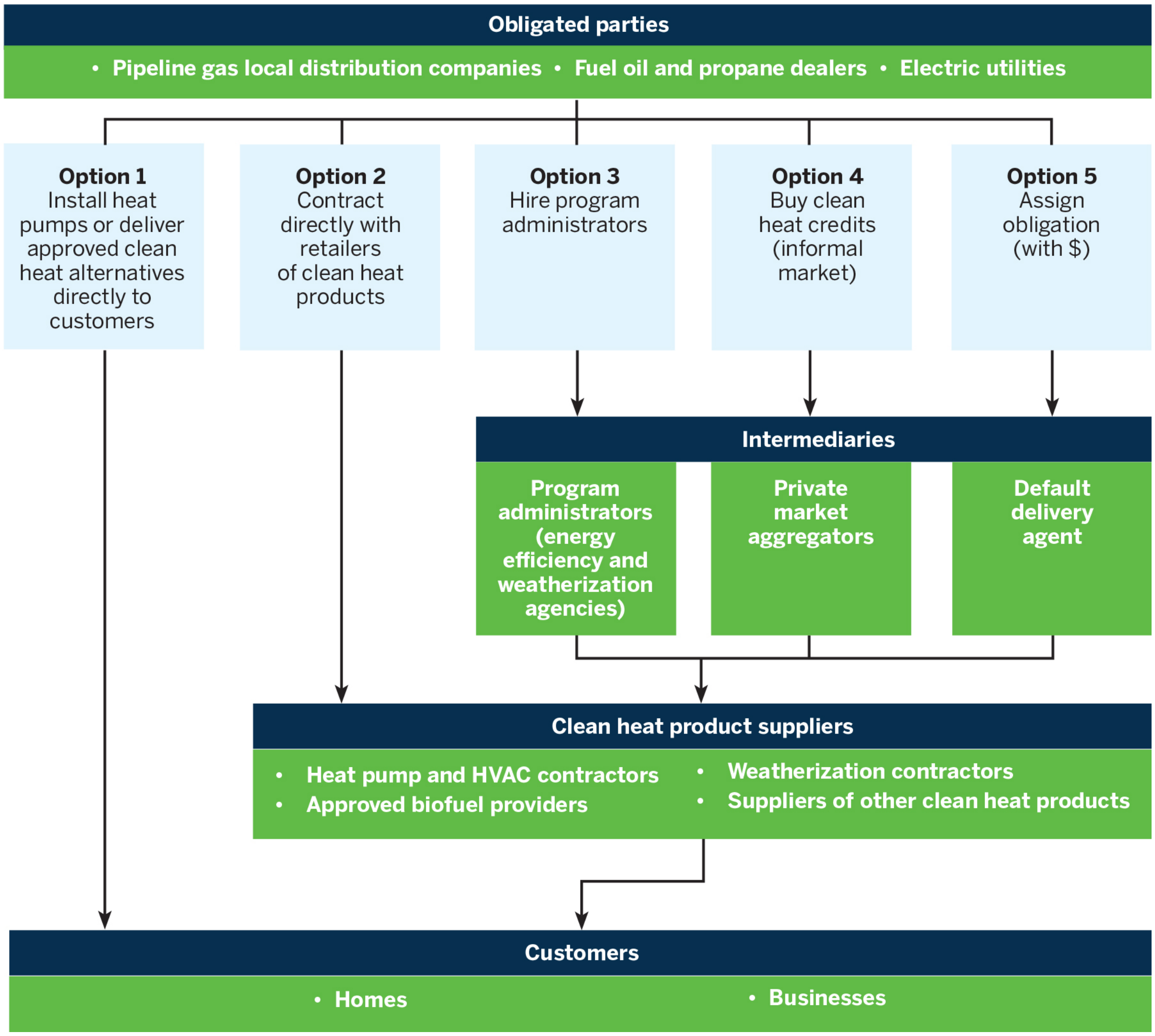
Many Ways to Acquire Credits

Flexibility will be essential to minimizing the costs of compliance with the Clean Heat Standard. It may also be essential to enabling the standard to be met, as different obligated parties will have different levels of capacity and interest in the way credits are developed or acquired. The system should be open to at least five options, as seen in Figure 10 on the next page.[48]

[47] Adjustments will be needed for landlord-tenant arrangements and related business arrangements where the occupier and operator of a building space is different from the owner of the property or the owner of the thermal equipment. For long-lived measures (e.g., new air-source heat pumps), RAP suggests that the person or entity that owns the newly installed equipment would be the initial owner of the clean heat credits.

[48] Adapted from Cowart & Neme, 2021.

Figure 10. Potential paths for earning clean heat credits



Source: Adapted from Cowart, R., & Neme, C. (2021). The Clean Heat Standard

1. Obligated parties should have the option to **generate credits directly,** by helping customers to install different emissions reduction measures (e.g., heat pumps and weatherization of buildings) or by purchasing and selling zero- to low-carbon fuels to customers, as this is the simplest way for them to comply with the Clean Heat Standard.
2. If an obligated party does not want to work with customers directly, it could **hire contractors to install** clean heat measures on its behalf. This is analogous to how many utility efficiency programs operate in Massachusetts and across the country.
3. An obligated party could hire a more broad-based **third-party program administrator**, who might earn credits through a range of services and might deliver them on behalf of multiple obligated parties.
4. The obligated party could **buy credits on the open market**, which allows a variety of private-sector businesses to use the Clean Heat Standard as a vehicle to advance

existing or new business models. For example, a current fuel oil dealer or an HVAC contractor could decide to diversify its business by selling heat pumps, generating credits that could then be sold to any obligated party. When an obliged party buys those credits, it would defray the cost of making the heat pump sales, ultimately lowering costs to customers or increasing the profitability of the business selling the clean heat products.

5. The final option would be making a payment to assign emissions reduction obligations to a **"default delivery agent"** designated by the lead agency implementing the Clean Heat Standard. This could be an option of last resort, providing an out for any obligated party that prefers making a payment to having to deal with the planning and management of efforts to acquire credits in some other way. The default delivery agent would then be required to use the funds to deliver clean heat savings to consumers.

Another important aspect of flexibility is the ability of an obligated party to acquire clean heat credits not just from its own customers, but for measures installed in any Massachusetts home or business. That would include customers who buy fossil fuels from other obligated parties. For example, pipeline gas retailer A could acquire credits resulting from installing heat pumps in homes served by pipeline gas retailer B or by weatherizing a home. Or fuel oil company A could acquire credits from an HVAC company that originally came from the installation of a heat pump in a home that had bought fuel oil from provider B.

Regardless of which of these options or combinations of options are utilized, a mechanism would be needed to register credits when they are claimed and track them when they are sold, to create a strong credits market and to avoid double-counting of credits. This is not a new challenge. For example, it currently exists to a degree with regard to bidding of efficiency resources into the New England Independent System Operator's capacity market and the attribution of renewable energy credits to obligated parties throughout the New England states.

Managing Credits From Long-Lived Measures

Some clean heat measures have a one-year life. For example, a gallon of zero- or low-emissions clean fuel reduces greenhouse gas emissions only in the year in which it is burned. Other clean heat measures, such as heat pumps and home weatherization projects, provide GHG emissions reductions for 15 years, 20 years or longer. The Clean Heat Standard needs to ensure that these long-lived measures are adequately supported, and it needs to assign emissions reduction credit values over the course of years. Such support is also appropriate because these measures cannot easily be reversed.

Long-Lived Measures Should Receive Lifetime Clean Heat Credits

There are, broadly, two ways to ensure that long-lived clean heat measures receive credits in proportion to the emissions they will avoid over their useful lives. One option is to credit a multiyear measure with its full lifetime emissions reductions in the year it is installed. For example, if a heat pump had a 15-year life and produced 10 clean heat credits per year, the regulatory agency could assign 150 credits to that heat pump in year 1. Thus, a heat pump installed in 2024 would provide 150 credits toward an obligated party's 2024 credit obligation (but no credits in subsequent years). The second option is to time-stamp a multiyear "strip" of credits for that measure. In this case, a heat pump installed in 2024 would earn 10 credits with a 2024 time stamp, another 10 credits with a 2025 time stamp, another 10 credits with a 2026 time stamp and so on through 2038 (the 15th year of its life). There may be other gradations of these two choices.

The first option of capturing the lifetime emissions reductions in the year a measure is installed is simpler and helps support installations by providing credits at the time that the investment expense is incurred. However, retiring a lifetime's worth of credits in the first year is inconsistent with the statutory requirements to achieve defined levels of greenhouse gas emissions reductions in specific years. It would result in substantially lower levels of emissions reductions in any given target year than required by the GWSA and the 2021 Climate Roadmap law. In addition, fully accelerating lifetime emissions reductions into the early years of the Clean Heat Standard program would add substantially to the supply of credits in those years, reducing credit prices and weakening the price signal that the program is intended to deliver to ensure substantial reductions.[49]

To illustrate this problem, consider a hypothetical situation in which obligated parties currently have 300 units of greenhouse gas emissions and face the statutory objective of a 40% reduction in current emissions by 2030 (300 x 40% = 120 units of GHG reductions by 2030). Assume each heat pump produces 1 unit of GHG reduction per year, and each heat pump lasts 15 years. If a heat pump's lifetime emissions reductions can all be claimed in the year it is installed, the obligated party would need to install only 36 heat pumps by 2030. The 36 heat pumps are expected to deliver 120 units of reduction eventually but will deliver only 36 units of GHG reduction in 2030, or only a 12% reduction from current emissions — far short of the 40% required by statute.[50]

Credits Awarded for Long-Lived Measures Should Be Protected

Regulatory agencies will, after appropriate public processes, establish clean heat credit values for a range of approved actions. These credit values will need to change over time as technologies and situations change and as everyone learns how particular measures work in practice. That is expected and necessary. However, it will be important to not alter the number of credits originally awarded at the time a long-lived measure was installed. For example, if in the fall of 2025 the regulatory agency approves an assumption that a 3-ton centrally ducted heat pump provides a defined stream of clean heat credits across the 15 years of its assumed life, any heat pump installed in 2026 would earn those credits in 2026 and each year thereafter through 2040 (its 15th year). Those credits would remain as assigned in 2026, even if a future evaluation suggests that such heat pumps produce more or less greenhouse gas emissions reduction than the quantity assigned in 2025.

This approach provides certainty for obligated parties regarding the number of credits they can earn for different measures. The market value of credits in each of those future

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49 This is akin to the problem faced in some greenhouse gas cap-and-trade programs, including the European Trading System, which created a large "overhang" of excess credits due to generous crediting of offsets and early actions. See Cowart, R., Buck, M., & Carp, S. (2017). *Aligning Europe's policies for carbon, efficiency, and renewables*. Regulatory Assistance Project. https://www.raponline.org/knowledge-center/aligning-europes-policies-for-carbon-efficiency-and-renewables-creating-a-virtuous-cycle-of-performance-and-emissions-reduction/

50 For a detailed explanation of this issue, see Cowart & Neme, 2021, pp. 50-52.

years, however, may be higher or lower than the market value of credits in the year the heat pump was installed. This result is similar to the risk that renewable energy providers face with respect to the value of renewable energy credits over the lifetime of a wind turbine or solar farm. It is also the primary reason that states have chosen to augment the broader RPS requirements with policies such as carve-outs and long-term contracting requirements. Therefore, decision-makers need to be conscious of the potential impact of price volatility on the ability of clean heat credits to attract sufficient clean heat investments. Options to address this issue are discussed in the next section.

Program Options to Encourage Investments in Long-Lived Measures

All policy options aimed at transforming the heating sector must overcome the slow turnover rates in buildings and heating systems and the high upfront costs of making long-term changes. The Clean Heat Standard is not unique in this regard, but it does offer some unique approaches to the problem. RAP recommends that policymakers consider a variety of options that could accelerate investments in long-lived measures under the standard, without undermining the emissions reduction goals the program needs to meet. These options are especially important to spur investments in weatherization (particularly low-income weatherization), heat pumps and renewable district heat systems. Among the options to consider are:

- Securitizing or contracting for the credits earned by long-lived measures. An alternative to putting a lifetime of credits into the market in year 1 of the measure's life is to securitize their value. Massachusetts could create or commission a patient lender or buyer of clean heat credits, which could pay for them at the time of installation and release them into the credit market in the years the measure is operating. This could be paid for in a number of ways, including green bonds, housing finance tools, loans secured by tariffed on-bill financing and other environmental finance tools.

- Carbon revenues could be used to finance clean heat investments, either as part of a securitization package or directly, as an element of a cap-and-invest program that could operate in tandem with the Clean Heat Standard.

- Utility regulation could support these outcomes. Regulated fossil gas utilities could be obliged, as part of their Clean Heat Standard obligation, to deliver a set fraction of clean heat credits from qualified long-lived measures. Alternatively, or in combination, regulated electric utilities could be directed to provide financial assurances that would encourage installation of qualified measures. In the case of weatherization, heat pumps and heat pump water heaters, financial tools such as tariffed on-bill financing could help to overcome the price barriers that customers face in installing the measures. The utility could purchase and hold the clean heat credits as part of that financing package.

- The Clean Heat Standard itself could be designed to ensure that an adequate fraction of all clean heat credits are derived from long-lived measures or those measures that are especially valued for public policy reasons (e.g., low-income weatherization, heat pumps, renewable district heating). This could be done through a credit carve-out or tiered credit system, as was done for solar electricity under various renewable portfolio requirements. Carve-outs are similar to the time-stamped credit approach in that the energy is counted on par with other options in calculating compliance with the broader annual standard, but it is different in that it can be used to require (vs. encourage) particular project categories.

The list above is by no means exhaustive. Whatever path is chosen, policymakers need to consider the trade-offs between a Clean Heat Standard program that leaves the mix of qualified solutions to the market, as chosen by providers and customers, and one that affirmatively promotes selected solutions that may also advance other public policy objectives.

Credit Markets and Compliance Flexibility Mechanisms

Several compliance flexibility mechanisms are typically offered in programs of this type. It is not expected that each individual fossil fuel provider acquires sufficient credits directly in a given year to satisfy its compliance obligation. First, the most straightforward flexibility mechanism is credit transfer, which in most cases will be structured as a purchase and sale in exchange for other valuable consideration. This requires a system for credits to be transferred to other parties, and appropriate security measures are necessary to ensure that credits are not transferred without the proper permission from the current owner. With these basic administrative structures, an informal credit market could arise but there are also more formal markets and exchanges that could be set up by the state agency in charge.

Second, obligated parties may acquire more clean heat credits than they need to meet their obligation for a given year and may "bank" those credits for use in a later year. Some amount of excess acquisition is highly likely to occur in many years if obligated parties see the cost of modest overcompliance to be lower than the cost of falling short of their obligations and having to make a noncompliance payment (see the discussion below on noncompliance payments). Allowing any such excess credits to be applied to a future year's obligation will lower the cost of meeting the state's emissions reduction goals. It will also enhance the likelihood of meeting annual goals by lowering the cost of overcompliance (since, from the perspective of the obligated parties, the credits from overcompliance are still useful and not wasted). Regulators will need to establish a system for tracking banked credits, but that should be relatively easy to implement. Any minted credit that has not yet been retired should continue to be registered in the system and thus can be used for compliance in the future.

However, the reverse option, known as borrowing, can have significant downsides. Borrowing credits from planned clean heat actions is not consistent with the goals of the GWSA and the 2021 Climate Roadmap law to physically deliver defined emissions reductions in specific years. Borrowing creates the risk that the borrowing entity will fail to perform in the future or even go out of business. These are unacceptable risks in an essential emissions reduction program, particularly since climate science tells us that near-term reductions are especially important to forestall the worst impacts of climate change. However, while not recommending it, RAP acknowledges that limited borrowing might be an option for addressing short-term market volatility, such as might be caused by abnormal variations in the weather or relative fuel prices.

Instead of borrowing, an alternative compliance payment is a typical feature of renewable portfolio standards and can be determined in a Clean Heat Standard. This means that if an obligated party has not otherwise acquired sufficient credits to meet its obligation, then the party can pay a predetermined dollar amount per unit of undercompliance to satisfy the regulation. Of course, this does lead to physical undercompliance in a given year, but the alternative compliance payment should be set at a level high enough to pay for near-term delivery of savings by other means. A good alternative compliance payment can provide a level of cost certainty for obligated entities and can lower the downside scenarios of potential overall compliance costs.

Program Administration

There are several administrative functions that one of the EEA agencies (the Department of Environmental Protection or Department of Energy Resources, which this paper refers to collectively as the regulatory agencies) would need to perform to establish and operate a Clean Heat Standard, such as preparing and promulgating regulations. Per Massachusetts law, the implementing agency would need to seek stakeholder input and initiate a public comment process. These processes should emphasize input from environmental justice and overburdened communities. This would serve as the foundation for the systems that follow to administer the program. The principles noted earlier can serve as a starting point for considering the process and areas for focus as the regulatory agencies begin their work and as touchstones to ensuring that the program design will meet the aims of the Commonwealth.

Administrative functions include areas such as:

- **Minting credits.** This requires a system that provides for the serialization of unique credits that can be used in a data system to track who buys, sells or owns them. The system also needs a mechanism that allows for banking credits to use in the future and a function to retire credits that are used to meet compliance obligations.
- **Reporting by obligated entities, and amendment/revision processes.** The data system needs to have functions that enable the obligated entities to demonstrate how they have met their compliance obligations and provide the regulatory agencies with the ability to amend, review or update these parties on at least an annual basis or perhaps more frequently, or even on demand (as businesses are sold and ownership changes).
- **Enforcement, fines, penalties and corrective action.** The regulatory agencies need to have authority to enforce the program if obligated entities do not meet their obligations. This needs to include fines and penalties that promote compliance (i.e., are significant enough to be an incentive to comply), and the regulatory agencies need to be able to request any corrective action deemed necessary to discourage any noncompliance from being repeated. For example, in the RGGI program if the surrendered allowances are not sufficient to meet a compliance obligation, the offending party must then surrender three allowances for every allowance it did not submit (a 3:1 penalty). That is in addition to paying a monetary penalty.

- **Program reviews and updates.** A program review every few years (RGGI's requirement is every three years) can ensure that improvements are made in the program and its governing regulations over time as issues arise. It also provides an excellent mechanism for updating areas like:
    - What options are creditable for compliance and how various options are valued.
    - How life cycle emissions are calculated as the science evolves.
    - Whether the compliance obligation needs to be increased to ensure that the GWSA goals are being met.
- **Centralized procurement mechanisms or default delivery agent structures.** These concepts envision a mechanism (which doesn't have to be a regulatory provision of the agencies) where a fuel dealer association could serve as a joint purchasing agent of credits (or an agent for developing credits) on behalf of its members.

The regulatory agencies will need to evaluate whether to undertake the tasks noted above themselves or set up other mechanisms through contracts; for example, the analysis of life cycle emissions by one of the national laboratories or a company familiar with GREET.

Other administrative functions may arise as the public process of implementing the program begins to be developed. The list above is not intended to be exhaustive.

Conclusion: Performance Standards Can Drive Thermal Decarbonization

Renewable energy standards and other performance standards have worked well to drive change in the electricity sector. In some jurisdictions, performance standards also apply to the regulated pipeline gas utilities successfully.

National and local experience with these performance standards reveals five broad observations:

1. **Performance standards can achieve change at scale.** Renewable portfolio standards and energy efficiency resource standards are responsible for a large fraction of the renewable energy and energy efficiency services received by end-use customers in the states that have enacted them.
2. **Performance standards can keep costs lower**. These programs have delivered clean energy improvements largely in the absence of carbon taxes or cap-and-trade regimes. They can bring about systemic changes without relying on higher prices as the main tool to change consumer behavior. Carbon revenues can be quite helpful, but carbon taxes are not required to deliver renewable energy or energy efficiency to replace fossil energy.

3. **It's important to focus on adding "good" resources, not just on limiting "bad" resources.** In many states the renewable portfolio standard and efficiency mandates have been designed to require the addition of desirable resources to energy systems, rather than imposing a cap or a penalty on the production or consumption of less-desirable resources. Even so, by adding low-emissions resources to energy systems, they have displaced higher-carbon energy sources and substantially reduced environmental harms, including greenhouse gases.

4. **Performance standards can elevate resources that are most needed and most desirable.** Many states have adopted portfolio standards with tiers or set-asides for resources that were especially desired or needed additional assistance, especially in the early years. Distributed resources, solar generation and other preferred resources can be called out in a performance standard to ensure delivery in the program. Efficiency programs have taken a similar approach, especially to ensure service delivery to low-income customers or in underserved communities.

5. **Regulators know how to administer them**. Performance standards require ways to measure and count performance, and states across the country have decades of successful experience. The details can be complicated, but across all these programs, utilities, governmental regulators and stakeholders have developed the procedures and verification methods to implement them successfully.

Competition lowers costs and drives innovation. To the degree that performance standards permit flexibility in resources and delivery methods, they can promote new ideas and uncover cost-savings opportunities. For example, spurred by RPS obligations, many utilities have conducted competitive solicitations for renewable supplies from independent producers, leading to rapid reductions in the cost of solar and wind power.

Competition lowers costs and drives innovation.
To the degree that performance standards permit flexibility in resources and delivery methods, they can promote new ideas and uncover cost-savings opportunities.

Designing the Clean Heat Standard to focus on the delivery of resources that are perceived as good avoids arguments over whether and how to limit the use of fossil resources that most people and businesses have long relied upon. As with numerous energy efficiency programs, Clean Heat Standard success requires finding ways to work with both upstream vendors and end-use customers to deliver solutions in millions of distributed locations. Multiple competitors, including non-utility providers, will increase the range of consumer choices in a sector where consumer acceptance is crucial. The standard will provide opportunities and incentives for consumers to switch away from fossil heat systems, but it does not require any individual end consumer to make that choice.

The Clean Heat Standard would be a performance-based obligation, without needing detailed prescriptions, imposed on fossil fuel sellers (or all heating energy providers) on a competitively neutral basis. Competition among obligated providers creates incentives for innovation and better customer service while lowering costs over time. However, as with

RPS and energy efficiency programs, a Clean Heat Standard can be designed with special tiers or set-asides for minimum and maximum percentages of resources in order to meet public policy goals. This could include positive assurance percentages for desired resources (e.g., beneficial electrification, service to lower-income households and communities), and caps on those resources that are deemed less desirable in the long run. Also like the RPS and efficiency programs, the Clean Heat Standard is not a fee-based system or a tax. Its continued success does not depend on annual governmental appropriations.

Finally, renewable portfolio standards have guided numerous electricity providers to new business models that work sustainably in the emerging low-carbon economy. In like manner, the Clean Heat Standard would be designed to help Massachusetts' heating enterprises, fossil gas, delivered fuel and possibly electricity companies to become clean heat suppliers, while helping their customers switch to cleaner, sustainable heating choices. This type of transition has not yet occurred at scale and is unlikely to occur through the actions of a few early adopters and the public programs now operating in the Commonwealth. To meet Massachusetts' climate objectives, a much larger driver is required. A Clean Heat Standard, operating in combination with a strong suite of complementary policies, could provide that framework.

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APPENDIX C: MASSACHUSETTS NATURAL AND WORKING LANDS GREENHOUSE GAS ASSESSMENT AND INVENTORY

C.1 OVERVIEW OF MASSACHUSETTS NWL GHG ASSESSMENT AND INVENTORY

This Appendix provides an assessment of the greenhouse gas (GHG) emissions and carbon sequestration occurring on Massachusetts' natural and working lands (NWL) and describes the inventory framework and methodology underlying this assessment.

BACKGROUND

The Act Creating a Next Generation Roadmap for Massachusetts Climate Policy (2021 Climate Law) requires EEA to track "the release of measurable greenhouse gases from and carbon sequestration by natural and working lands and the products derived from these lands to the maximum extent practicable" and include in the 2025 and 2030 Clean Energy and Climate Plan (2025/2030 CECP) a baseline estimate of NWL carbon fluxes in Massachusetts, statewide goals to reduce NWL GHG emissions and increase carbon sequestration, and an NWL plan that outlines actions to achieve these statewide goals. To meet these requirements and support the goals and actions described in Chapter 8 of the 2025/2030 CECP, EEA has developed an NWL GHG inventory that generally follows the methods and reporting conventions developed by the Intergovernmental Panel on Climate Change (IPCC)[39] for Agriculture, Forestry, and Other Land Use (AFOLU) emissions inventories and used by the U.S. Environmental Protection Agency (EPA) in the U.S. National Greenhouse Gas Inventory for the Land Use, Land Use

Natural and Working Lands (NWL) Definition from the 2021 Climate Law

Natural and working lands are lands within the Commonwealth that:

- Are actively used by an agricultural owner or operator for an agricultural operation that includes, but is not limited to, active engagement in farming or ranching;
- Produce forest products;
- Consist of forests, grasslands, freshwater and riparian systems, wetlands, coastal and estuarine areas, watersheds, wildlands or wildlife habitats;

OR

- Are used for recreational purposes, including parks, urban and community forests, trails or other similar open space land.

[39] IPCC. 2006. Volume 4: Agriculture, Forestry, and Other Land Use *Volume 4: Agriculture, Forestry, and Other Land Use - 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. eds. Simon Eggleston et al. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
IPCC. 2019. Volume 4: Agriculture, Forestry, and Other Land Use *Volume 4: Agriculture, Forestry, and Other Land Use - 2019 Refinement to 2006 IPCC Guidelines for National GHG Inventories*. eds. Calvo Buendia et al. Switzerland: Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme. https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

Change, and Forestry (LULUCF) sector.[40] In addition to IPCC and EPA guidance, the Massachusetts NWL GHG inventory and assessment draw on guidance provided by the World Resources Institute,[41] scientific literature, Massachusetts-specific data sources, and technical feedback from a range of subject matter experts.

C.2 SCOPE

The intent of this NWL GHG inventory and assessment is to provide comprehensive, quantified estimates of all major sources and sinks of GHGs in Massachusetts territory that result from land cover/use, land cover/use change, and natural ecosystem processes, following EPA LULUCF and IPCC AFOLU guidance. This includes sequestration of carbon dioxide (CO_2) and emissions of CO_2, as well as smaller quantities of methane (CH_4) and nitrous oxide (N_2O),[42] in four major land cover/use classes: Forest Land, Wetlands, Settlement Lands, and Croplands & Grasslands, as well as fluxes associated with conversions among land cover/use classes. NWL GHG emissions and carbon cycling include a complex system of pools, fluxes, and drivers with varying degrees of natural and anthropogenic influence. The NWL GHG inventory includes major emissions sources and sinks regardless of attribution or which fluxes may count for net zero compliance.[43] Carbon sequestration and GHG emissions are often occurring simultaneously on any given piece of land (e.g., plant photosynthesis and respiration), so most NWL categories report *net* GHG emissions (hence emissions can be negative or positive depending on whether sequestration is lesser or greater than emissions).

Emissions are reported for four major categories associated with each of the major land cover/use and land cover/use conversion classes, as well as for 13 sub-categories. The primary source for these emissions estimates is the EPA's state-level disaggregation of the U.S. National GHG Inventory for LULUCF.[44] All significant emissions categories with reliable, Massachusetts-specific and -relevant estimates are included (see below for minor exceptions). The NWL GHG inventory reports net emissions annually going back to 1990, similar to the current Massachusetts statewide GHG inventory maintained by Massachusetts Department of Environmental Protection (MassDEP). However, many data sources are not updated annually (e.g., every 5-10 years for forest inventory data) and reporting lags by about three years (e.g., most recent inventory estimates are for 2019). While this inventory is comprehensive and based on scientifically sound data, methods, and reporting practices, it is also the first NWL GHG inventory produced for the Commonwealth of Massachusetts and reported figures should be

[40] EPA, U.S. Environmental Protection Agency. 2022. "Chapter 6. Land Use, Land-Use Change, and Forestry." In *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020*, Reports and Assessments, U.S. Environmental Protection Agency, 178. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

[41] WRI, World Resources Institute. 2020. "Natural & Working Lands Inventory Improvements: A Guide for States." https://static1.squarespace.com/static/5a4cfbfe18b27d4da21c9361/t/604652f0d82ffb5074df3b3d/1615221491785/Guide+to+NWL+Inventory+Improvements.pdf

[42] The NWL GHG inventory does not include CO_2 from urea and lime applications, CH_4 from enteric fermentation, CH_4 and N_2O from manure, and N_2O from agricultural soils in the gross emissions accounting, because these emissions are counted as gross emissions in the Agriculture portion of the statewide GHG inventory.

[43] A GHG emissions accounting framework to track net emissions for compliance with Massachusetts 2050 net zero emissions limit will be developed later in 2022.

[44] US EPA. 2022. "Inventory of U.S. Greenhouse Gas Emissions and Sinks by State." State GHG Emissions and Removals. March 2022. https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals.

interpreted as *estimates* considering inventory limitations (relatively high levels of simplification and uncertainty relative to other sectors, and the possibility of significant omissions. EEA will continue to refine and update the NWL inventory in the coming years to include additional emissions categories, more state-specific data, best available science, and greater utility at sub-state spatial scales.

C.3 ASSESSMENT OF MASSACHUSETTS NWL GHG SOURCES AND SINKS

Table C.1 below shows the net NWL emissions in 2019, the latest year with available data, by major land class categories and subcategories. As of 2019, Massachusetts NWL are estimated to have net GHG emissions of -7.0 $MMTCO_2e$ per year, meaning they are a net GHG sink, sequestering quantities of CO_2 equivalent to 9.6% of statewide gross GHG emissions. Forest Land is responsible for most of this carbon sequestration, with net emissions of -5.8 $MMTCO_2e$/year (84% of total NWL emissions) primarily from sequestration of CO_2 in forest ecosystem carbon stocks. Settlement land is the next largest NWL emissions category, with net emissions of -1.3 $MMTCO_2e$/year, driven by sequestration in settlement trees and forest biomass. Wetlands (-0.2 $MMTCO_2e$/year) and Croplands & Grasslands (0.3 $MMTCO_2e$/year) represent emissions of smaller magnitude, while emissions on Other Land (largely unvegetated and only 2% of Massachusetts territory) are presumed to be negligible.

Table C.1. Massachusetts NWL GHG Emission Estimates for 2019 by Reporting Category and Subcategory

NWL Reporting Categories / Land Classes	Net Emissions, 2019 ($MMTCO_2e$/year)		
Forest Land (2.9 million acres)			**-5.8**
Forest Land Remaining Forest Land		-5.24	
Forest Ecosystem Carbon Stock Change	*-4.58*		
Harvested Wood Products Carbon Stock Change	*-0.66*		
Land Converted to Forest Land		-0.60	
New Forest Ecosystem Carbon Stock Change	*-0.60*		
Croplands & Grasslands (0.4 million acres)			**0.3**
Crop/Grassland Remaining Crop/Grassland		0.22	
Cropland Soil Carbon Stock Change	*0.22*		
Grassland Ecosystem Carbon Stock Change	*0.01*		
Land Converted to Crop/Grassland		0.08	
New Crop/Grassland Ecosystem Carbon Stock Change	*0.08*		
Wetlands (0.5 million acres, including inland open water)			**-0.2**
Wetlands Remaining Wetlands		-0.20	
Coastal Wetlands Ecosystem Carbon Stock Change	*-0.20*		
Inland Wetland Ecosystem Carbon Stock Change	*TBD*		
Land Converted to Wetlands		0.00	
New Wetland Ecosystem Carbon Stock Change	*0.00*		
Settlements (1.3 million acres)			**-1.3**
Settlements Remaining Settlements		-1.80	
Biomass Carbon Stock Changes	*-2.68*		
Soil Carbon Stock Changes	*0.88*		
Land Converted to Settlements		0.54	
New Settlement Ecosystem Carbon Stock Change	*0.54*		
Other Land (0.1 million acres)			**0.0**
Total Net NWL Emissions:			**-7.0**

Note: Currently, the estimates for Inland Wetlands are not yet included. On-going efforts involve providing an estimate for Inland Wetlands.

Figure C.1 below compares the 13 reported NWL subcategories of net NWL emissions in Table 1. Net emissions in these subcategories range from -4.6 $MMTCO_2e$/year (Forest Ecosystem) to 0.9 $MMTCO_2e$/year (Settlement Soils), with fluxes in Forest Land and Settlement subcategories all significantly larger in magnitude (more than 0.5 $MMTCO_2e$/year in absolute value) than those in Cropland & Grassland and Wetland subcategories (less than 0.2 $MMTCO_2e$/year in absolute value). This matches the degree to which Massachusetts' land base is dominated by Forest Land (54%) and Settlement (24%) land uses. Subsequent sections discuss NWL categories and subcategories in greater detail.

Figure C.1. Massachusetts NWL GHG Emission Estimates by Subcategory for 2019

Red bars = Settlement subcategories, yellow bars = Cropland & Grassland subcategories, blue bars = Wetland subcategories, green bars = Forest Land subcategories.

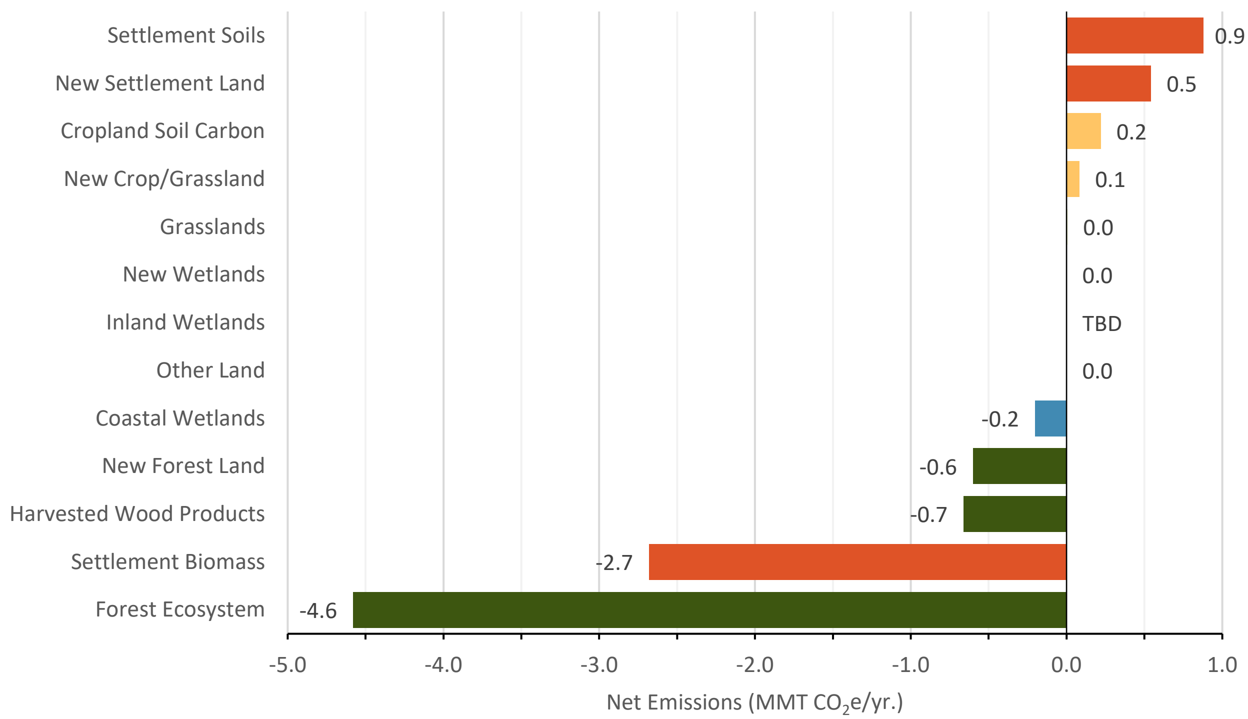


Table C.2 below shows the complete NWL GHG emissions inventory, with estimates for all categories, subcategories, and years available. Figure C.2 shows the emissions trends of the subcategories, and overall net NWL emissions, over time. Net NWL emissions have decreased (i.e., net sequestration has increased) at a relatively steady rate over the past 30 years, dropping from -5.9 $MMTCO_2e$/year in 1990 by -1.1 $MMTCO_2e$/year (19%) to their present level. This trend appears to have shifted in the past five to seven years, moving between -7.0 $MMTCO_2e$/year and -7.1 $MMTCO_2e$/year since 2013. Changes in overall NWL emissions are largely driven by changes in the three largest sub-categories: Forest Ecosystem emissions have followed the same pattern of decrease then plateau as total NWL emissions, while Settlement Biomass emissions have been steadily decreasing, and Settlement Soil emissions have been steadily increasing (though at a slower rate) over the entire record period.

Figure C.2. Massachusetts NWL GHG Emission Estimates by Sub-Category Over Time, 1990-2019

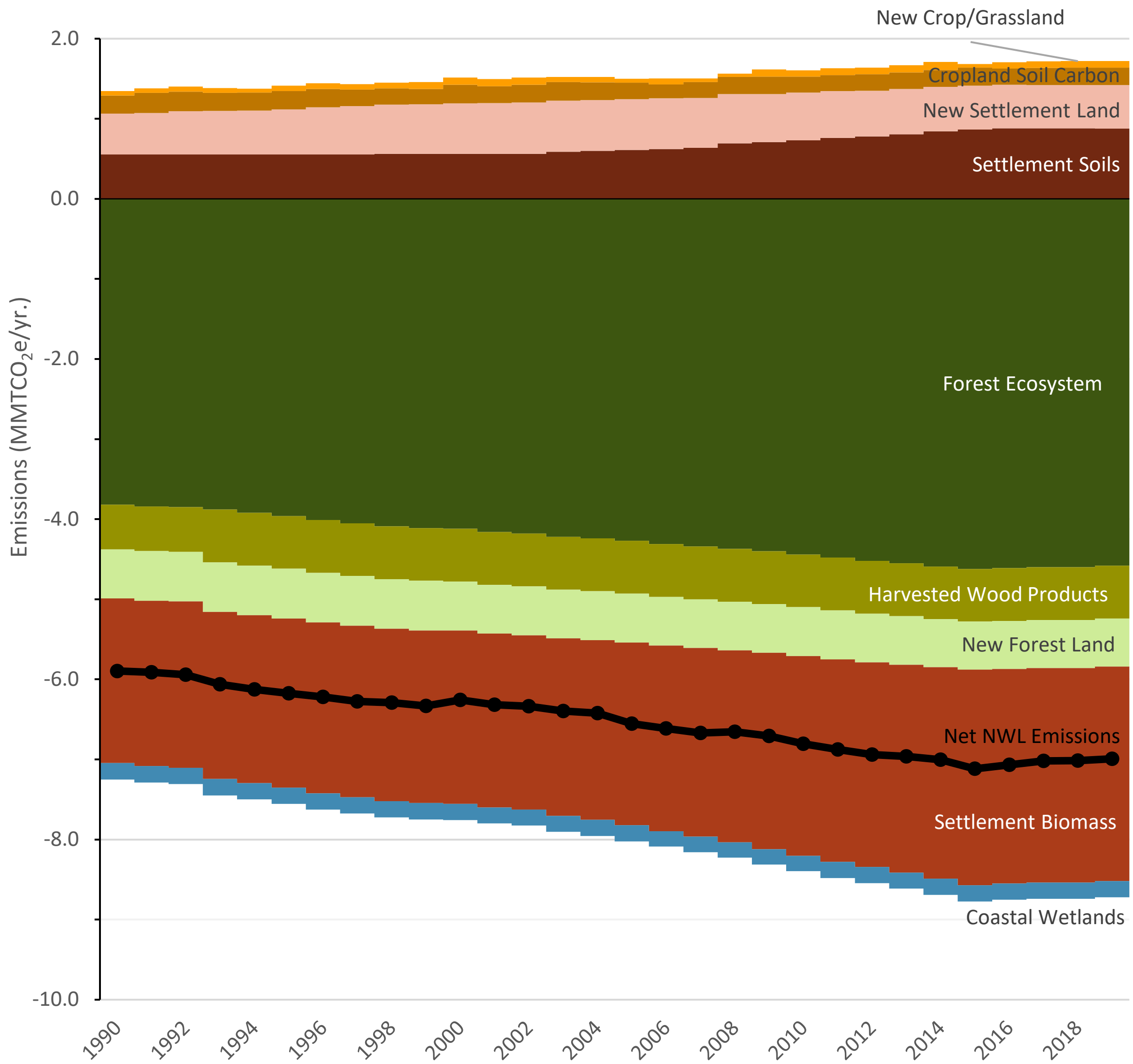


Table C.2. Massachusetts NWL Greenhouse Gas Inventory, 1990-2019. Data from EPA (2022) Inventory of U.S. Greenhouse Gas Emissions and Sinks by State, except for Harvested Wood Products (EPA, 2022, State Inventory and Projection Tool), and Inland Wetlands (EEA-developed methodology).

Reporting Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Forest Land	-5.0	-5.0	-5.0	-5.2	-5.2	-5.2	-5.3	-5.3	-5.4	-5.4	-5.4	-5.4	-5.4	-5.5	-5.5	-5.5	-5.6	-5.6	-5.6	-5.7	-5.7	-5.7	-5.8	-5.8	-5.8	-5.9	-5.9	-5.9	-5.9	-5.8
Forest Land Remaining Forest Land	**-4.38**	**-4.40**	**-4.41**	**-4.54**	**-4.58**	**-4.62**	**-4.67**	**-4.71**	**-4.75**	**-4.77**	**-4.78**	**-4.82**	**-4.84**	**-4.88**	**-4.90**	**-4.93**	**-4.97**	**-5.00**	**-5.03**	**-5.06**	**-5.10**	**-5.14**	**-5.18**	**-5.21**	**-5.25**	**-5.28**	**-5.27**	**-5.26**	**-5.26**	**-5.24**
Forest Ecosystem Carbon Stock Change	-3.82	-3.84	-3.85	-3.88	-3.92	-3.96	-4.01	-4.05	-4.09	-4.11	-4.12	-4.16	-4.18	-4.22	-4.24	-4.27	-4.31	-4.34	-4.37	-4.40	-4.44	-4.48	-4.52	-4.55	-4.59	-4.62	-4.61	-4.60	-4.60	-4.58
Harvested Wood Products Carbon Stock Change	-0.56	-0.56	-0.56	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66
Land Converted to Forest Land	**-0.61**	**-0.62**	**-0.62**	**-0.62**	**-0.62**	**-0.62**	**-0.62**	**-0.62**	**-0.62**	**-0.62**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.61**	**-0.60**	**-0.60**	**-0.60**	**-0.60**	**-0.60**	**-0.60**
Ecosystem Carbon Stock Change	-0.61	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61	-0.60	-0.60	-0.60	-0.60	-0.60	-0.60
Cropland & Grassland	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3
Crop/Grassland Remaining Crop/Grassland	**0.23**	**0.24**	**0.21**	**0.23**	**0.22**	**0.20**	**0.19**	**0.17**	**0.19**	**0.15**	**0.22**	**0.19**	**0.20**	**0.22**	**0.23**	**0.18**	**0.14**	**0.18**	**0.22**	**0.21**	**0.18**	**0.17**	**0.17**	**0.19**	**0.19**	**0.20**	**0.18**	**0.22**	**0.22**	**0.22**
Cropland Soil Carbon Stock Change	0.23	0.25	0.24	0.22	0.23	0.23	0.23	0.21	0.20	0.19	0.23	0.21	0.22	0.23	0.22	0.21	0.17	0.20	0.21	0.21	0.20	0.20	0.21	0.21	0.21	0.23	0.20	0.21	0.22	0.22
Grassland Ecosystem Carbon Stock Change	0.01	-0.01	-0.04	0.00	0.00	-0.03	-0.04	-0.03	-0.01	-0.04	-0.01	-0.01	-0.03	-0.02	0.01	-0.03	-0.03	-0.01	0.01	-0.01	-0.01	-0.02	-0.03	-0.02	-0.02	-0.03	-0.02	0.01	0.01	0.01
Land Converted to Crop/Grassland	**0.06**	**0.06**	**0.06**	**0.06**	**0.05**	**0.07**	**0.07**	**0.07**	**0.07**	**0.08**	**0.09**	**0.09**	**0.09**	**0.06**	**0.07**	**0.05**	**0.08**	**0.04**	**0.04**	**0.09**	**0.08**	**0.09**	**0.08**	**0.09**	**0.10**	**0.04**	**0.08**	**0.08**	**0.08**	**0.08**
Ecosystem Carbon Stock Change	0.06	0.06	0.06	0.06	0.05	0.07	0.07	0.07	0.07	0.08	0.09	0.09	0.09	0.06	0.07	0.05	0.08	0.04	0.04	0.09	0.08	0.09	0.08	0.09	0.10	0.04	0.08	0.08	0.08	0.08
Wetlands	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Wetlands Remaining Wetlands	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.19**	**-0.19**	**-0.19**	**-0.19**	**-0.19**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**
Coastal Wetlands Ecosystem Carbon Stock Change	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.19	-0.19	-0.19	-0.19	-0.19	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20
Inland Wetland Ecosystem Carbon Stock Change	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Land Converted to Wetlands	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Ecosystem Carbon Stock Change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Settlements	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.2	-1.2	-1.2	-1.2	-1.2	-1.3	-1.3	-1.3	-1.3	-1.3
Settlements Remaining Settlements	**-1.50**	**-1.51**	**-1.52**	**-1.53**	**-1.54**	**-1.56**	**-1.58**	**-1.59**	**-1.59**	**-1.59**	**-1.60**	**-1.61**	**-1.62**	**-1.63**	**-1.65**	**-1.67**	**-1.69**	**-1.72**	**-1.70**	**-1.74**	**-1.76**	**-1.77**	**-1.77**	**-1.79**	**-1.80**	**-1.82**	**-1.80**	**-1.80**	**-1.80**	**-1.80**
Biomass Carbon Stock Change	-2.06	-2.07	-2.08	-2.09	-2.10	-2.11	-2.13	-2.14	-2.15	-2.16	-2.16	-2.17	-2.18	-2.22	-2.25	-2.28	-2.31	-2.36	-2.39	-2.45	-2.49	-2.53	-2.55	-2.59	-2.64	-2.69	-2.68	-2.68	-2.68	-2.68
Soil Carbon Stock Change	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.59	0.60	0.61	0.62	0.64	0.69	0.71	0.73	0.76	0.78	0.81	0.84	0.87	0.88	0.88	0.88	0.88
Land Converted to Settlements	**0.51**	**0.52**	**0.54**	**0.54**	**0.55**	**0.56**	**0.59**	**0.60**	**0.62**	**0.62**	**0.63**	**0.64**	**0.64**	**0.64**	**0.63**	**0.63**	**0.63**	**0.62**	**0.61**	**0.60**	**0.60**	**0.59**	**0.57**	**0.57**	**0.56**	**0.55**	**0.54**	**0.54**	**0.54**	**0.54**
Ecosystem Carbon Stock Change	0.51	0.52	0.54	0.54	0.55	0.56	0.59	0.60	0.62	0.62	0.63	0.64	0.64	0.64	0.63	0.63	0.63	0.62	0.61	0.60	0.60	0.59	0.57	0.57	0.56	0.55	0.54	0.54	0.54	0.54
Other Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Net NWL Emissions	**-5.9**	**-5.9**	**-5.9**	**-6.1**	**-6.1**	**-6.2**	**-6.2**	**-6.3**	**-6.3**	**-6.3**	**-6.3**	**-6.3**	**-6.3**	**-6.4**	**-6.4**	**-6.6**	**-6.6**	**-6.7**	**-6.7**	**-6.7**	**-6.8**	**-6.9**	**-6.9**	**-7.0**	**-7.0**	**-7.1**	**-7.1**	**-7.0**	**-7.0**	**-7.0**

FOREST LAND & FOREST PRODUCTS (CRF CATEGORIES 4A & 4G)

As shown in Figure C.3 below, Forest Land in Massachusetts is estimated to have net emissions of -5.8 $MMTCO_2e$/year, an increase of -0.8 $MMTCO_2e$/year or 17% from 1990. The largest Forest Land GHG flux has been sequestration in Forest Ecosystem carbon stocks (-4.6 $MMTCO_2e$/year), which includes above- and below-ground live biomass, dead wood, soil, and litter pools. An additional -0.7 $MMTCO_2e$/year represents transfers into the Harvested Wood Product carbon pools, which include both products in use and stored in landfills.[45] An additional -0.6 $MMTCO_2e$/year is sequestered by recently re-/afforested land (Land Converted to Forest Land). Harvested Wood Products and Land Converted to Forest Land fluxes have remained relatively steady since the mid-1990s.

Figure C.3. Massachusetts Forest Land GHG Emissions Estimates by Sub-Category Over Time, 1990-2019

Uncertainty for Forest Ecosystem emissions is ±30%.

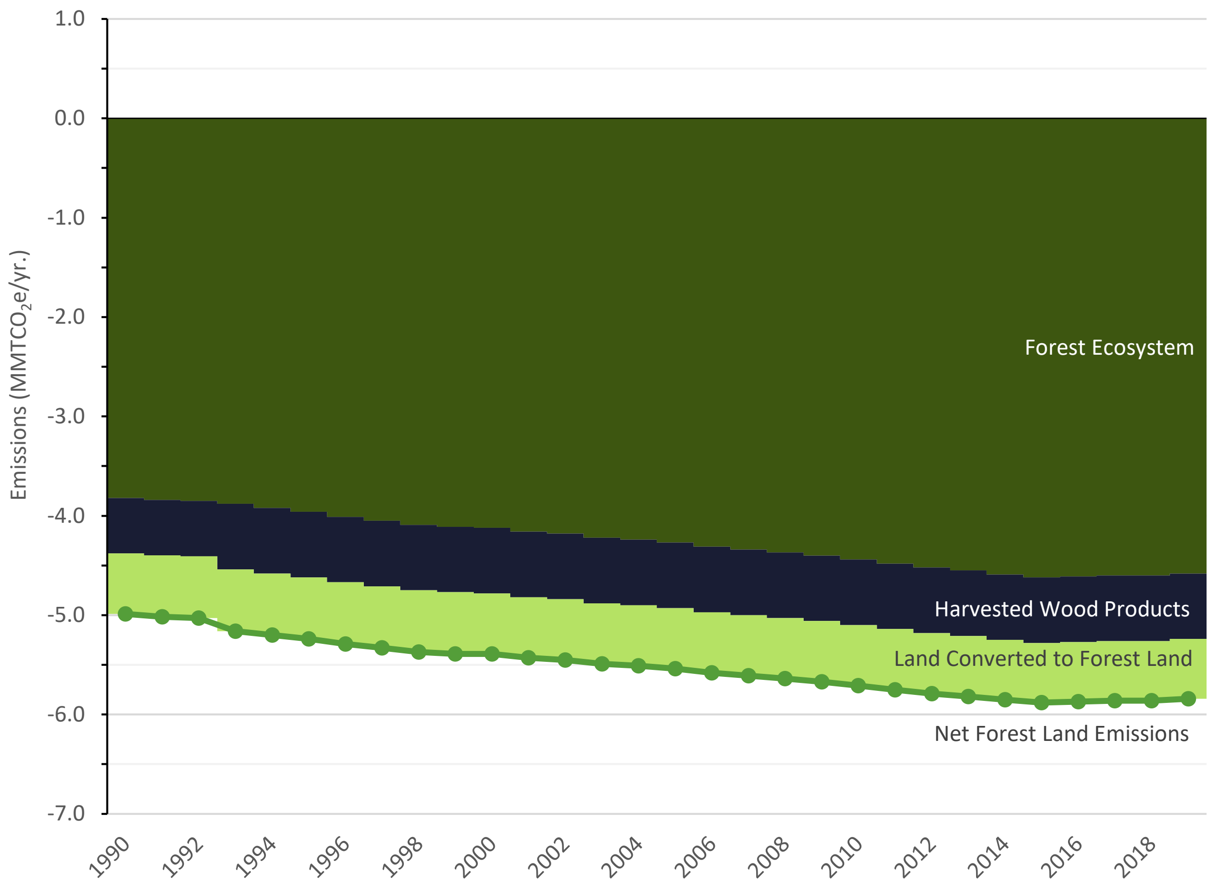


Figure C.4 below shows the accumulation of carbon in the Forest Land Remaining Forest Land pools (both Forest Ecosystem and Harvested Wood Products categories) over time. While the forest soil

[45] Emissions from the decay of Wood Products are captured in the biogenic Waste emissions category of the statewide GHG emissions inventory and are thus not part of the NWL GHG inventory.

carbon pool is by far the largest, the aboveground live biomass and wood products pools are growing faster.

Figure C.4. Massachusetts Forest Land carbon stocks in tracked pools, 1990-2019.

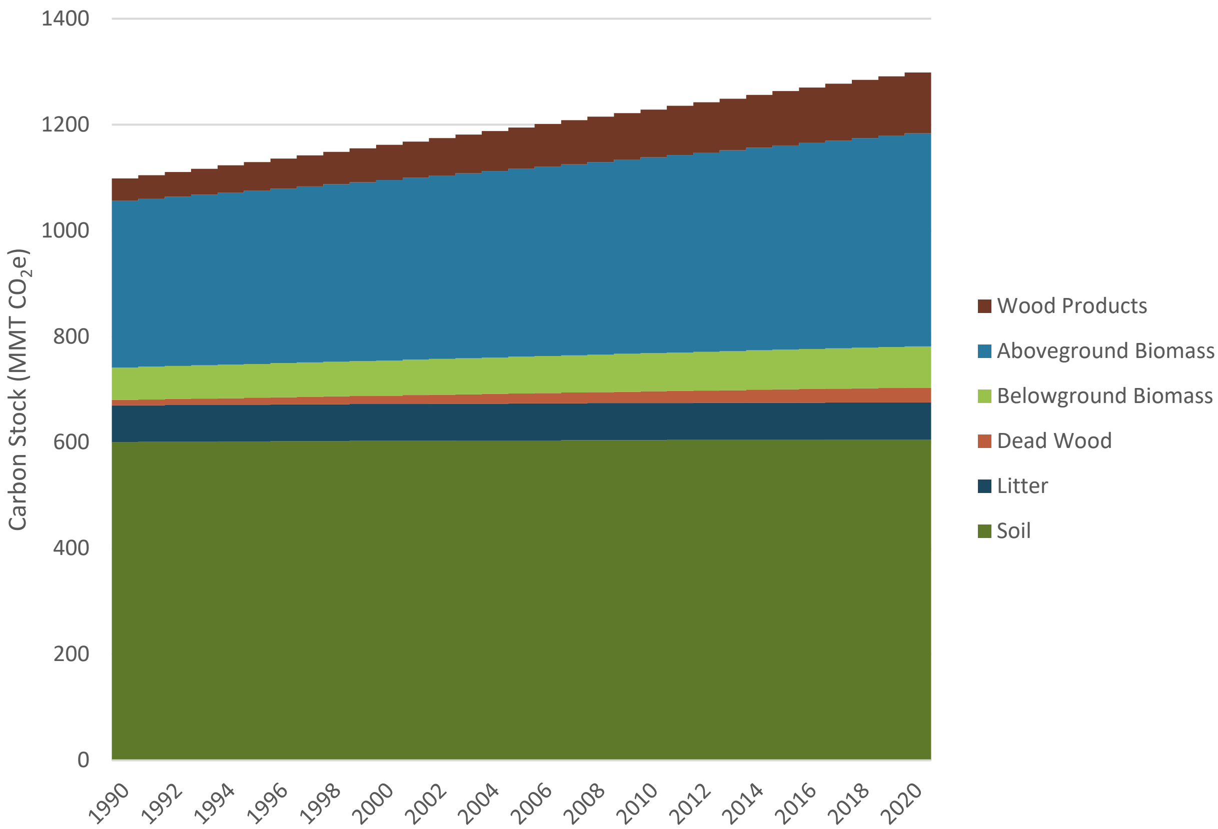
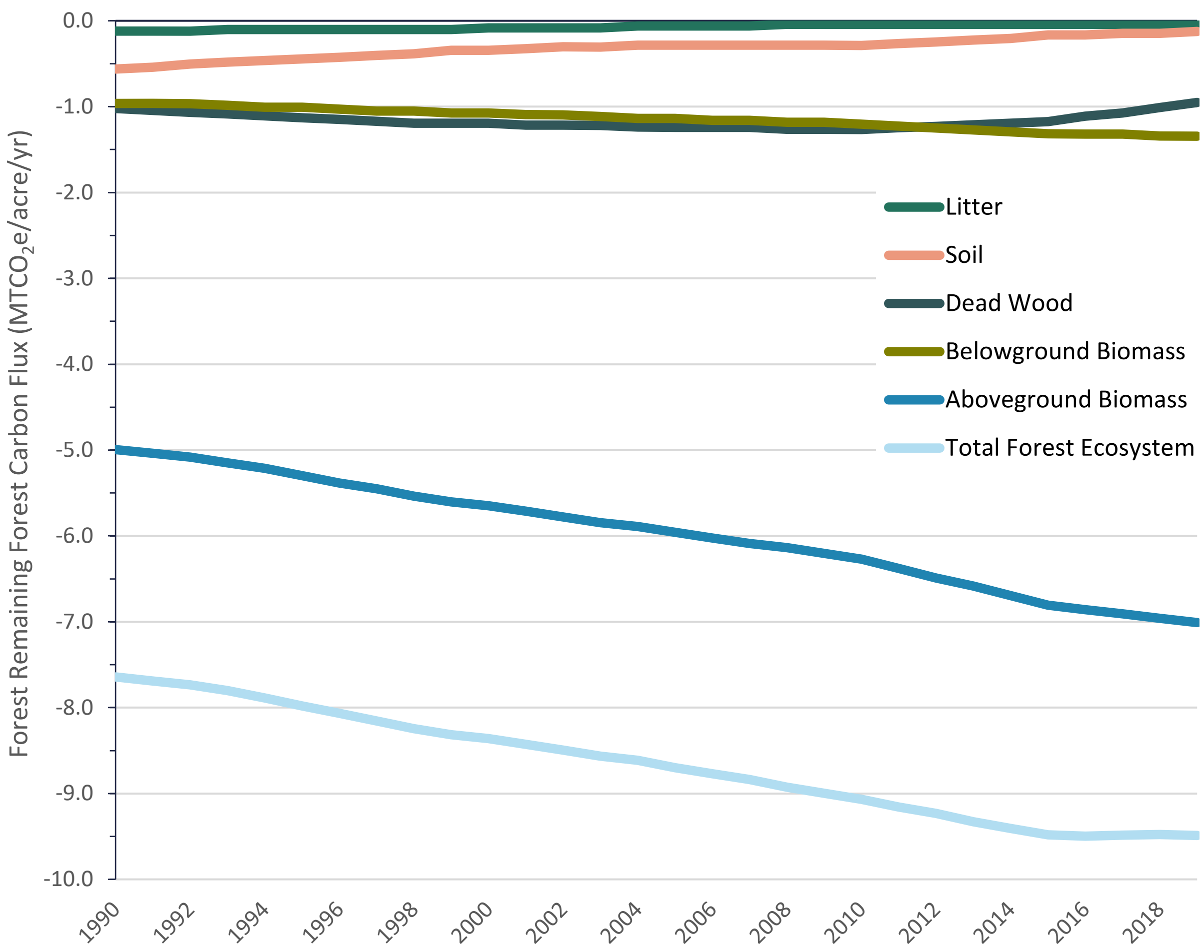


Figure C.5 below shows changes in Forest Ecosystem carbon fluxes (i.e., emissions per unit area) over time, which illustrates changes in the Forest Ecosystem carbon sink regardless of changes in Forest Land area. While sequestration in live biomass (above- and below-ground) has been increasing relatively steadily since 1990, sequestration in litter and soils has been steadily decreasing over the same time period, and sequestration in dead wood was increasing until around 2010, but has since declined. The decline in soil, litter, and particularly dead wood sequestration is responsible for the apparent plateau in Forest Ecosystem (and total NWL) emissions in the past 5-7 years. This warrants careful interpretation and further investigation, in light of data limitations and uncertainties. Uncertainty is estimated to be ±30% for total Forest Ecosystem carbon stock changes, and is likely much higher for individual fluxes, particularly soil, litter, and dead wood, which are sampled in fewer inventory plots than biomass.

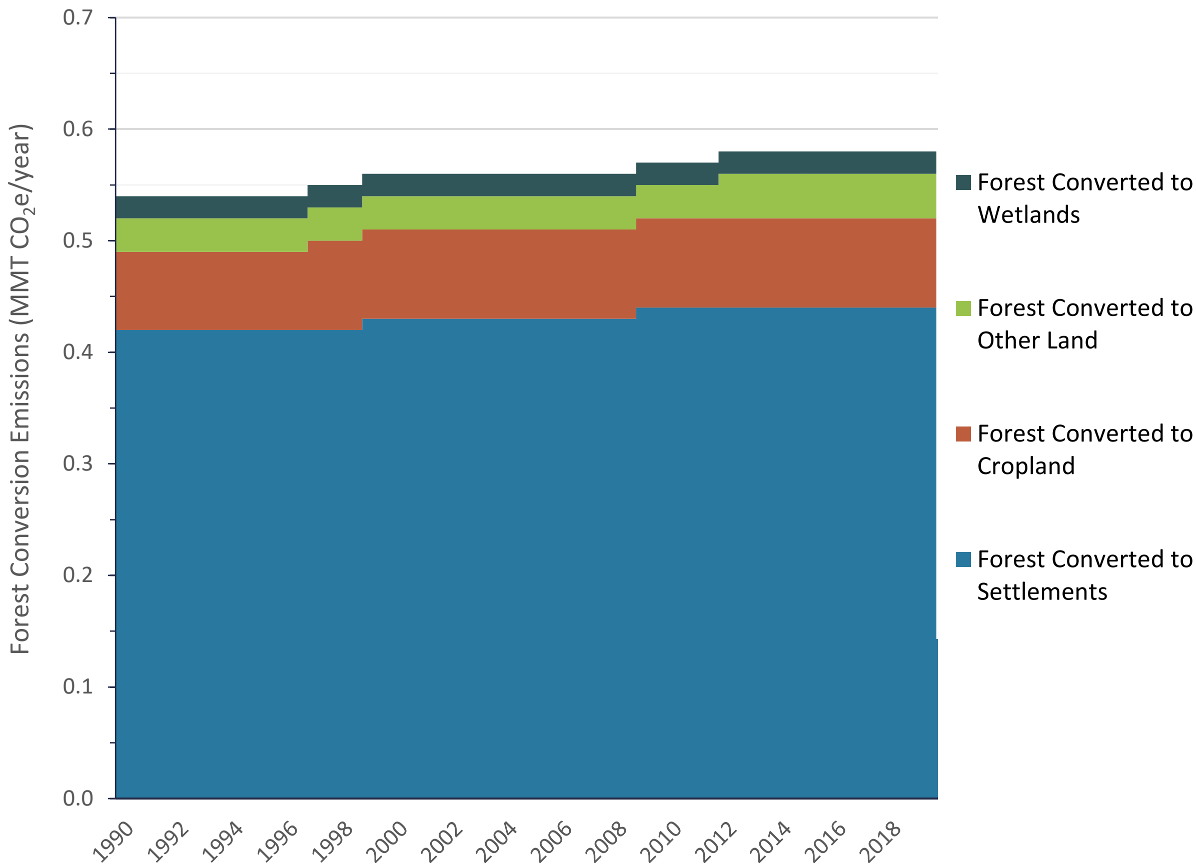
Figure C.5. Massachusetts Forest Land Carbon Fluxes (Emissions per Unit Land Area) by Carbon Pool, 1990-2019



FOREST LAND CONVERTED TO LAND (FOREST CONVERSION)

Emissions from the conversion of Forest Land to other land cover/use classes are attributed to and reported in those other land class emission categories. However, due to the importance of forest conversion in Massachusetts' NWL overall net GHG emissions, a comprehensive overview of forest conversion emissions is shown below in Figure C.6. These estimates are based on U.S. Forest Service estimates of Forest Land conversion (see Section 3), which averages 6,150 acres/year going back to 1990 (range of 5,300 to 8,000 acres/year). Forest Land Converted to Settlements makes up nearly half of this forest conversion area (average = 2,900 acres/year), with the remaining mostly converted to Cropland (average = 2,000 acres/year) and lesser amounts converted to Wetland and Other Land. However, Forest Land Converted to Settlements is responsible for a disproportionate amount of forest conversion emissions (~75%, ~0.4 $MMTCO_2e$/year). This can be attributed to the more intensive disturbance of development relative to other land uses.

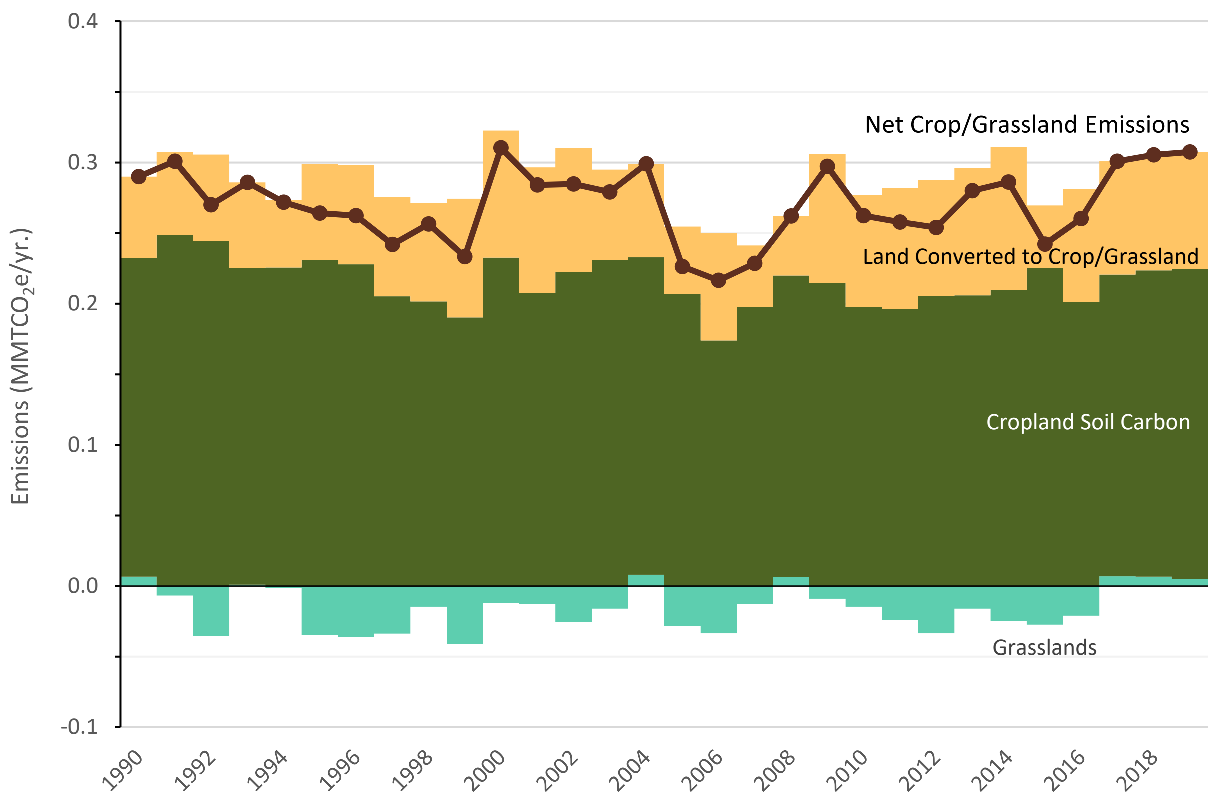
Figure C.6. Emissions from Massachusetts Forest Land Converted to Other Land Classes, 1990-2019.



CROPLANDS & GRASSLANDS (CRF CATEGORY 4B & 4C)

Figure C.7 shows the change in Cropland & Grassland GHG fluxes over time, with total net emissions remaining relatively steady at 0.3 $MMTCO_2e$/year. Individual fluxes include Cropland Soil Carbon (about 0.2 $MMTCO_2e$/year),[46] Land Converted to Cropland/Grassland (about 0.1 $MMTCO_2e$/year), and Grassland Ecosystems (less than -0.05 $MMTCO_2e$/year).

Figure C.7. Cropland and Grassland GHG Emissions in Massachusetts, 1990-2019

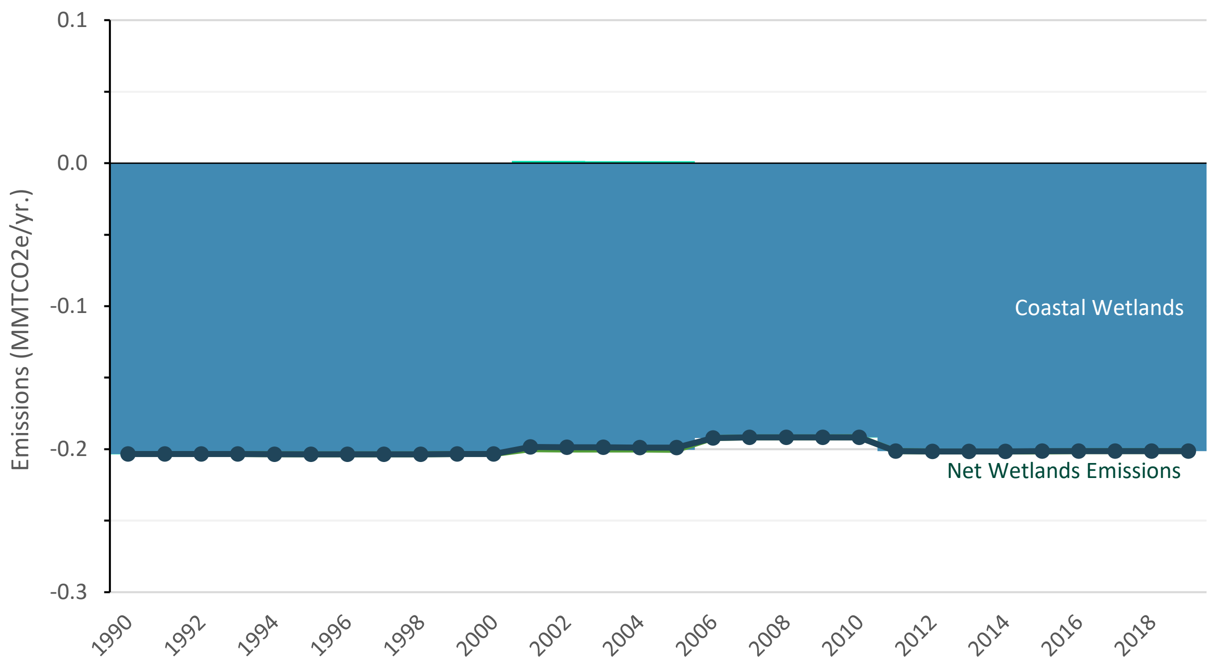


[46] Note that most GHG emissions associated with agricultural practices (e.g., fertilization, liming, enteric fermentation) are reported as gross emissions in the Agriculture sector of the statewide GHG inventory. Cropland fluxes in the NWL GHG inventory are predominantly those that affect soil organic carbon stocks.

WETLANDS (CRF CATEGORY 4D)

Figure C.8shows GHG fluxes associated with wetlands over time, including Coastal Wetlands which appear to have steady net emissions of -0.2 MMTCO$_2$e/year (i.e. GHG sink) since 1990. EEA is developing estimates of GHG fluxes associated with Inland Wetlands and will include them in the NWL GHG inventory once completed.

Figure C.8. Wetlands GHG Emissions in Massachusetts, 1990-2019

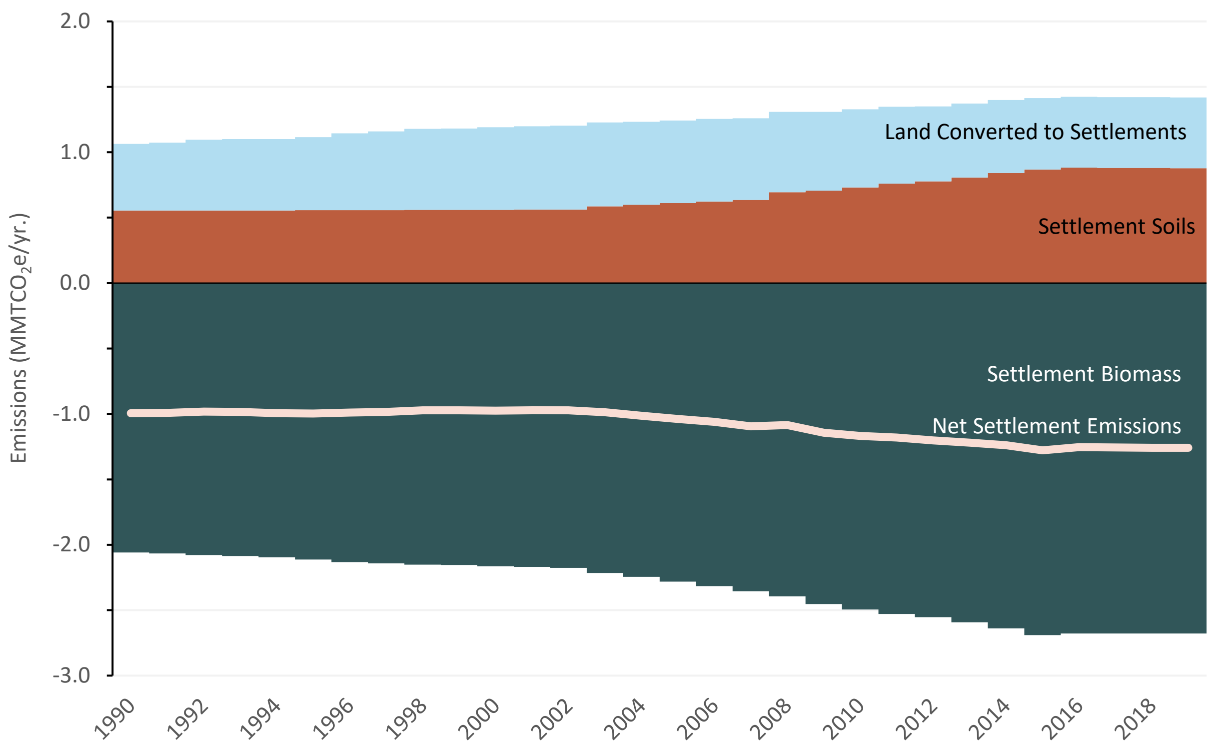


Note: Estimates for Inland Wetlands GHG emissions are under development.

SETTLEMENT LAND (CRF CATEGORY 4E)

Figure C.9 shows GHG fluxes associated with Settlement land over time, with total net emissions of -1.3 $MMTCO_2e$/year in 2019, slightly down from -1.0 $MMTCO_2e$/year in 1990. Settlement emissions include Land Converted to Settlements (steady at about 0.5 $MMTCO_2e$/year) and Settlement Soils, which have increased since 1990 from about 0.6 $MMTCO_2e$/year to about 0.9 $MMTCO_2e$/year in 2019. The Settlement Soils emissions category reflects emissions resulting from development on carbon-rich organic soils (e.g., peatlands), and the increase in recent decades is likely a secondary effect of expanding Settlements. Given that Settlement Soils is the largest category of NWL GHG emissions into the atmosphere in Massachusetts, and has been growing, this flux warrants further investigation. Compensating for the growth in Settlement Soil emissions has been increasing carbon sequestration in Settlement Biomass (i.e., trees and forests in and around developed areas). Net emissions from Settlement Biomass have gone from -2.0 $MMTCO_2e$/year in the 1990-2000 period, to -2.7 $MMTCO_2e$/year in 2019 (-30%), a decrease that is responsible for the overall decrease in net Settlement emissions since 2000.

Figure C.9. Settlement Land GHG in Massachusetts, 1990-2019



C.4 MASSACHUSETTS NWL GHG INVENTORY METHODS

Massachusetts NWL GHG inventory currently relies primarily on the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks by State*,[47] a state-level disaggregation of the U.S. National GHG Inventory (NGGI). Detailed methods are described in the NGGI's *Chapter 6: Land Use, Land-Use Change, and Forestry* [48] and *Annex 3: Methodological Descriptions for Additional Source or Sink Categories,*[49] and are briefly described here and in the following category-specific sections. Following IPCC protocols,[50] the basis for an NWL/LULUCF GHG inventory is a representation and estimate of land areas in six different land cover/use classes (Forest Land, Cropland, Grassland, Wetlands, Settlement, and Other Land).

Massachusetts NWL GHG inventory combines the Cropland and Grassland classes due to their relatively small area (~7%, ~0.4 million acres total)[51] and the difficulty of distinguishing between these land covers/uses in Massachusetts (e.g., grass fields with varying degrees of management). The Other Land class (~2%, 0.1 million acres)[11] includes all areas not falling into the other five land-use categories (e.g., rock, sand, bare soil). Following IPCC guidance, emissions for Other Land are assumed to be zero in Massachusetts because these areas are largely devoid of biomass, litter, and soil carbon pools.[52]

The NGGI uses a so-called Approach 3 land representation, which tracks land area in the six land cover/use classes, as well as transitions among classes, based on spatially explicit location data, such as field surveys of sample locations and maps derived from remote sensing products. Lands are treated as remaining in the same class (e.g., Forest Land Remaining Forest Land) if a land-use change has not occurred in the last 20 years. Otherwise, the land is classified by the current use and most recent use before conversion (e.g., Forest Land Converted to Cropland). The NGGI land representation is primarily based on National Resource Inventory (NRI)[53] and Forest Inventory and Analysis (FIA)[54] survey data, with the remote sensing-based National Land Cover Dataset (NLCD)[55] used for non-forest, federal lands. IPCC standards for the NWL/LULUCF sector call for reporting of all GHG emissions and sequestration occurring on so-called managed land—land whose condition is affected by direct human intervention.

[47] US EPA. 2022. "Inventory of U.S. Greenhouse Gas Emissions and Sinks by State." State GHG Emissions and Removals. March 2022. https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals.

[48] US EPA. 2022. "Chapter 6. Land Use, Land-Use Change, and Forestry." In *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020*, Reports and Assessments, U.S. Environmental Protection Agency, 178. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

[49] US EPA. 2022. "Annex 3. Methodological Descriptions for Additional Source or Sink Categories." In *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020*, Reports and Assessments, U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

[50] IPCC. 2006. Volume 4: Agriculture, Forestry, and Other Land Use *Volume 4: Agriculture, Forestry, and Other Land Use - 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. eds. Simon Eggleston et al. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm.

[51] Based on EEA processing of data from U.S. Geological Survey *LCMAP Collection 1.2* land cover products (https://www.usgs.gov/special-topics/lcmap/collection-12-conus-science-products). The NGGI does not report the area associated with different land use classes at the state level, but EEA is developing its own land use classification that is intended to be consistent with the NGGI based on LCMAP data.

[52] Land Converted to Other Land can include emissions from legacy carbon pools, but these are estimated to be negligible (<0.05 MMT CO_2e) in Massachusetts.

[53] https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/results/

[54] https://www.fia.fs.fed.us/

[55] https://www.mrlc.gov/data/type/land-cover

Nearly all land in the contiguous United States and all land within 10 km of roads, is considered managed in the NGGI.[56] Thus, for this assessment, EEA assumed that all land in Massachusetts can be considered managed and did not exclude any land.

Definitions of the land cover/use classes are described in detail in the NGGI[8] (p. 14-15) and summarized here:

Forest Land: Forest land is land at least 120 feet (36.6 m) wide and at least 1 acre (0.4 ha) in area with a minimum of 10% live tree cover/stocking, including land formerly with such cover that is regenerating. Trees are defined as woody plants with erect perennial stems capable of achieving at least 16.4 feet (5 m) in height, at least 3 inches (7.6 cm) wide at breast height or 5 inches (12.7 cm) wide at root collar. Forest Land includes unimproved roads, trails, streams, and clearings that are no wider than 120 ft (36.6m) or no more than 1 acre (0.4 ha) within otherwise forested land. This category does exclude area completely surrounded by Settlements or predominantly under agricultural use.

Cropland & Grassland: Cropland consists of areas used for crop production and harvest, including cultivated and non-cultivated lands, row crops, close-grown crops, pasture-cultivated crop rotations, continuous hay, perennial crops (e.g., orchards), and horticultural cropland, as well as agroforestry, temporarily fallow, and conservation reserve-enrolled land that does not meet the Forest Land criteria. Grassland consists of areas with plant cover composed principally of grasses, forbs, grass-like plants, or shrubs suitable for grazing and browsing. The category includes pastures, native rangelands areas of occasional hay production (no more than three continuous years), and management-maintained grassland. It also includes areas of drained wetlands, shrubland, and agroforestry meeting criteria for Grassland vegetation, but not Forest Land.

Wetlands: Wetlands consist of land covered or saturated by water for all or part of the year, in addition to lakes, reservoirs, and rivers with artificially changed water levels. This category excludes certain saturated/flooded areas in Croplands (e.g., cranberry production), Grasslands (e.g., wet meadows), and Forest Lands (e.g., riparian forests).

Settlements: Settlements consist of land at least 0.25 acres (0.1 ha) that is developed, including: residential, industrial, commercial, and institutional land; construction sites; transportation corridors and facilities; landfills; water control structures; heavily-managed or urban open space. This category also includes areas no more than 10 acres (4 ha) that would otherwise be defined as Cropland, Grassland, Other Land, or Forest Land (of any size), but are completely surrounded by urban or built-up land.

Methods used to estimate GHG emissions in each of the land cover/use classes are described in detail in the NGGI's LULUCF chapter and methods annex,[8,9] while methods used to disaggregate NGGI estimates to the state level are described in the documentation for the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks by State*.[7] The *Inventory of U.S. Greenhouse Gas Emissions and Sinks by State* does

[56] Ogle, Stephen M. et al. 2018. "Delineating Managed Land for Reporting National Greenhouse Gas Emissions and Removals to the United Nations Framework Convention on Climate Change." *Carbon Balance and Management* 13(9). https://cbmjournal.biomedcentral.com/articles/10.1186/s13021-018-0095-3.

not include estimates of Inland Wetlands or Harvested Wood Product GHG fluxes. For Harvested Wood Products, EEA used the EPA's State Inventory Tool,[57] which includes Massachusetts-specific carbon storage estimates. For Inland Wetlands, EEA is developing its own methodology based on a literature review of emissions factors and NOAA CCAP wetland land cover data.

Several minor emissions categories included in NGGI state-level reporting were omitted from inventory owing to questions over their applicability in Massachusetts. These include the Settlement category Landfilled Food Scraps and Yard Trimmings (landfilling yard trimmings is illegal in Massachusetts) and the Wetland category Peatland Ecosystem Carbon (subsumed by EEA's estimates for Inland Wetland emissions).

In addition to EPA sources, more detailed reporting of GHG emissions and carbon stocks was possible for Forest Land (Figures C.3–C.6) based on independent state-level reporting published by the U.S. Forest Service of the numbers underlying the NGGI.[58]

C.5 LIMITATIONS & PLANNED IMPROVEMENTS OF MASSACHUSETTS' NWL GHG INVENTORY

The major limitation of the NGGI LULUCF land representation is that while it is nominally spatially explicit, it is not spatially continuous (i.e., does not include a comprehensive map of land cover/use classes), and it does not report the area of land assigned to each land cover/use class at the state level.[59] This makes the inventory less informative at the state level and does not allow for any sub-state analysis. Additionally, given that the NGGI land representation relies primarily on sampled plot data and does not take advantage of spatially-continuous, remotely-sensed data, the accuracy of the underlying land area estimates is likely not optimal, particularly for a small, urbanized state like Massachusetts where land cover and use is highly fragmented at fine spatial scales.

Given these limitations, one of the primary focus areas for improvements to the Massachusetts NWL GHG inventory is an improved, spatially-continuous land representation that maps land cover/use and land cover/use change on an annual basis across the Commonwealth. EEA has begun developing this new land cover/use representation, modifying the U.S. Geological Survey (USGS) Land Change Monitoring, Assessment, and Projection (LCMAP) land cover data products[60] to be appropriate for NWL GHG estimation in Massachusetts and consistent with IPCC/NGGI land use definitions. The LCMAP land cover data collection was selected over other spatially continuous, remotely-sensed land cover data products (e.g., NLCD) because LCMAP was explicitly designed to detect land cover change and provides

[57] US EPA. 2022. *State Inventory and Projection Tool*. https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool.

[58] Walters et al. 2021. "Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2019: Estimates and quantitative uncertainty for individual states." Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2021-0035.

[59] Areas for Forest Land and Forest Land conversion categories used in the NGGI are published by the U.S. Forest Service in Walters et al. 2021. "Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2019: Estimates and quantitative uncertainty for individual states." Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2021-0035.

[60] U.S. Geological Survey. *Land Change Monitoring, Assessment, and Projection (LCMAP)*. https://www.usgs.gov/special-topics/lcmap/data.

consistent tracking of land cover changes on an annual basis going back to 1990 (and earlier). EEA has modified LCMAP's primary land cover data product (LCPRI) to classify forested wetlands (LCPRI = wetland, LCSEC = tree cover) as Forest Land, rather than as Wetlands, consistent with the NGGI land class definitions and other land cover data sources (e.g., FIA survey data, NLCD, MassGIS's high-resolution 2016 land cover/use data[61]).

Additional limitations in Massachusetts NGGI-based NWL inventory include under-developed approaches to estimating fluxes in Settlements and Wetlands, land uses that are less significant nationally but make up substantial portions of Massachusetts' area (24% and 13%, respectively, based on EEA's processing of the LCMAP data). Estimates for carbon storage in Harvested Wood Products is based on data collected in the 1980s and 1990s that may not reflect improvements in efficiency of timber harvest and processing; EEA is working with researchers at UMass-Amherst to get updated data for wood products carbon accounting. Uncertainty in Forest Ecosystem emissions for 2019 is estimated to be ±30%,[62] but state-level uncertainty has not been estimated for other NWL/LULUCF emissions categories. National-level uncertainties published in the NGGI are not directly applicable at the state level but could give an order-of-magnitude approximation (state-level uncertainties are likely higher). These range from about 10%-30% for Forest Land emissions categories, more than 100% for Cropland & Grass categories, about 10%-30% for Wetland categories, and about 30%-50% for Settlement categories.

[61] MassGIS's 2016 Land Cover/Land Use data product is available at https://www.mass.gov/info-details/massgis-data-2016-land-coverland-use.

[62] Walters et al. 2021. "Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2019: Estimates and quantitative uncertainty for individual states." Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2021-0035.

APPENDIX D: MACROECONOMIC IMPACT AND EQUITY ANALYSIS OF DECARBONIZATION PATHWAYS IN MASSACHUSETTS

This Appendix is prepared by BW Research Partnership and Industrial Economics, Incorporated, the contract research team that developed the employment and economic impact analysis to support the Massachusetts Clean Energy Climate Plan for 2025 and 2030.

D.1 EMPLOYMENT AND ECONOMIC IMPACTS ANALYSIS

To analyze the varied impacts of decarbonization on Massachusetts residents and the economy, the research team developed three different types of model outputs. Initial Employment Outputs (IEOs) summarize the workforce impacts across energy sectors, sub-sectors, and industries. Secondary Employment Outputs (SEO) break down impacts even further, examining the types of occupations, wages, and geographic location of the employment and economic impacts around the state. The research team also estimated the change in energy expenditures at the household level, to see how the energy transition would affect households' budgets. Examining the economic and employment impacts at these three levels provides a comprehensive view of the scale and nature of the economic activity resulting from decarbonization efforts, and how these efforts will impact Massachusetts. The research team also analyzed the non-employment economic impacts of air quality (which can be found in Appendix D-5) and natural and working lands (which can be found in Appendix D-6).

To model the employment and economic impacts of activities in the Clean Energy and Climate Plan for 2025 and 2030 (2025/2030 CECP), the research team leveraged decarbonization data developed by Evolved Energy Research (EER). The data from EER included forecasted values for capital expenditures, commodities purchases, operations and maintenance costs, and energy demand. The research team then used these as inputs to develop models using IMPLAN and JEDI multipliers. IMPLAN and JEDI are input-output (I/O) models that illustrate the interdependent relationships between different sectors of the statewide economy. IMPLAN focuses on the overall employment impacts that would be felt across a given economic region, in this case, Massachusetts. JEDI models are National Renewable Energy Laboratory (NREL) tools to estimate the local economic impacts of the construction and operation of power generation and biofuel plants. NREL provides JEDI models for various energy sub-sectors, including onshore wind, offshore wind, solar, and biofuels. JEDI estimates job creation by running user input of project location, facility size, and construction year, in combination with the built-in model defaults and economic multipliers.[63]

Investments or activities in a particular sector are used as inputs into the model to estimate the ripple or multiplier effect on business, household, government expenditures, and industry employment. Estimates include direct, indirect, and induced employment:

[63] For example, data for the Buildings sector was calibrated by analyzing data on Massachusetts' building retrofit and electrification activities.

- **Direct** = employment associated with the initial economic activity of a given investment or activity (e.g., changes in wages, production, or jobs).
- **Indirect** = employment associated with the supply chain connected to the initial economic activity of the original investment or activity (e.g., purchases of goods and services or business tax impacts).
- **Induced** = employment based on the additional household spending resulting from the additional direct and indirect employment that is generated from the initial economic activity of the original investment or activity (e.g., wages paid, household purchases, or household tax impacts).

For more information on the development of economic impact models, please see Appendix D-1. There are seven different primary sectors used to model the impacts of decarbonization. These sectors are similar to the sectors used in the other chapters of the 2025/2030 CECP, however, some of these sectors do not directly overlap. Industrial Energy Efficiency and Municipal Solid Waste, which are listed separately in this chapter, are clustered together as a Non-Energy & Industrial Policy Sector throughout the rest of the 2025/2030 CECP.

The **Electricity** sector is responsible for generating electric power and contains 10 sub-sectors.[64]

- Solar PV
- Offshore Wind
- Onshore Wind
- Hydropower
- Other Generation (Biomass, CHP, Geothermal, & Hydrogen)
- Distribution
- Transmission
- Storage
- Natural Gas Generation
- Other Fossil Generation

The **Fuels** sector is responsible for producing fuels that power transportation and machinery, and it contains four sub-sectors.

- Hydrogen Fuels
- Biofuels
- Natural Gas Fuels
- Petroleum Fuels

The **Buildings** sector captures activities around making buildings more energy efficient, such as adding insulation or energy efficient lighting, and has five sub-sectors.

- Commercial HVAC
- Commercial Other

[64] Employment related to the decommissioning of the Pilgrim Power Station is not included within this sector because the closure of that plant precedes the baseline employment data used in this analysis.

- Residential HVAC
- Residential Buildings Envelope
- Residential Other

The **Transportation** sector includes the production, maintenance, and fueling of vehicles and contains five sub-sectors.

- Vehicle Manufacturing
- Vehicle Maintenance
- Wholesale Trade Parts
- Conventional Fueling Stations
- Charging and Hydrogen Fuel Stations

The **Industrial Energy Efficiency** sector captures activities that reduce the energy consumption of industrial processes, such as the production of cement or plastics. The industrial sector is broken out into three sub-sectors:

- Electronics
- Construction, Machinery, Transportation Equipment
- Other Materials Production

The **Natural and Working Lands** sector includes the activities around agriculture, carbon sequestration via natural environmental resources, and remediation of brownfields. This sector is broken into five employment categories:

- Community Planning
- Tree Planting
- Healthy Soils
- Forest Resilience
- Forest Viability

The **Municipal Solid Waste** sector includes activities related to the collection and disposal of solid waste, encompassing various waste management methods, including disposal (e.g., landfill and waste-to-energy), recycling, organic material processing (e.g., composting, animal feed, and anaerobic digestion), and out-of-state transfer. As discussed in the employment results for the Municipal Solid Waste sector, we model employment for only one sub-sector:

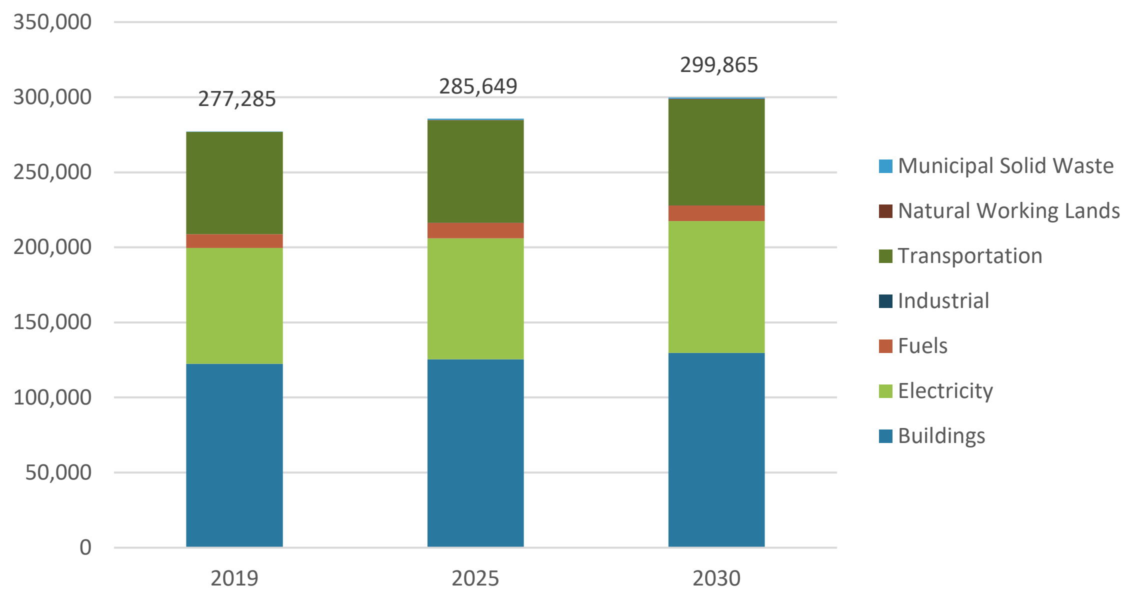
- Organic Waste Composting

D.2 INITIAL EMPLOYMENT OUTPUTS

Initial Employment Outputs (IEOs) provide snapshot figures of employment between 2019 and 2030.[65] These snapshots allow us to see the overarching trends in the economy as Massachusetts decarbonizes.

By 2030, the seven sectors will account for an estimated 299,900 jobs across the state and reach 343,300 jobs by 2050. The Buildings sector accounts for the greatest share (43%) of jobs in 2030, followed by Electricity (29%) and Transportation (24%) (Figure D.1).

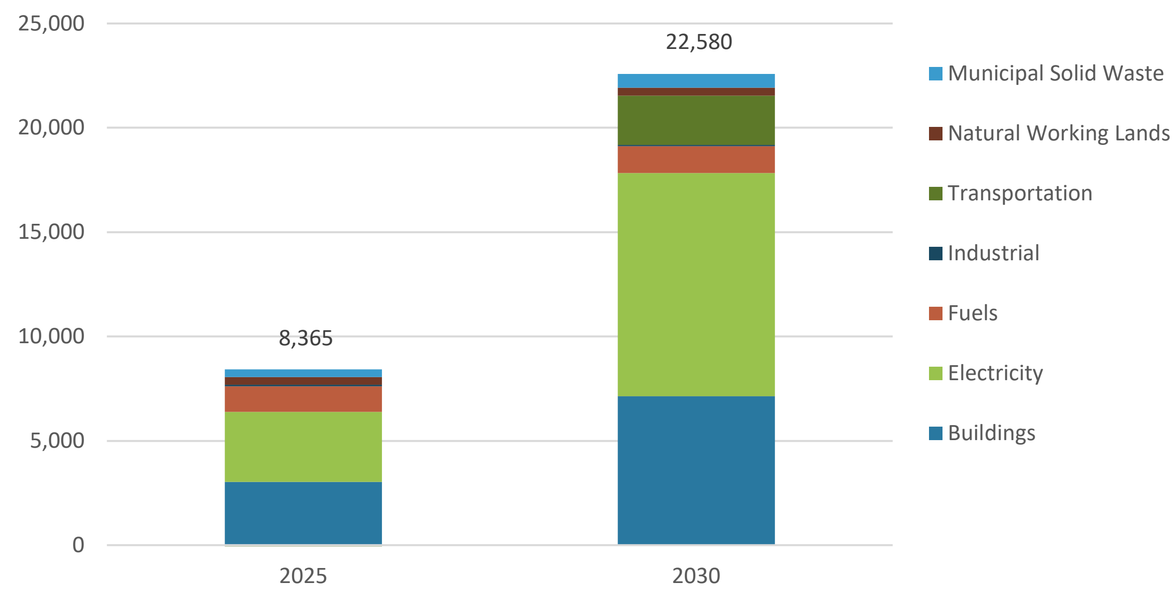
Figure D.1. Total Employment by Sector



The Electricity[66] sector is responsible for adding the greatest number of jobs, adding 10,700 jobs by 2030 and 34,300 jobs by 2050 from the 2019 baseline. This equates to a 14% increase in Electricity jobs from 2019-2030 and a 44% increase by 2050. The Buildings sector is estimated to add 7,100 jobs by 2030, and 15,300 jobs by 2050 relative to 2019 levels. The Fuels sector is projected to grow by 14% between 2019 and 2030, and 57% by 2050, though this growth is attributable to forecasted growth in market demand rather than CECP policies. The Transportation sector sees a modest increase in employment between 2019 and 2030 (4%) (Figure D.2) and greater growth (15%) by 2050. The smaller sectors of Industrial Energy Efficiency, Natural and Working Lands, and Municipal Solid Waste see large percentage growth in employment, though the absolute employment figures are relatively small.

[65] 2019 used as the baseline year due to the disrupting effects of the COVID-19 pandemic on employment figures across industries and sectors.
[66] The Electricity sector does not include employment from decommissioning activities at the Pilgrim Nuclear Power Station.

Figure D.2. Change in Total Employment From 2019 by Sector



EV Chargers (+5,900), Solar PV (+4,000), Residential Buildings Envelope (+3,700), Transmission (+2,900), and Offshore Wind[67] (+2,800) are the sub-sectors that are projected to add the greatest total number of jobs between 2019 and 2030 (Table D.1). Nascent sub-sectors, such as EV Chargers and Offshore Wind, are poised to see exponential growth during this time, while larger and more established industries like Solar PV and Residential Buildings Envelope see strong double-digit growth. It is notable that Transmission, which had 2,300 workers in the state in 2019, is projected to more than double between 2019 and 2030.

Employment in Fueling Stations is estimated to see the greatest decline between 2019 and 2030, shedding 4,100 jobs. This decline is driven by a decrease in the demand for gas stations and their employees as Electric Vehicles make up a greater share of vehicles on the road. This decline in Fueling Stations employment may not occur if current gas stations retail operations remain to serve as electric charging stations or hydrogen fueling stations.[68] Natural Gas Generation, and Other Fossil Fuel Generation are each estimated to shed more than 1,000 jobs each (Table D.2). For a breakdown of change in employment by sub-sector, please see Appendix D-3.

[67] Given the nascency of the offshore wind industry and the specialization in manufacturing it requires, the research team has developed three different scenarios for offshore wind investment and local content production. The figures throughout this report are determined using the "Continued Policies" offshore wind scenario, which projects continued effort and investment by the state in the "lowest-hanging fruit" opportunities for local content. For more information on this scenario, and the other scenarios developed, please see page 45.

[68] The transition to electric vehicles makes the future of gas stations and their accompanying retail employment unknown. For this study, the research team projected that home charging stations and fast-chargers will make fueling station retail stores largely obsolete, however it is possible that future technology makes rapid electrical charging roughly time equivalent to filling up a gas tank, and therefore fueling station employment will remain largely unchanged.

Table D.1. Change in Total Employment Among Sub-sectors with Greatest Job Growth

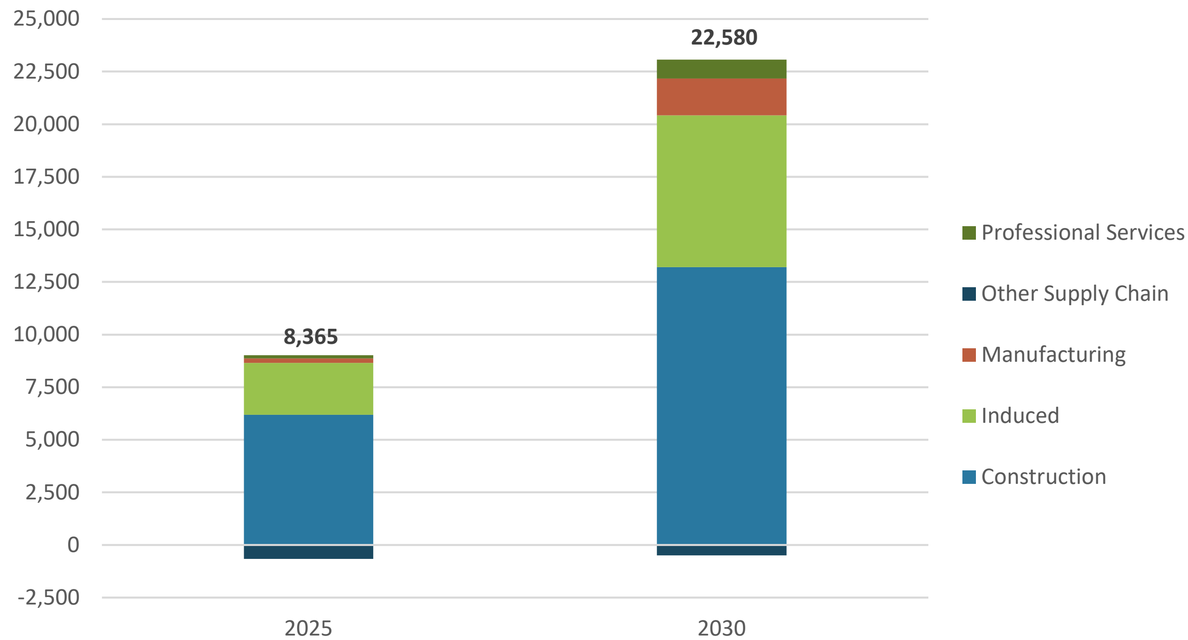
Top Employment Growth Sub-sectors	2019 Employment	2030 Employment	2019-2030 Change	2019-2030 Change (%)
EV Chargers	64	5,924	5,860	9,163.7%
Solar PV	23,964	27,972	4,008	16.7%
Residential Buildings Envelope	15,626	19,283	3,657	23.4%
Transmission	2,325	5,252	2,927	125.9%
Offshore Wind	334	3,178	2,844	851.2%

Table D.2. Change in Total Employment Among Sub-sectors with Greatest Employment Declines

Top Employment Growth Sub-sectors	2019 Employment	2030 Employment	2019-2030 Change	2019-2030 Change (%)
Other Fossil Generation	3,356	2,318	-1,039	-31.0%
Natural Gas Generation	8,114	6,476	-1,637	-20.2%
Fueling Stations	21,305	17,219	-4,086	-19.2%

Jobs in the Construction industry are projected to see the most growth between 2019 and 2030, adding 13,200 jobs to the Massachusetts economy by 2030 (Figure D.3) **and 35,600 jobs by 2050 from 2019 levels.** Induced employment accounts for the second-largest addition of jobs, equating to 7,200 additional jobs by 2030 and 20,800 jobs by 2050 from 2019 levels. The Manufacturing industry sees the greatest percentage increase in workers, growing 20% between 2019 and 2030, equating to 1,700 additional jobs. By 2050, there will be an estimated 83% more energy-related Manufacturing jobs than in 2019, resulting in a sizeable workforce of 7,200.

Figure D.3. Change in Total Employment by Industry



ELECTRICITY

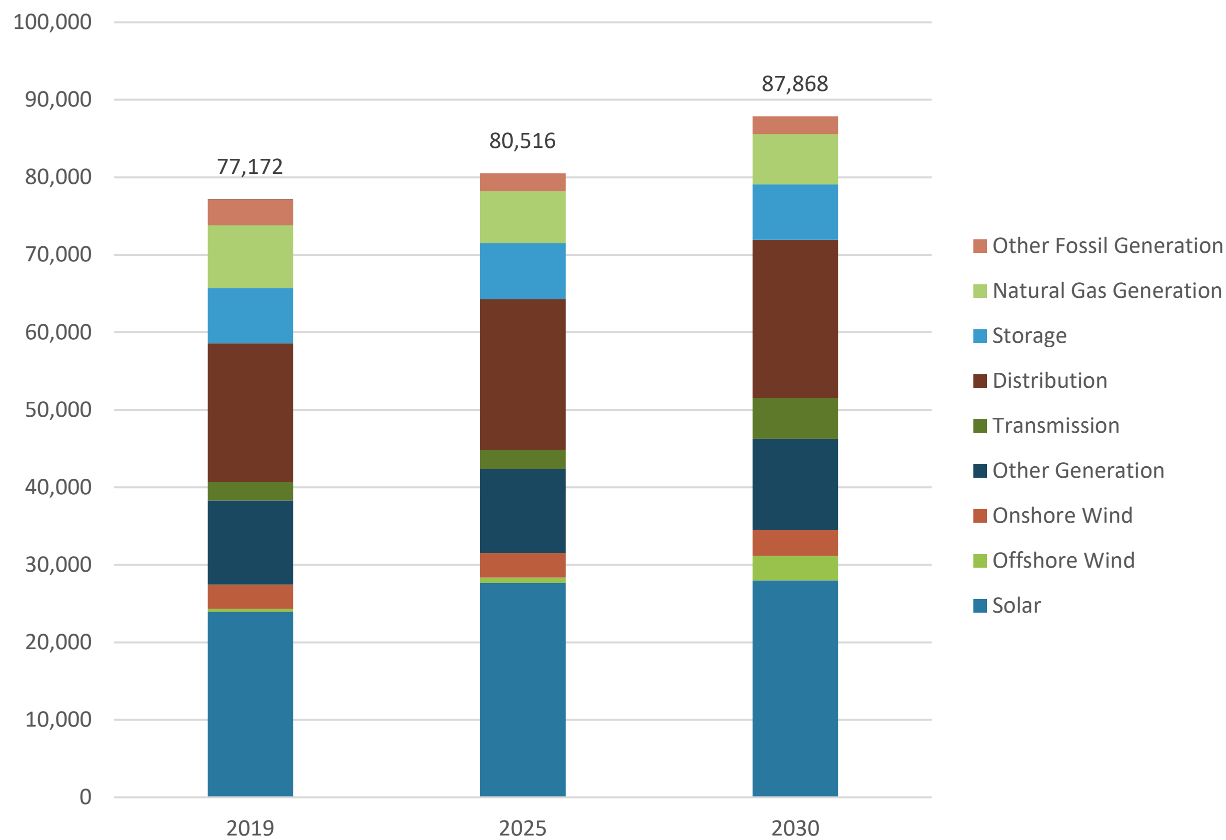
Electrifying and decarbonizing the Massachusetts economy will drive multiple changes in the Electricity sector and its workforce. The first effect is a significant increase in the demand for electricity. The second effect is a transition in electricity sources; electricity generation using hydrocarbon fuel sources—including natural gas and other fossil fuel sources—will be phased out in favor of renewable options. The scale of these renewable sources is substantial; at least 15 GW of Offshore Wind[69] capacity is slated for construction off the Southern New England[70] coast by 2050. This activity will also require enhanced grid infrastructure to ensure that all aspects of the increasingly electrified economy are connected and secure, as more homes install charging infrastructure and more renewable sources come online. By 2030, this electrification activity is projected to account for roughly $11.6 billion in Gross State Product (GSP), about equivalent to Software Publishing activities throughout the Commonwealth. This change in the economy will also have significantly transformational effects on the types of jobs demanded around the state.

[69] Given the nascency of the offshore wind industry and the specialization in manufacturing it requires, the research team has developed four different scenarios for offshore wind investment and local content production. The figures throughout this report are determined using the "Continued Policies" offshore wind scenario, which projects continued effort and investment by the state in the "lowest-hanging fruit" opportunities for local content. For more information on this scenario, and the other scenarios developed, please see page 45.

[70] Connecticut and Rhode Island are supporting the development of OSW projects which will have power transmitted onshore to transmission centers in Massachusetts. While Massachusetts is not funding these projects, the activity off of Massachusetts coast will provide economic benefits to the state's OSW workforce as well as the broader economy.

The Electricity sector is the second-largest sector by total job increase, accounting for 77,200 jobs in 2019, 87,900 jobs in 2030, and 111,400 jobs by 2050. Solar PV[71] accounts for the largest share (32%) of Electricity Sector jobs in 2030. Distribution[72] of electricity also accounts for a significant share (23%) of Electricity sector jobs in 2030 and 29% by 2050. A large number of Distribution jobs are needed to ensure that electricity can travel from substations to their final destinations. Other Generation (including hydropower and biomass) is another sub-sector that accounts for a large share (13% in 2030) of Electricity sector jobs (Figure D.4). Offshore Wind employment will grow almost ten-fold between 2019 and 2030, accounting for 3,200 jobs statewide by 2030 and 12,600 by 2050.

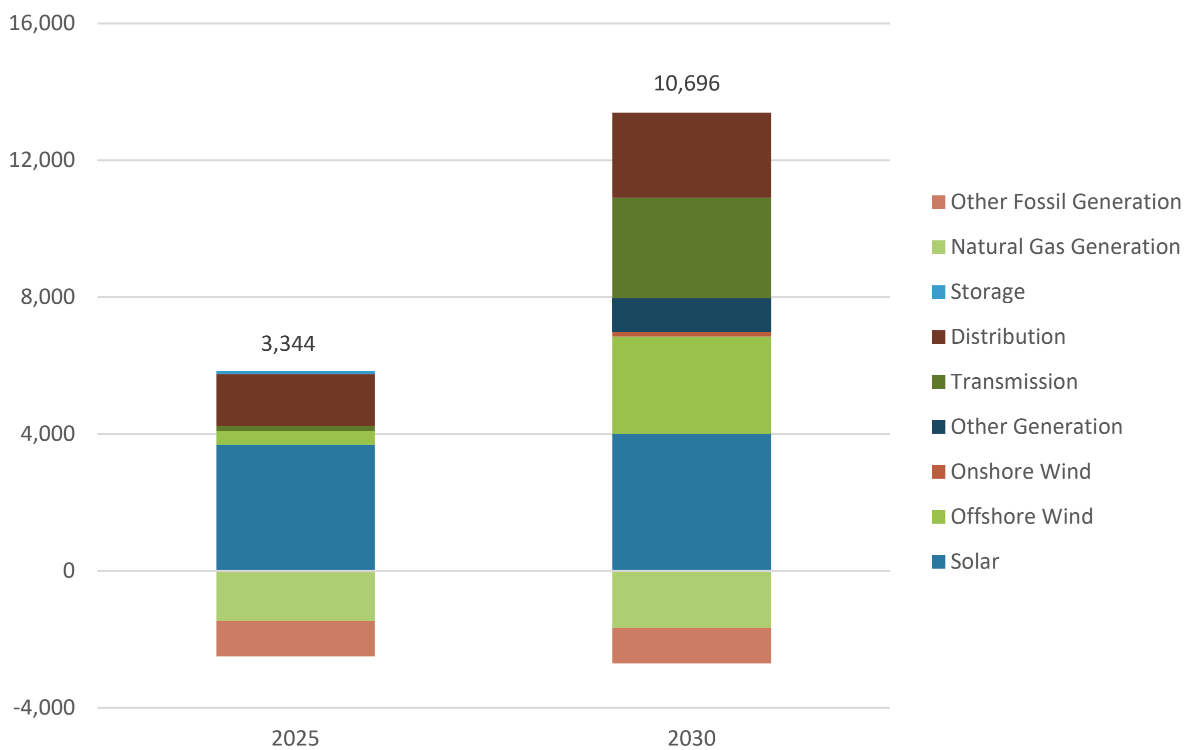
Figure D.4. Electricity Sector Employment by Sub-sector



[71] This includes both distributed solar and utility-scale solar projects.
[72] Transmission and Distribution are separated into distinct sub-sectors because separate inputs were used in both the energy and workforce models used to generate these estimates.

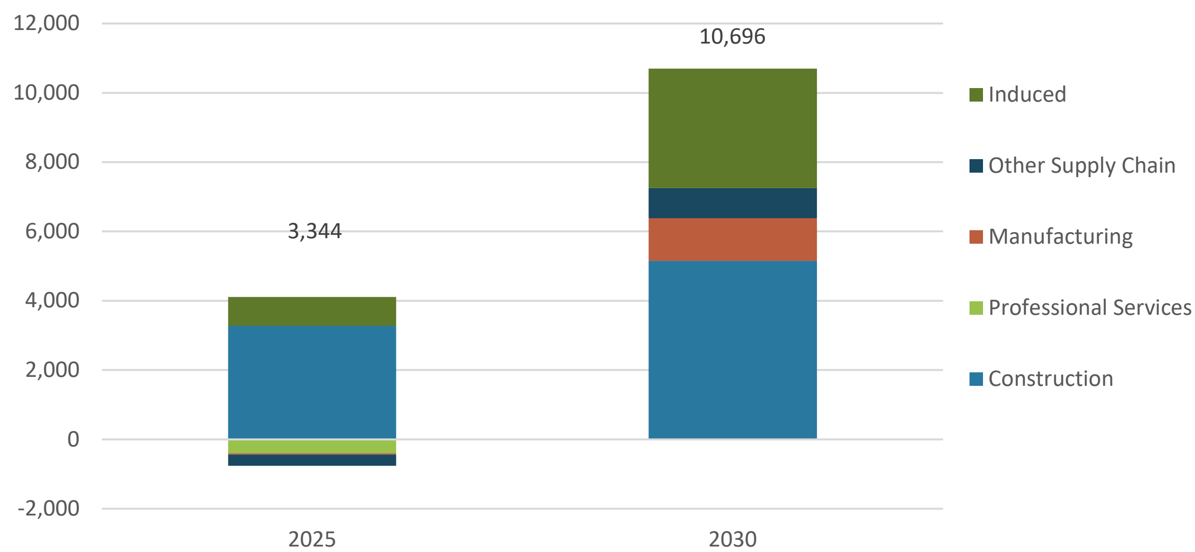
The Electricity sector is largest source of energy employment growth, adding a net 10,700 jobs by 2030 and a net 34,200 jobs by 2050 from a 2019 baseline year. Solar PV (4,000), Transmission (2,900), and Offshore Wind (2,800) are the sub-sectors that add the greatest number of new jobs by 2030. Natural Gas Generation (-1,600), and Other Fossil Generation (-1,000) are estimated to see the greatest employment losses between 2019 and 2030 (Figure D.5). Transition opportunities for these displaced workers may require intentional policy, as a worker at a natural gas generation plant may have fewer directly-transferable skills to Solar PV or Offshore Wind opportunities. The growth in Other Generation (which includes biomass and hydropower) employment may provide more feasible transition opportunities, including roles such as Power Plant Operators.

Figure D.5. Net New Electricity Sector Employment by Sub-Sector From 2019 Baseline



Most of the added jobs in the Electricity sector are Construction industry jobs. Between 2019 and 2030, the Construction sector is estimated to add 5,200 Construction jobs, or 48% of the net employment gains for the sector. Induced employment (jobs created throughout the Massachusetts economy as energy workers spend their wages on food, recreation, healthcare, and other goods and services) is the second-largest source of employment created through the Electricity sector activity, adding 3,400 jobs by 2030. Job losses are attributed to the decline in workers involved in Natural Gas Generation, and Other Fossil Fuel Generation (Figure D.6).

Figure D.6. Net New Electricity Sector Employment by Industry From 2019 Baseline

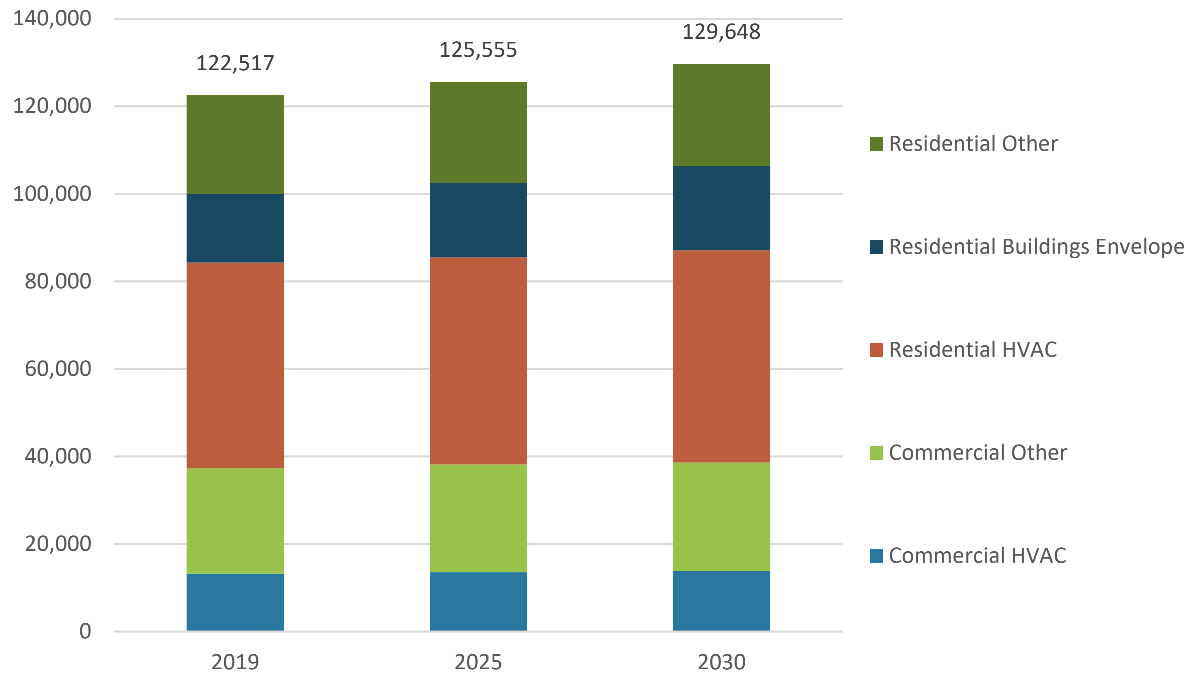


BUILDINGS

Another key aspect in decarbonization is preventing energy waste and increasing the efficiency of its use. Residential and commercial buildings present some of the greatest opportunities to decrease energy demand through greater efficiency. These efforts will require an array of activities, ranging from installing electric heat pumps to insulating attics and crawlspaces. The $5.8 billion in economic activity generated by this sector by 2030 is greater than the GSP contributions of Full-Service Restaurants. These activities will also require a significant number of workers that will add to Massachusetts' already large energy efficiency workforce, with 122,500 workers across the state.

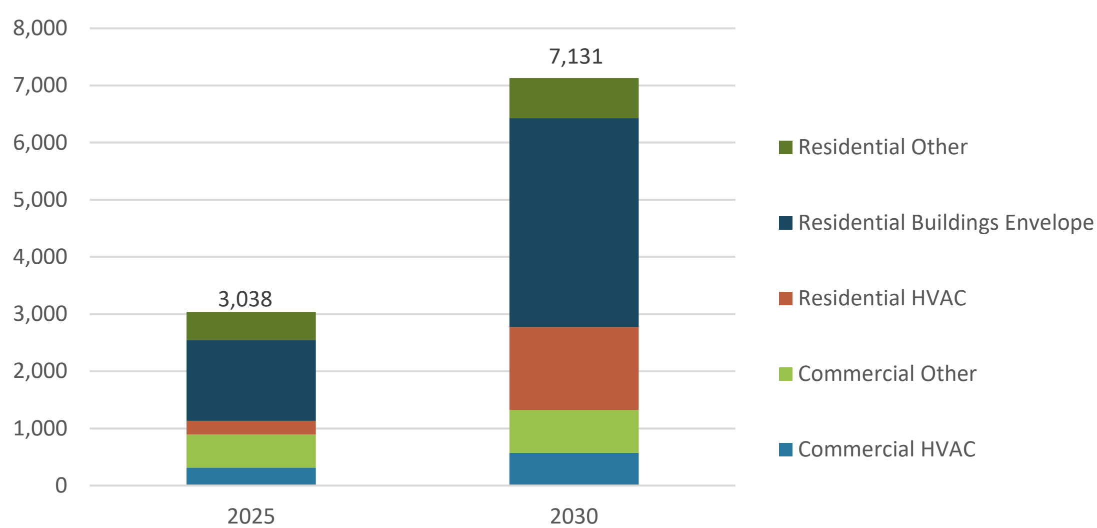
The Buildings sector will continue to be the largest sector of energy workers, projected to employ more than 129,600 workers across the state in 2030. Nearly four-in-ten (37%) of Buildings sector workers in 2030 will work in Residential HVAC, which includes activities like installing heat pumps and other energy efficient heating and cooling systems. Commercial Other (which includes things like energy efficient lighting, software development, etc.), Residential Other (similar activities to Commercial Other, but on the residential side), and Residential Buildings Envelope are the next largest sub-sectors, accounting for 19%, 18%, and 15% of 2030 employment respectively (Figure D.7).

Figure D.7. Buildings Sector Employment by Sub-sector



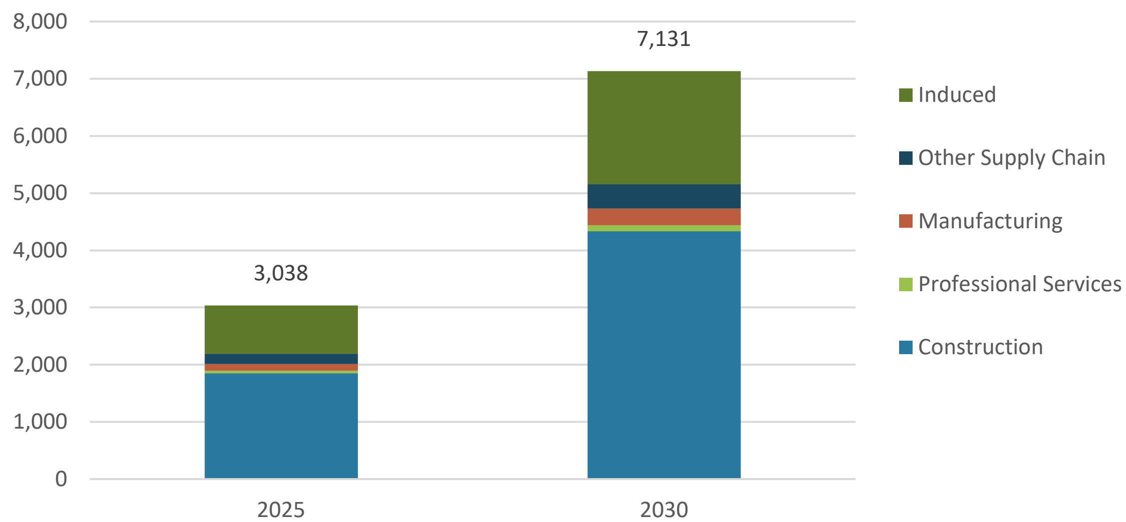
Between 2019 and 2030, the Buildings sector will add an estimated 7,100 jobs. Most of these additional jobs will be in Residential Buildings Envelope, which adds 3,700 jobs by 2030 (Figure D.8). Residential HVAC, which is involved in the installation of heat pumps and other efficient HVAC equipment, is projected to add roughly 1,500 jobs. Commercial Other and Residential Other are expected to add more than 700 jobs each.

Figure D.8. Net New Building Sector Employment by Sub-Sector From 2019 Baseline



A majority (61%) of new Building sector employment by 2030 will be in Construction. Induced employment will account for another 28% of these additional jobs, meaning Other Supply Chain, Manufacturing, and Professional Services combined account for just 13% of new Building sector jobs (Figure D.9).

Figure D.9. Net New Building Sector Employment by Industry From 2019 Baseline



FUELS

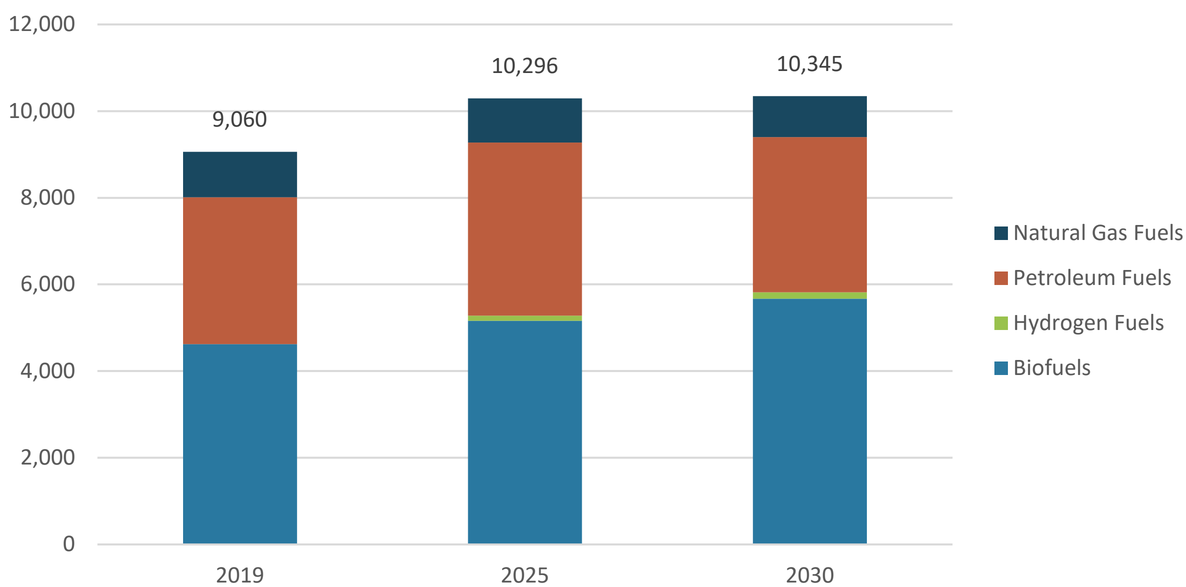
Not every part of the Massachusetts economy can be electrified in a cost-effective or technologically feasible way. To decarbonize some of these hard-to-electrify sectors, such as aviation, long-haul shipping, and industrial production, new fuels that are renewable and result in fewer net carbon emissions will be crucial. Biofuels are the primary tool used to decarbonize these sectors in the short-term and include a range of fuels such as ethanol, which is produced from corn and is a common additive to gasoline, and renewable diesel, which is produced from feedstocks like leftover restaurant grease and other plant and animal oils and substituted in place of traditional diesel fuel. The production of biofuels in the U.S. is projected to increase by 18% to 55% between 2019 and 2050, according to U.S. Energy Information Administration projections.[73] The feedstocks of biofuels are often carbon-fixing or recycled materials, meaning that they have lower net greenhouse has contributions, resulting in an array of social, environmental, economic, and health benefits. While the 2025/2030 CECP does not include any additional policies on biofuels or blending, strong projected market demand means that these fuels will continue to see growing use. The decarbonization pathways modeled in this report projects future scaling of both established products like biofuels in the immediate term, and more nascent fuels like hydrogen over the longer-term, in years beyond 2030.

Employment in the Fuels sector is projected to grow by 14% by 2030 and grow by more than half (57%) by 2050 from 2019 levels. Most of this employment growth comes from growth in the Biofuels

[73] "EIA projects US biofuel production to slowly increase through 2050." March 9, 2020. https://www.eia.gov/todayinenergy/detail.php?id=43096.

sub-sector, which accounted for 4,600 jobs in 2019, and is projected to reach 5,700 jobs by 2030 (Figure D.10). Workers in the Fuels sector create, blend, transport, and sell fuels, and this activity will generate more than $5.8 billion in GSP, about equivalent to the GSP of Engineering Services in the state. The creation, transportation, and use of Hydrogen Fuels is expected to take longer to scale in the Massachusetts economy, however, 1,300 people are projected to work full-time on Hydrogen-related activities by 2050.

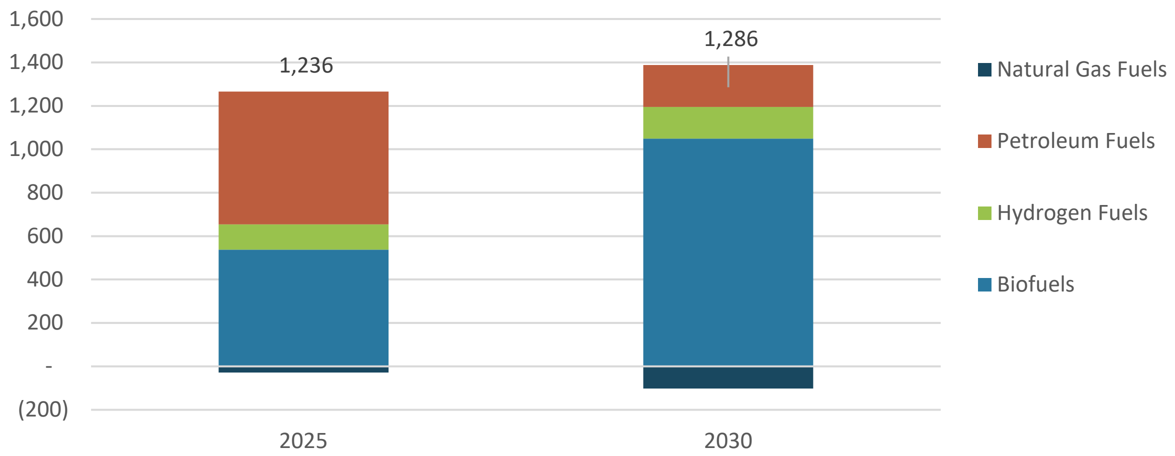
Figure D.10. Fuels Sector Employment by Sub-Sector



Employment gains in Biofuels offset the losses in fossil fuels. While the Biofuels sub-sector is projected to add more than 1,000 jobs by 2030 and 7,100 jobs[74] by 2050 from 2019 levels, Petroleum Fuels and Natural Gas Fuels are projected to see some employment losses in the long run. Petroleum Fuels is estimated to grow by 100 jobs by 2019 but shed 2,700 jobs by 2050. The Natural Gas Fuels sub-sector is projected to also see declines, shedding 100 jobs by 2030 and 500 jobs by 2050. These declines in employment are offset in net by new jobs created through Biofuels activity (Figure D.11), so examining transition opportunities for these displaced workers will be important. Some of these roles may find the transitions to be easy; for example, a fuel transport driver is not likely to care whether they are hauling traditional or renewable diesel.

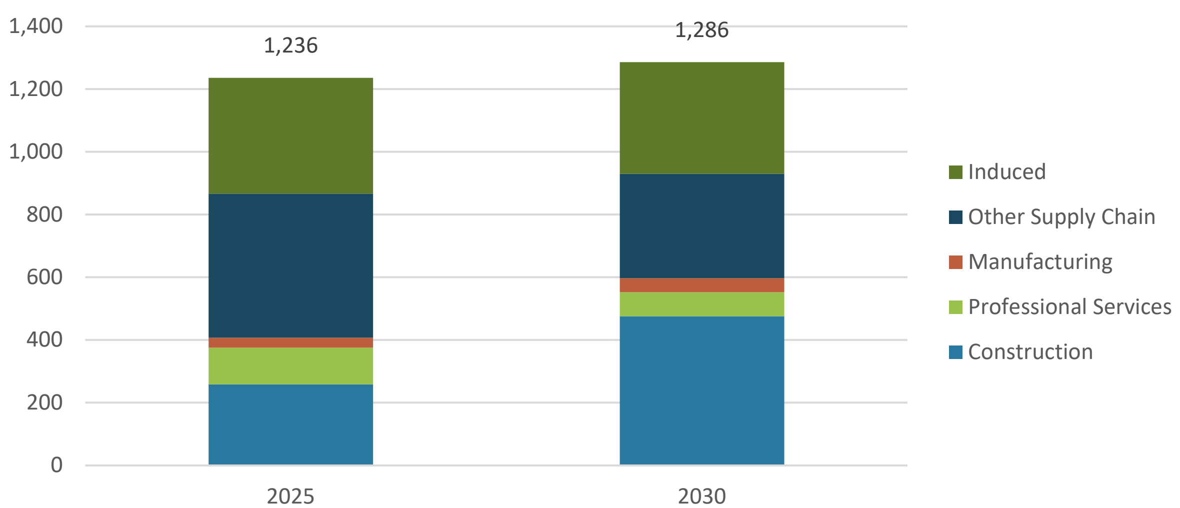
[74] This growth in biofuels is due to a projected increase in market demand for biofuels and not via an explicit state policy.

Figure D.11. Net New Fuels Sector Employment by Sub-Sector From 2019 Baseline



Construction jobs are projected to account for more than a third (37%) of Fuels sector employment gains. This could include jobs such as installing additional pipelines and fuel transportation infrastructure. Other Supply Chain, which includes agriculture and the wholesale trade and distribution of goods, accounts for 26% of additional employment. Induced employment accounts for another 28% (Figure D.12). It is worth noting that most of the fossil fuels employment losses by 2030 are in the Other Supply Chain industry, though this industry sees net growth across all sectors. A majority of Other Supply Chain jobs would include fuel transportation workers, so many of these roles likely have many transferrable skills from fossil fuels to biofuels; a safety inspector of fossil fuels is likely to have much of the knowledge needed for a safety inspector involved in biofuels. Because Biofuels employment growth is projected to outpace the fossil fuel employment losses, many these disruptions may end up being more transitionary than eliminatory.

Figure D.12. Net New Fuels Sector Employment by Industry From 2019 Baseline

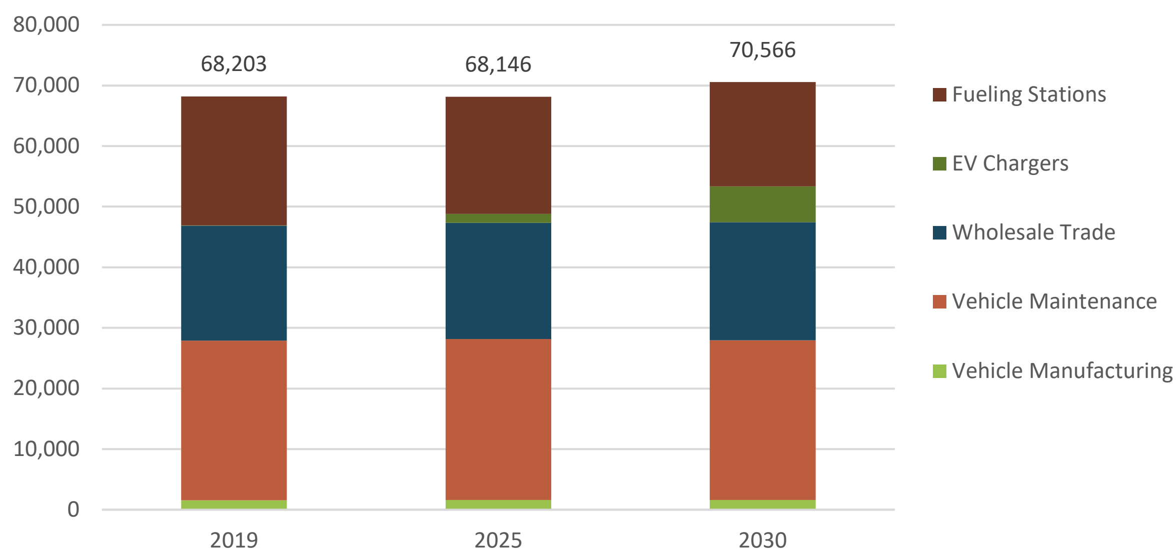


TRANSPORTATION

The Transportation sector represents a significant share of total GHG emissions in the Commonwealth, and thus plays a key role in decarbonization. The forecasted technology transition from conventional vehicle technologies to battery electric and hydrogen fuel cell vehicles will change the demand for different types of labor across the various transportation sub-sectors examined in this analysis.

Employment in the Transportation sector is substantial and expected to remain so through 2050. The Transportation sector supported 68,000 jobs in 2019 and is projected to grow to 71,000 jobs by 2030 and 78,000 jobs by 2050 – a growth of 3 percent and 15 percent from 2019 levels, respectively (Figure D.13). Activities across the Transportation sector are expected to generate more than $6.3 billion in Gross State Product by 2030, roughly equivalent to the GSP of Administrative Management and General Management Consulting Services.

Figure D.13. Transportation Sector Employment by Sub-sector



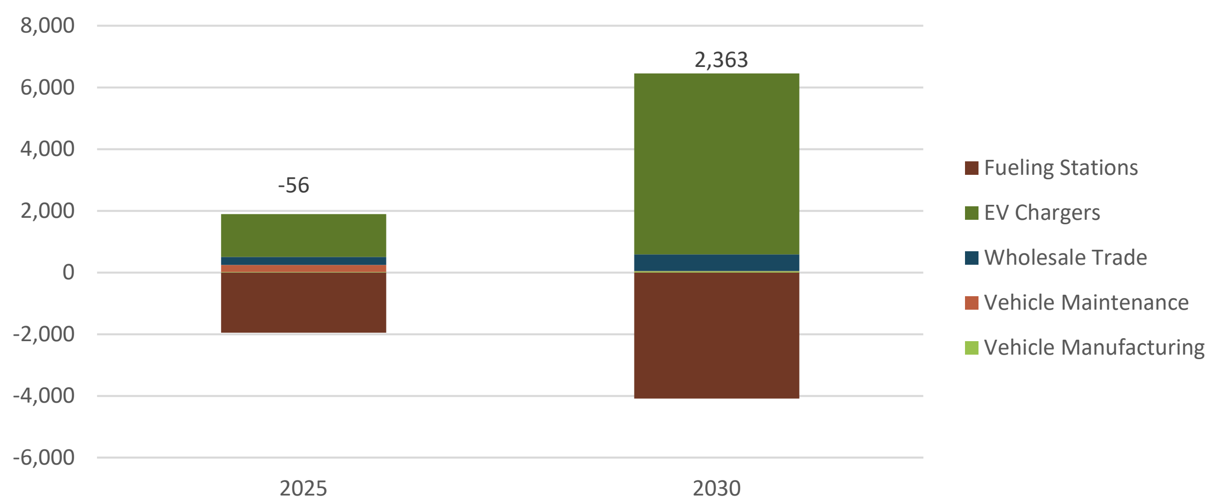
Employment related to EV Chargers is projected to increase significantly through 2030 and 2050. While the Transportation sector is expected to experience slight growth over time, employment trends within sub-sectors differ greatly. In order to support a growing fleet of electric vehicles, the EV Chargers sub-sector is expected to experience substantial growth, adding 5,900 jobs by 2030 and 21,000 jobs by 2050. As baseline 2019 employment in the EV Chargers sub-sector is minimal, activities in this sub-sector represent a largely new source of employment for the Commonwealth. Most of the Charger sub-sector employment within Massachusetts is related to the installation and maintenance of charging units.

Offsetting the substantial job growth related to EV Chargers, employment at Fueling Stations is expected to decline as consumption of fossil fuels decreases over time, with around 4,100 jobs lost by

2030 (a decrease of 19%) and 11,000 jobs lost by 2050 (a decrease of 52%).[75] Because alternative vehicle technologies have lower maintenance requirements,[76] employment in the Vehicle Maintenance sub-sector is also expected to decline in the long run, despite a modest increase in total fleet size: by 2030, employment is essentially the same as in 2019, while by 2050, there will be approximately 1,600 fewer vehicle maintenance jobs than in 2019.

Employment in the Wholesale Trade and Vehicle Manufacturing sub-sectors is expected to remain relatively stable through 2030 and 2050. The total size of the vehicle fleet is expected to experience modest growth, and changes in the composition of the motor vehicle fleet (e.g., market share of conventional vehicles versus electric vehicles) are unlikely to affect employment in the Wholesale Trade sub-sector. Because Vehicle Manufacturing employment in Massachusetts is low in the 2019 baseline values, and most vehicle parts manufactured in the Commonwealth are destined for markets outside of Massachusetts (which are assumed to be unaffected by the 2025/2030 CECP), only a minor portion of an already-small sub-sector is potentially affected by Massachusetts' technological transitions (Figure D.14).

Figure D.14. Net New Transportation Sector Employment by Sub-Sector From 2019 Baseline



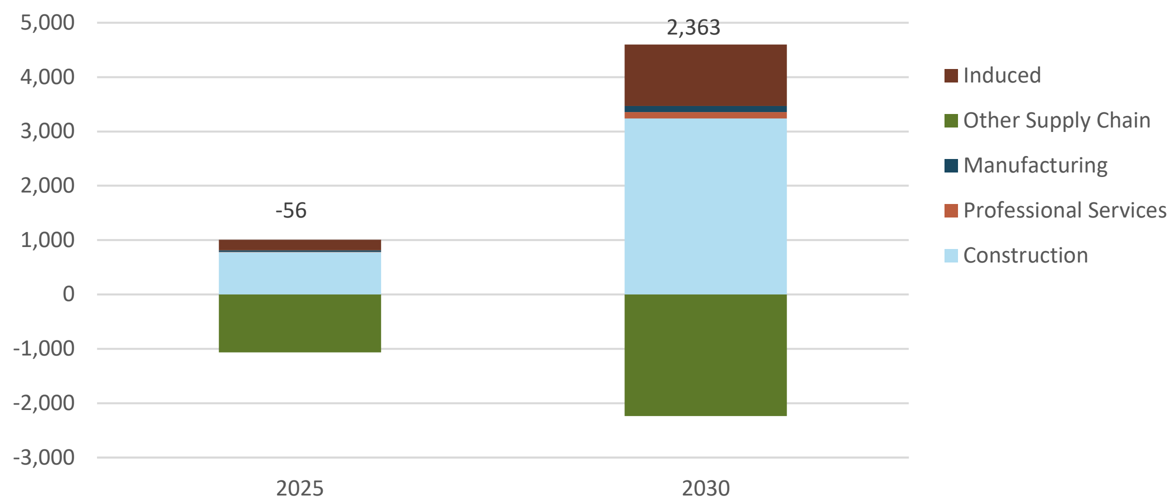
Most job losses in Transportation are in Other Supply Chain industries. Other Supply Chain employment, on net, decreases by 2,200 jobs by 2030 relative to 2019 levels (a 5% decrease) and 6,400 jobs by 2050 (a 14% decrease); this trend is driven by changes in the Fueling Station sub-sector. **Construction jobs related to the Transportation sector increase by 3,200 by 2030 and 11,000 by 2050—both very large gains from low 2019 baseline employment.** These trends are driven by changes

[75] Our analysis accounts for the diversified structure of fueling stations: 31 percent of fueling stations in Massachusetts also have convenience stores onsite, and convenience store sales account for 39 percent of the revenues at these fueling stations. Our analysis also assumes that no fueling stations convert to electric vehicle charging stations.

[76] For example, maintenance costs for light duty battery electric vehicles are $0.14 per mile, compared to $0.17 per mile for conventional vehicles. These maintenance cost differences are due largely to the fact that electric motors and battery packs have lower maintenance requirements than conventional internal combustion engines and transmission systems. Maintenance costs for brakes are also nearly 50 percent lower for alternative vehicles due to the use of regenerative braking technology, which lowers the wear on brake pads and rotors.

in the EV Chargers sub-sector, as certain aspects of charger installation are classified as construction employment. Construction employment accounts for approximately 70% of net employment gains in both 2030 and 2050, while Induced employment accounts for approximately 25%, with Professional Services and Manufacturing employment constituting a minor portion of employment gains (Figure D.15).

Figure D.15. Net New Transportation Sector Employment by Industry From 2019 Baseline



Other non-employment benefits related to the Transportation sector are related to increased use of non-vehicular modes of transportation. Increased pedestrian and bicycling infrastructure, such as bike lanes and shared-use paths, is expected to increase utilization of these modes of transport, which in turn bring about numerous benefits. Increased physical activity associated with "active transport" (walking, bicycling, scootering, or other similar modes of transit) leads to improved health, with effects ranging from moderate health benefits to avoided premature death.[77] Investments in bicycle and pedestrian infrastructure also result in a higher total number of bicyclists or pedestrians, which confers a "safety in numbers" effect to the entire group. For example, the greater the number of cyclists using bicycle lanes, the safer each individual cyclist is. Investments in non-vehicular infrastructure may also include other safety improvements, further reducing the risks of pedestrian/bicycle transit compared to the baseline.[78] Increased pedestrian transit may lead to increased sales revenue and, via increased sales, increased property values for businesses located on or near pedestrian or bike paths.[79] Complementing these benefits related to local businesses, improvements to non-vehicular travel conditions can also help achieve social equity goals by providing increased mobility options for physically, economically, and

[77] Cambridge Systematics. "Transportation Investment Strategy Tool Documentation, 2021." December 2021. Pages 6-2. Accessed at https://www.georgetownclimate.org/files/report/GCC_Investment_Tool.pdf.
[78] Cambridge Systematics. "Transportation Investment Strategy Tool Documentation, 2021." Pages 6-1. Accessed at https://www.georgetownclimate.org/files/report/GCC_Investment_Tool.pdf.
[79] Boarnet et al. "The Economic Benefits of Vehicle Miles Traveled (VMT)-Reducing Placemaking: Synthesizing a New View." November 2017. Page 24. Accessed at https://escholarship.org/content/qt5gx55278/qt5gx55278_noSplash_4363a77ca3b382db16b06b54dae4996a.pdf?t=psmezd.

socially disadvantaged populations.[80] Increased participation in non-vehicular transit may also result in benefits to people who continue to use automobiles, as a reduction in vehicles on the road may lead to reduced traffic, congestion, and travel times, as well as general societal benefits from reduced roadway maintenance expenditures.[81] At an urban planning level, transportation planning that favors walking, cycling, and public transit tends to encourage more compact, mixed development, which has a number of associated economic, social, and environmental benefits, including economies of agglomeration (i.e., cost savings, increased market participants [both suppliers and customers], and network effects arising from denser development), improved community cohesion, and greenspace and habitat preservation, among others.[82]

INDUSTRIAL ENERGY EFFICIENCY[83]

There is also potential for energy efficiency improvements in the industrial sector, many of which involve the manufacture and installation of more efficient industrial equipment. The industrial sectors making these investments include, but are not limited to, computers and electronic product manufacturing, machinery manufacturing, and paper and allied product manufacturing. To the extent that new equipment is manufactured in Massachusetts, these activities will further contribute to Massachusetts' already strong energy efficiency workforce.[84] Estimated job impacts for the industrial sector are organized here into three sub-sectors: Electronics; Construction, Machinery and Transportation Equipment; and Other Materials Production.

With fewer than 100 job additions across the state in 2030 and 200 jobs by 2050, investments in the Industrial Energy Efficiency sector will create a small share of new employment in Massachusetts. Two-thirds of these additions are in the Other Materials Production sub-sector, driven by additions in fabricated metals production, which alone represents fewer than 100 job additions in 2030. Additions in the Electronics sub-sector are dominated by investments in the computer and electronic products production sector (Figure D.16). The job impacts for investments in Industrial Energy Efficiency are relatively low as compared with other sectors due to both the overall magnitude of the modeled investments and the nature of the spending, of which only a portion is met by in-state manufacturing of new equipment.

Figure D.16. New Industrial Energy Efficiency Sector Employment by Sub-sector

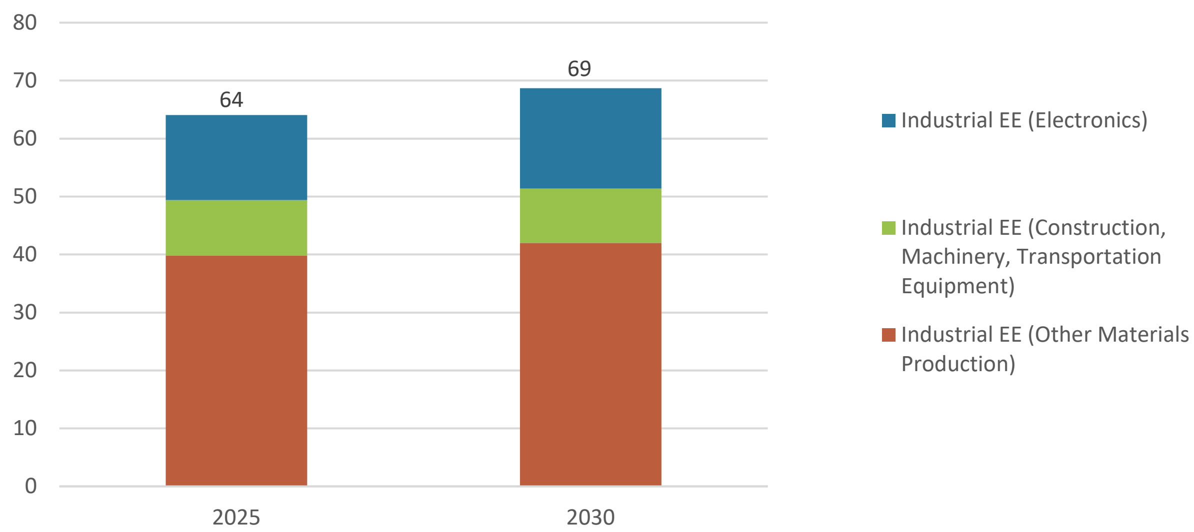
[80] Litman, Todd. "Evaluating Active Transport Benefits and Costs Guide to Valuing Walking and Cycling Improvements and Encouragement Programs." Victoria Transport Policy Institute. March 2022. Page 15. Accessed at https://www.vtpi.org/nmt-tdm.pdf.

[81] Litman, Todd. "Evaluating Active Transport Benefits and Costs Guide to Valuing Walking and Cycling Improvements and Encouragement Programs." Victoria Transport Policy Institute. March 2022. Pages 21, 25. Accessed at https://www.vtpi.org/nmt-tdm.pdf.

[82] Litman, Todd. "Evaluating Active Transport Benefits and Costs Guide to Valuing Walking and Cycling Improvements and Encouragement Programs." Victoria Transport Policy Institute. March 2022. Pages 30-31. Accessed at https://www.vtpi.org/nmt-tdm.pdf.

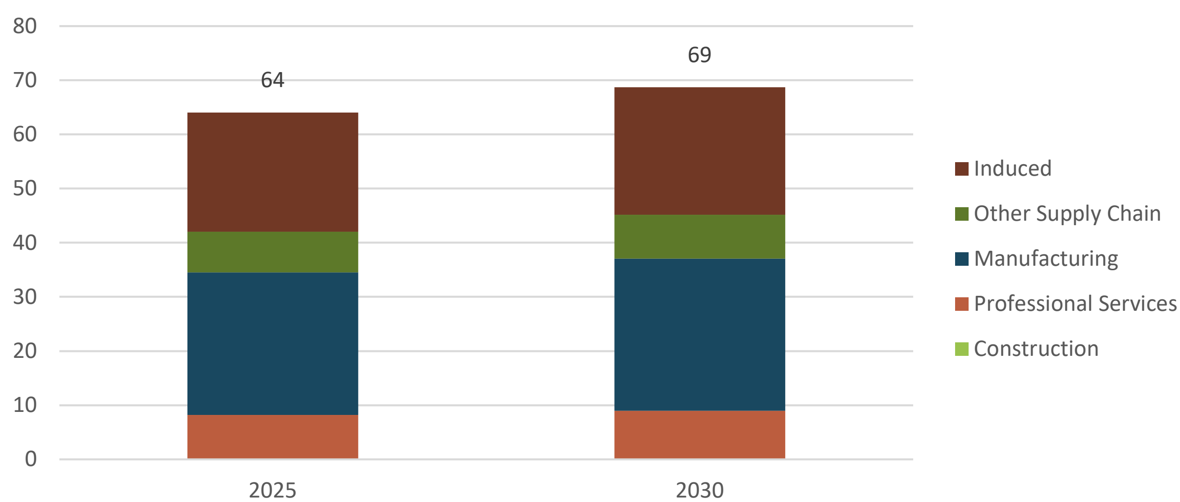
[83] Because there is little to no measurable Industrial energy efficiency employment currently in Massachusetts, the job additions equate to total employment in the sector.

[84] A difference of note is that these job impacts reflect gains in employed persons resulting from the new investments in industrial energy efficiency. These employment estimates do not account for the substantial existing employment in the industrial energy efficiency sector as of 2022.



Additions to the Industrial Energy Efficiency workforce are dominated by Manufacturing (40% in 2030) and Induced (35% in 2030) employment. Employment in Professional Services and Other Supply Chain making up the remaining 25% with a roughly even split (Figure D.17).

Figure D.17. Net New Industrial Energy Efficiency Sector Employment by Industry From 2019 Baseline



NATURAL AND WORKING LANDS

As a component of the 2025/2030 CECP, Massachusetts is proposing a suite of new policy proposals targeting the state's natural and working lands (NWL). These policies are designed around formal strategies to protect, manage, and restore NWL, as well as to incentivize the long-lived durable wood products market within Massachusetts and to explore additional carbon sequestration beyond the capability of the state's NWL. The proposals include new investments in land conservation grant programs and incentives, funding for climate-smart forestry practices, support for the expansion of the state's market for native timber products, and multiple new initiatives focused on tree retention and new tree planting. Together, these new initiatives represent a heightened level of support for the preservation and management of NWL in Massachusetts.

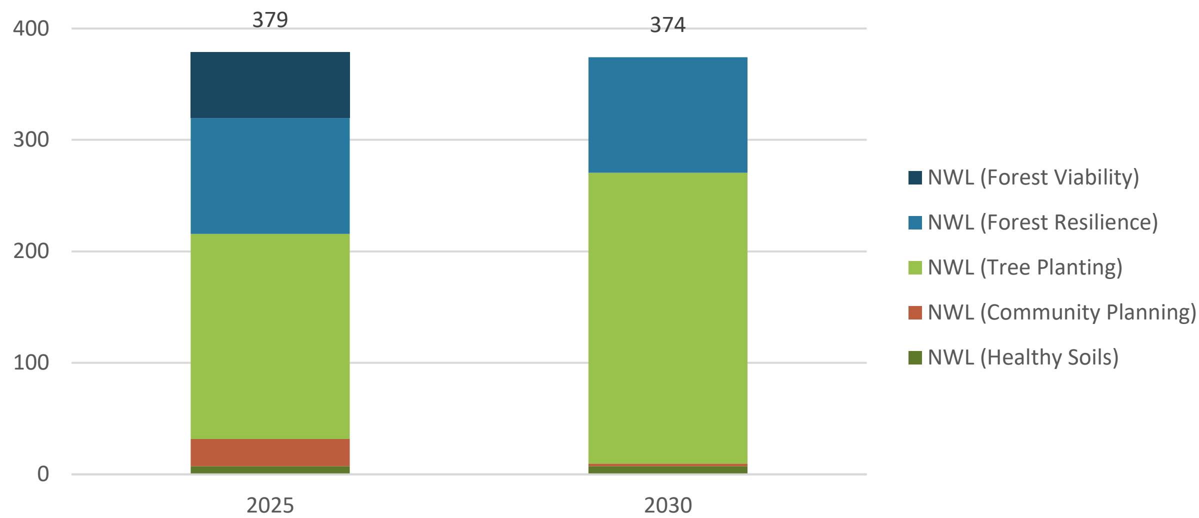
To assess the employment impacts associated with these new proposed investments in NWL, we employed a bottom-up approach focused on the details of each individual policy proposal. This differs from sector-wide employment impacts as modeled in other parts of this analysis.[85] The research team identified the proposals with substantial and measurable direct employment impacts and modeled future employment impacts based on anticipated spending levels. Results are segmented into five direct employment categories analogous to the sub-sector breakdowns for other sectors: Healthy Soils, Community Planning, Tree Planting, Forest Resilience, and Forest Viability.

Natural and Working Lands policies in the 2025/2030 CECP are projected to add nearly 400 jobs by 2030. Most of this employment growth is related to the Tree Planting category, accounting for roughly 300 jobs in 2030. These workers will largely support the implementation of new or expanded tree planting programs, including an expansion of the Greening the Gateway Cities program, a new riparian tree planting program, and tree planting award payments to communities passing Natural Resources Protection Zoning and tree protection bylaws. A share of new employment in Tree Planting also stems from new demand for trees from in-state nurseries. New employment associated with the Forest Resilience category makes up the second-largest share of new employment at 100 jobs in 2030, driven by demand for forest management activities on additional forest lands and the associated thinning and downstream processing of new timber harvests (Figure D.18). These two categories will generate $29.8 million in additional GSP in 2030, about equivalent to the economic contributions of Wineries in the state. The smaller categories of Forest Viability (assumed to be funded through 2027 for this analysis), Community Planning, and Healthy Soils represent additional employment gains that are highest in 2023, decreasing out to 2030.[86]

[85] A further difference of note is that these job impacts reflect gains in employed persons resulting from the new increases in funding for NWL programs. These employment estimates do not account for the substantial existing employment in the NWL sector as of 2022.

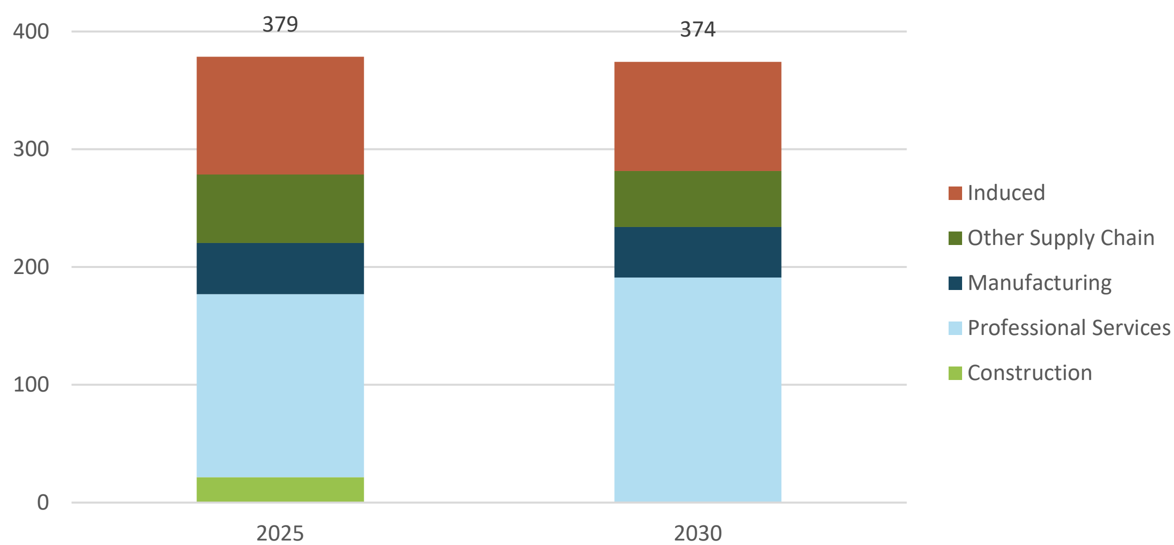
[86] The NWL policies' funding is proposed to continue through 2030 for this analysis, resulting in no employment impact estimates for 2050.

Figure D.18. Net New Natural and Working Lands Employment by Employment Category



From 2023 to 2030, most of employment associated with the new NWL policy proposals are in the Professional Services industry, which includes a wide range of NWL job types, including foresters, tree planters, landscapers, sawmill employees, and timber product manufacturers. Professional Services jobs are projected to account for more than half (51%) of NWL employment gains. Other Supply Chain, which includes wholesale trade and distribution of goods, accounts for 13% of additional employment, and Induced employment accounts for another 25% (Figure D.19).

Figure D.19. Net New NWL Sector Employment by Industry From 2019 Baseline



New investments in Massachusetts' NWL will result in a wide range of benefits extending beyond employment impacts. The substantial new land protections, conservation activities, tree planting, and wetland preservation stemming from these initiatives will positively influence a number of environmental and social factors, including the state's air quality, health and safety, urban heat islands and related energy costs, erosion control, and recreational opportunities. These benefits are assessed in greater detail in the Appendix D-6, which includes detailed benefits descriptions with supporting research, as well as a detailed charting of the overlapping pathways between policy strategies and outcomes, environmental changes, and social and environmental benefits. These connections highlight that there are a wide range of social environmental benefits affected by investments in NWL, with complex and interrelated pathways to realization. Many benefits also likely have additional impacts on the Massachusetts economy, such as improvements to health and safety and improved recreational opportunities on the state's lands. These potential additional economic impacts are in addition to the direct employment impacts estimated elsewhere in this analysis.

MUNICIPAL SOLID WASTE

Massachusetts' Solid Waste Master Plan aims to reduce waste disposal by 1.7 million tons annually by 2030, and 5.1 million tons annually by 2050; these goals represent a 30% reduction in waste disposal by 2030 and a 90% reduction in waste disposal by 2050. Increased organic waste composting represents the largest source of GHG reductions in the Master Plan, both because a large proportion of existing waste is compostable (in particular, food waste), and because an increasing proportion of waste that is not currently compostable may be compostable in the future in order to meet waste reduction goals. We therefore focused our analysis of employment impacts in the Waste sector specifically on organic waste composting.

We combined projected volumes of organic waste composted from the Master Plan with industry estimates on the number of employees per ton of material processed[87] to estimate employment levels directly from projected waste quantities. Because we examine only this single waste stream, the employment estimates presented for the Waste sector represent a lower-bound estimate of employment impacts in this sector.

Employment related to organic material composting is projected to experience substantial growth relative to 2019 levels, adding nearly 700 jobs by 2030 and 1,100 jobs by 2050—a growth of 200% and 320% from 2019 levels, respectively. Activities related to organic waste composting are expected to generate approximately $125 million in GSP in 2030, equivalent to the economic contribution of the Computer and Office Machine Repair and Maintenance industry. Employment related to organic waste composting is largely classified under the Professional Services industry, with some indirect employment in the Other Supply Chain industry. Given that we project Waste sector employment for only a single sub-sector, the proportion of employment by industry remains constant over the period, with approximately 60% of overall employment in the Professional Services industry, 10% in the Other Supply Chain industry, and 30% Induced employment across industries (Figure D.20 & Figure D.21).

Figure D.20. Waste Sector Employment by Industry

[87] Platt, Brenda; Bell, Bobby; and Harsh, Cameron. *Pay Dirt: Composting in Maryland to Reduce Waste, Create Jobs, & Protect the Bay*. Institute for Local Self-Reliance. May 2013. Accessed at https://ilsr.org/wp-content/uploads/2013/05/ILSR-Pay-Dirt-Report-05-11-13.pdf.

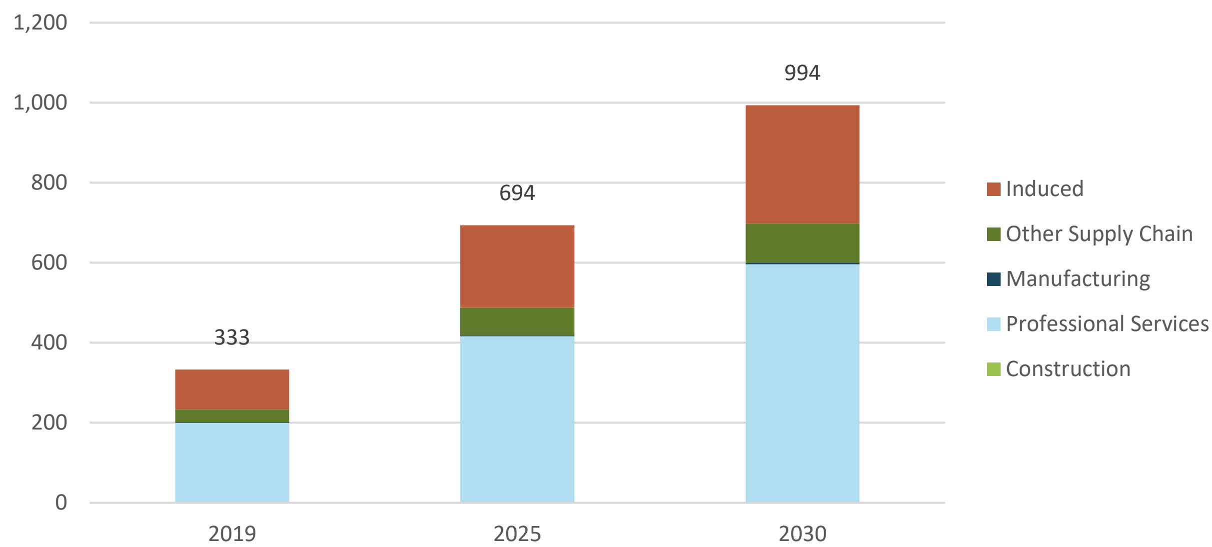
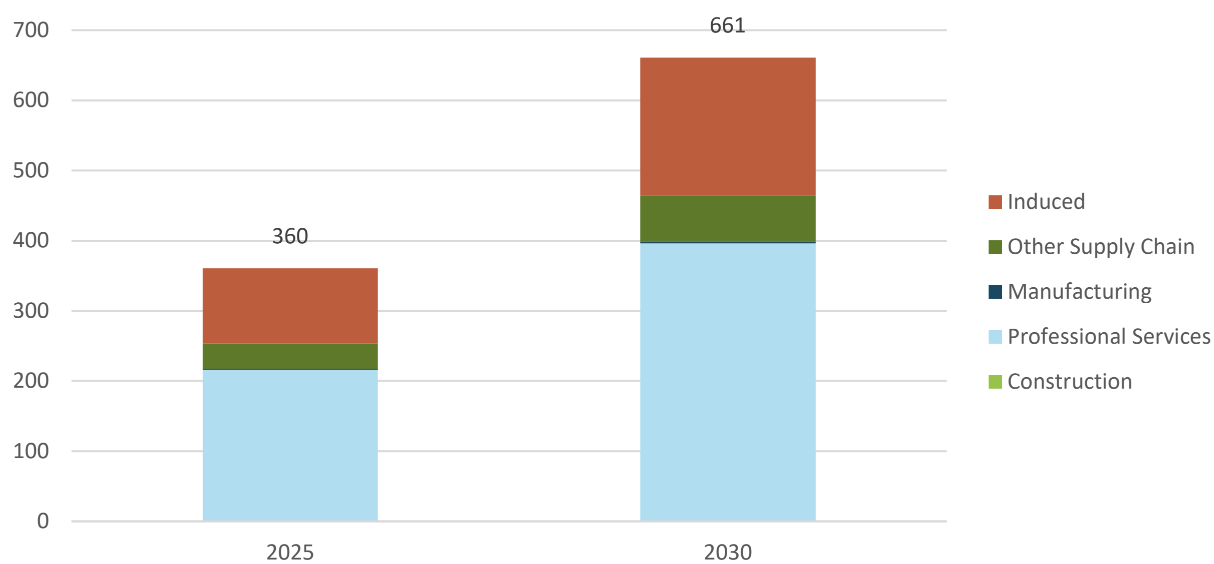


Figure D.21. Net New Waste Sector Employment by Industry From 2019 Baseline



In addition to employment impacts related to organic waste composting, implementation of the other disposal reduction strategies in the Master Plan may impact employment in the Waste sector. Based on the Master Plan's goals, it is likely that the Commonwealth will experience increased employment in recycling and other organics processing methods (anaerobic digestion and animal feed) and decreased employment related to disposal. However, there are uncertainties that render it difficult to reliably quantify these employment impacts.

A key point of uncertainty arises from the fact that Massachusetts' waste reduction goals are likely to be met by a combination of increased reuse and recycling and by source reduction (i.e., policies that reduce waste at the source). The employment impacts of disposal reduction (which is more labor-dependent) are likely more significant than for source reduction (which, in many cases, is much less labor-intensive). In addition, the network of industries and activities engaged in recycling—e.g., collectors, processors, wholesalers, and users—may differ greatly based on the material recycled. Employment impacts related to increased recycling are thus sensitive to the extent to which waste disposal goals will be met via source reduction or increased recycling, as well as the mixture of materials recycled. Without specific data for these parameters, modeling employment impacts would entail a high degree of uncertainty.

Separately, waste collection employment may remain relatively constant even with significant reductions in total waste quantities. More specifically, if municipalities continue curbside waste collection with the same frequency as a matter of public hygiene and convenience, collection-related employment may not decline significantly with reduced waste disposal.

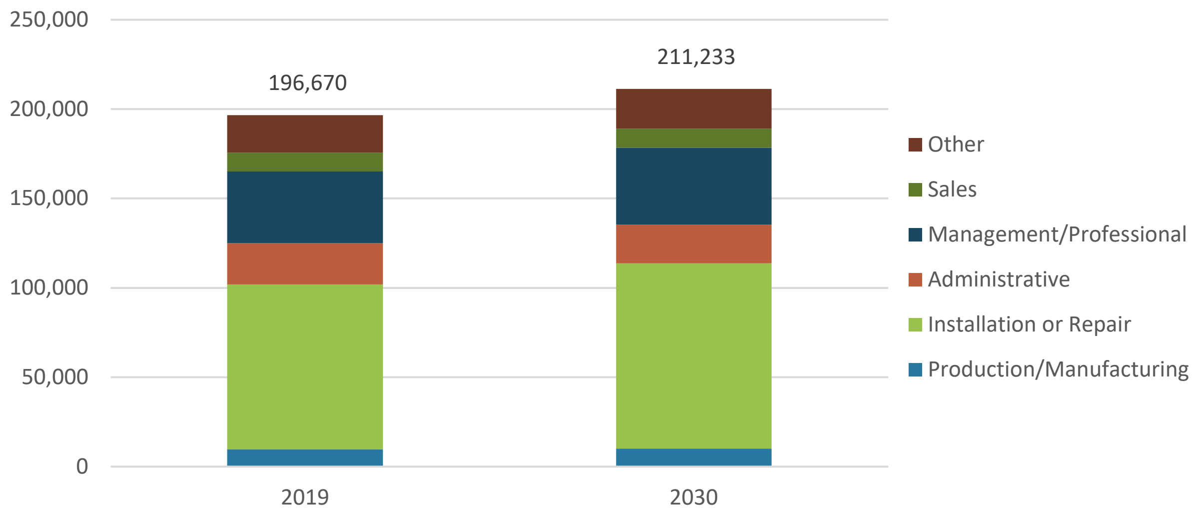
D.3 SECONDARY EMPLOYMENT OUTPUTS

Secondary Employment Outputs (SEOs)[88] provide an estimate of how jobs will change from 2019 to 2030 by occupation, wages, and geography across the Commonwealth of Massachusetts. SEOs highlight energy-related jobs only, and therefore do not include induced employment. SEOs also do not include employment from Natural and Working Lands, Industrial Energy Efficiency, or Municipal Solid Waste because the relatively small size of these industries prevents the research team from confidently estimating the composition of their workforce. This means total employment numbers will differ between IEOs and SEOs.

Installation and Repair roles are projected to account for about half (49%) of all energy-related jobs in Massachusetts by 2030 and account for 82% of all net energy-related jobs created between 2019 and 2030. It is notable that 96% of current Installation and Repair jobs around the Commonwealth are held by men, suggesting that intentional efforts to diversify these occupations will be essential in ensuring that the job opportunities created are accessible to all. Management and Professional roles (20%), and Other[89] (11%), Administrative (10%) roles also account for a substantial portion of the energy-related occupations by 2030 (Figure D.22). Administrative positions are projected to shed 7% of their jobs, which is driven by employment losses in declining industries (such as gas stations and fossil fuel electricity generation).

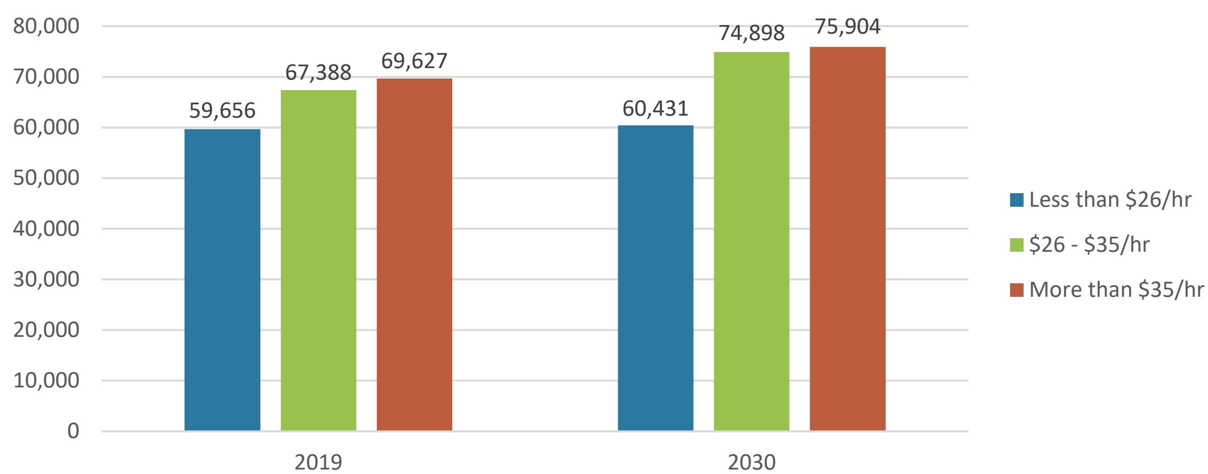
[88] The SEOs include the direct and indirect employment from the IEOs, but do not include induced employment from the IEOs.
[89] “Other” serves as a catch-all category but is primarily composed of transportation and logistics occupations.

Figure D.22. Energy-Related Occupations by Occupation



Nearly all (96%) of the jobs created through decarbonization activities have wages of $26 per hour or more, which is above the state's living wage[90] and close to the statewide median hourly wage ($28 per hour). Many of these jobs offer even higher compensation; 45% of the jobs created between 2019 and 2030 will offer hourly wages that exceed $35 per hour (Figure D.23), which is roughly equivalent to the living wage for a family of three with one parent working. This means that the job opportunities created through decarbonization activities will create a range of great-paying opportunities for Massachusetts residents.

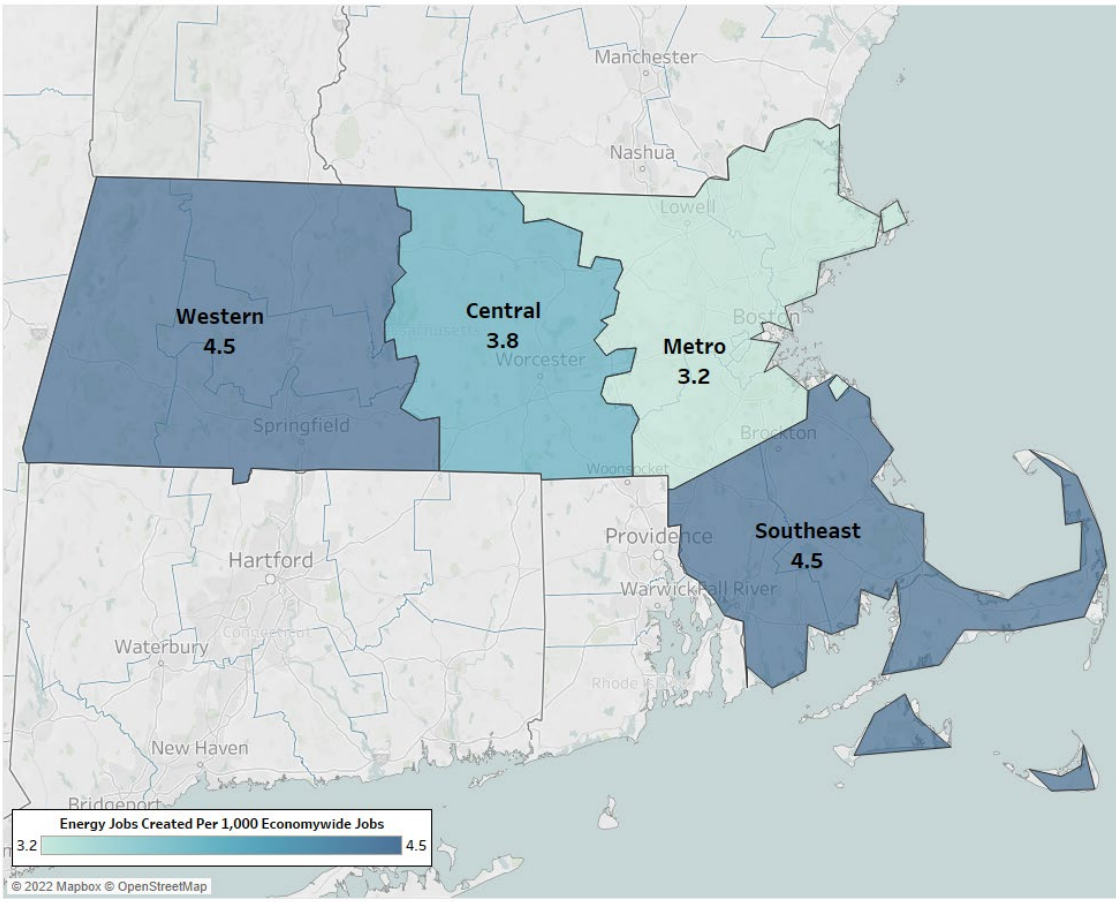
Figure D.23. Employment by Wage Category



[90] Living wages account for regional differences in the cost of goods and services. This makes living wages a better indicator of economic wellbeing than the poverty line, which is set at a nationwide level. The living wage, as calculated by MIT's Living Wage Calculator, in Massachusetts is about $20 per hour for a single person with no dependents.

Western and Southeastern Massachusetts will see the greatest number of energy-related jobs created for every 1,000 economy-wide jobs, and every region of the state will see at least three energy-related jobs created for every 1,000 economywide jobs. Western and Southeast Massachusetts are projected to see 4.5 new energy-related jobs created by 2030 for every current 1,000 economywide jobs. This means that opportunities will be available to Massachusetts residents throughout the state (Figure D.24).

Figure D.24. Energy-Related Jobs Created For Every 1,000 Economy-Wide Jobs[91]



D.4 HOUSEHOLD IMPACTS

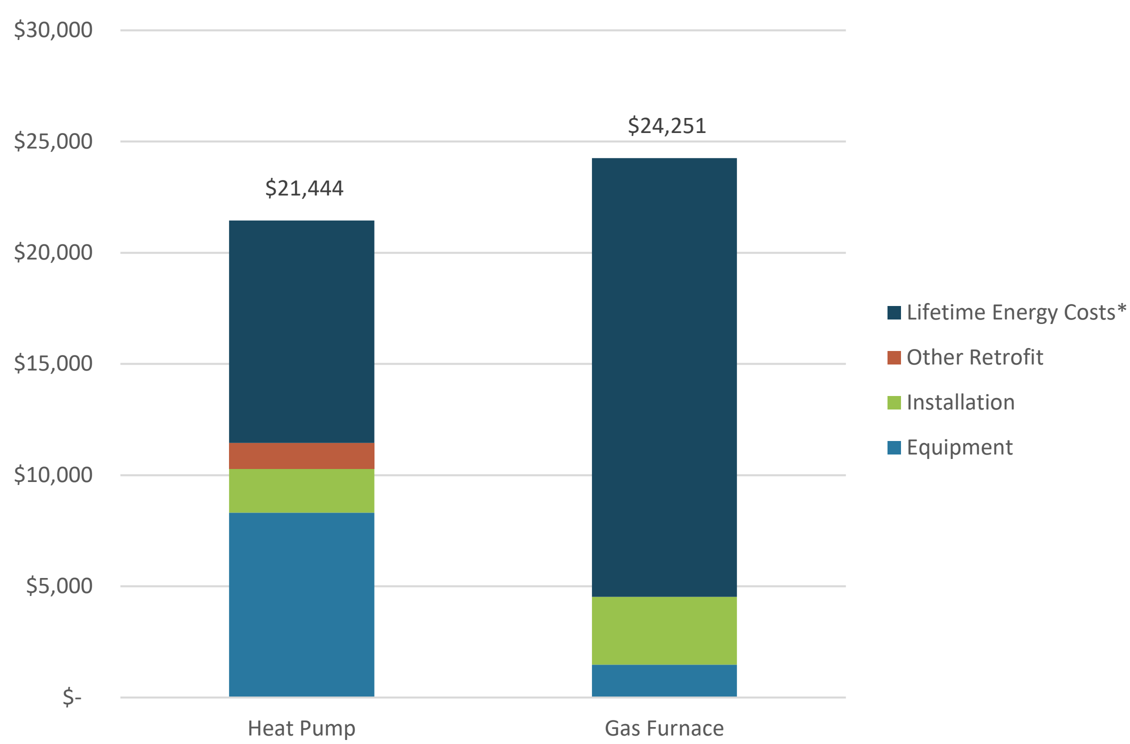
Alongside understanding the macroeconomic and employment impacts resulting from decarbonization activities in Massachusetts, it is important to examine how households and household budgets are likely to be impacted. Understanding the household-level dynamics can help policymakers better design policies to mitigate any negative or unintended impacts that may arise from the decarbonization

[91] Western MA includes Berkshire, Franklin, Hampshire, and Hampden Counties. Central MA includes Worcester County. Southwest MA includes Bristol, Plymouth, Barnstable, Dukes, and Nantucket Counties. The Metro area includes Norfolk, Suffolk, Middlesex, and Essex Counties.

transition. The research team modeled the change in energy use and costs among households to determine the net impact on households by geography,[92] income, and among environmental justice (EJ) communities. This analysis includes households' expenditures on electricity, gasoline, natural gas, and other heating fuels such as propane.[93] For a more detailed methodology, please see Appendix D-1.

Ultimately, households that embrace more electrification and energy efficiency activities will see greater declines in energy expenditures while households that undertake little or no electrification or energy efficiency measures will see no cost reductions in their energy expenditures. For example, a household that installs a whole home heat pump system in 2025 will see a lifetime savings of $2,800, or about 12% of the lifetime cost, compared to a household that installs a new gas furnace instead (Figure D.25).

Figure D.25. Estimated Lifetime Costs of Heat Pump vs Gas Furnace[94]



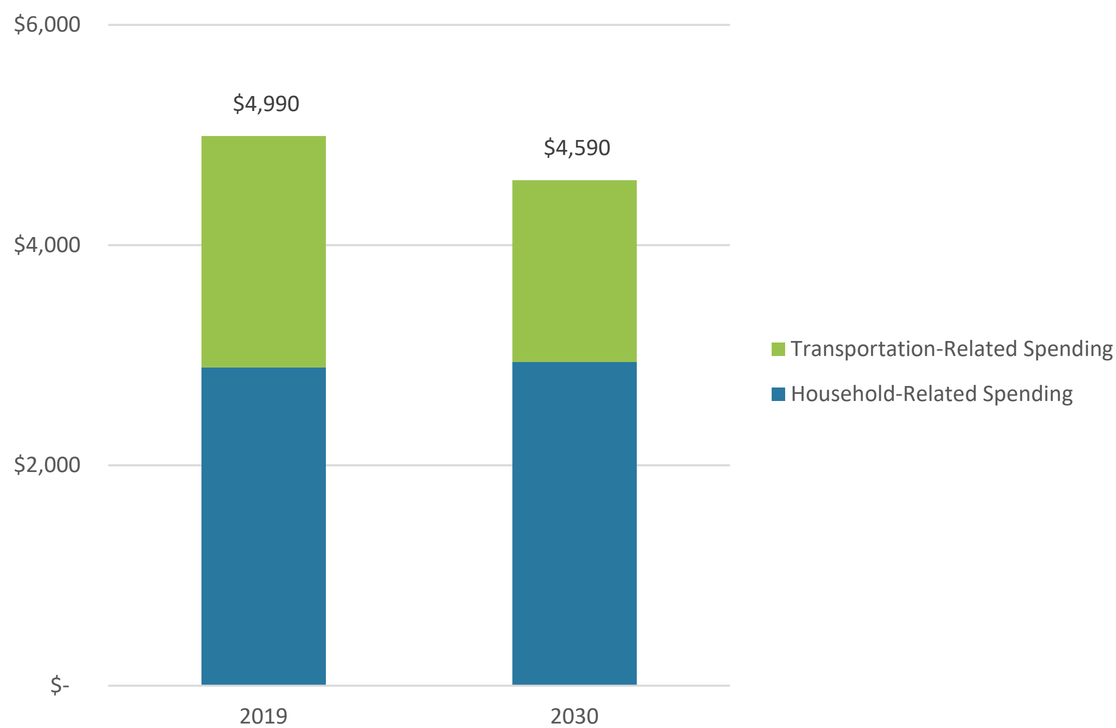
**Assumes a 4% Discount Rate and 20 Year Equipment Lifespan*

92 This includes the 26 regions developed by EEA. These regions are defined at the Census Block Group level.
93 This estimation incorporates projected change in the price of electricity and natural gas, though the prices of gasoline and Liquid Propane Gas (LPG) and other heating fuels are assumed constant. Electricity prices are projected to decline by nearly 3% by 2030 while natural gas prices are projected to increase by 23% by 2030 from 2019 levels. Electricity and natural gas prices are forecasted because they will make up a majority—and eventually nearly all—of energy expenditures in coming years.
94 Calculations using EER projections.

To conduct the regional analysis, the research team linked geographic-specific changes in energy demand to demographic data at the census block group level. The figures below estimate the household impacts on average, which includes a range of households that fully undertake electrification and efficiency measures, those that do not undertake any of these measures, and households in between.

The increased adoption of electrified transportation and household efficiency systems mean that the average Massachusetts household will spend less money on energy every year. Average overall household energy expenditures, which include transportation-related energy, are projected to decline 8% by 2030 relative to 2019 levels, for an average household savings of $400 per year.[95] Decreases in Transportation-related expenditures are the primary driver of energy expenditure savings, while household-related energy expenditures remain relatively flat between 2019 and 2030 (Figure D.26). As noted previously, households that electrify and improve efficiency will see even greater savings, while households that pursue none of these changes will see no cost savings.

Figure D.26. Change In Household and Transportation-Related Energy Expenditure (2019-2030)

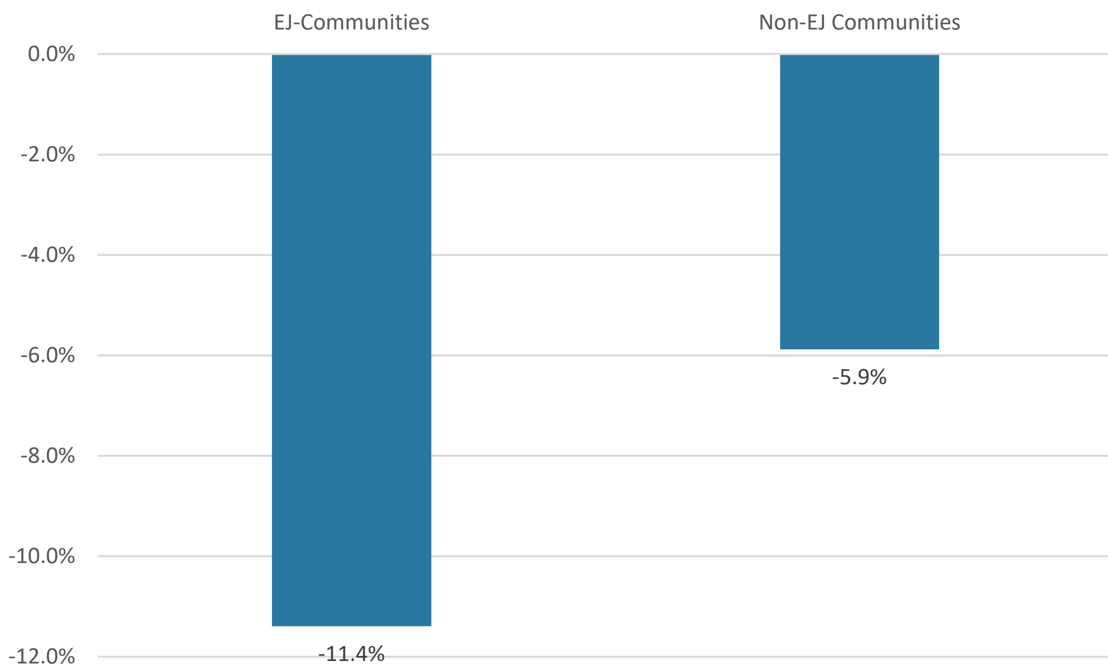


Historically disenfranchised populations are projected to see equal or greater household savings than the overall population, though additional policy safeguards can guarantee that these communities are not disadvantaged by these decarbonization policies. Households in EJ[96] designated census block

[95] These values are in 2019 real dollars and do not account for inflation.
[96] Environmental Justice Populations meet one or more of the following criteria: A) the annual median household income is not more than 65 per cent of the statewide annual median household income; B) minorities comprise 40 per cent or more of the population; C) 25 per cent or more of households lack English language proficiency; or D) minorities comprise 25 per cent or more of the population and the annual median household income of the

groups are estimated to see greater savings (11% decreases in expenditures) than households in non-EJ communities (-6%) (Figure D.27). Some of the driving forces in these outcomes are geographic and demographic; EJ-Communities are more often found in regions with higher levels of multifamily housing and less likely to have and maintain legacy heating systems that are reliant on expensive heating gases.

Figure D.27. Change in Average Household Energy Expenditures (2019-2030)



Changes in the proportion of household income spent on energy fluctuate little across different household incomes, though we recognize that lower income households are less likely to be able to afford the initial expenditures required to electrify and generate savings down the road. To further ensure that lower-income households—which spend a greater share of their household income on energy—are not disproportionately impacted, Massachusetts could consider expanding policies that charge higher rates for the highest energy-use consumers. Another potential option could be the creation of an electrification tax credit that is available to households below a certain income threshold.

municipality in which the neighborhood is located does not exceed 150 per cent of the statewide annual median household income. For more information, please see https://www.mass.gov/info-details/environmental-justice-populations-in-massachusetts.

CHAPTER APPENDIX D-1: MODEL INPUTS AND DATA SOURCES

OVERVIEW

The methodology for this study was continually revised and refined throughout the project work period. At its foundation, the methodology was developed from three pillars:

1. **The literature review**: To develop the methodologies for modeling the various specialized sectors that comprise the bulk of activities driven by the decarbonization pathways, the research team examined comparable research and models to gain a comprehensive view of the different approaches to modeling employment scenarios in response to lowering greenhouse gas emissions and mitigating climate change.

2. **The combined experience of the BW Research contractor team**: The literature review demonstrated that a large proportion of the work done on modeling employment under different climate change mitigation scenarios has been done by members of BW Research Partnership and Industrial Economics, incorporated. The contractor team has conducted several of these previous research projects together, and worked collaboratively to share their experience and refine the final project methodology.

3. **The direction provided by EEA and Massachusetts Clean Energy Center (MassCEC) Staff**: Because of the nuances involved in modeling a variety of new and changing technologies, the research team worked with EEA and MassCEC staff to develop a robust methodology and devise objective assumptions.

These pillars produced a project methodology that is responsive to the nuances of each sector and sub-sector.

SUMMARY OF INPUT-OUTPUT MODELS

Input-output (I/O) modeling is used to generate employment estimates based on different investments or changes in a given economy over time. The research team used two different I/O models, **IMPLAN** and the National Renewable Energy Laboratory's (NREL) **JEDI** (Jobs and Economic Development Impact) model software for this purpose. Input-output models illustrate the interdependent relationships between different sectors of a region's economy. Investments or activities in a given sector are used as inputs into the model to estimate the ripple or multiplier effect on business, household, and government expenditures and industry employment.

Figure D.28. Explanation of Direct, Indirect, and Induced Effects in the IMPLAN model

IMPLAN is not an energy-specific industry analysis, but instead is focused on the overall employment impacts that would be felt across a given economic region (Figure D.28). NREL provides JEDI models for various energy sub-sectors, including onshore and offshore wind, biomass, and hydropower. JEDI estimates job creation by running user input of project location facility size, and year of construction, in combination with the built-in model defaults and economic multipliers. JEDI is used in the electricity and fuels sectors as a technical data source to split investments into industries and to generate initial employment outputs for both onshore and offshore wind electricity sub-sectors.

INITIAL EMPLOYMENT OUTPUT METHODOLOGY

The initial employment outputs (IEO) generated for this analysis follow the same general methodological approach across the six primary sectors, with the most relevant tools and data sources based on what is appropriate for each sub-sector. Assumptions made within specific sub-sectors vary due to the nature of the different activities, however the general structure remains consistent.

The IEO's are meant to produce the quantity of jobs that change over time for each of the sectors and sub-sectors. The IEO's were generated for 2019 (Baseline year[97]) for 2025, 2030, 2035, 2040, 2045, and 2050.

The IEO methodology follows the six steps below.

1. Initially, the research team determines the unit inputs for the model. Unit inputs typically come from the forecasts developed with EER data and take the form of device stocks and sales, electricity capacity (MW), and fuel demand.
2. Next, the research team determines the unit and total investments. Investment inputs come from the forecasts developed with EER data where provided, and any additional investments are assumed from secondary sources that have been noted.
3. Next, the research team processes the investment data to levelized inputs that reduce inter-annual variation as needed.
4. Next, the research team allocates the processed investment data into the relevant industry categories based on the activities associated with the investments by using technical cost data from secondary sources.
5. Next, the research team applies IMPLAN/JEDI industry employment multipliers based on the allocation described in step 4 to calculate employment outputs.
6. Finally, employment outputs are reported by industry category (Construction, Professional Services, Manufacturing, Other Supply Chain, and Induced). The 2019 baseline employment is derived from the 2019 Massachusetts Clean Energy Industry Report (MACEIR) unless otherwise stated.

SECTOR SPECIFIC ASSUMPTIONS & SOURCES

The following assumptions and data sources were used in the modeling of each of the primary sectors, electricity, fuels, buildings, and transportation.

Electricity

The electricity growth sub-sectors—solar, hydropower, hydrogen, biomass, distribution, transmission, and storage—use investment data derived from the forecasts developed by EER.

Solar PV & Storage

Solar PV and storage use technical cost data from NREL's U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020 to split investment data into industry inputs.

- Storage uses the 60MW, 2hr standalone Li-ion model.
- Distributed solar CAPEX investments are input into data derived from a weighted average of the 7kW mixed residential model and the 0.2MW commercial ground mount model, and operations and maintenance (O&M) investments are input into data derived from the weighted average of the residential and commercial ground mount models.

[97] 2019 was determined to be the baseline, rather than 2020, because the employment numbers would not be impacted by the pandemic.

- Utility solar CAPEX investments are input into data derived from the single axis tracker 100MW model, and O&M investments are input into data derived from the tracking model.

Hydrogen

Hydrogen investments include hydrogen fuel cell investments, hydrogen combustion investments, and investments in hydrogen-compatible combustion systems originally running on natural gas.

Transmission & Distribution

Baseline employment in Massachusetts combined electric transmission & distribution from the 2019 MACEIR is split into employment in both electric transmission and electric distribution using the proportion of 2019 employment in NAICS 221121 – Electric Bulk Power Transmission and Control and NAICS 221122 – Electric Power Distribution within NAICS 221120 – Electric Power Transmission, Control, and Distribution. Upstream delivery investments from EER are then used as input into the transmission sector model, while downstream delivery investments are used as input in the distribution model.

Offshore & Onshore Wind

The research team contracted with Xodus Group, a global energy consultancy that had previously conducted an offshore wind supply chain study for Massachusetts, to develop four separate local content assumptions. These four scenarios are 1) a “do-nothing” scenario where the state develops no further investment or initiatives to attract offshore wind manufacturers, 2) a “business as usual” scenario that assumes the state is able to secure a few of the most likely and economical opportunities for local content creation; 3) an optimistic but realistic scenario which requires extensive involvement from the state in attracting suppliers and manufacturers; and 4) a “moonshot” scenario that would result in several original equipment manufacturers (OEMs) or larger suppliers entering the state. These scenarios were reviewed by Massachusetts Clean Energy Center experts in the state’s offshore wind efforts. Offshore wind scenarios also involved $100 million in planned port infrastructure investments as announced by Governor Baker in Summer 2021.

Offshore wind outputs are generated using NREL’s JEDI Offshore Wind Model Rel. 2021-1, using installed capacity from the forecasts developed by EER as input. The 2019 baseline employment for offshore wind is derived from the MACEIR developed by BW Research.

Onshore wind outputs are generated using NREL’s JEDI Land Based Wind Model Beta rel. W10.30.20, using installed capacity from the forecasts developed by EER as input.

Electricity Displacement

The electricity displaced sub-sectors—natural gas generation, and other fossil generation—use scaled 2019 baseline utilities employment as input into IMPLAN multipliers. The 2019 baseline utilities employment from the 2019 MACEIR is scaled by capacity retirements as detailed in the forecasts developed by EER data. This scaled employment serves as the direct input into the IMPLAN model to generate the supply chain and induced impacts.

Fuels

Fuels Growth

The fuels growth sub-sectors, hydrogen, and bioenergy, use investment data derived from the forecasts developed by EER. Industry allocation of investments for bioenergy fuels are derived from the NREL JEDI Biorefinery Sugars to Hydrocarbon Model rel. SH1.13.17.

Fuels Displacement

The fuels displacement sub-sectors, natural gas and petroleum fuels, scale 2019 baseline MACEIR data in natural gas fuels and petroleum fuels based on declining fuel investments from the forecasts developed by EER. The baseline 2019 employment in natural gas distribution, not detailed in the 2019 MACIER, is extrapolated from employment in NAICS 221210—Natural Gas Distribution. The 2019 baseline natural gas distribution employment is scaled by the change in residential buildings with natural gas connections provided by the forecasts developed by EER.

Buildings

The buildings sub-sectors use investment data derived from the forecasts developed by EER. Buildings sector data was also calibrated by an analysis of data on Massachusetts's building electrification activities.

Commercial & Residential HVAC

Commercial and residential HVAC sub-sector industry spending patterns are adjusted based on Building Energy and Environmental Modeling (BEEM) and Integration Analysis data, allocating supply chain expenditures to the following commodities:

- Air conditioning, refrigeration, and warm air heating equipment;
- Sheet metal;
- Fabricated pipes and pipe fittings; and
- Power boilers and heat exchangers.

Commercial & Residential Buildings Envelope

Commercial and Residential Buildings Envelope sub-sector industry spending patterns are adjusted based on BEEM and Integration Analysis data, allocating supply chain expenditures to the following commodities:

- Paints and coatings;
- Mineral wool (insulation);
- Metal windows and doors; and
- Wood windows and doors.

Commercial & Residential Other

Commercial and residential other sub-sector industry spending patterns are adjusted based on BEEM and Integration Analysis data for, allocating supply chain expenditures to the following commodities:

- Household laundry equipment;
- Household refrigerators and home freezers;

- Lighting fixtures;
- Heating equipment (except warm air furnaces);
- Other major household appliances;
- Household cooking appliances; and
- Air conditioning, refrigeration, and warm air heating equipment.

Transportation

Vehicle Manufacturing

To estimate employment for the vehicle manufacturing sub-sector, the research team scales baseline 2019 employment (as reported by the U.S. Census Bureau) by projected vehicle sales data provided by the forecasts developed by EER. This approach assumes that vehicle manufacturing employment grows or declines proportionally with sales of the vehicle types served by each manufacturing sector. In applying this approach, the research team distinguishes between vehicle manufacturing related to conventional vehicles, manufacturing related to alternative vehicles, and vehicle manufacturing that is common to both conventional and alternative vehicles. In addition, the research team distinguishes between employment related to vehicles sold in the Massachusetts market and employment related to vehicles sold outside the Massachusetts market. The research team assumes that the former scales with Massachusetts vehicle sales and that the latter remains constant over time.

Vehicle Maintenance

The research team's assessment of employment related to vehicle maintenance reflects differences between the maintenance requirements of alternative vehicles and the maintenance requirements for conventional vehicles. Information on maintenance costs per mile by vehicle type and component category (e.g., engine, braking system, transmission, etc.) were obtained from the California Air Resources Board (CARB) and research published at the International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium. The research team calculates total maintenance costs using estimated maintenance costs per mile and projected vehicle miles traveled by vehicle type from the forecasts developed by EER. Next, the research team adjusts the 2019 baseline employment (obtained from the U.S. Census Bureau) by changes in total maintenance expenditures over time to reflect changing needs for maintenance labor.

Wholesale Trade Parts

The research team estimates changes in employment related to wholesale trade for vehicle parts based on projected changes in the vehicle stock over time. As a starting point for the analysis, the research team obtained 2019 baseline employment data from the U.S. Census Bureau. The research team also distinguishes between wholesale employment serving the Massachusetts market and employment serving other markets. To project changes in employment over time, the research team scales wholesale employment serving the Massachusetts market based on projected changes in Massachusetts' vehicle stocks over time, as obtained from the forecasts developed by EER. The research team assumes no change in employment serving non-Massachusetts market and assumes the same employment requirements across vehicle technologies.

Fueling Stations

The research team estimates changes in fueling station employment based on projected changes in fossil fuel and biofuel consumption over time. As an initial step, the research team estimates 2019 baseline employment at fueling stations using U.S. Census Bureau data. These data report employment separately for fueling stations with and without convenience stores. For fueling stations with convenience stores, the research team estimates that 61% of revenues are related to fuel sales, based on research from the National Association of Convenience Stores. For this segment of the fueling station market, the research team assumes that baseline employment scales proportionately with projected changes in fossil fuel and biofuel consumption over time, based on fuel consumption projections developed by EER. The other 39 % of employment for these fueling stations is assumed to remain unchanged over time. For fueling stations without convenience stores, the research team scales all baseline employment with projected changes in fossil fuel and biofuel consumption over time. The research team assumes no gas stations transition to charging stations, which yields a high-end estimate of potential job reductions; to the extent that fueling stations are able to convert to electric charging stations, a portion of the projected employment losses may be mitigated. Additionally, this analysis scales employment proportionally with fuel consumption, without consideration of the need for a threshold level of fueling stations to support fossil fuel vehicles. In reality, fueling stations may experience employment losses at a different rate than decreases in fuel consumption—e.g., at a lower rate in the initial years in order to provide continued support to fossil fuel vehicles, and at a greater rate after a critical threshold of transition to electric vehicles.

Electric Vehicle EV Chargers

For the electric vehicle charger sub-sector, the research team projects growth in employment to meet increased demand for chargers by type. This includes manufacturing, installation labor, and maintenance (in-state manufacturing of installation materials is minimal and therefore excluded). Total charger investments across alternative fuel types are derived from the forecasts developed by EER and are broken out into hardware, installation materials, and installation labor investments following data collected by the International Council on Clean Transportation. Expected maintenance hours per year per charger are derived from the European Association of Electrical Contractors (AIE/EuropeOn). The research team assumes medium-duty and heavy-duty vehicles exclusively use DC fast chargers, the share of light-duty vehicles using DC fast chargers remains constant (9.5% DC fast, 90.5% Level 2), 100% of maintenance and installation labor is in-state, and in-state charger hardware manufacturing increases from 0% in 2019 to 10% in 2050 (i.e., in 2019, all employment related to charger hardware manufacturing is outside Massachusetts, while by 2050, 10% of employment related to charger hardware manufacturing occurs in the Commonwealth).

Industrial Energy Efficiency

To estimate employment investments in industrial energy efficiency, the research team applied forecasted investment in each industrial sector as provided by EER to employment impact multipliers associated with the equipment demands of each industrial sector. In the cases where multiple IMPLAN employment sectors correspond to the given industrial sector, the research team relied on an average employment multiplier weighted by each sector's total economic output in Massachusetts. We then use regional production coefficients from IMPLAN to determine the share of resulting employment that will take place within Massachusetts. Results for industrial energy efficiency investments are then grouped into sub-sectors according to similar industries.

Natural and Working Lands

To estimate employment impacts associated with new NWL policy proposals under the 2025/2030 CECP, the research team employed a bottom-up analytic approach, assessing each policy proposal's potential employment impacts individually. This method differs from the estimation of employment impacts from modeled sector-wide spending employed elsewhere in this analysis. The research team first worked with EEA staff and other state personnel to identify the policy proposals with substantial and measurable employment impacts. Proposals not resulting in specific changes in NWL management practices (and associated employment impacts) include those focused on changes in land protection status or imposing additional requirements on development projects. Employment under policy proposals that are expected to result in job impacts is grouped into the following direct employment categories, which are analogous to the subsectors considered elsewhere in this analysis: Tree Planting, Community Planning, Forest Resilience, Forest Viability, and Healthy Soils. The following sections describe assumptions and methods specific to each category.

Tree Planting

To estimate employment associated with new spending on Tree Planting, the research team leveraged information provided by state employees managing existing tree planting programs (such as the Greening the Gateway Cities program) to identify the share of new spending that would be spent on labor, trees, and materials. The research team assumes all new labor requirements are met in-state, while the share of new trees and materials met by in-state supply is informed by regional production coefficients derived from IMPLAN. Direct tree planting labor is calculated as new spending on labor divided by the average cost per seasonal employee. Labor associated with tree supply is calculated as the effect from additional in-state output, while materials supply for tree planting is captured under the indirect labor impacts calculated using IMPLAN multipliers (i.e., upstream from workers planting trees).

Community Planning

The research team's assessment of employment related to Community Planning includes impacts following new spending on planning for new bylaw or zoning changes, or contracted studies on topics including sites for new solar installations. This spending is modeled as increased sectoral output, with new employment impacts derived using the IMPLAN multipliers.

Forest Resilience

The Forest Resilience category includes employment impacts stemming from the Forest Resilience Program, expected to be piloted between 2023 and 2028, and the Chapter 61C incentive program for climate smart forest management, expected to start in 2028 as an extension of the Forest Resilience Program. The research team assumes that the total output of new climate-smart forestry practices will be double expected spending on incentives to landowners, with the difference made up by landowner revenues from new timber harvesting. Employment impacts include those from the new forest management practices, the new timber harvests, and downstream processing of newly harvested timber. New low carbon forestry practices and new timber harvesting activities are modeled as additional sectoral output, with new employment impacts derived using IMPLAN multipliers. The relative magnitude of downstream timber processing labor impacts is derived from labor impacts research by Sorenson et al. [98] and 2019 timber harvest data for the northeastern U.S. from the U.S. Department of Agriculture (USDA). The research team excludes indirect or upstream supply chain impacts for timber harvesting labor impacts to avoid double counting impacts already captured in the timber harvest calculations.

Forest Viability

The Forest Viability direct employment category includes several new spending categories, the largest of which is new grants to forest product businesses, followed by new funding for wood product marketing, young professional support, and native timber construction pilot projects. The research team assumes these business grants correspond to increased sectoral output, with new employment impacts derived using the IMPLAN multipliers. Increased sectoral output is, in some cases, an imperfect representation of how the Forest Viability grants will be spent, but without more detailed information (e.g., specifications for how grant recipients must spend their awards, such as on new equipment or lowering product costs), it is a reasonable approximation given the relatively low overall level of spending. EEA and DCR indicated that 60% of the business grants would go toward the cross-laminated timber market in Massachusetts. The research team distributed the remaining 40% of new business grants spending according to data from Vermont's Working Lands Enterprise Fund, a grant program that the Massachusetts Forest Viability program is modeled after.

Healthy Soils

The research team's assessment of employment related to Healthy Soils follows new incentives for landowners to adopt sustainable practices for healthy soils management (e.g., no or low tillage, cover crop). Unlike the incentives for the Forest Resilience category, the research team assumes that the level of increased industry output for Healthy Soils is equal to the level of the incentives provided. This spending is modeled as increased sectoral output, with new employment impacts derived using the IMPLAN multipliers.

Municipal Solid Waste

Our analysis of impacts to the waste management sector focuses on the disposal reduction goals presented in the Massachusetts 2030 Solid Waste Master Plan (SWMP) issued by MassDEP in October 2021. In the SWMP, MassDEP set a goal of reducing annual disposal from a 2018 baseline of 5.7 million tons to 4.0 million tons by 2030. Additionally, MassDEP set a goal to reduce annual disposal to 570,000 tons by 2050, a 90% reduction from the 2018 baseline.[99]

[98] Colin B. Sorenson, Charles E. Keegan, III, Todd A. Morgan, Chelsea P. McIver, Michael J. Niccolucci, Employment and Wage Impacts of Timber Harvesting and Processing in the United States, *Journal of Forestry*, Volume 114, Issue 4, 1 July 2016, Pages 474–482, https://doi.org/10.5849/jof.14-082.

[99] MassDEP 2021. "Massachusetts 2030 Solid Waste Master Plan: Working Together Toward Zero Waste." https://www.mass.gov/doc/2030-solid-waste-master-plan-working-together-toward-zero-waste/download. See page 8.

MassDEP proposed a mixture of waste diversion and source reduction to achieve these disposal reduction goals. In particular, the SWMP focuses on diversion of food waste and other organic materials to non-disposal waste management methods, and source reduction of materials that are difficult to divert. The Plan includes an analysis of disposal tonnage by type of material, including actual disposal in 2018 and projected disposal in 2030, consistent with the total disposal reduction goal.

One of the most GHG-reducing disposal reduction strategies is the diversion of organic materials from disposal to composting. We therefore focus our analysis on the labor force impacts that will result from the increased tonnage of waste that will be composted by 2030 and 2050.

To assess changes in employment resulting from the diversion of waste from disposal to composting, we estimate employment from composting in each year as a function of the tonnage of waste that is composted.

First, we estimate the tonnage of waste that will be composted in 2030 and 2050. As a starting point for these projections, we use the estimated tonnage of waste composted in 2019 from the Massachusetts Materials Management Capacity Study.[100] Next, we assume that the 2030 and 2050 reduction in disposal of organic materials outlined in the SWMP, relative to 2019, will result entirely from the diversion of that material to other management methods (composting, anaerobic digestion, and waste-to-animal feed), rather than source reduction.[101] We assume that 79% of the organic waste not disposed of will be diverted to composting, consistent with composting's share of total organic waste processed in 2019. We also assume that 100% of compostable paper not disposed of will be diverted to composting. We add the quantity of reduced disposal diverted to composting to the baseline 2019 composting tonnage to obtain estimates of the total quantity of organic waste composted in 2030 and 2050.

The second step in our analysis is estimation of the direct employment impacts associated with the annual tonnage of composted waste. We multiply the total tonnage of composted waste in each year by an estimate of the number of full-time employees needed at organic waste composting facilities per ton of waste received.[102] The estimate that we use (.00041 jobs per annual ton) comes from the total number of full-time employees (147) at 23 organic waste composting operations in the state of Maryland that receive a total of 358,000 tons of waste per year. We assume that composting operations in Massachusetts have the same labor intensity as those in Maryland (i.e., the same number of workers are employed per ton of composted material), and that all organic waste which is composted is composted in-state.

[100] MassDEP 2019. "Massachusetts Materials Management Capacity Study." https://www.mass.gov/doc/massachusetts-materials-management-capacity-study-february-2019/download. See Section 2-6.

[101] Because some organic waste disposal reduction may be achieved through source reduction, the employment estimates based on our approach may be considered high-end values.

[102] Brenda Platt et al 2013. "Pay Dirt: Composting in Maryland to Reduce Waste, Create Jobs, and Protect the Bay." *Institute for Local Self Reliance.* https://ilsr.org/paydirt/. See page ii.

As additional context for this approach, in 2016 MassDEP commissioned an analysis of the impact of the Massachusetts Commercial Food Waste Ban on employment in the organic waste sector.[103] This analysis utilized survey responses from several organic waste processors in Massachusetts (including composting, anaerobic digestion, and waste-to-animal feed facilities) to obtain an average employment per facility, and estimated total employment in organic waste processing by multiplying this average employment per facility by the total number of organic waste processors in Massachusetts. We use a different approach, estimating the total employment in composting as a function of the tonnage of waste composted. Our approach is more suited to estimating future employment based on current waste quantities and waste reduction goals, both measured in tons. We estimate that there were 164 composting jobs in Massachusetts in 2019, while the 2016 MassDEP study estimated that there were 150 organic waste processing jobs in 2016.

IEO TO SEO PROCESS

The methodology for conversion of IEO data to SEO outputs includes three (3) steps and both primary (2019 MACEIR) and secondary (IMPLAN, BLS, OEWS, etc.) data sources. The steps are as follows:

1. Complete a crosswalk of IMPLAN industry categories to 6-digit North American Industry Classification System (NAICS) codes for each of the sub-sectors by each of the value chain categories as defined in the IEOs:
    a. Construction
    b. Professional services
    c. Manufacturing
    d. Other supply chain (i.e., utilities, wholesale trade, repair and maintenance, etc.)
2. Run staffing patterns (NAICS to SOC) in Massachusetts for each of the value chain categories within each sub-sector for 2019. Augment staffing patterns for 2030 using occupational forecasts by 6-digit SOC categories for the state of Massachusetts. Outputs include total employment by aggregated occupational categories for each of the sub-sectors for 2019 and 2030 scenarios.
3. Using finalized staffing patterns and proportional employment within sub-sector and value chain categories, wages provided by the BLS Occupational Employment and Wage Statistics (OEWS) data series are grouped into three tiers: tier 1 or above a sustaining wage (under $26/hr), tier 2 or at a sustaining wage (between $26 and $35/hr), and tier 3 or below a sustaining wage (more than $35/hr). Proportional employment by wage tier is presented for 2019 and 2030 scenarios using 2019 dollars.

GEOGRAPHIC DISTRIBUTION OF JOBS

The research team used the existing geographic distribution of workers by industry and supply chain to determine where employment would grow or be displaced by 2030.

[103] MassDEP 2016. “Massachusetts Commercial Food Waste Ban Economic Impact Analysis.” https://www.mass.gov/files/documents/2016/12/nx/orgecon-study.pdf.

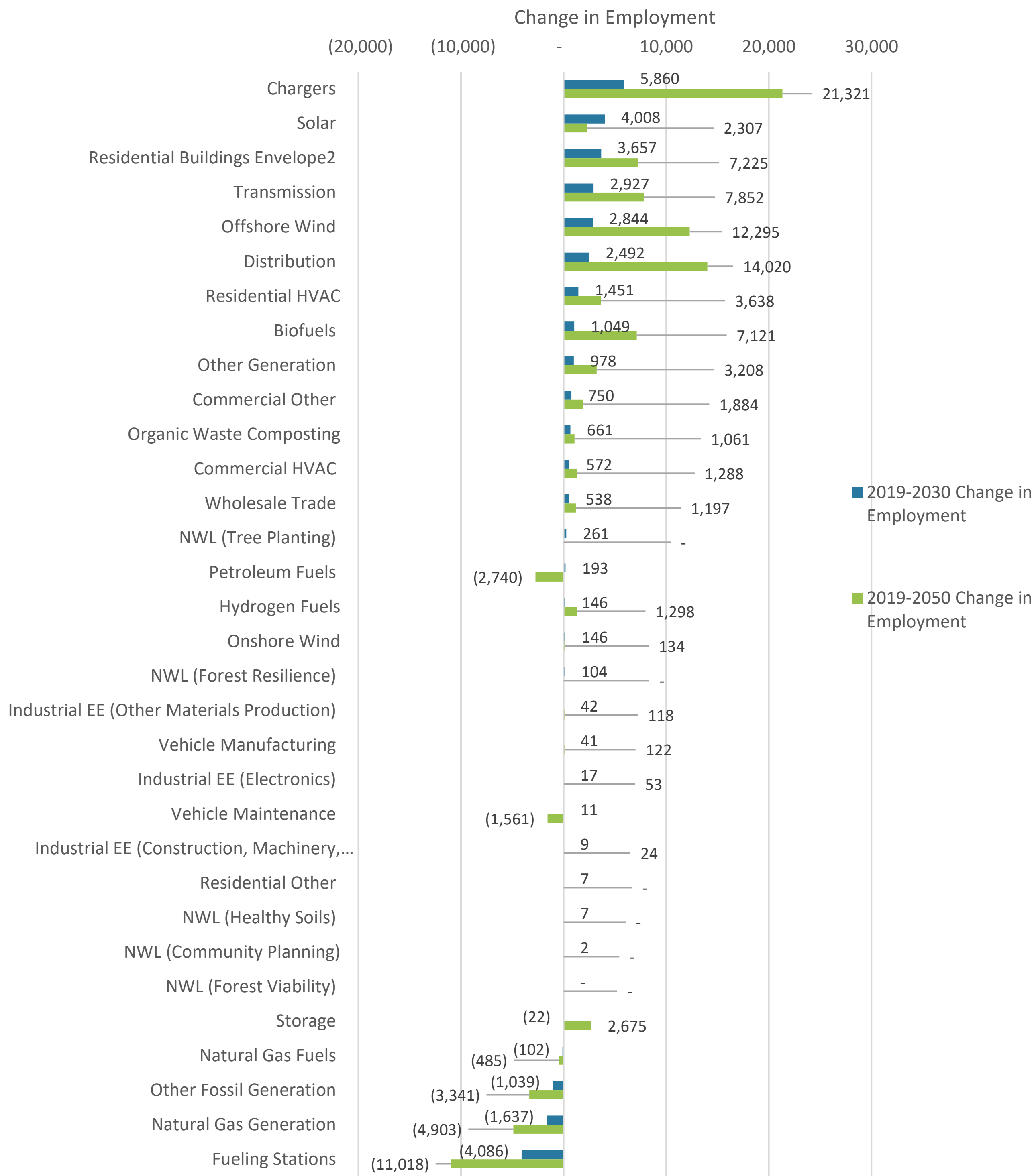
HOUSEHOLD LEVEL IMPACTS

The MA EEA and EER team had previously developed a census block-group level compilation of population demographics, including number of residents and households, average household income, number of vehicles, vehicle miles traveled, and rate of new vehicle purchases. The BW Research team linked this data to corresponding energy demand and pricing data generated by EER for each of the 26 regions developed and defined by EEA. Forecasted changes in energy prices and energy demand were proportioned against baseline (2019) energy uses and expenditures. Household-related energy expenditure data was sourced from the U.S. Department of Energy's Low-Income Energy Affordability Data (LEAD). Transportation-related energy expenditure data was retrieved from the Bureau of Labor Statistics Consumer Expenditure Survey (2019) Table 1203, and the U.S. Energy Information Agency (EIA)'s Motor Gasoline Expenditure Estimates by State (2019).

Residential electricity and natural gas prices were projected because these fuels eventually make up most of the consumer energy mix. The price of all other types of energy were held constant. Each region's demand for specific energy was then proportioned to the share of population (for demand of home-related energy expenditures) and share of vehicles (for demand of transportation-related energy expenditures). This proportioning allowed the research team to then generate household-weighted changes within regions and specific populations, including EJ populations.

CHAPTER APPENDIX D-2: EMPLOYMENT BY SUB-SECTOR

Figure D.29. Change in Employment from 2019 Baseline by Sub-sector



CHAPTER APPENDIX D-3: OFFSHORE WIND DEEP DIVE

OFFSHORE WIND SCENARIOS

Offshore wind (OSW) is a unique industry; the substantial size and complexity of the turbines and their foundations mean that production of their components requires heavily specialized manufacturers. Nearly all of the current manufacturing of OSW turbines and their components occurs abroad, meaning, under current market dynamics, little manufacturing and assembly employment would be generated within Massachusetts. OSW manufacturers, having noticed the scale of planned OSW projects along the East Coast and incentivized by some states' local content requirements, are increasingly looking to bring manufacturing operations to the United States. Attracting these developers presents substantial potential job growth for the state, though other states are competing for these facilities as well.

The nascency of the domestic OSW industry and the activities in surrounding states mean that there are several possible scenarios for OSW manufacturing in Massachusetts. To capture the range of the possibilities and their accompanying economic impacts, the research team developed four scenarios. The three scenarios describe differing MA local input projections that stem from variations in public sector interventions to support supply chain and workforce development in Massachusetts. The efforts being taken to increase Massachusetts local input are reflected as either an increase in supply chain capability, an acceleration of when capability become available, or both. Each progressive scenario builds upon the previous one.

Scenario 1 – "Maintaining Policies, Investments, and Supports"

This scenario describes the current path for additional supply chain and workforce development in state. In this scenario, Tier 1 manufacturing in MA is limited to the announced Prysmian subsea cable facility expected to provide partial supply of export cables. This scenario also includes support to existing companies with capability captured in Scenario 1 to diversify and expand their service offering; identifying and connecting new lower tier manufacturers with opportunities to supply components in OSW; and increased presence of skilled workforce to support quayside finishing of components, and offshore installation and commissioning services. Further workforce training support is anticipated to result in an increased number of local workers to provide offshore O&M. This is the scenario used throughout the body of the 2025/2030 CECP.

Scenario 2 – "Plausible but Optimistic"

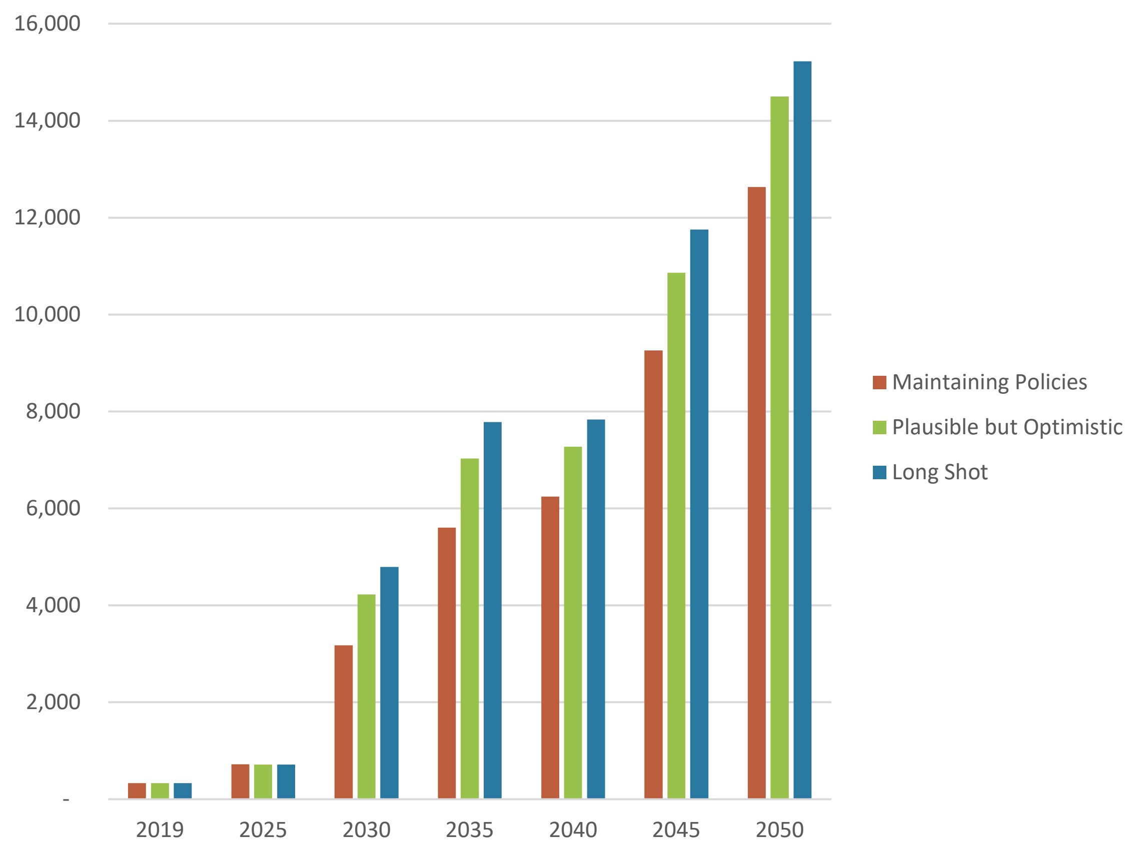
This scenario describes an achievable supply chain development pathway that results in significant additional Tier 1 manufacturing to land in the state. The scenario includes the establishment of facilities to manufacture towers, transition pieces and blades in MA as well as an expansion of the capabilities of the expected export cable facility to also produce array cables. These facilities are considered the most achievable to capture due to the current gaps in the U.S. East Coast OSW supply chain landscape working in combination with the expected MA project pipeline opportunity providing a plausible investment case for OEMs. The scenario also includes uncovering or better connecting a greater number of lower-tier suppliers or attracting them to set up in the state to support Tier 1 supply.

Scenario 3 – "Long Shot"

This scenario describes the potential best case for local content that assumes additional component manufacturing and expansion of supply chain services beyond those captured in previous scenarios. This includes the establishment of a turbine nacelle assembly facility and a facility to manufacture electrical subcomponents for the offshore substation transmission infrastructure. This additional manufacturing capability will be more challenging to capture in state due to the limited requirement for U.S. facilities, more challenging investment case for suppliers, and strong competition from other states to secure supply.

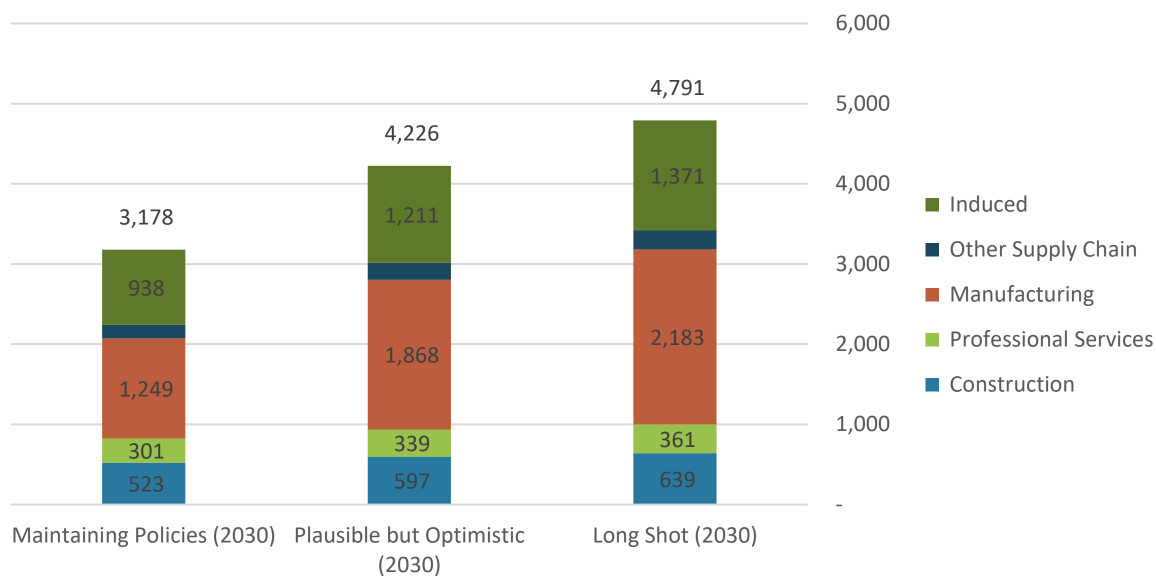
The Plausible but Optimistic scenario is projected to create and sustain more than 1,000 (33%) more jobs than the Maintaining Policies scenario by 2030. In comparison, the Long Shot scenario is projected to add 1,600, or about 51% more jobs by 2030 than the continued policies scenario (Figure D.30). This highlights that increased efforts to bring OSW manufacturing in-state will have substantial jobs benefits.

Figure D.30. OSW Employment by Scenario



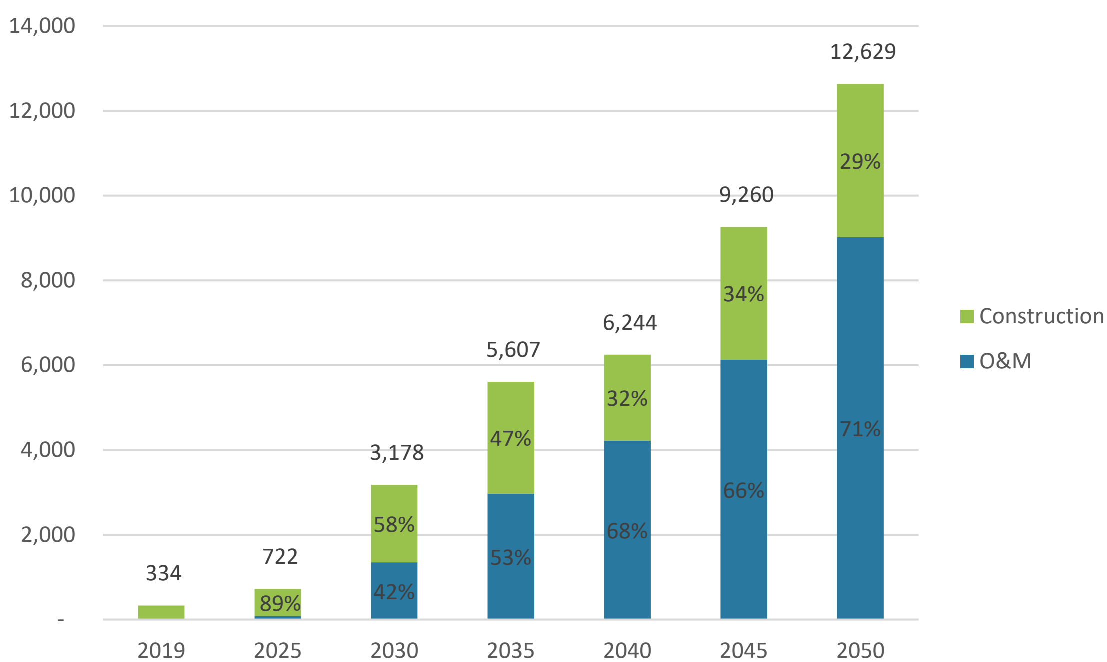
Most of the jobs created across all scenarios are in Manufacturing; in the Maintaining Policies scenario, manufacturing accounts for 39% of the jobs created by 2030, and in the Long Shot scenario, manufacturing jobs account for 46% of job gains. Induced employment is the next-largest source of employment created under these scenarios (Figure D.31).

Figure D.31. OSW Employment in 2030 by Scenario



By 2030, OSW employment is roughly split between the operations phase activities (42%) and construction phase activities (58%). As project capacity is built out, a greater share of employment takes place under the operations phase, eventually account for 71% of all OSW employment by 2050 (Figure D.32).

Figure D.32. OSW Employment in the Maintaining Policy Scenario by Project Phase

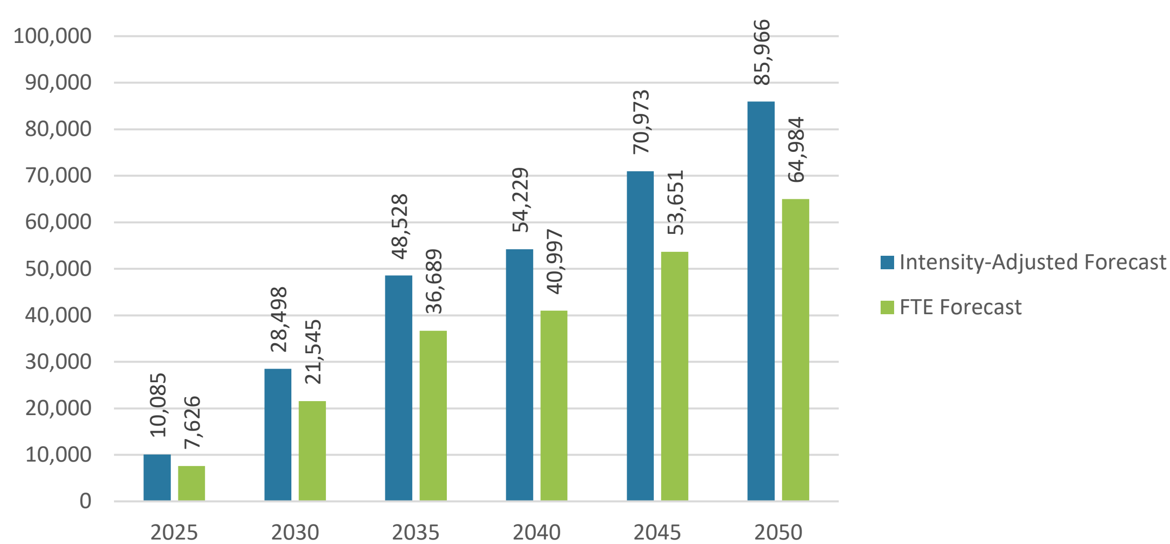


CHAPTER APPENDIX D-4: INTENSITY-ADJUSTED EMPLOYMENT ESTIMATES

The 2019 baseline employment figures in this report are derived[104] from data collected for the 2019 U.S. Energy and Employment Report (USEER) developed for the U.S. Department of Energy and used in the Massachusetts Clean Energy Industry Reports (MACEIR). These employment numbers include any workers that spend any of their time on energy-related activities. This means that an electrician who only spends half of their time working on installing charging infrastructure for electric vehicles will still be counted as one energy worker in the Charging sub-sector under the USEER and MACEIR definition.[105] In contrast, the models used throughout this report generate outputs in job-years, which is equivalent to a Full-Time Equivalent (FTE). This means that a model output of one additional worker in Charging by 2025 is equivalent to an additional worker that is spending 100% of their time on EV charging infrastructure. The difference in worker intensity between baseline 2019 employment figures and the model outputs means that the model is likely undercounting some of the additional "jobs" relative to how energy jobs are defined in the USEER and MACEIR. The research team opted to use the FTE equivalent figures throughout the report because it shows the unaltered scale of economic activity generated. Additionally, energy workers have been spending an increasing share of their time on energy-related work, suggesting that these two methods of counting will converge over time.

Adjusting for the intensity of a worker's activity shows that there is a notable difference between "USEER-equivalent" jobs and the FTE jobs which are reported. By 2030, there are nearly 7,000 additional jobs created under the USEER-equivalent (workers not spending all their time on energy-related activities) definition than the FTE equivalent. By 2050 the gap is 21,000 jobs (Figure D.33).

Figure D.33. Growth in Jobs by Intensity-Adjusted and Full-Time Equivalent Forecasts



[104] With the exception of the Transportation, Industrial Energy Efficiency, Natural and Working Lands, and Municipal Solid Waste sectors.
[105] On average, workers spend 75.6% of their time working on the activity they are classified under.

CHAPTER APPENDIX D-5: ECONOMIC BENEFITS OF AIR QUALITY

Decarbonization of the Massachusetts economy will not only reduce GHG emissions but will also improve air quality across the Commonwealth. These improvements, as measured by ambient concentrations of fine particulate matter ($PM_{2.5}$), will arise from reduced emissions of direct $PM_{2.5}$ and $PM_{2.5}$ precursors such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Because of the link between ambient $PM_{2.5}$ and several adverse health effects, public health across the Commonwealth will improve as concentrations of ambient $PM_{2.5}$ decline. More specifically, improved air quality will reduce the incidence of the following health effects:

- Premature mortality
- Acute bronchitis
- Acute myocardial infarction (heart attacks)
- Asthma exacerbation
- Asthma-related emergency department visits
- Lower respiratory symptoms
- Upper respiratory symptoms
- Minor restricted activity days
- Work loss days

Each of these effects has been linked to ambient $PM_{2.5}$ in peer-reviewed epidemiological studies.

The economic value associated with reduced incidence of these effects may be estimated based on the costs of treating each illness, the average reduction in earnings per case for each effect (due to lost work time), and individuals' willingness to pay to avoid a specific health effect.

To estimate the air quality benefits associated with decarbonizing the Massachusetts economy, EEA used the U.S. Environmental Protection Agency's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA). COBRA is a streamlined air quality assessment tool that, based on user-provided emissions inputs, estimates county-level changes in ambient $PM_{2.5}$, the resulting changes in incidence for various health effects related to $PM_{2.5}$, and the value of these improvements in public health.

Based on the criteria pollutant emissions projected under the Phased scenario[106] and outputs generated by COBRA, Table D.3 presents the estimated health effects avoided in 2030 and 2050. Table D.4 presents the economic value of these effects.

[106] EER provided air quality impacts relative to a reference case, rather than relative to 2019 as in other portions of this report. See Appendix A for more information about the Phased scenario.

Table D.3. Reduced Incidence of Adverse Health Effects under Phased[107] Scenario, 2030 and 2050

Health Effect	2030	2050
Adult Mortality, All Causes	36.80 - 83.16	181.38 - 409.16
Infant Mortality	0.12	0.56
Hospital Admissions, All Cardiovascular (less Myocardial Infarctions)	9.38	44.62
Hospital Admissions, All Respiratory	7.15	34.91
Hospital Admissions, Asthma	0.65	3.08
Hospital Admissions, Chronic Lung Disease	1.84	8.49
Emergency Room Visits, Asthma	25.56	120.44
Acute Myocardial Infarction, Nonfatal	4.21 - 39.10	20.06 - 185.25
Lower Respiratory Symptoms	563.58	2,730.30
Upper Respiratory Symptoms	803.55	3,907.91
Asthma Exacerbation, Cough	189.65	920.18
Asthma Exacerbation, Shortness of Breath	255.39	1,238.97
Asthma Exacerbation, Wheeze	390.22	1,893.61
Acute Bronchitis	44.28	214.22
Lost Days of Work	4,590.01	21,698.41
Minor Restricted Activity Days	26,890.47	127,259.15

[107] EER provided air quality impacts relative to a reference case, rather than relative to 2019 as in other portions of this report.

Table D.4. Estimated Economic Value of Avoided Health Effect Incidence under Phased Scenario, 2030 and 2050

Health Effect	2030	2050
Mortality, All Causes	$414,783,387 - $937,235,426	$2,044,228,639 - $4,611,581,889
Infant Mortality	$1,470,442	$7,096,231
Subtotal: Mortality	$416,253,829 - $938,705,869	$2,051,324,870 - $4,618,678,121
Hospital Admissions, Cardiovascular Disease	$470,125	$2,236,166
Hospital Admissions, Respiratory	$349,726	$1,694,368
Emergency Room Visits, Asthma	$14,400	$67,856
Acute Myocardial Infarction, Nonfatal	$653,575 - $6,063,952	$3,107,920 - $28,706,571
Lower Respiratory Symptoms	$15,403	$74,623
Upper Respiratory Symptoms	$34,746	$168,979
Asthma Exacerbation	$62,731	$304,379
Acute Bronchitis	$27,653	$133,789
Lost Days of Work	$918,860	$4,343,742
Minor Restricted Activity Days	$2,385,816	$11,290,876
Subtotal: Morbidity	$4,933,036 - $10,343,413	$23,422,698 - $49,021,349
Total	**$421,186,865 - $949,049,281**	**$2,074,747,568 - $4,667,699,469**

By 2030, air quality improvements under the Phased scenario will result in 37 to 83 reduced premature deaths, 4 to 39 avoided cases of acute myocardial infarction, 45 fewer hospital and emergency room admissions, 4,600 fewer lost days of work, and 27,000 fewer days of minor restricted activity, among other benefits. By 2050, each of the health endpoint improvements estimated by COBRA is approximately 4.5 to 5 times greater than in 2030.

In economic terms, quantifying all outcomes in dollars makes comparisons across health outcomes possible. In total, air quality improvements under the Phased scenario will generate improved health outcomes with a total value of $421 million to $949 million by 2030, and $2.1 billion to $4.7 billion by 2050.[108] The value of avoided premature mortality dominates the economic benefits of air quality, accounting for approximately 98% of the total economic value of air quality-related health improvements. This result reflects a higher per-case value for mortality than non-fatal health endpoints. Among morbidity outcomes (hospital and emergency room visits, non-fatal acute myocardial infarction, respiratory symptoms, asthma exacerbation, and acute bronchitis), avoided incidence of acute myocardial infarction is the largest benefit, constituting between 40 and 86% of total morbidity-related

[108] These values were calculated using a 3% discount rate in the COBRA model.

benefits in monetized terms. Reduced days with restricted activity or lost work are also substantial benefits, with greater economic value than most morbidity outcomes (though lower than mortality and acute myocardial infarction).

CHAPTER APPENDIX D-6: OTHER BENEFITS – NATURAL AND WORKING LANDS

In addition to the macroeconomic and employment benefits described in the main body of this report, the NWL policy proposals will result in other social and environmental benefits. These proposals represent investments in the protection, restoration, and conservation of natural and working lands in Massachusetts, which will effect environmental changes relevant to the overall wellbeing of the state's residents. The benefits associated with these changes are wide ranging and vary across the natural and working lands policy proposals. This appendix identifies the benefits relevant to each policy proposal, outlines the relationships between policy outcomes, environmental changes, and benefits realization, and describes relevant research related to these benefits.

To take stock of the benefits associated with each proposed NWL action, Table D.5 identifies the applicable benefits associated with the policy outcomes for each proposal, organized according to the overarching NWL strategies. Complementing this table, Figure D.34 through Figure D.37 delineate the relationship between policy outcomes, environmental changes, and resulting benefits for each NWL strategy.[109]

[109] Figure D.34 through Figure D.37 do not include the Carbon Sequestration strategy, as the only two policy proposals (frameworks for net-zero accounting and sequestration markets) are less applicable to NWL specifically.

Table D.5. Ecosystem Service Benefits of Policy Outcomes[110, 111]

Row	Strategy	Action	Key Policy Outcome(s)	Improved visibility	Reduced heat island impacts	Improved aesthetics	Reduced energy costs	Improved recreational access	Improved land stability	Reduction in public health risks	Improved drinking water quality	Reduced timber waste	Meet GHG emissions reduction
1		Expand Land Conservation Grant Programs	Water supply protection, open lands preservation, improved erosion prevention	*		P		P	P	*	P		*
2	L1 - Protect NWL	Expansion of Chapter 61, 61A forest and agricultural land protection programs	Forestland conservation, farmland conservation, open lands preservation, improved erosion prevention	*		P		P	P	*	P		*
3		Incentivize Natural Resource Protection Zoning, tree retention bylaw planning	Open lands preservation, tree planting, improved erosion prevention	*	P	P	P	P	P	*	P		*

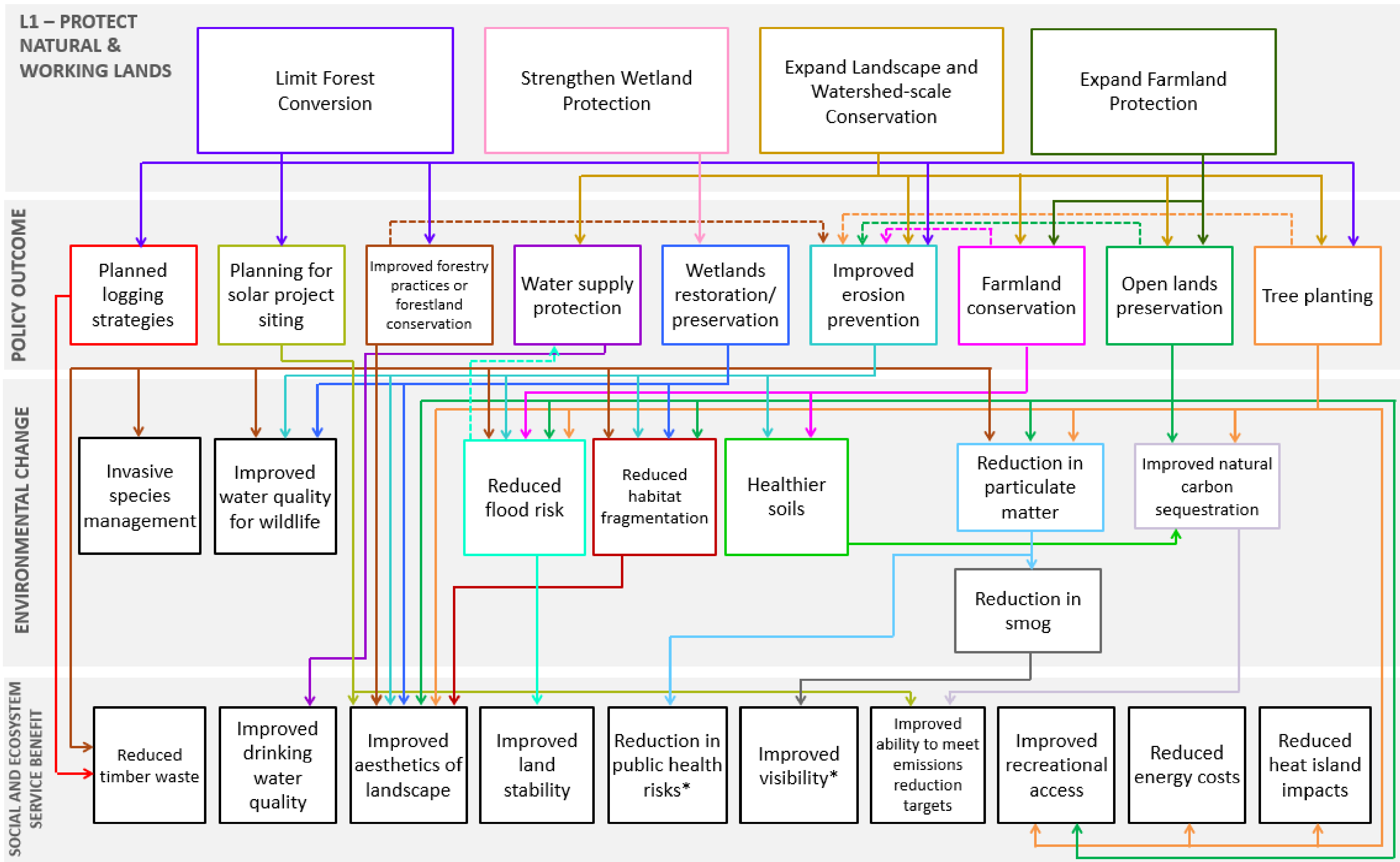
[110] An asterisk (*) for improved visibility, reductions in public health risk, and meeting GHG emissions reduction targets indicate air benefits from protecting existing trees or open lands, while checkmarks for these categories indicate air benefits from adding new trees. Note, there is some evidence to suggest trees or open lands improve air quality, although studies are mixed on the magnitude of the effect. For more information, see the benefit-specific descriptions below for information on improved visibility, reduction in public health risks, and improved ability to meet emissions reduction targets.

[111] The "Meet GHG Emissions Reduction Targets" benefit applies to policy outcomes affecting both decreases in GHG emissions and increases in carbon sequestration. This is in accordance with the MA 2050 Decarbonization Roadmap. For more information, see the benefit-specific description below.

4		Tree planting award payments to communities passing NRPZ, tree retention bylaws	Open lands preservation, tree planting, improved erosion prevention	P	P	P	P	P	P	P	P		P
5		Forest protection/tree planting payments from developers to offset tree removal	Reduced timber waste, improved forestry practices, tree planting, improved erosion prevention	P	P	P	P	P	P	P	P	P	P
6		Expand farmland protection through new state incentive program from MDAR	Farmland conservation, improved erosion prevention			P		P	P				
7		Streamlined permitting of development projects in wetland buffer zone that permanently protect the wetland and adjacent 50 ft.	Wetlands restoration/preservation, improved erosion prevention			P			P				
8		Comprehensive assessment and policy guidance of future solar siting (cross referenced in E4)	Land use planning			P							P
9		Forest Resilience Program	Reduced timber waste, improved forestry practices, improved erosion prevention			P			P	*	P	P	*
10	**L2 - Manage NWL**	Chapter 61C incentives for climate-smart forest management	Reduced timber waste, improved forestry practices, carbon sequestration, improved erosion prevention	P		P			P	P	P	P	*
11		Additional funding for the MA Coordinated Soil Health Program incentives	Open lands preservation, improved erosion prevention, carbon sequestration		P	P		P	P	*	P		*
12	**L3 - Restore NWL**	Increase funding for Greening the Gateway Cities urban tree planting program	Tree planting, improved erosion prevention	P	P	P	P		P	P	P		P

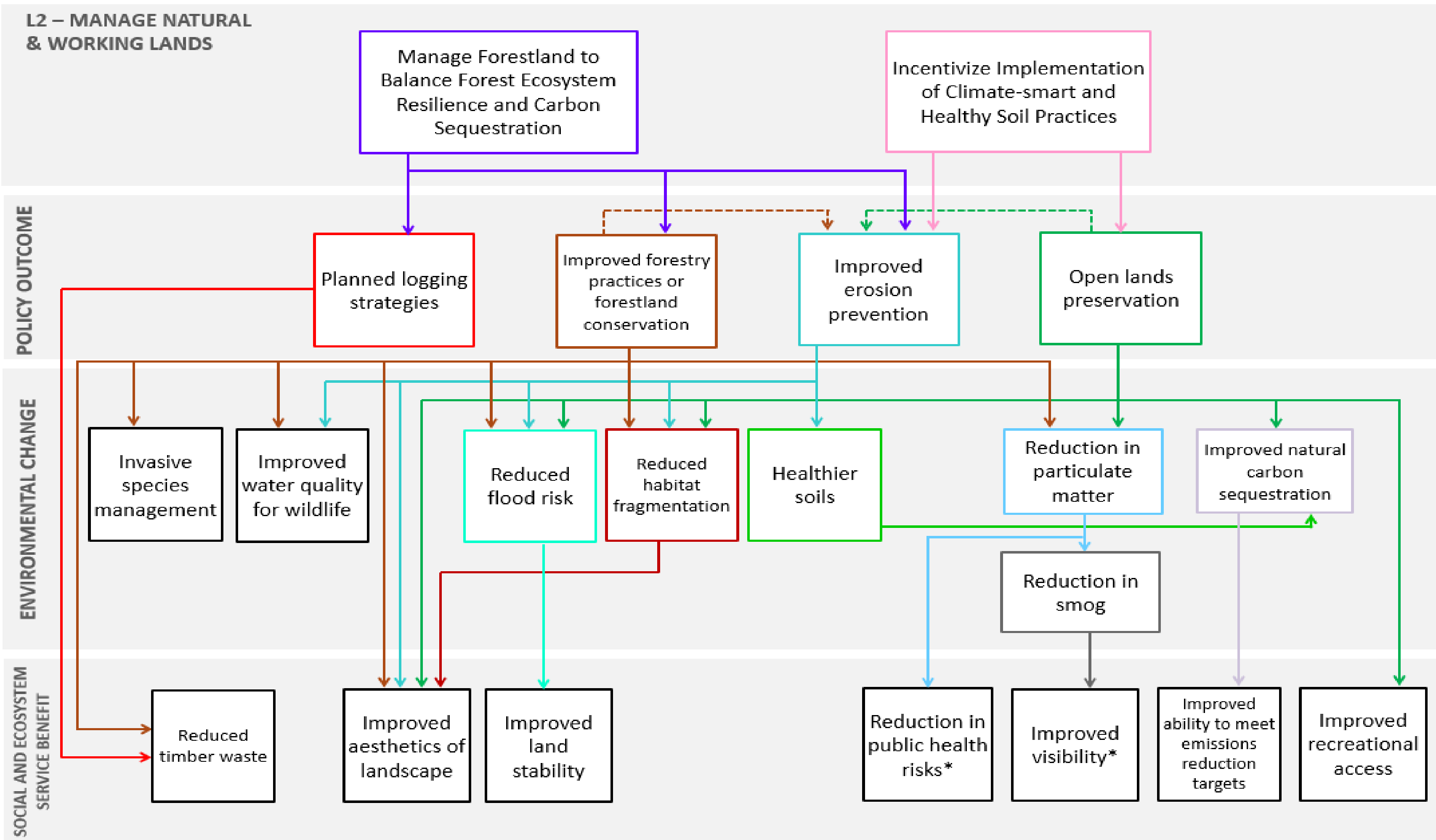
13		New riparian tree planting program	Open lands preservation, tree planting, improved erosion prevention	P	P	P	P	P	P	P	P		P
14		Municipal Vulnerability Preparedness (MVP) program's action grants for greening and nature-based projects	Open lands preservation, tree planting, improved erosion prevention	P	P	P	P	P	P	P	P		P
15		No net loss of stored carbon in wetlands and 2:1 replacement-to-loss ratio memorialization	Wetlands restoration/preservation, improved erosion prevention			P			P				
16		Streamline permitting for projects restoring wetland carbon storage functions	Wetlands restoration/preservation, improved erosion prevention			P			P				
17	**L4 - Incentivize Long-Lived Durable Wood Products**	Analyze timber market	Reduced timber waste, improved forestry practices							P	P	P	
18		Forest Viability Program	Reduced timber waste, improved forestry practices							P	P	P	*
19		Require full cost of carbon emissions analysis for state projects	Reduced timber waste, improved forestry practices							P	P	P	*
20		Track timber flows	Reduced timber waste, improved forestry practices							P	P	P	
21	**L5 - Carbon Sequestration**	Develop frameworks for net zero accounting	Meet emissions reduction targets										P
22		Develop frameworks for carbon sequestration markets	Meet emissions reduction targets										P

Figure D.34. Protect Natural and Working Lands: Relationship Between Policy Outcomes, Environmental Changes, and Benefits[112]



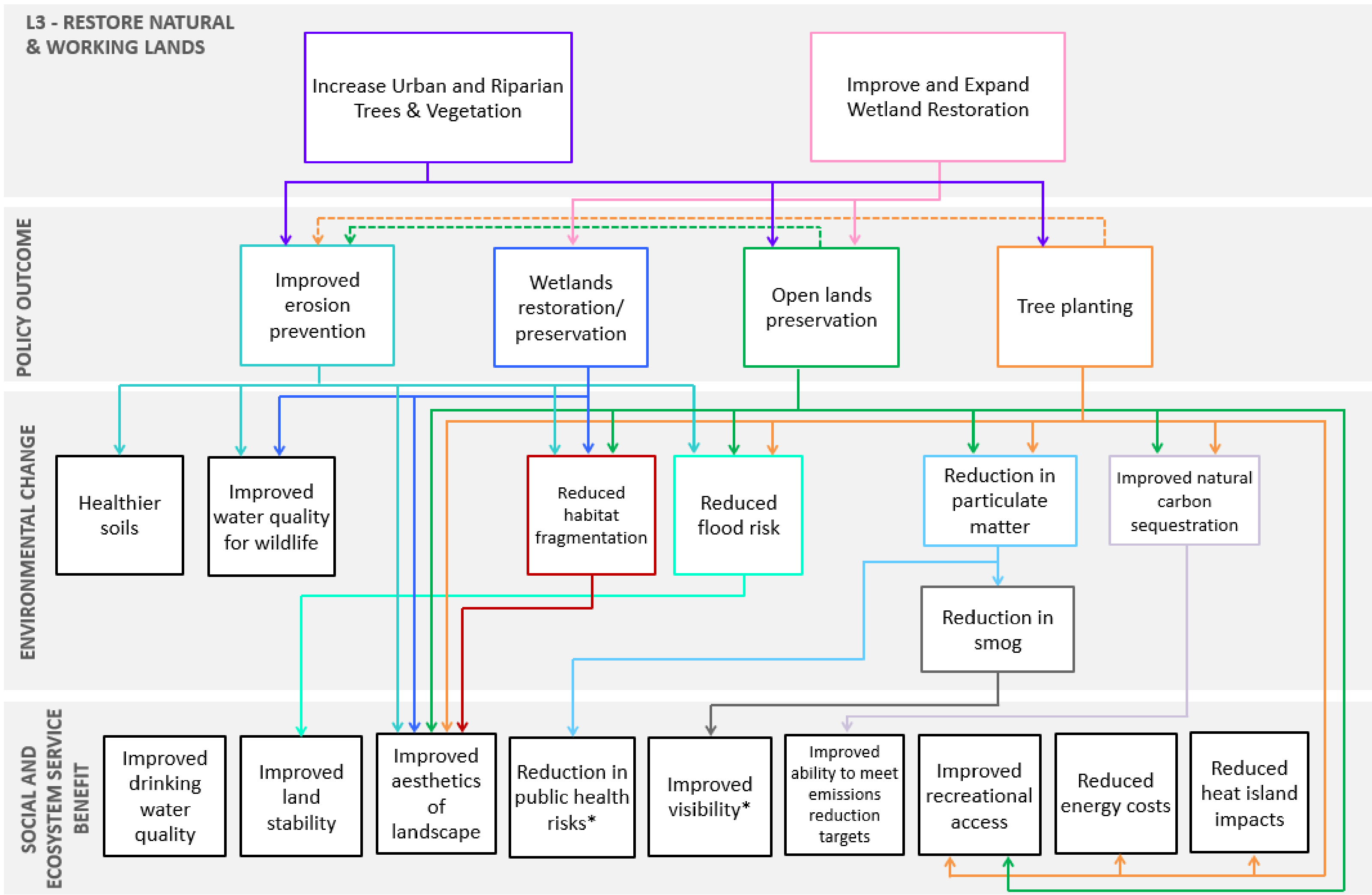
[112] Solid lines represent downstream effects while dotted lines represent upstream or additional effects. Benefits with an asterisk (*) indicate that there is some evidence to suggest trees or open lands improve air quality, although studies are mixed on the magnitude of the effect. See the benefits descriptions below for improved visibility and reduction in public health risks.

Figure D.35. Manage Natural and Working Lands: Relationship Between Policy Outcomes, Environmental Changes, and Benefits[113]



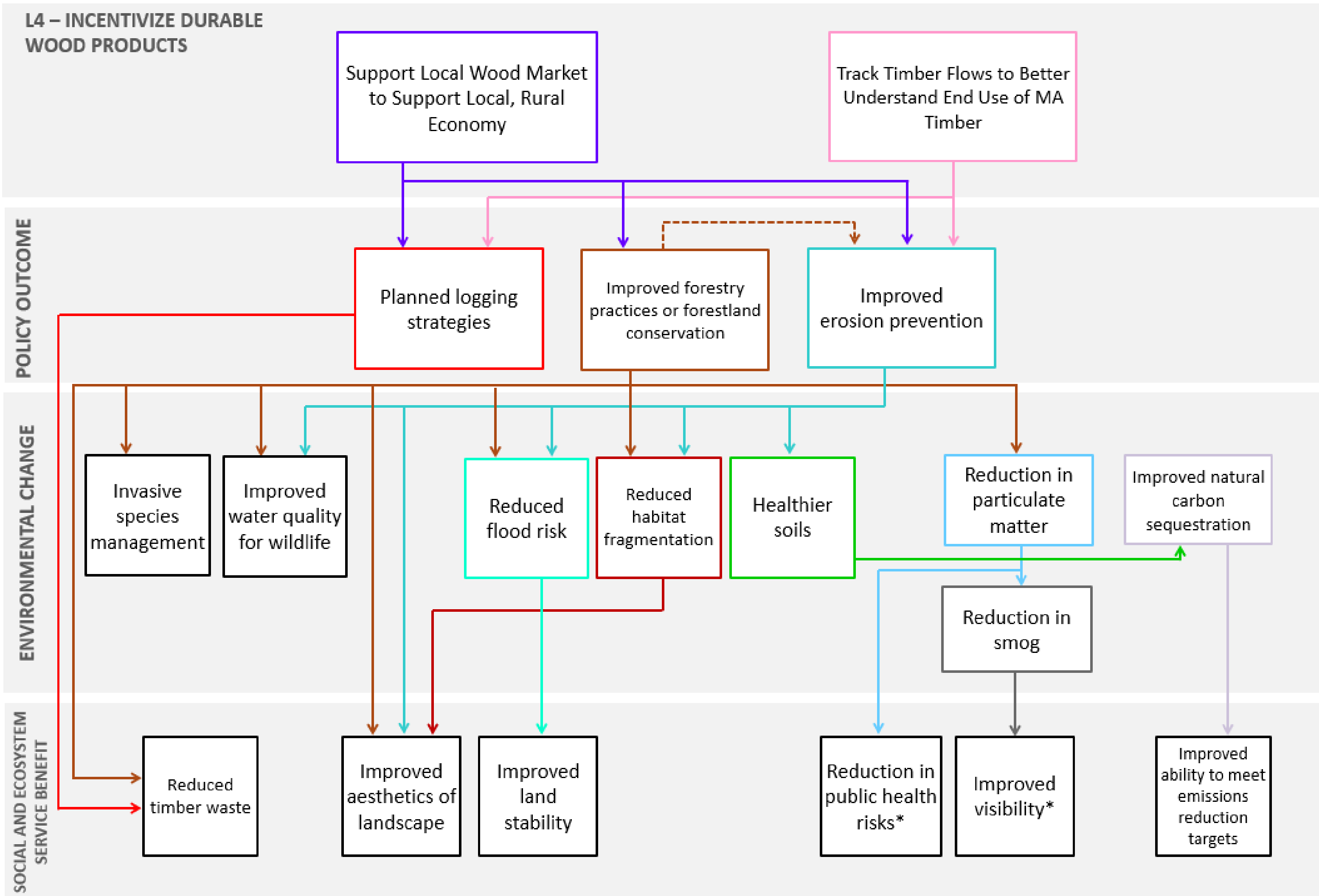
[113] Solid lines represent downstream effects while dotted lines represent upstream or additional effects. Benefits with an asterisk (*) indicate that there is some evidence to suggest trees or open lands improve air quality, although studies are mixed on the magnitude of the effect. See the benefits descriptions below for improved visibility and reduction in public health risks.

Figure D.36. Restore Natural and Working Lands: Relationship Between Policy Outcomes, Environmental Changes, and Benefits[114]



[114] Solid lines represent downstream effects while dotted lines represent upstream or additional effects. Benefits with an asterisk (*) indicate that there is some evidence to suggest trees or open lands improve air quality, although studies are mixed on the magnitude of the effect. See the benefits descriptions below for improved visibility and reduction in public health risks.

Figure D.37. Incentivize Durable Wood Products Logic Pathway: Relationship Between Policy Outcomes, Environmental Changes, and Benefits[115]



[115] Solid lines represent downstream effects while dotted lines represent upstream or additional effects. Benefits with an asterisk (*) indicate that there is some evidence to suggest trees or open lands improve air quality, although studies are mixed on the magnitude of the effect. See the benefits descriptions below for improved visibility and reduction in public health risks.

The sections below provide descriptions of the categories of benefits included in Table D.5, examples of the benefits pathways associated with each benefit category, and examples of the research related to each benefit.[116]

SOCIAL AND ECOSYSTEM SERVICE BENEFITS

Improved Drinking Water Quality

The risk of drinking water contamination can increase due to mistreatment of source water or due to poor maintenance of a waterway's distribution system. Such contamination can lead to adverse health impacts, including gastrointestinal illness or reduced reproductive function.[117] Drinking water quality can be improved through water supply protection, such as the protective measures included in the 2025/2030 CECP. Research by Cooke and Kennedy (2001),[118] Davies and Mazumder (2003),[119] and Patrick et al. (2019)[120] highlights the importance of protecting water sources to improve downstream drinking water quality and its role in public health. Cooke and Kennedy (2001) found strong links between unmaintained watersheds and drinking water problems, including taste, odor, and toxic algae and suggested methods to protect, improve, and maintain water reservoirs to improve public health, including methods consistent with those proposed in the CECP. Davies and Mazumder (2003) reached a similar conclusion and noted that protected watersheds reduce the amount of human waste, nutrients, and chemicals in surface water. They found that water protection should focus on the quality of source water, which reduces the number of pathogens and the amount of organic matter in drinking water. Patrick et al. (2019) examined the effect of contaminants in source water on Canadian First Nation communities and determined that source water protection planning can help improve drinking water quality and decrease human health risks. In addition, research by Valatin et al. (2022)[121] found that planting trees enhanced watershed services through nutrient retention, erosion control, and stream flow regulation.

Policy initiatives in the CECP that would contribute to water quality improvements include, but are not limited to, expanding land conservation programs to watershed-scale conservation, incentivizing natural resource protection zoning, and adding a new riparian tree planting program.

[116] Note that these descriptions and the cited examples from the literature are meant to illustrate how each benefits pathway functions following policy outcomes, rather than serve as an exhaustive review of the literature.
[117] CDC. (2020). *Water Quality and Testing.* CDC. https://www.cdc.gov/healthywater/drinking/public/water_quality.html.
[118] Cooke, G., & Kennedy, R. (2001). Managing Drinking Water Supplies. *Lake and Reservoir Management, 17*(3), 157-174. https://doi.org/10.1080/07438140109354128.
[119] Davies, J-M., & Mazumder, A. (2003). Health and environmental policy issues in Canada: the role of watershed management in sustaining clean drinking water quality at surface sources. *Journal Environmental Management, 68*(3), 273-86. https://doi.org/10.1016/S0301-4797(03)00070-7.
[120] Patrick, R., et al. (2019). Reclaiming Indigenous Planning as a Pathway to Local Water Security. *Water, 11*(5), 936. https://doi.org/10.3390/w11050936.
[121] Valatin, G., et al. (2022). Approaches to cost-effectiveness of payments for tree planting and forest management for water quality services. *Ecosystem Services, 53*. https://doi.org/10.1016/j.ecoser.2021.101373.

Reduced Timber Waste

A number of the NWL policy initiatives included in the 2025/2030 CECP will aid in the more efficient management and use of timber resources, thereby easing waste management burdens. Planned logging strategies, such as those considered in several of the NWL policy initiatives, are a useful tool for achieving such efficiency improvements. Planned logging strategies include developing and following a timber harvesting schedule and mapping natural resources while also protecting the health of the forest. Barreto et al. (1998)[122] found that planning logging maneuvers reduced the volume of felled timber, which limits damage to forests and leaves more timber to be extracted in the future. Efficient timber resource management can include repurposing wood for home construction. For instance, Mallo and Espinoza (2014)[123] noted how cross-laminated timber manufacturing helps reduce waste as compared to production methods supporting traditional wood construction materials.

Policy initiatives in the Plan that would ease the timber waste management burden include, but are not limited to, the Forest Resilience Program, the Forest Viability Program, and the Chapter 61C incentives for climate-smart forest management.

Improved Land Stability

Soil erosion damages land, natural resources, infrastructure, and poses a significant safety risk. Soil erosion can also cause landslides.[124] Landslides occur when rock or debris move down a slope and usually follow heavy rains and floods, leading to a mudslide. Land stability can be improved through natural means such as tree planting, which lowers water flow speed and reinforces the slope surface. This relationship has been documented in research by Lovell and Sullivan (2006)[125], Sutton-Grier (2018)[126], and Graziano et al. (2022)[127]. Lovell and Sullivan (2006) noted that conservation buffers such as trees and grass help control stream bank erosion. Sutton-Grier (2018) also noted that investment in green infrastructure such as vegetation can help prevent flooding and coastal erosion. Graziano et al. (2022) found that riparian vegetation helps maintain the physical structure of soil and reduces soil erosion.

Policy initiatives in the 2025/3020 CECP that may improve land stability and limit erosion through greening include, but are not limited to, incentivizing natural resource protection zoning, increasing

[122] Barreto, P., et al. (1998). Costs and benefits of forest management for timber production in eastern Amazonia. *Forest Ecology and Management, 108*(1-2), 9-26. https://doi.org/10.1016/S0378-1127(97)00251-X.
[123] Mallo, L., & Espinoza. (2014). Outlook for CLT. *BioResources, 9*(4), 7427-7443. http://dx.doi.org/10.15376/biores.9.4.7427-7443.
[124] Notable landslides have previously occurred in Massachusetts. In 2011, Tropical Storm Irene caused landslides in Deerfield Watershed, Cold Rivers, Charlemont, and Savoy. See The Massachusetts Geological Survey. *Landslides*. University of Massachusetts, Amherst. https://mgs.geo.umass.edu/resources/landslides.
[125] Lovell, S., & Sullivan, W. (2006). Environmental benefits of conservation buffers in the United States: Evidence, promise, and open questions. *Agriculture, Ecosystems & Environment, 112*(4), 249-260. https://doi.org/10.1016/j.agee.2005.08.002.
[126] Sutton-Grier, A., et al. (2018). Investing in Natural and Nature-Based Infrastructure: Building Better Along Our Coasts. *Sustainability, 10*(2), 523. https://doi.org/10.3390/su10020523.
[127] Graziano, M., et al. (2022). Riparian Buffers as a Critical Landscape Feature: Insights for Riverscape Conservation and Policy Renovations. *Diversity, 14*(3), 172. https://doi.org/10.3390/d14030172.

funding for Greening the Gateway Cities program, and establishing a new riparian tree planting program.

Increased or Improved Recreational Opportunities

Recreational areas provide space for physical activity, socializing, and time to experience nature. Improving access to green spaces through walkways or increasing the number of public lands and parks with trees and open spaces will help provide more opportunities for outdoor recreation. Research by Sherer (2006)[128] and Konijnendijk et al. (2013)[129] noted that city parks and open spaces encourage physical activity resulting in increased frequency of exercise and improved mental health. Sherer (2006) noted that in previous research conducted by the Center for Disease Control and Prevention, creation of or better access to places for physical activity led to a 25.6% increase in the percentage of the population exercising three or more days per week. In addition, Konijnendijk et al. (2013) found that urban parks strengthened social ties by providing a venue for establishing relationships within communities.

Policy initiatives in the CECP that may improve recreational opportunities include, but are not limited to, expanding land conservation programs to open lands, incentivizing natural resource protection zoning, increasing funding for Greening the Gateway Cities program, and the Municipal Vulnerability Preparedness program funding for greening and nature-based projects.

Reduced Energy Costs

Reduced energy costs include lower electricity, natural gas, and other fuel expenses for households, businesses, and industries. This benefit can stem from reduced heat island impacts, leading to lower household summer cooling costs. For instance, tree planting provides natural canopy cover, leading to cooler temperatures, and establishing windbreaks. Research by Nowak et al. (2017)[130] and the Trees Energy Conservation (2019)[131] documented how planting trees and forests reduced electricity use and costs by providing shade and altering wind speeds. Nowak et al. (2017) found that urban areas in the US could save $7.8 billion per year in electricity use and heating costs from increased tree density since trees help reduce heat island impacts and establish windbreaks that help reduce heating needs in the winter. Pandit and Laband (2010)[132] also found that energy savings resulted from shade coverage during the summer months in Auburn, Alabama.

[128] Sherer, P. (2006). *The Benefits of Parks: Why America Needs More City Parks and Open Space*. The Trust for Public Land. http://www.gethealthysmc.org/sites/main/files/file-attachments/benefits_of_parks_tpl.pdf.
[129] Konijnendijk, C., et al. (2013). *Benefits of Urban Parks A Systematic Review – A Report for IFPRA*. IFPRA. https://www.researchgate.net/publication/267330243_Benefits_of_Urban_Parks_A_systematic_review_-_A_Report_for_IFPRA.
[130] Nowak, D., et al. (2017). Residential building energy conservation and avoided power plant emissions by urban and community trees in the United States. *Urban Forestry & Urban Greening, 21*, 158-165. https://doi.org/10.1016/j.ufug.2016.12.004.
[131] Trees for Energy Conservation. (2019). *Tree Planting for Lower Power Bills*. Trees for Energy Conservation. https://trees-energy-conservation.extension.org/tree-planting-for-lower-power-bills/.
[132] Pandit, R., & Laband, D. (2010). Energy savings from tree shade. *Ecological Economics, 69*(6), 1324-1329. https://doi.org/10.1016/j.ecolecon.2010.01.009.

Policy initiatives in the 2025/2030 CECP that may reduce energy costs through tree planting include, but are not limited to, incentivizing natural resource protection zoning (NRPZ), tree planting award payments to communities passing NRPZ, and increasing funding for the Greening the Gateway Cities program.

Improved Aesthetics of Landscape

Improved landscape aesthetics can be achieved through increasing the number of green spaces and open lands, where people can enjoy and admire nature. Maintaining the availability of open lands through conservation or preservation can help protect the visual beauty of existing landscapes. Urban aesthetics are also improved through tree planting and urban community farmlands or gardens. Research by Klein et al. (2015),[133] Wang et al. (2019),[134] and Konijnendijk et al. (2013)[135] noted how conservation of green spaces improves aesthetic appreciation and can improve individuals' mental health. Klein et al. (2015) found that visual aesthetic preference for landscape structures increased with greater amounts of buffer vegetation. Aesthetic preference refers to the perceived visual quality, satisfaction, or opinion of natural landscapes and green spaces. Similarly, Wang et al. (2019) found aesthetic preference increased with the number of visible trees, flowers, and water features. Konijnendijk et al. (2013) also noted that nature and green spaces can reduce stress and improve mental health. Furthermore, the aesthetic quality of land can positively influence restation or preservation efforts while increasing property values.

Policy initiatives in the 2025/2030 CECP that increase, preserve, or restore green space across the Commonwealth, include, but are not limited to, expanding land conservation grant programs to open lands, increasing funding for the Greening the Gateway Cities program, the Forest Resilience Program, and expanding wetland restoration.

Improved Visibility

Air pollution is composed of particulate matter and other pollutants which create smog or haze and reduce visibility. Tree planting or community garden development in urban areas could help reduce air pollution in cities. In rural areas, conserving open lands and forestlands could also help reduce air pollution. Trees and greenspaces remove air pollution by intercepting particles in the air.[136] Note, while some evidence suggests vegetation improves air quality, studies are mixed on the magnitude of the effect. Research by Vos et al. (2013)[137] found that, in some cases, urban vegetation does not reduce local air pollution and increased pollutant concentrations instead, due to the aerodynamic effect

[133] Klein, L., et al. (2015). Linking ecology and aesthetics in sustainable agricultural landscapes: lessons from the Palouse region of Washington, USA. *Landscape and Urban Planning, 134*, 195-209. https://doi.org/10.1016/j.landurbplan.2014.10.019.

[134] Wang, R., et al. (2019). Characteristics of urban green spaces in relation to aesthetic preference and stress recovery. *Urban Forestry & Urban Greening, 41*, 6-13. https://doi.org/10.1016/j.ufug.2019.03.005.

[135] Konijnendijk, C., et al. (2013). *Benefits of Urban Parks A Systematic Review – A Report for IFPRA*. IFPRA. https://www.researchgate.net/publication/267330243_Benefits_of_Urban_Parks_A_systematic_review_-_A_Report_for_IFPRA.

[136] Nowak, D. (2002). *The Effects of Urban Trees on Air Quality*. USDA Forest Service. https://www.nrs.fs.fed.us/units/urban/local-resources/downloads/Tree_Air_Qual.pdf.

[137] Vos, P., et al. (2013). Improving local air quality in cities: to tree or not to tree? *Environmental Pollution, 183*, 113-122. https://doi.org/10.1016/j.envpol.2012.10.021.

vegetation has on urban ventilation. However, research by Beckett et al. (2000)[138] noted how trees improve local air quality by reducing particulate matter concentrations. They found that trees with rough leaf surfaces are most effective at capturing particles. Research by Sullivan et al. (2018)[139] also examined how reductions in particulate matter and other pollutants increase visibility by improving haze.

Policies in the 2025/2030 CECP that may improve local air quality through greening, include, but are not limited to, incentivizing natural resource protection programs, tree retention bylaws, the Forest Resilience Program, and increasing funding for Greening the Gateway Cities program.

Reduced Heat Island Impacts

The urban heat island effect is a phenomenon where urban areas experience higher temperatures because buildings and roads absorb and re-emit the sun's heat more than natural landscapes.[140] Increasing park acreage or planting trees can help reduce heat islands by providing canopy covers and lowering temperatures. This relationship has been documented in studies by Cheela et al. (2021)[141] and Shishegar (2014),[142] who found that tree canopies and green spaces reduce daytime temperatures by providing shade and through evapotranspiration, the process by which water is transferred from earth's surface into the atmosphere. Cheela et al. (2021) found that integrating more urban forestry and green infrastructure can reduce the heat emitted from pavements. Shishegar (2014) also found that a major source of urban heat islands is the amount of heat produced from urban structures. As a mitigation measure, they suggested increasing urban green areas such as parks, trees, and green roofs to reduce air temperatures. In addition to direct cooling benefits, reductions in the heat island effect can also help reduce energy costs associated with cooling.

Policies in the 2025/2030 CECP that would reduce heat island impacts include, but are not limited to, tree planting award payments to communities passing NRPZ, tree planting payments from developers to offset tree removal, and increasing funding for the Greening the Gateway Cities program.

Reduction in Public Health Risks

Particulate matter poses several public health risks, including lung diseases, asthma, other respiratory diseases, and cardiovascular diseases. Some ways to reduce particulate matter and public health risks include protecting or conserving open lands, planting trees or gardens, and improving energy efficiency.

[138] Beckett, K., et al. (2000). Effective tree species for local air quality management. *Journal of Arboriculture, 26*(1). https://doi.org/10.48044/jauf.2000.002.

[139] Sullivan, T., et al. (2018). Air pollution success stories in the United States: the value of long-term observations. *Environmental Science & Policy, 84*, 69-73. https://doi.org/10.1016/j.envsci.2018.02.016.

[140]**Error! Hyperlink reference not valid.** US EPA. Learn About Heat Islands. US EPA. https://www.epa.gov/heatislands/learn-about-heat-islands.

[141] Cheela, V., et al. (2021). Combating Urban Heat Island Effect – A Review of Reflective Pavements and Tree Shading Strategies. *Buildings, 11*(3), 93. https://doi.org/10.3390/buildings11030093.

[142] Shishegar, N. (2014). The Impacts of Green Areas on Mitigating Urban Heat Island Effect: A Review. *The International Journal of Environmental Sustainability, 9*(1), 119-130. https://doi.org/10.18848/2325-1077/CGP/v09i01/55081.

As noted in the above section on improved visibility, while some evidence suggests vegetation improves air quality, studies are mixed on the magnitude of the effect (Vos et al., 2013; Beckett et al., 2000)[143, 144]

The relationship between reductions in particulate matter and public health benefits has been documented in research by Di et al. (2017)[145] and Woodruff et al. (2008).[146] Di et al. (2017) evaluated a cohort of nearly 61 million American adults over the age of 64, finding a nearly linear relationship between particulate matter exposure and mortality. Additional research by Woodruff et al. (2008)[147] document a similar relationship between elevated particulate matter exposure and neonatal death in a population of over 3.5 million infants.

Policies in the 2025/2030 CECP that may reduce public health risks through greening include, but are not limited to, tree planting award payments to communities passing NRPZ, adding a new riparian tree planting program, and the Forest Viability Program.

Improved Ability to Meet Emissions Reduction Targets

Greenhouse gas emissions targets are designed to reduce emissions by a certain amount at a specified date. Massachusetts's 2021 Climate Law requires at least 50% reduction in emissions by 2030, at least 75% reduction in emissions by 2040, and at least 85% reduction in emissions and achievement of net zero emissions by 2050.[148] Conservation and expansion of the state's natural carbon sequestration processes contributes toward attaining these targets. This can be achieved through policies designed to protect or conserve open lands, plant new trees or gardens, and preserve natural carbon sinks such as soils. Research by Akbari (2002)[149] noted the contribution urban trees make to carbon sequestration, finding that a tree planted in Los Angeles sequesters 18 kg of carbon annually.

Policies in the 2025/2030 CECP that may reduce emissions include, but are not limited to, expanding land conservation grant programs to forests, tree planting award payments to communities passing NRPZ, the Forest Resilience Program, the Municipal Vulnerability Preparedness program, and the Forest Viability Program.

[143] Vos, P., et al. (2013). Improving local air quality in cities: to tree or not to tree? *Environmental Pollution, 183*, 113-122. https://doi.org/10.1016/j.envpol.2012.10.021.
[144] Beckett, K., et al. (2000). Effective tree species for local air quality management. *Journal of Arboriculture, 26*(1). https://doi.org/10.48044/jauf.2000.002.
[145] Di, Q, Wang, Y, Zanobetti, A, Wang, Y, Koutrakis, P, Choirat, C, Dominici, F and Schwartz, JD (2017). Air pollution and mortality in the Medicare population. *New England Journal of Medicine,* 376(26): 2513-2522.
[146] Woodruff, TJ, Darrow, LA and Parker, JD (2008). Air pollution and postneonatal infant mortality in the United States, 1999–2002. *Environmental Health Perspectives*, 116(1): 110-115.
[147] Woodruff, TJ, Darrow, LA and Parker, JD (2008). Air pollution and postneonatal infant mortality in the United States, 1999–2002. Environmental Health Perspectives 116(1): 110-115.
[148] Chapter 8 of the Acts of 2021.
[149] Akbari, H. (2002). Shade trees reduce building energy use and CO2 emissions from power plants. *Environmental Pollution, 116*(S1), S119-S126. https://doi.org/10.1016/S0269-7491(01)00264-0.

APPENDIX E: CECP BENCHMARKS AND METRICS

E.1 OVERVIEW

An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy (The 2021 Climate Law) requires the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) to set several numerical benchmarks and track progress toward them over time. Based on the Pathways modeling conducted by Evolved Energy Research (see Appendix A for details on model methodology and results) to support the development of the 2025 and 2030 Clean Energy & Climate Plan, the following tables include key metrics related to the implementation of the Plan. In addition, where available, historical values for 2015 and 2020 are included in table.[150]

Following the publication of this Plan, EEA will commence work to develop a web-based dashboard where these metrics will be posted and tracked.

[150] Due to the COVID-19 pandemic, many of the key metrics for 2020 are outliers from both historical trends and projections. This includes significant reductions to vehicle miles traveled, severe curtailment of passenger air travel, and changes in residential and commercial occupancy patterns in 2020 relative to past and future years. In addition, the late winter and early spring of 2015 was much colder than an average winter, both in terms of total heating degree days and minimum temperature. The summer of 2015 was also abnormally warm. In contrast, the late winter and early spring of 2020 were exceptionally mild. In addition to weather variation and the global pandemic, between 2015 and 2020, many key decarbonization policies saw advances, such as a nearly ten-fold increase in the number of electric vehicles on the road between 2015 and 2020. Together these two historical years should provide a snapshot of how much—or how little—key technologies can turn over, the extent to which societal trends and external factors can impact energy use and GHG emissions, the scale of possible change over a five-year period, and the level of uncertainty associated with evaluating only a single year.

E.2 TRANSPORTATION SECTOR METRICS

Transportation Sector Metrics	2015 Historical	2020 Historical	2025 Targets	2030 Targets	Historical Source	Model Source
Travel Demand						
Total annual light duty VMT (billion miles) [151]	53.6	51.9	57.9	59.1	FHWA	AEO Forecast
Total light-duty vehicles (thousands)	4,979	5,165	5,177	5,226	Mass. RMV	AEO Forecast
Total medium- and heavy-duty vehicles (thousands)	301	215	242	273	Mass. RMV	AEO Forecast
Light-duty vehicles per household	2.0	1.9	1.9	1.8	Computation	Computation
Total households (millions)	2.55	2.66	2.79	2.90	ACS	AEO Forecast
Vehicle miles traveled (VMT) per household (thousand miles)	21.0	19.5	20.8	20.4	Computation	Computation
Share of commuting trips by single-occupancy vehicles	72%	not yet available	n/a	60%	ACS	n/a
Vehicle Electrification						
Number of light-duty electric vehicles (EVs) (thousands) [152]	4.7	29.3	224.4	1,003.2	MassDEP EVIP	EnergyPathways
EV Share of light-duty fleet	0.1%	0.6%	4.3%	19.2%	Computation	Computation
Number of zero emissions trucks and buses	33	40	3,200	26,936	n/a	EnergyPathways
EV share of MHDV fleet	0.0%	0.0%	1.3%	9.9%	Computation	Computation
Public-Access Chargers (ports)	-	unknown	15,000	75,000	n/a	Cadmus EVSE Model [153]
Transportation Energy Use						
Total energy consumption (trillion BTU)	466	364	390	338	EIA SEDS	EnergyPathways
Electricity consumption (trillion BTU)	1	1	6	23	EIA SEDS	EnergyPathways
Motor gasoline consumption (trillion BTU)	324	266	242	181	EIA SEDS	EnergyPathways
Diesel consumption (trillion BTU)	66	63	63	55	EIA SEDS	EnergyPathways
Jet fuel consumption (trillion BTU)	59	28	71	70	EIA SEDS	EnergyPathways
All other transportation fuel consumption (trillion BTU)	15	6	8	9	EIA SEDS	EnergyPathways

[151] Light-Duty VMT includes a small amount of commercial light-duty mileage.
[152] Includes battery-electric, plug-in hybrid electric, and hydrogen fuel-cell vehicles.
[153] See the 2050 Roadmap Study's Transportation Sector Technical Report for model methodology and details.

E.3 BUILDINGS SECTOR METRICS

Buildings Sector	2015 Historical	2020 Historical	2025 Targets	2030 Targets	Historical Source	Model Source
Total households (millions)	2.55	2.66	2.79	2.90	ACS	AEO Forecast
Primary Electric Space Heating						
Total homes with electric space heating (millions)	0.37	0.60	0.72	1.11	ACS	EnergyPathways
Homes with electric resistance space heating (millions)	unknown	0.32	0.33	0.31	n/a	EnergyPathways
Homes with partial-home heat pump space heating (millions)	unknown	0.22	0.32	0.61	n/a	EnergyPathways
Homes with whole-home air source heat pump space heating (millions)	unknown	0.04	0.05	0.14	n/a	EnergyPathways
Homes with whole-home ground source heat pump space heating (millions)	unknown	0.02	0.02	0.04	n/a	EnergyPathways
Share of total households electrified	14%	22%	26%	38%	Computation	EnergyPathways
Weatherization						
Total households with upgraded envelopes (millions)	unknown	-	0.05	0.23	n/a	EnergyPathways
Residential Final Energy Demand						
Total energy consumption (trillion BTU)	303	280	275	257	EIA SEDS	EnergyPathways
Electricity consumption (trillion BTU)	69	87	86	95	EIA SEDS	EnergyPathways
Pipeline gas consumption (trillion BTU)	130	115	111	93	EIA SEDS	EnergyPathways
Distillate fuel oil consumption (trillion BTU)	83	54	53	46	EIA SEDS	EnergyPathways
Liquid petroleum gas consumption (trillion BTU)	8	13	12	10	EIA SEDS	EnergyPathways
All other fuel consumption (trillion BTU)	13	12	13	13	EIA SEDS	EnergyPathways
Commercial Final Energy Demand						
Total energy consumption	232	210	218	200	EIA SEDS	EnergyPathways
Electricity consumption (trillion BTU)	89	72	80	87	EIA SEDS	EnergyPathways
Pipeline gas consumption (trillion BTU)	108	81	84	65	EIA SEDS	EnergyPathways
Petroleum and other fuels (trillion BTU)	34	57	54	48	EIA SEDS	EnergyPathways
Alternative Renewable Thermal Resources						
Solar thermal generation (GWh)	-	not yet available	22	22	RPS/APS Compliance Report	Future years assumed to include 2019 generation used to meet APS obligation
Percent reduction in fuel oil carbon intensity	-	-	0%	20%	n/a	RIO
Percent reduction in pipeline gas carbon intensity	-	-	2%	5%	n/a	RIO

E.4 ELECTRICITY SECTOR METRICS

Electricity Sector	2015	2020	2025	2030	Historical Source	Model Source
Electricity Demand						
MA total load, inclusive of line loss (TWh)	58.1	53.0	60.8	72.8	ISO-NE	RIO
ISO-NE total load, inclusive of line loss (TWh)	107.9	116.9	137.4	165.8	ISO-NE	RIO
ISO-NE clean energy generation (TWh)[154]	55.8	53.4	82.8	126.3	ISO-NE	RIO
MA contribution toward ISO-NE coincident peak (GW)	11.5	11.7	12.9	13.4	ISO-NE	RIO
ISO-NE coincident peak (GW)[155]	24.4	25.1	28.2	30.1	ISO-NE	RIO
Deployment of Renewables						
MA installed offshore wind capacity (GW)	-	-	0.0	3.2	ISO-NE	RIO
MA installed photovoltaic capacity (GW)	1.0	3.4	4.5	8.4	ISO-NE	RIO
MA installed energy storage capacity (GW)[156]	1.8	1.8	2.6	2.9	ISO-NE	RIO

E.5 NON-ENERGY & INDUSTRIAL SECTOR METRICS

Non-Energy & Industrial Sector	2015	2020	2025	2030	Historical Source	Model Source
Industrial Final Energy Demand						
Total energy consumption	112	78	74	70	EIA SEDS	EnergyPathways
Electricity consumption (trillion BTU)	27	23	24	23	EIA SEDS	EnergyPathways/RIO
Fossil and other fuels and feedstocks (trillion BTU)	85	55	50	48	EIA SEDS	EnergyPathways
Waste						
Anaerobic Digesters (MWh)	43,837	not yet available	43,000	43,000	RPS/APS Compliance Report	n/a
Total Waste Disposal (million short tons)	5.5	5.9	n/a	4.0	MassDEP	Solid Waste Master Plan

[154] Clean energy generation includes solar, wind, nuclear, hydro, and net clean energy imports, such as from HydroQuebec.
[155] New England grid has proven reliable at a systemwide peak of 28 GW (July 2006).
[156] Includes bulk grid-connected storage, such as pumped hydro, but not distributed, behind-the-meter resources.

E.6 NATURAL & WORKING LANDS METRICS

Natural & Working Lands	2015	2019	2025	2030	Historical Source	Model Source
Net NWL Emissions	-7.0	-7.0	-7.0	-7.4	EPA NGGI, EPA SIT, EEA	Goal
Forest Ecosystem GHG flux ($MMTCO_2e$)	-5.9	-5.8	n/a	n/a	EPA NGGI, EPA SIT	n/a
Cropland & Grassland GHG flux ($MMTCO_2e$)	0.2	0.3	n/a	n/a	EPA NGGI	n/a
Wetlands GHG flux ($MMTCO_2e$) * Includes only coastal wetland GHG flux at this time but will be updated to include inland wetland GHG flux	-0.2*	-0.2*	n/a	n/a	EPA NGGI, EEA	n/a
Settlements GHG flux ($MMTCO_2e$)	-1.3	-1.3	n/a	n/a	EPA NGGI	n/a
NWL Conservation						
Land and water permanently conserved (million acres)	unknown	1.38 (27% of all land and water, as of 2021)	1.45 (28%)	1.55 (30%)	MassGIS OpenSpace datalayer	Goal
NWL Management						
Privately-owned forests adopting climate-smart management practices	unknown	<11% (as of 2021)	n/a	20%	MassGIS Property Tax Parcels data: Chapter 61 enrollment	Goal
Tree Planting						
Urban and riparian trees planted (trees)	n/a	~30,000 (as of 2021)	35,000	46,100	DCR	Goal

APPENDIX F: SUMMARY OF PUBLIC PROCESS AND COMMENTS

F.1 SUMMARY OF PUBLIC ENGAGEMENT

Massachusetts Executive Office of Energy and Environmental Affairs (EEA) solicited public feedback throughout the development of the 2025 and 2030 Clean Energy and Climate Plan (2025/2030 CECP). The process to finalize the 2025/2030 CECP included reviewing the comments on the interim Clean Energy and Climate Plan for 2030 (Interim 2030 CECP), which EEA released for public comment in December 2020. EEA received stakeholder input and feedback through multiple public engagements and public comment processes.

Two advisory groups held meetings that helped to provide input and feedback that informed development of the 2025/2030 CECP:

- The Global Warming Solutions Act Implementation Advisory Committee (IAC) is a public body that advises EEA on GHG reduction measures. The IAC provided input on the approaches that the Commonwealth could take to reduce GHG emissions, particularly through the development of the Interim 2030 CECP. The IAC provided comments that included recommendations of policies for EEA's consideration in finalizing the scope of the 2050 Decarbonization Roadmap Study.[157] The IAC also provided recommendations for policy priorities for 2020 through 2030.[158] The IAC held six meetings throughout development of the 2025/2030 CECP: April 12, 2021; June 28, 2021; October 12, 2021; December 10, 2021; February 28, 2022; and April 29, 2022. In addition, the IAC held working group meetings on a regular basis to discuss sector-specific policies and consult on other topics related to the CECP. The IAC working groups include the Buildings Working Group, Transportation Working Group, Climate Justice Working Group, Land Use and Nature-Based Solutions Working Group, and Electricity Working Group.
- The Commission on Clean Heat, established in late 2021, is set up to advise the Baker-Polito Administration on policies to reduce GHG emissions from heating fuels. The Commission on Clean Heat held eight meetings prior to the development of this 2025/2030 CECP: January 12, 2022; January 26, 2022; February 9, 2022; February 17, 2022; March 9, 2022; March 23, 2022; April 6, 2022; and April 27, 2022.

Numerous other entities held public meetings or discussions with EEA regarding Massachusetts policies and practices that indirectly informed development of the 2025/2030 CECP or were incorporated into the 2025/2030 CECP. Those include:

[157] The IAC submitted these recommendations to EEA on August 22, 2019. The recommendations are available at https://www.mass.gov/doc/master-policy-list/download.
[158] The IAC submitted these recommendations to EEA on October 22, 2020. The recommendations are available at https://www.mass.gov/doc/iac-work-group-proposed-guiding-principles-and-policy-priorities-updated-10262020/download.

- The Zero Emission Vehicle (ZEV) Commission, a Massachusetts commission established to expand access to and encourage the purchase and lease of zero emission vehicles, held four meetings on February 12, 2021; May 5, 2021; July 23, 2021; and April 15, 2022.
- EEA hosted four Environmental Justice (EJ) Stakeholder Focus Group Sessions on March 29, 2021; April 1, 2021; May 25, 2021; and May 26, 2021. These sessions covered the topics of *Urban and Rural Land Preservation and Land Use; Protection, Use, and Stewardship of Natural Resources; Energy and the Green Transition*; and *Urban Water Quality, Air Quality and Toxics*.[159]
- The Massachusetts Environmental Policy Act (MEPA) Advisory Board regularly engaged with EEA staff and stakeholders.
- The Energy Efficiency Advisory Council (EEAC) regularly engaged with EEA staff and stakeholders on the energy efficiency programs.
- The Commission on Clean Heat held four public webinars: two on March 1, 2022, and two on March 24, 2022.
- The Department of Energy Resources (DOER) held five public webinars on the straw proposal for Stretch Code updates and a new Specialized Stretch Code on March 2, 2022 (focused on the Western Region); March 3, 2022 (focused on Metro Boston and the Northeastern Region); March 4, 2022 (focused on EJ communities); March 7, 2022 (focused on the Central Region); and March 8, 2022 (focused on the Southeastern Region).
- EEA held a technical workshop on November 9, 2021, with technical experts on ways to characterize land use, land cover, and carbon dynamics for Massachusetts' natural and working lands (NWL) GHG Inventory.
- EEA held a technical workshop on March 28, 2022, with technical and subject matter experts and members of the IAC's Land Use and Nature-Based Solutions Work Group on NWL GHG accounting and goal setting.

In addition to these engagements, EEA directly solicited public comment on the CECP:

- EEA solicited public feedback on the Interim 2030 CECP from January 7, 2021, through March 22, 2021. EEA accepted comments by e-mail; through an online survey; by phone; and at two public webinars on March 9, 2021, and March 15, 2021.
- EEA held virtual public meetings on its approach to the 2025/2030 CECP on the evening of October 14, 2021, and the afternoon of October 15, 2021. Public feedback was solicited through December 24, 2021, on the following questions:
    1. Do you have any concerns with EEA setting limits on gross emissions while tracking and lowering net emissions through goal setting and policy development?
    2. Do you have any concerns with EEA setting emissions sublimits to be consistent with the categories already in the statewide greenhouse gas emissions inventory?

[159] Summary of these focus session comments is available in multiple languages at https://www.mass.gov/info-details/environmental-justice-public-involvement.

3. Do you have any concerns regarding moving forward with the approach described today in completing the Clean Energy and Climate Plan for 2025 and 2030?

- EEA held three public webinars to inform the development of the Natural and Working Lands Plan of the 2025/2030 CECP, as required by the 2021 Climate Law. The first was held on December 21, 2021, and focused on Natural and Working Lands strategies. Webinars held on January 14, 2022, and February 11, 2022, focused specifically on potential forest carbon goals and policies.
- EEA held virtual public hearings on proposed economy-wide emissions limits, sector-specific sublimits, goals, and policies for the 2025/2030 CECP on April 14, 2022 (afternoon and evening sessions), and April 15, 2022 (afternoon session). A copy of the presentation slide deck for the hearings was posted online and emailed to a distribution list on April 12, 2021. EEA accepted public comments submitted via a web survey and by email through April 30, 2022.

F.2 COMMENTS RECEIVED

EEA received a total of 1,277 public comments on the Interim 2030 CECP and proposals for the 2025/2030 CECP. All comments were reviewed and considered in the development of the 2025/2030 CECP.

During the Interim 2030 CECP public comment period (January 7, 2021 – March 22, 2021), EEA received 1,136 total comment submissions, in the form of letters, survey responses, emails, letters, public meeting comments, and voicemails. Form letters comprised about half of submitted comments. EEA received three different form letters: one organized by Mass Audubon; another concerning Canadian hydropower; and a third addressing environmental justice.

There were 352 submissions of a letter organized by Mass Audubon. This letter included suggestions for increasing the 2030 emissions reduction target, strengthening protections for natural and working lands, developing additional strategies to manage trade-offs between sectors (e.g., solar development vs. forest protection), minimizing impacts of offshore wind development, and prioritizing projects benefiting EJ communities.

There were 138 submissions of a letter concerning Canadian hydropower. The letter urged EEA to remove Canadian hydropower from the plan due to concerns about the impact of operations on Indigenous lands in Canada and concerns that the hydroelectricity produced in Canada is not environmentally friendly.

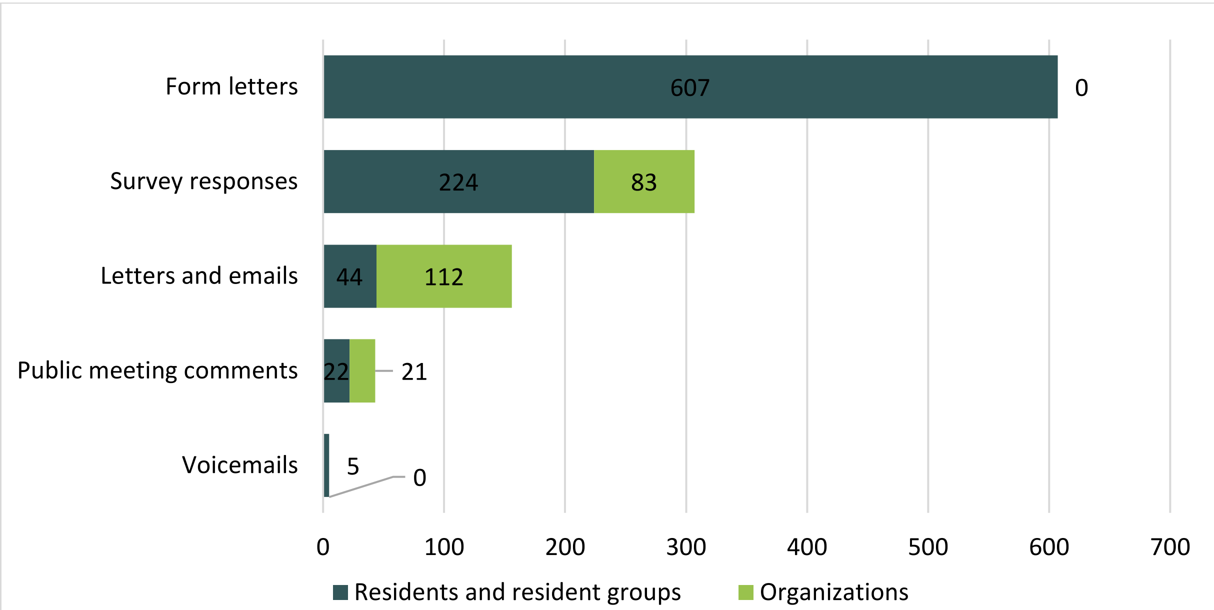
The third letter, relating to EJ, was submitted 117 times. That letter provides four recommendations: provide incentives for heat pumps for low- and moderate-income families; set goals for accessible, clean transportation options for all; set pollution targets for polluted neighborhoods; protect and expand tree cover.

The largest number of unique comments were submitted through the online survey (307 comments) or by email (156 comments). The online survey allowed users to indicate specific topics of their comments, input free text, and optionally attach files, while many emailed comments included letter attachments.

In addition, EEA received oral comments at public meetings on March 9, 2021, and March 15, 2021 (43 total comments) and as voicemails (5 comments).

Figure F.1 shows the breakdown of comments received, by mode of submission and by type of submitter (i.e., individual residents and resident groups, or organizations).

Figure F.1. Types of Public Comments Received During Comment Period for the Interim 2030 CECP, January 7–March 22, 2021



Massachusetts residents and resident-led groups submitted 80% of all comments during the Interim 2030 CECP comment period. Examples of resident-led groups include local environmental interest groups, residential groups, and resident advocacy groups. In the two public meetings regarding the Interim 2030 CECP, resident-led groups voiced over one-quarter of all comments.

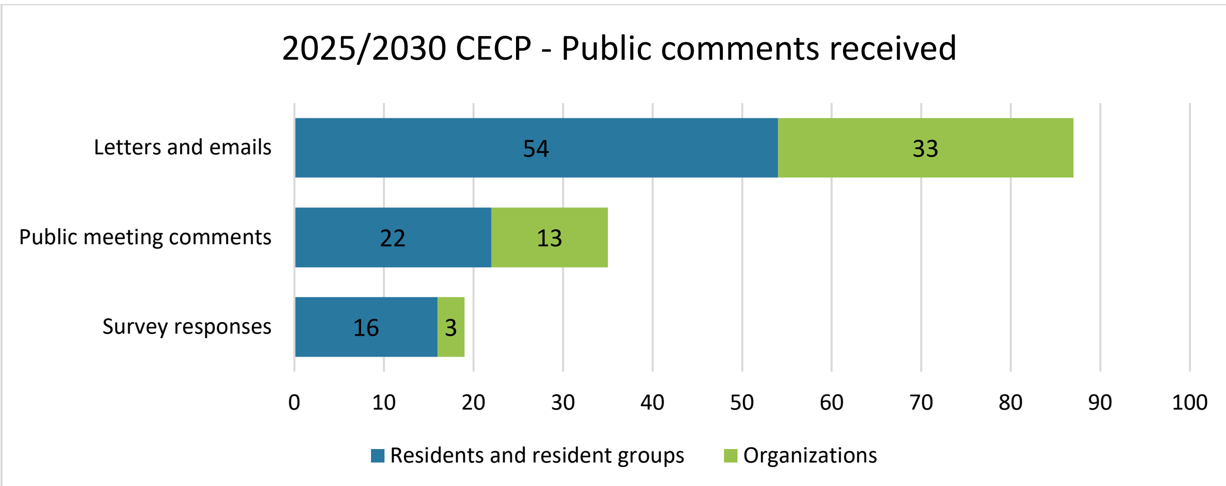
Other organizations provided their comments primarily by emailing letters to EEA. One hundred twelve (112) letters or emails were identified as being submitted by organizations. The types of organizations submitting letters are shown in Table F.1. Business groups and non-governmental organizations (NGOs) submitted the most organizational letters.

Table F.1. Letters and Emails Received During Comment Period for the Interim 2030 CECP, January 7–March 22, 2021.

Organization Type	Letters and Emails
Business	48
Non-Governmental Organizations	44
Political or Municipal Groups	13
Labor Representatives	4
Health Care Sector	3
Total	112

EEA received additional comments for the 2025/2030 CECP. EEA's email account remained opened throughout 2021 and until April 30, 2022, to receive public comments. During that time, EEA received 141 comments, especially after April 12 when a copy of the public hearing presentation slides was available to the public and after the public hearings were conducted on April 14 and 15. As shown in Table F.2, the majority of these comments (87 comments) were submitted by email. Comments provided at the April 14 and 15 public meetings totaled 35. EEA's survey received 19 responses.

Table F.2. Types of Public Comments Received on the 2025/2030 CECP, October 2021–April 30, 2022.



Residents and resident-led groups submitted 65% of all comments during the comment period on the 2025/2030 CECP. Organizations, which often submit longer, more detailed comments compared with residents and resident groups, submitted 35% of comments and 38% of letters and emails submitted during this period. A total of 33 letters or emails were identified as being submitted by organizations as shown in Table F.3. During the 2025/2030 CECP comment period, environmental NGOs comprised the majority of organizations submitting letters.

Table F.3. Organizational letters and emails received during the 2025/2030 CECP comment period, October 2021 – April 30, 2022.

Organization Type	Letters and Emails
Business	**10**
Non-Governmental Organizations	**21**
Political or Municipal Groups	**2**
Total	**33**

A review of the types of organizations submitting comments shows that environmental interests were the most prevalent. Similarly, the majority of resident commenters expressed a desire to protect and restore the environment. Key topics and recommendations are summarized in the next section.

F.3 SUMMARY OF KEY FEEDBACK AND EEA RESPONSES

Generally, most commenters broadly supported the 2025/2030 CECP. Commenters raised specific points on which they offered ideas for improving the Plan. EEA has reviewed all comments received and incorporated public input into the 2025/2030 CECP where possible. Some comments received and suggestions made may not be reflected in this 2025/2030 CECP, but they will be considered in the development of future CECPs.

The bulleted list below summarizes feedback received, followed by EEA's response. The feedback summarized here includes the most common and most actionable comments pertaining to the Interim 2030 CECP or the 2025/2030 CECP. EEA will continue to solicit, document, and consider public feedback as a valuable source of insight and suggestions.

Below, comments are presented in three groups:

A. Feedback that EEA incorporated into the 2025/2030 CECP;
B. Feedback that EEA has not incorporate into the 2025/2030 CECP, but will consider in future CECPs; and
C. Feedback that EEA has considered, but has decided that the perspective provided or the approach suggested are not fitting for the 2025/2030 CECP.

A. FEEDBACKS THAT HAVE BEEN INCORPORATED INTO THE 2025/2030 CECP

Feedback: Anchor equity and justice throughout the CECP in a cross-cutting manner; consider EJ throughout plan development.

- Response: The Administration is committed to enhancing EJ considerations in all aspects of policy development and the 2025/2030 CECP. Guided by the EJ Policy and informed by feedback from the IAC's Climate Justice Work Group and the EJ Stakeholder Focus Group Sessions in 2021, this CECP includes considerations for prioritizing climate investments in EJ neighborhoods while ensuring that improvement actions do not induce the displacement of residents of those neighborhoods. This CECP includes policies that help reduce the cost of clean energy to low- and moderate-income (LMI) residents; ensure training and workforce development for incumbent workers and new entrants to the work force, prioritizing traditionally hard-to-reach and EJ populations; and minimize negative outcomes on EJ populations, particularly those who have been already disproportionately affected through historical development, permitting, and siting decisions.

Feedback: Zero emission vehicles (ZEV) incentives should be offered at point of sale; increase incentives for LMI consumers.

- Response: The 2025/2030 CECP includes providing ZEV rebates at point of sale with targeted additional incentives for LMI residents and high mileage drivers.

Feedback: Electrify more vehicles sooner, including state and municipal fleets, and add goals for medium- and heavy-duty vehicles.

- Response: The 2025/2030 CECP includes goals and policies to aggressively electrify cars and trucks of varying duty cycles, including policies to increase the electrification of state and municipal vehicle fleets. The Administration is focused on achieving these ambitious goals, which will require significant investments in private and public vehicle fleets.

Feedback: Set an explicit goal for electric vehicle (EV) charging infrastructure buildout by charger type.

- Response: The 2025/2030 CECP includes a breakdown of EV charging infrastructure goals for level 2 (L2) and direct current fast charging (DCFC) chargers.

Feedback: Support alternative transportation methods, including bike/pedestrian and transit infrastructure, e-bike incentives, hydrogen fuel cell vehicles, and pods.

- Response: The 2025/2030 CECP includes objectives to increase bike, pedestrian, and bus infrastructure through recommended additional funding for the Massachusetts Department of Transportation (MassDOT) Complete Streets and Shared Streets and Spaces grant programs, and through a recommended new incentive for e-bikes. Hydrogen fuel cell vehicles have been included in vehicle incentive programs, and the Administration recently committed to joining a regional consortium to explore hydrogen buildout for hard-to-electrify segments and other applications.

Feedback: Some commenters wanted to implement mandatory net zero codes sooner; others wanted to delay statewide net zero implementation due to its cost. Some commenters did not want to allow municipalities to opt in to net zero code, but instead create a uniform statewide code.

- Response: The Stretch Energy Code and Specialized Stretch Energy Code are both being implemented by DOER pursuant to legislative mandates from the 2021 Climate Law, including applicability and timing. Comments received are being considered in the ongoing development of the building codes.

Feedback: Some commenters suggested incentivizing other heating options as the suggested pace of electrification is infeasible; others suggested that potential future use of alternative heating options should not delay electrification. Existing gas infrastructure could be used to develop geothermal micro-districts.

- Response: The Commonwealth's near-term building decarbonization strategy focuses on the rapid deployment of electrified space heating in as many feasible and cost-effective instances as possible. In the long term, this strategy focuses on full and widespread electrification of heating systems, including both air-source and ground-source (geothermal) heat pumps. However, the 2025/2030 CECP also includes the objective of piloting and evaluating several nascent alternative technologies, including low-carbon liquid and gas drop-ins and micro-district approaches. Future CECPs will need to adapt to the changes to technologies and their relative costs.

Feedback: Gas utilities' plans submitted to the Department of Public Utilities (DPU) 20-80 include findings that do not seem to be consistent with the 2050 Roadmap.

- Response: The 2025/2030 CECP includes the objective of continuing to work with the gas and electric utilities after the conclusion of DPU Docket 20-80 to develop integrated infrastructure plans that are consistent with the pathways modeling executed to support development of the CECP.

Feedback: Some commenters recommended more wind and solar development than what is in the plan.

- Response: As discussed in the 2025/2030 CECP, DOER and the Massachusetts Clean Energy Center are evaluating ways to remove barriers to such technologies. Offshore wind projects take many years to develop, site, and build. All projects that can be complete by 2030 are currently underway. DOER is already working on projects that are likely to be completed as late as 2034.

The Commonwealth has several policies intended to support the development of solar resources as they are an important component of the future clean energy portfolio.

Feedback: General concerns were raised around infrastructure siting and impacts on EJ communities.

- Response: The 2025/2030 CECP includes key objectives around explicitly incorporating EJ in siting decisions.

Feedback: Rate protections will be needed for LMI customers continuing to use natural gas.

- Response: The 2025/2030 CECP includes key objectives around reducing rate impacts and developing new rates to protect LMI customers.

Feedback: Some commenters suggested setting specific goals for biogenic sequestration, conservation, reforestation, and restoration of natural and working lands (NWL).

- Response: The 2025/2030 CECP includes specific goals for net NWL emissions, NWL conservation, tree planting, and restoration of wetland carbon storage.

Feedback: Include more strategies to reduce emissions in the agricultural sector and provide incentives to support farmers.

- Response: The 2025/2030 CECP includes a policy to provide additional incentives to Massachusetts farmers for implementing healthy soils practices that can reduce emissions from agricultural soil management.

Feedback: Include a goal to protect and restore tree cover, especially in urban EJ communities.

- Response: The 2025/2030 CECP includes a specific goal for new tree planting and policies to increase tree planting in and near EJ neighborhoods. The Plan also has a policy to enhance municipalities' adoption of a tree protection bylaw.

Feedback: Opinions varied on whether any logging or tree cutting should occur, particularly on public lands. Some commenters believe no logging should occur, while others, including forestry organizations, suggested some logging is beneficial to forest health and sequestration.

- Response: The Administration understands the importance of forests and the ecosystem services they provide. Policies in the 2025/2030 CECP are focused on the primary strategy of protecting NWL from conversion and climate-smart management of forest lands (i.e., forests remaining forests) for wildlife habitat and ecosystem resilience, especially in response to invasive pests and more frequent severe weather events from climate change.

Feedback: Opinions varied on whether the use of wood as a building material is a net positive benefit or a net negative benefit for carbon. In particular, commenters cited embodied carbon in concrete and steel as evidence that wood is preferable. Opponents of wood use cited lifecycle considerations, including tree cutting.

- Response: Policies in the 2025/2030 CECP are focused on the primary strategy of protecting NWL from conversion, with a secondary focus on climate smart management of forest lands (i.e., forests remaining forests) that does include some tree removal for invasive pest management, wildlife habitat, and continued ecosystem resilience. This Plan also includes objectives to better track the carbon emissions associated with timber harvest and wood processing in Massachusetts and determine how to further reduce carbon emissions from necessary tree removal.

Feedback: Some commenters, including environmental NGOs, opposed development in the outer 50-foot wetland buffer, but supported streamlined permitting for wetlands restoration projects in this zone.

- Response: The Administration hears the concerns from public comments on incentivizing development within the 100-foot wetland buffer zone. MassDEP will further investigate how best to protect wetlands and adjacent land against conversions for development.

Feedback: Maximize/incentivize solar siting on degraded or low-quality farmland and developed areas and protect forests from solar development.

- Response: DOER is considering updates to its Solar Massachusetts Renewable Target (SMART) program to increase dual-use of land for agriculture and solar. SMART already includes stipulations to reduce forest conversions for solar deployment.

Feedback: More connected storage and pumped-storage hydropower will be needed.

- Response: Modeling does indicate that additional electricity storage will be needed to cost-effectively and reliably operate an electricity grid composed of mostly renewable resources. DOER's SMART II tariff includes adders to encourage solar projects to include storage and the Clean Peak Standard will support the deployment and utilization of storage connected to clean resources instead of "peaker" plants.

Feedback: Several commenters advocated for going beyond "no net loss" of NWL and instead increase protected/natural lands.

- Response: The 2025/2030 CECP commits the EEA and state agencies to double statewide conservation of NWL through 2030. The Plan also has a policy to enhance municipalities' adoption of a tree protection bylaw. The Administration will partner with municipalities, land trusts, and others to encourage additional NWL conservation.

Feedback: Several commenters expressed concerns about the accuracy of EPA/MassDEP gas leak accounting.

- Response: MassDEP and the U.S. Environmental Protection Agency (EPA) continually monitor emerging research and routinely incorporate new information into its procedures.

B. SOME FEEDBACK WASNOT INCORPORATED INTO THIS 2025/2030 CECP, BUT WILL BE CONSIDERED IN FUTURE CECPS OR DURING CLIMATE POLICY IMPLEMENTATION BECAUSE THEY SERVE LONGER-TERM GOALS.

Feedback: Ensure funding is available, with particular attention to ensuring accessibility in LMI and EJ communities.

- Response: The Administration continues to seek sustainable funding to support decarbonization efforts in Massachusetts and is cognizant of the costs of policies to rate payers and residents, particularly EJ and LMI communities.

Feedback: Ensure equitable distribution of access, funding, and benefits from proposals and inclusion of people of color, LMI individuals, renters, and Tribes and Indigenous communities.

- Response: The Administration is committed to increasing language access, participatory processes, and benefits to EJ communities and LMI residents. While the 2025/2030 CECP has policies with these objectives, the Administration will continue to improve. Through the EJ Office, the Administration will continue to reach out to and engage with EJ populations, Tribes and Indigenous communities, and other underrepresented groups in future policy development.

Feedback: Support, expand, and electrify public transit infrastructure and expand service.

- Response: The 2025/2030 CECP emphasizes the importance of supporting the Massachusetts Bay Transportation Authority (MBTA) to fully execute its Bus Modernization Program, including the full electrification of the MBTA bus fleet by 2040 and expanded bus service to nearly 300,000 Massachusetts residents by 2030. The Administration is also committed to providing safe and reliable public transit infrastructure and will consider ways to expand transit service in places where it is likely to be an effective and attractive mode of travel, using additional available funding.

Feedback: Reduce, don't just stabilize, vehicle miles traveled (VMT).

- Response: Massachusetts will continue to expand policies to reduce VMT, by encouraging municipalities to build more housing near transit; expanding infrastructure to support bikes and pedestrians through the Complete Streets and Shared Streets and Spaces grant programs; improving public transportation in places where it makes sense to do so; and working with employers to cut down on unnecessary work-related driving. Recognizing the limits of state policy to influence personal transportation behavior, the difficulty achieving VMT reductions thus far, and the legally binding nature of the state's obligations under the GWSA, our modeling anticipates only modest reductions compared to baseline assumptions. However, these programs may inspire greater changes in travel behavior than we anticipate, which would achieve greater emissions reductions.

Feedback: Many commenters supported the Transportation and Climate Initiative Program (TCI-P). In the absence of TCI-P adoption, commenters advocated for the establishment of alternative funding sources to replace it.

- Response: The Commonwealth welcomes new federal funding for transportation infrastructure, which will provide five years' worth of additional support for maintaining and improving all of our transportation facilities. The Commonwealth will also explore additional sources of funding for transportation investments.

Feedback: Increase the Clean Energy Standard to 100% by 2035.

- Response: MassDEP will evaluate this option as it begins administrative procedures to update the Clean Energy Standard.

Feedback: Many commenters called for an end to incentives for biomass combustion, while other commenters suggested efficient biomass combustion could help immediately reduce fossil fuel use.

- Response: EEA and DOER are working to develop nuanced policies that drive forward as many key priorities as possible.

Feedback: Utilities noted that meeting SF_6 regulations will be challenging given the need for more electricity infrastructure.

- Response: Going forward, more work is necessary to deploy approaches that reduce SF_6 in electricity infrastructure.

Feedback: Several commenters advocated to end waste incineration.

- Response: MassDEP will make a concerted effort to improve the performance of existing combustion capacity and analyze potential approaches to reducing carbon dioxide emissions from municipal waste combustors (MWCs), including capping the emissions from MWCs. Going forward, MassDEP anticipates that replacement of MWC capacity will be required to meet tighter emissions and efficiency standards and increase separation of recyclable materials.

Feedback: Some energy companies expressed a preference for pumped-storage hydropower as energy storage.

- Response: Modeling of electricity systems finds lithium-ion batteries to be more cost effective than building new pumped-storage hydropower in cases where short-duration storage is needed. However, new pumped-storage may become more cost effective in the future when long-duration storage is needed. More analyses on pumped-storage will be needed for future CECPs.

C. SOME FEEDBACK WAS REVIEWED AND CONSIDERED, BUT DIFFERENCES IN PERSPECTIVES HAVE LED TO EEA NOT ADOPTING THE SUGGESTIONS MADE.

Feedback: Some commenters expressed concerns regarding the speed of development and lack of time and information to provide informed comments on the 2025/2030 CECP.

- Response: The Administration published the Interim 2030 CECP for public comment—alongside the 2050 Roadmap Study, six technical appendices, and the data resources behind these analyses—18 months before the 2025/2030 CECP is finalized. Since then, EEA has held nine public sessions explicitly about the CECP and reviewed more than 1,200 public comments. Based on these comments, the Administration has amended and redrafted many policies, taking into account the feedback received. In addition, updated analyses for the 2025/2030 CECP helped to evaluate some suggested directions in detail. The final text and data published herein include and incorporate many comments received since January 2021.

Feedback: Utilities and industry groups supported technology-agnostic approaches instead of incentives for specific technologies, specifically for energy and buildings.

- Response: The pathways analysis supporting the 2025/2030 CECP includes the deployment of a range of technologies and solutions. Given what is known today and what is knowable today, electric heat pumps seem to be the best approach to decarbonize building heat. If technologies evolve in the future such that better technologies or lower cost approaches materialize, Massachusetts will shift its policies and programs in the new direction(s).

Feedback: Some advocates wanted to end Mass Save incentives for fossil fuel equipment immediately; some commenters associated with utilities and the fuel industry argued that abandoning fossil fuel incentives is premature.

- Response: Directionally, the dominant strategy for decarbonizing building heat is through electrification in this 2025/2030 CECP. A public commission (the Energy Efficiency Advisory Council) and utilities will continue to analyze future options for delivering on this objective.

Feedback: Many commenters opposed procurement of hydropower from Canada; a form letter against importing Canadian hydropower was submitted over 100 times.

- Response: Modeling of electricity systems finds hydroelectric resources, such as those from Canada, to be the lowest-cost approach for providing clean, dispatchable electricity.

Feedback: Many residents suggested banning gas-powered leaf blowers.

- Response: The 2025/2030 CECP does not have an objective on this explicitly, but greater use of electric appliances is directionally consistent with the CECP.