DECEMBER 2022

Clean Energy and Climate Plan for 2050

Executive Office of Energy and Environmental Affairs

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LETTER FROM THE SECRETARY

I am pleased to present the Massachusetts Clean Energy and Climate Plan for 2050 ("2050 CECP" or "Plan"), as required by the Global Warming Solutions Act of 2008 and the 2021 Climate Law (An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy). The Commonwealth continues to be a recognized national leader in climate action through strategic planning, robust outreach, and thoughtful policy development. Over the past eight years, the Baker-Polito Administration has taken an ambitious approach to combat climate change and lay the groundwork for Massachusetts to successfully achieve Net Zero in 2050 in an equitable and just manner.

Similar to the Clean Energy and Climate Plan for 2025 and 2030, this Plan continues Massachusetts' nation-leading efforts in identifying comprehensive and detailed strategies to achieve Net Zero in 2050. Together, these Plans continue to build the pathway to a future that will provide clean air for our citizens, improve the built environment, construct reliable energy systems, and achieve greenhouse gas emissions reduction over both the near and the longer term. Significantly, this Plan builds upon years of clean energy and climate planning and diligent efforts to advance climate mitigation and resiliency strategies while also considering feedback that numerous organizations and residents have provided to the Administration.

While technologies and practices will change over time, today, EEA is setting sector-specific sublimits based on the best available information. The sublimits will collectively reduce 2050 greenhouse gas emissions by more than 85% relative to the 1990 baseline level, and carbon sequestration will be used to absorb and store the remaining emissions to achieve Net Zero in 2050. Acknowledging that climate change poses a unique and potentially irreversible threat, this 2050 CECP underscores the Commonwealth's collective action plan for a future in which the energy used to heat our homes and businesses, power our vehicles, and generate electricity is cost-effective, equitable, and relies mainly on clean and renewable resources. Specifically, this Plan incorporates strategies to reduce negative environmental impacts and increase investments in environmental justice communities.

In addition to setting sector-specific strategies and the greenhouse gas emissions limits, this Plan prioritizes actions to achieve Net Zero through strategies that span across all sectors of our economy, such as expanding workforce development, supporting clean energy innovation, and ensuring a thriving and just economic transition that will benefit everyone.

I look forward to transitioning our work to the next Administration so that the implementation of the policies and programs in this 2050 CECP can continue to move our economy away from fossil fuels and ensure that all communities share in the benefits of a more sustainable future for our Commonwealth.

Sincerely,
BETHANY A. CARD
Secretary of Energy and Environmental Affairs

ACKNOWLEDGMENTS

Developing the Clean Energy and Climate Plan for 2050 required extensive analysis and planning under the leadership of:

Charlie Baker, Governor
Karyn Polito, Lieutenant Governor
Bethany A. Card, Secretary of Energy and Environmental Affairs
Judy Chang, Undersecretary of Energy and Climate Solutions

Numerous state agencies and programs, key stakeholders and stakeholder groups, technical and subject matter experts, and members of the public contributed valuable time and insights to ensure this Clean Energy and Climate Plan reflects the critical steps Massachusetts must take to decarbonize its economy over the coming three decades. The Executive Office of Energy and Environmental Affairs would especially like to acknowledge and thank the following individuals for their direct contributions to this Plan.

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EXPLANATION OF TERMS AND ACRONYMS

2021 Climate Law	An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy, signed into Massachusetts law in 2021
2022 Climate Act	An Act Driving Clean Energy and Offshore Wind, signed into Massachusetts law in 2022
AIM Act	American Innovation and Manufacturing Act, signed into U.S. law in 2020
AMI	Advanced metering infrastructure
Anaerobic Digesters	Sealed tanks that allow microorganisms to break down sewage and organic waste without using oxygen. The process emits methane gas that is captured and burned to create electricity and heat.
APS	Alternative Energy Portfolio Standard
ARPA	The American Rescue Plan Act, signed into U.S. law in 2021
Carbon Sequestration	The removal and storage of carbon dioxide from the atmosphere, commonly by plants and soil.
CCUS	Carbon capture, utilization, and storage
CDR	Carbon dioxide removal
CECP	Clean Energy and Climate Plan
CES	Clean Energy Standard
CHS	Clean Heat Standard
CO_2	Carbon dioxide
CPS	Clean Peak Standard
DCR	Massachusetts Department of Conservation and Recreation
DER	Distributed energy resource
DESE	Massachusetts Department of Elementary and Secondary Education
DFG/DER	Massachusetts Department of Fish and Game/Massachusetts Division of Ecological Restoration
DOER	Massachusetts Department of Energy Resources
DPH	Massachusetts Department of Public Health
DPU	Massachusetts Department of Public Utilities

E-bike	Electric bicycle
EDCs	Electric distribution companies
EEA	Massachusetts Executive Office of Energy and Environmental Affairs
EFSB	Energy Facilities Siting Board
EIA	U.S. Energy Information Administration
EJ	Environmental justice
EJTF	Environmental Justice Task Force
Emissions Limits	The level at which greenhouse gas emissions in Massachusetts cannot exceed
Emissions Sublimits	The level at which greenhouse gas emissions from a specific sector cannot exceed
EOHED	Massachusetts Executive Office of Housing and Economic Development
EOLWD	Massachusetts Executive Office of Labor and Workforce Development
EPA	U.S. Environmental Protection Agency
EVs	Electric vehicles
FERC	Federal Energy Regulatory Commission
FCEM	Forward Clean Energy Market
F-Gas	Fluorinated gas – Greenhouse gases that have fluorine, such as different types of hydrofluorocarbons (HFCs) and sulfur hexafluoride (SF_6).
GHG	Greenhouse gas – Greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), different types of hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6), trap heat and cause the average global air temperature to rise, thus changing weather patterns globally.
GHG Inventory	Greenhouse gas inventory – A report of emission sources and their annual emissions estimated using standardized methods
GMAC	Grid Modernization Advisory Council
Ground-Mounted Solar	Solar panels that are set up on the ground to capture energy from the sun to create electricity. (Rooftop solar is solar panels that are installed on top of buildings.)
GW	Gigawatt – Unit of power equivalent to one million kilowatts

GWh	Gigawatt hour – Unit of energy that is equivalent to one million kilowatt-hours, and often used as a measure of the output of large electricity power stations
GWP	Global warming potential
GWSA	Global Warming Solutions Act, as amended, signed into law in Massachusetts in 2008
HFC	Hydrofluorocarbon
HVAC	Heating, ventilation, and air conditioning
IAC	Implementation Advisory Committee
IIJA	Infrastructure Investment and Jobs Act, signed into U.S. law in 2021, also known as the Bipartisan Infrastructure Law or "BIL"
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act, signed into U.S. law in 2022
ISO-New England	Independent System Operator-New England
LBE	Leading by Example program, administered by DOER
LDCs	Local distribution companies – Investor-owned utilities that operate natural gas distribution systems
LMI	Low-to-moderate income
MassCEC	Massachusetts Clean Energy Center
MassDEP	Massachusetts Department of Environmental Protection
MassDevelopment	Massachusetts Development Finance Agency
MassDOT	Massachusetts Department of Transportation
Mass Save®	An initiative administered by Massachusetts' natural gas and electric utilities and energy efficiency service providers to offer a wide range of services promoting energy efficiency
MBTA	Massachusetts Bay Transportation Authority
MEPA	Massachusetts Environmental Policy Act
MDAR	Massachusetts Department of Agricultural Resources
$MMTCO_2e$	Million metric tons of carbon dioxide equivalent – A measure of greenhouse gas emissions. An emission of 1 $MMTCO_2e$ is equivalent to burning 112,523,911 gallons of gasoline.
MSBA	Massachusetts School Building Authority

MSW	Municipal solid waste
MW	Megawatts – Unit of power
MWh	Megawatt hour – Unit of energy that is equivalent to one thousand kilowatt-hours
MWBE	Minority and women-owned small business enterprises
NEPOOL	New England Power Pool
NESCOE	New England States Committee on Electricity
NO_x	Nitrogen oxides
NWL	Natural and working lands, as defined in Chapter 8 of the Acts of 2021
OSW	Off-shore wind
PIP	Public Involvement Plans
PM	Particulate matter
PV	Photovoltaics
RFS	Renewable Fuel Standard
RPS	Renewable Portfolio Standard
SF_6	Sulfur hexafluoride
SO_x	Sulfur oxides
SMART	Solar Massachusetts Renewable Target
Stretch building or energy code	Standards for energy usage in buildings and tightness of the building shell which newly constructed buildings must meet
SWMP	2030 Solid Waste Master Plan: Working Together Toward Zero Waste
TBtu	Trillion Btu (British Thermal Units) – Unit of heat energy
TWh	Terawatt Hour – Unit of energy equal to one thousand gigawatt hours
VMT	Vehicle miles traveled

EXECUTIVE SUMMARY

The Clean Energy and Climate Plan for 2050

By letter issued contemporaneously with this Clean Energy and Climate Plan for 2050 ("2050 CECP" or "Plan"), the Secretary of the Executive Office of Energy and Environmental Affairs (EEA) has established Net Zero as the 2050 statewide greenhouse gas (GHG) emissions limit. Reaching this limit requires an 85% reduction in GHG emissions from 1990 levels and a level of total emissions equal in quantity to the amount that is removed from the atmosphere and attributable to the Commonwealth. This 2050 CECP represents the Commonwealth of Massachusetts' overall policies and strategies to achieve Net Zero in 2050.

This Plan builds on years of analyses, stakeholder meetings, public hearings, and reports, including the 2020 Clean Energy and Climate Plan, the 2050 Massachusetts Decarbonization Roadmap, and the Clean Energy and Climate Plan for 2025 and 2030. It reflects the efforts of executive branch officials, legislators, advocacy groups, scientists, environmental justice (EJ) partners, industry stakeholders, utilities, and residents who care deeply about the Commonwealth's answers to critical questions facing our climate and energy systems.

Years of success in Massachusetts' climate and energy policy provide the foundation for this work. Over the past eight years, Massachusetts has led the nation in its response to the climate crisis. Working closely with the Legislature, the Baker-Polito Administration has made unprecedented commitments to reducing GHG emissions attributable to Massachusetts. In 2017, Massachusetts closed the last coal-fired power plant in operation in the state, Brayton Point, and that location is currently being turned into a hub to support the development of the offshore wind industry. In 2020, Massachusetts became one of the first states in the country to establish a Net Zero emissions limit. In addition to expanding clean energy production, the Commonwealth has consistently ranked among the most energy-efficient states in the nation thanks to our strong consumer incentives, saving consumers billions of dollars on their energy bills.[1]

Massachusetts has positioned itself such that the near-term components of the path to Net Zero are clear, with the flexibility to adapt to new technologies if and when they become available and economical. A combination of offshore wind, hydroelectricity, solar photovoltaics (PV), and existing regional generation such as nuclear energy—together with investments in

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1 Massachusetts Department of Energy Resources, "Massachusetts Named Most Energy Efficient State in Nation" (October 4, 2018), https://www.mass.gov/news/massachusetts-named-most-energy-efficient-state-in-nation.

smart grid management and energy storage—will support a decarbonized electricity grid. Electric vehicles (EVs) and heat pumps represent scalable technologies that can help transition our transportation and buildings to zero emissions.

In other areas, the precise path to a Net Zero economy is uncertain. Many analysts expect that mechanisms to support carbon removal from the atmosphere will emerge over the next few decades, but exactly what approaches will be used and at what cost remains to be seen. Despite these uncertainties, the Commonwealth will take steps to prepare the state to incorporate regional and/or technological solutions to achieve Net Zero. Continued planning, flexibility, and ingenuity will ensure a swift, successful, and cost-effective transition to a clean future. This Plan identifies places where technology or other uncertainties will require Massachusetts policies to remain flexible to changing conditions.

Net Zero Limit and Sector-Based Sublimits

The Global Warming Solutions Act (GWSA), as most recently amended by Chapter 8 of the Acts of 2021, requires Massachusetts to achieve Net Zero in 2050. The requirement has two components: (1) achieve gross emissions reductions of 85% below 1990 levels, and (2) ensure that the total statewide GHG emissions released into the atmosphere are less than or equal to the amount removed from the atmosphere. Furthermore, the GWSA requires EEA to set sector-specific sublimits for transportation, residential heating and cooling, commercial and industrial heating and cooling, electric power, industrial processes, and natural gas distribution and services. EEA has established sublimits for 2050, shown in Table ES-1, that collectively reduce economy-wide emissions to achieve slightly more than the 85% emissions reduction requirement to provide individual sectors some room for uncertainty.

The limit and sublimits in this Plan are based on the best available data, information, and assumptions standing in 2022. Future changes in the economy, technology, national and international policies, and conventional practices could affect how Massachusetts achieves the limit and sublimits. This Plan calls for an enormous number of technologies, infrastructure, and solutions to be implemented here in Massachusetts: heat pumps, electric vehicles, charging stations, solar panels, wind turbines, energy storage, advanced transmission and distribution infrastructure, multimodal transportation infrastructure, electrified bus facilities and rail lines, and housing near public transportation, among others. Unless the necessary infrastructure is permitted and built, the Commonwealth's progress could be slowed, impacting the state's ability to meet Net Zero. Simultaneously, all of this infrastructure needs to be built responsibly, protective of natural and working lands, and observant of EJ.

TABLE ES-1. EMISSIONS LIMIT AND SECTOR-SPECIFIC SUBLIMITS FOR 2050

	2050	
Emissions Limit & Sublimits	**Emissions Limit as a % Reduction from 1990**	**Emissions Limit Expressed in $MMTCO_2e$***
Statewide Limit	**85%**	**14.0**
Sector-Specific Sublimits		
Transportation	86%	4.1
Residential Heating and Cooling**	95%	0.8
Commercial & Industrial Heating and Cooling**	92%	1.2
Electric Power	93%	2.0
Natural Gas Distribution & Service	72%	0.5
Industrial Processes	-27%	0.8

*These numbers represent the $MMTCO_2e$ based on the statewide GHG emissions inventory, published December 2022. If the inventory methodologies change, the equivalent $MMTCO_2e$ numbers will change.

**Due to how emissions are tracked in the statewide GHG inventory, emissions associated with the use of electricity for cooling in residential, commercial, and industrial buildings are covered under the Electric Power sublimit.

Notes: To account for the emissions reductions required by the GWSA in a way that comports with current emissions tracking in the statewide GHG emissions inventory by the Department of Environmental Protection, EEA has organized statewide emissions into the following policy sectors, consistent with the 2025/2030 CECP: transportation, buildings, power, non-energy and industrial, and natural and working lands. Additionally, Table ES-1 does not include the agriculture and waste categories in the statewide GHG emissions inventory. These categories have projected total emissions of approximately 1.1 MMTCO2e in 2050, and are not subject to a sublimit. By including these emissions, the modeled data would result in about an 89% reduction which is beyond the 85% that is required. The combined reduction levels that are above the 85% economy-wide GHG emissions reduction are designed to provide some room for uncertainties around individual sectors' ability to achieve the sector-specific emissions sublimits. This is discussed further in Chapter 3 of this report.

2050 CECP *KEY BENCHMARKS*

Achievement of the Commonwealth's greenhouse gas emissions limit of at least 85% below the 1990 baseline level and net-zero emissions in 2050

TRANSPORTATION

97%
of light-duty vehicles (5 million) electrified

93%
of medium- and heavy-duty vehicles (over 350,000) electrified or non-emitting

BUILDINGS

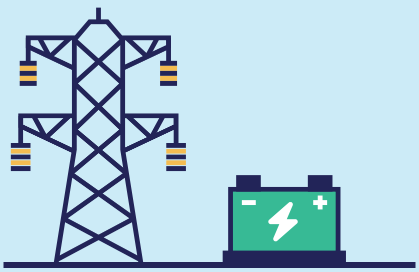
80%
of homes (over 2.8 million) heated and cooled by electric heat pumps (including those with on-site fuel backups)

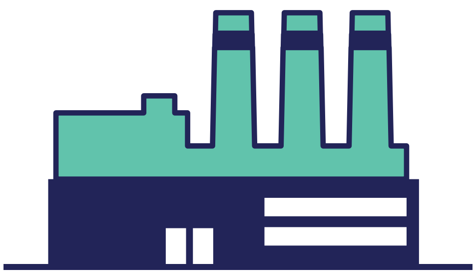
87%
of commercial space heated by either electricity or alternative fuels

ELECTRIC POWER

2.5-fold
increase in electric load compared to 2020

97%
of electricity consumed is from clean and renewable sources





NON-ENERGY AND INDUSTRIAL

52%
of industrial energy use electrified

90%
reduction in solid waste disposal

NATURAL AND WORKING LANDS

40%
of lands and waters in MA permanently conserved

64,400 acres
of new riparian and urban tree cover

JOB AND HEALTH BENEFITS

65,000
additional full-time jobs created from the clean energy transition

Up to **$4.7 billion**
in health benefits

Commitment to Environmental Justice

Pollution created by the combustion of fossil fuels impacts all Massachusetts residents, but some communities bear a heavier burden than others. Communities of color and low-income neighborhoods face disproportionately higher exposure than other areas to health and climate risks because of decades of decisions about siting highways, power plants, and other sources of pollution. Tenants and people with limited incomes or limited English language proficiency face significant barriers and need additional support switching to clean energy.

The Commonwealth will ensure that EJ neighborhoods and low- and moderate-income residents are not left behind in the energy transition, which will require prioritizing investments in clean energy in EJ neighborhoods. EEA will work with stakeholders and the Environmental Justice Council[2] to identify climate investments it will dedicate to EJ neighborhoods or income-targeted programs. EEA will continue to use best practices for community engagement, particularly when implementing programs that could affect EJ neighborhoods. The Department of Environmental Protection (MassDEP) will continue and enhance its air monitoring and community-based air sensor deployment efforts in EJ areas to determine existing air quality and opportunities to reduce pollution in these areas.

Cross-Sector Strategies

This Plan sets out policies specific to each of the sectors of the economy, targeting the reduction of fossil fuel combustion in our vehicles, in the furnaces and boilers that heat our homes and businesses, in electricity generation, and in industrial applications and waste management. As we look to 2050, however, these targeted approaches will increasingly interact with one another as transportation and heating become powered by electricity. The 2050 CECP recognizes that clean energy technologies across sectors face some common challenges and solutions.

One area of common interest is coordinated electrification. The dominant strategy to decarbonize transportation and buildings is electrification. Thus, power sector planning is essential. Massachusetts is evaluating how to integrate an increasing amount of renewable energy with larger and different generation profiles and growing electricity demand with varying dynamics based on charging and heating patterns. The state will need to implement load flexibility measures, rate designs, and demand-side management strategies to integrate the new generation and load safely and reliably. The Commonwealth is also conducting

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2 The Environmental Justice Council, made up of local community leaders, business leaders, and academic researchers, advises the EEA Secretary on policies and standards to achieve environmental justice principles.

analyses on land use to ensure that new renewable and transmission infrastructure does not compromise the land relied on for carbon sequestration.

Another area where cross-sectoral coordination will be critical is in workforce development. To reach the Commonwealth's 2050 requirements, Massachusetts' clean energy sector will need over 65,000 additional full-time workers, many of whom will be in high-paying jobs such as electricians, offshore wind workers, construction workers, and heating, ventilation, and air conditioning (HVAC) technicians.[3] To expand the number of qualified clean-energy workers, the Massachusetts Clean Energy Center (MassCEC) will work with the Workforce Skills Cabinet (or future equivalent entity) to identify ways to expand vocational and training programs, increase awareness of clean energy opportunities at all levels of education, connect people to jobs through apprenticeship programs, and develop a plan for a Massachusetts Climate Service Corps to inspire all to take on careers in the clean energy and climate-related sectors.

Combating climate change represents an important opportunity for Massachusetts to demonstrate leadership on the national and international stage. As home to many of the world's leading universities and high-tech industries, Massachusetts has an outsized role to play in the development and deployment of clean energy technologies around the world. The Commonwealth will continue to play an important role in supporting clean energy companies, particularly in helping companies establish commercial viability while ensuring that historically under-represented investors participate and lead in advancing clean energy technologies. Massachusetts will further establish partnerships to help expand technology transfer programs at Massachusetts universities.

Massachusetts state agencies and municipal governments should lead the transition to clean energy. The existing Leading by Example program requires Massachusetts agencies to meet high-performance standards for buildings, transition to using more EVs, and develop on-site renewable energy. The Green Communities program, administered by the Department of Energy Resources (DOER), provides municipalities with grants to meet climate and energy goals. The state also plans to assess how state-funded buildings can better align with our decarbonization goals.

Sector-Based Strategies

Achieving our emissions limit for 2050 will require transitioning all passenger vehicles, most medium- and heavy-duty trucks and buses, and most of the 6.5 million buildings in Massachusetts away from fossil fuels such as oil and natural gas to clean electricity. To power

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[3] Please see Chapter 8 for an analysis on economic and employment factors.

those vehicles and homes, Massachusetts must increase the amount of clean energy on its electric grid through investments in offshore wind, hydroelectricity, transmission systems, solar PV, distribution systems, and energy storage.

Transportation

The Commonwealth will improve public transportation and invest in housing and multimodal transportation infrastructure to help residents travel without a personal vehicle when possible. At the same time, Massachusetts will achieve deep decarbonization through the electrification of vehicles. The primary driver of electrification is the implementation of vehicle emission standards that require auto manufacturers to produce an increasing number of zero-emission vehicles. By statute, these standards will ensure that all sales of *new* passenger vehicles, and the majority of *new* medium- and heavy-duty vehicles, are electric by 2035. Massachusetts will provide support for consumers through convenient point-of-sale incentives, with additional support for low- and moderate-income residents, as well as targeted assistance for fleets that have important equity and public health benefits, including school buses, vehicles for hire, and delivery trucks.

As EVs begin to dominate the market for new passenger vehicles, Massachusetts plans to shift from providing incentives to purchase EVs to providing incentives to retire old internal combustion vehicles. For the portion of the transportation sector that is difficult to electrify, the Commonwealth will explore market-based mechanisms to reduce GHG emissions. Massachusetts will also provide strong incentives to encourage smart charging of electric vehicles, which can help make EVs an asset for the grid to reduce distribution and transmission costs.

Buildings

The Commonwealth's strategy to reduce emissions from buildings includes performance standards, financial support, consumer outreach, and regulatory requirements. A Clean Heat Standard will require gradual reductions in building emissions through an approach similar to the successful Clean Energy Standard. A Climate Finance Accelerator (sometimes referred to generically as a "green bank") will help attract private capital and connect consumers to upfront capital needed to switch to clean energy, helping them save money over the long run. Massachusetts plans to establish a Building Decarbonization Clearinghouse to provide streamlined offerings, assistance in navigating incentive programs, and informational resources for consumers exploring options for upgrading and electrifying their homes and vehicles to be zero-emitting. Continued improvements and reforms to the Mass Save® programs will further improve the energy efficiency of our buildings and support electrification. Future updates to the state's building codes will continue to increase the requirements for energy efficiency and electrification for new residential and commercial buildings.

As Massachusetts works toward Net Zero, managing the impact of building electrification on the electric grid and natural gas distribution infrastructure will be critical. DOER and the Department of Public Utilities (DPU) will work with the electric and natural gas utilities to examine opportunities for both accelerated electrification and strategic decommissioning of natural gas infrastructure in a joint energy system plan. In addition, the DPU will evaluate how electricity and natural gas rates can be reformed to provide appropriate incentives for accelerating electrification and increasing load flexibility and smart grid management while balancing cost concerns for low-income residents. Ultimately, the transition to clean energy will require Massachusetts to set policies that will maintain the safety and reliability of the natural gas distribution systems, when in use, while minimizing the risks of passing on any stranded costs to consumers, especially EJ populations.

Electric Power

How Massachusetts generates, transmits, distributes, and ultimately consumes electric power will need to change drastically over the next three decades to meet decarbonization requirements. By 2050, Massachusetts will need more than 50 GW of clean energy resources, a majority of which will include offshore wind and solar PV with energy storage. Massachusetts will work with the federal government and regional partners to deploy offshore wind technology in the most efficient manner, plan transmission upgrades at the regional level, and modernize the electric distribution system. The Commonwealth's Grid Modernization Advisory Council (GMAC), established by An Act Driving Clean Energy and Offshore Wind (2022 Climate Act),[4] will work with stakeholders to provide recommendations to utilities to improve grid reliability and resiliency, further enable distributed energy resources and electrification, and minimize or mitigate costs and risks to ratepayers.

Non-Energy & Industrial

Emissions from remaining sectors, including industrial energy and processes as well as natural gas distribution and services, will reduce through a combination of strategies. This includes phasing out fluorinated gases (F-gases) in the industrial process sector, increasing electrification and using alternative fuels that reduce GHG emissions in the industrial energy sector, and

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[4] Mass. Acts 2022, Ch. 179, https://malegislature.gov/Laws/SessionLaws/Acts/2022.

reducing gas leaks in gas delivery systems. Additionally, Massachusetts will reduce solid waste disposal by 90% by 2050 in line with the 2030 Solid Waste Master Plan (SWMP).

Natural and Working Lands

Protecting natural and working lands is an important component of Massachusetts' strategy to achieve Net Zero. The growth of trees and the accumulation of organic matter in healthy soils and wetlands provide valuable and cost-effective carbon removal and storage. To limit the loss of sequestered carbon and maintain ongoing carbon sequestration capacity on natural and working lands, Massachusetts aims to permanently conserve at least 40% of Massachusetts lands and waters by 2050, develop solar siting guidelines consistent with the protection of critical Massachusetts land and habitats, and evaluate and set additional regulatory pathways to limit forest clearing. To enhance nature-based carbon sequestration, the Commonwealth will expand tree planting to at least 64,400 additional acres of urban and riparian areas by 2050. The Commonwealth aims to reduce GHG emissions on natural and working lands through wetland restoration and healthy soil practices.

Future of Fuels

While electrification remains the dominant strategy to decarbonize most sectors, Massachusetts recognizes that some sectors of the economy will be difficult to electrify. These applications will likely be served primarily by "alternative fuels" produced from biological feedstocks to help the Commonwealth achieve its decarbonization goals. Hydrogen produced from clean electricity may play a modest but important role in specialized applications such as high-temperature industrial uses and as a fuel for electricity generation to ensure reliability when other clean energy resources are not available. This Plan includes an overview of different liquid and gaseous fuels that could provide a sustainable, low- or zero-carbon alternative to fossil fuels for hard-to-electrify sectors. Such fuels will likely be costly and limited in availability, and thus will be used primarily in high-value processes and difficult-to-electrify portions of the Massachusetts economy.

While alternative fuels will play a limited role in Massachusetts' economy in 2050, clear policies will be developed to provide guidance to the private sector that encourages the cleanest possible fuels for the most critical use cases. By 2024, MassDEP will consider whether changes are needed to the state GHG emissions inventory conventions, guiding principles, and/or accounting methodologies for combustion emissions from conventional and advanced biofuels, hydrogen, and synthetic fuels. In addition, Massachusetts will accelerate innovation for alternative fuels by coordinating with other states to directly fund research and development, considering policies to encourage alternative fuel production and use, and building experience with alternative fuels for high-value sectors that lack substitutes. Such efforts will amplify the Commonwealth's impact beyond the direct effects of reducing GHG emissions from its own fuel use.

Carbon Removal in 2050

Even with ambitious decarbonization efforts and carbon sequestration on Massachusetts natural and working lands, achieving Net Zero in 2050 will likely require additional carbon dioxide removal and storage beyond the sequestration capacity of lands in the Commonwealth. The additional sequestration capacity is expected to come from procurements of carbon sequestration on natural and working lands outside of the state and/or from engineered carbon removal technologies. A variety of nature-based and engineered carbon sequestration approaches are available or in development regionally and globally. The Commonwealth will need to weigh a range of factors in assessing the different approaches, including effectiveness, environmental integrity, co-benefits, negative externalities, costs, risks, and EJ.

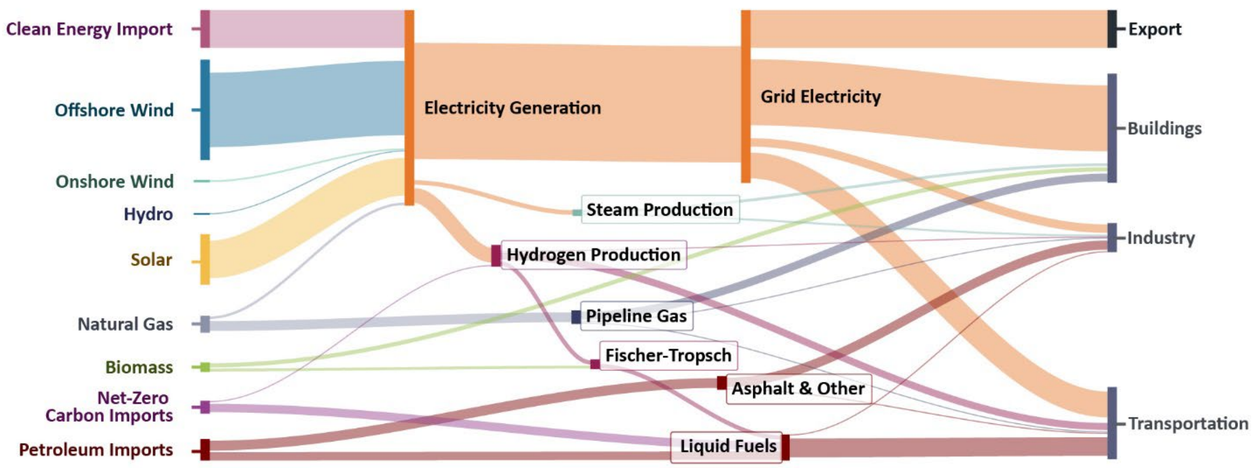
As a first step towards acquiring necessary carbon sequestration, the Commonwealth will develop a policy framework for carbon sequestration procurement over the next three years, including accounting parameters and a procurement process. Specifically, the Commonwealth will specify how and when in-state and out-of-state carbon removal can be used to balance residual GHG emissions and determine the policy mechanisms to govern the exchange of carbon sequestration resources. The Commonwealth will develop a carbon sequestration strategy that will be incorporated into future CECPs, and, starting in 2030, set up necessary accounting and exchange infrastructure so that sequestration procurements can begin well before 2050.

The Path Ahead

Figure ES-1 below shows a summary of projected energy supplies and uses in 2050 for Massachusetts. It shows the reliance on renewable and clean energy, and the residual need for some non-emitting fuels in some of the sectors. Remaining GHG emissions will need to be balanced by net carbon sequestration capabilities attributable to Massachusetts. The transition to such a future will require significant engagement with all residents, communities, local leaders, businesses, and policymakers. Designing the policies and programs to reach this future will need to build on Massachusetts' strength in education, training, innovation, and climate leadership.

While one can only anticipate what the coming decades will bring, Massachusetts is committed to maintaining the focus and flexibility necessary to achieve Net Zero.

FIGURE ES-1. 2050 COMMONWEALTH ENERGY USE



This illustrative Sankey diagram approximates Massachusetts energy flows in 2050 under the CECP "Phased Pathway." Details of the Phased Pathway are provided in Chapter 3 of the 2025/2030 CECP.

Chapter 1: Introduction

Massachusetts continues its leadership in reducing GHG emissions with the commitment and plan to achieve Net Zero emissions in 2050. Building on the success of the 2008 Global Warming Solutions Act (GWSA) and Green Communities Act (GCA), in 2021, Massachusetts passed An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy (2021 Climate Law)[5] with the ultimate goal of achieving Net Zero greenhouse gas (GHG) emissions in 2050. The 2021 Climate Law requires the EEA Secretary to adopt interim statewide limits and sector-specific sublimits every five years to maximize the Commonwealth's ability to achieve Net Zero in 2050. The law requires the limits and sublimits to be accompanied by a comprehensive, clear, and specific roadmap plan to achieve the established limits and sublimits.

By determination letter issued contemporaneously with this Clean Energy and Climate Plan for 2050 ("2050 CECP" or "Plan"), the Secretary established Net Zero as the limit in 2050, defined as follows:

> A level of statewide greenhouse gas emissions that is equal in quantity to the amount of carbon dioxide or its equivalent that is removed from the atmosphere and stored annually by, or attributable to, the Commonwealth; provided, however, that in no event shall the level of emissions be greater than a level that is 85 percent below the 1990 level.[6]

In the determination letter, the Secretary also established the sector-based sublimits for 2050 for the transportation, residential heating and cooling, commercial and industrial heating and cooling, electric power, industrial processes, and natural gas distribution and service sectors. This Plan sets the policies and programs to achieve Net Zero in 2050 and ensure consistency in meeting interim statewide GHG emissions limits and sublimits.

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5 Mass. Acts 2021, Ch. 8, https://malegislature.gov/Laws/SessionLaws/Acts/2021.

6 "Net Zero" will be used throughout this Plan to refer to the established statewide GHG emissions limit for 2050 which encompasses the above definition. This Plan will use "net-zero emissions" to refer to a level of GHG emissions that is equal in quantity to the amount of GHG that is removed from the atmosphere.

Overall, most of the policies and programs specified in the 2025/2030 CECP will continue to drive progress toward 2050 and are referenced in this Plan. Recent legislation in Massachusetts, specifically An Act Driving Clean Energy and Offshore Wind (2022 Climate Act)[7] and An Act Relating to Economic Growth and Relief for the Commonwealth,[8] and federal legislation, including the Infrastructure and Investment Jobs Act (IIJA)[9] and the Inflation Reduction Act (IRA),[10] complement, reaffirm, and in some cases, fund many of the policies and programs described in this Plan. Maintaining the four pillars of decarbonization, discussed further below, will allow for future flexibility in adjusting the policies and programs to adapt to technological evolution, changes in the relative economics of approaches, and new information as it becomes available to achieve the Net Zero Limit over the next 28 years.

This 2050 CECP is organized as follows:

- Chapter 1, this Chapter, introduces the framework and guiding principles for the policy development and programs detailed throughout the Plan to help the Commonwealth achieve Net Zero in 2050 and the accompanying sector-specific sublimits.
- Chapter 2 reaffirms and describes the Commonwealth's commitment to centering EJ principles in policy and program development to ensure that our most vulnerable populations are protected and prioritized as the state decarbonizes.
- Chapter 3 defines and identifies the Net Zero limit and sector-specific sublimits and a vision for the future in which the Commonwealth achieves its 2050 limit and sublimits.
- Chapter 4 highlights that the policies and programs in each sector are interrelated and outlines important cross-sector strategies.
- Chapter 5 describes the Commonwealth's policies and programs that will reduce the GHG emissions in each sector of the economy to achieve the 2050 sublimits.
- Chapter 6 provides information on potential alternative fuels that may exist as Massachusetts approaches 2050 and the need to account for their uses.
- Chapter 7 outlines the need to sequester and store residual GHG emissions to achieve Net Zero in 2050.

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7 Mass. Acts 2022, Ch. 179, https://malegislature.gov/Laws/SessionLaws/Acts/2022.

8 Mass. Acts 2022, Ch. 268, https://malegislature.gov/Laws/SessionLaws/Acts/2022.

9 Pub. L. No. 117-58 (Nov. 15, 2021), https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.

10 Pub. L. No. 117-169 (Aug. 16, 2022), https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf.

- Chapter 8 summarizes the expected macroeconomic and employment impacts of achieving Net Zero in 2050.

Development of 2050 Clean Energy and Climate Plan (CECP)

PICTURE 1-1. BAKER-POLITO ADMINISTRATION ANNOUNCES MORE THAN $11M IN MASSTRAILS GRANT FUNDING

The 2050 CECP builds on years of analysis, stakeholder input, public feedback, and industry information, including the 2020 CECP, the 2050 Decarbonization Roadmap, and the 2025/2030 CECP. It reflects the joint efforts of executive branch officials, legislators, advocacy groups, scientists, EJ partners, industry stakeholders, utilities, and residents of Massachusetts who have voiced their concerns and care to transform the Commonwealth's economy and its energy system to one that is less emitting and more sustainable.

EEA solicited public feedback throughout the development of this Plan. EEA received stakeholder input and feedback through multiple public engagement and public comment processes, most recently with public hearings being held in October of 2022. Three advisory groups held meetings that helped provide input and feedback that informed the development of this Plan:

- The Global Warming Solutions Act Implementation Advisory Committee (GWSA IAC) is a public body that advises EEA on GHG reduction measures. The IAC provided comments that included recommendations of policies for EEA's consideration in finalizing the scope of the 2025/2030 CECP, the 2050 Decarbonization Roadmap Study, and this Plan. The IAC held two meetings throughout the development of the 2050 CECP, on August 11 and October 5, 2022. In addition, the IAC held working group meetings to discuss sector-specific policies and consult on other topics related to this Plan. 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 Baker-Polito Administration established the Commission on Clean Heat to advise the Governor on the framework for long-term GHG reductions from heating fuels.[11] The Commission on Clean Heat held 19 meetings prior to and during the development of this

[11] Massachusetts Executive Order No. 596: Establishing the Commission on Clean Heat (Sept. 21, 2021), https://www.mass.gov/executive-orders/no-596-establishing-the-commission-on-clean-heat.

2050 CECP.[12] Four public webinars were held on March 1 and 24, 2022. In addition, the public hearings on the 2025/2030 CECP and the 2050 CECP included a report on the progress of the Commission on Clean Heat, including the areas in which the Commission was likely to provide recommendations. The Commission's final recommendations were finalized and provided publicly on November 30, 2022.

- Governor Baker appointed members to the Environmental Justice Council to advise the state on policies to promote EJ. The Environmental Justice Council met four times prior to the release of this 2050 CECP to discuss the definition of "environmental justice" used in the Commonwealth's Environmental Justice Policy, as well as policies and strategies in this Plan.[13] Recommendations from the Environmental Justice Council helped shape the approach to equity in this Plan.

Guiding Principles

Based on recommendations from the GWSA IAC and feedback from other stakeholders and the public, EEA has developed a set of principles to guide the Commonwealth's decarbonization strategy. These principles are rooted in the commitment to (1) close the gap between EJ and non-EJ communities in receiving the benefits of the clean energy transition and (2) achieve Net Zero in the most credible manner, based on the best available scientific understanding and data. More specifically, these principles include:

1. **Support a People-Centered Approach**
   When determining policy, program design, and implementation approaches, Massachusetts needs to use people-centered approaches, providing for and ensuring broad-based stakeholder participation and input. This means that the Commonwealth has a responsibility to ensure that the people and infrastructure in Massachusetts are resilient to a changing climate.

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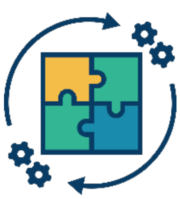
[12] The Commission on Clean Heat held full Commission meetings on January 12 and 26, February 9 and 17, March 9 and 23, April 6 and 27, May 18, June 10, July 7, August 10, September 15, October 6 and 18, November 3, 14, and 21, and December 7, 2022. In addition, the Commission set up several working groups that met numerous times between September and November of 2022.

[13] The Environmental Justice Council met on July 28, September 15, September 27, and October 27, 2022.

2. **Prioritize and Anchor Equity and Justice in Policymaking**
   A Net Zero Massachusetts will simultaneously improve air and water quality for all residents, increase access to clean transportation, provide clean energy to homes and businesses, and protect greenspaces. To ensure the equitable distribution of these benefits to all people in the Commonwealth, vulnerable populations must be prioritized, heard, and included in the policy and program development process. Chapter 2 of this report lays out Massachusetts' approach to prioritizing equity and EJ.

3. **Use the Best Available Science, Technology, and Data with Timely Analysis and Transparent and Clear Public Reporting**
   Over the next 28 years, Massachusetts' clean energy programs must evolve with changes in science, technology, and costs. Massachusetts must achieve Net Zero in 2050 while recognizing inevitable changes in the future. One of the areas of evolving scientific understanding centers on GHG fluxes and, as more accurate and precise data become available over time, policy makers in Massachusetts must pivot and adapt to using the best available information. For now, the Commonwealth must acknowledge the uncertainties around the magnitude of how natural and working lands can sequester GHG and the potential for technological innovations to assist in this area over the next three decades.



4. **Support Partnerships and Collaboration to Increase Positive Impacts**
   Acknowledging that Massachusetts is only one state within the U.S. and contributes a small part of overall global emissions, the Commonwealth must collaborate with others to mitigate the effects of climate change. To tackle the global climate change problem, Massachusetts should lead in international efforts to address climate change by engaging in public and private partnerships, especially to spur innovation and reduce the costs of solutions.

5. **Ensure GHG Emissions Reductions and Carbon Sequestration are Real, Verifiable, and Transparently Reported**
   Planning to achieve Net Zero requires data to track and demonstrate real and verifiable progress toward emissions limits and sublimits. To

ensure accuracy and credibility, Massachusetts must continue to use transparent methods to track and report GHG emissions reductions and carbon sequestration. Using reporting and accounting approaches that are compatible with other jurisdictions will decrease the chances of double-counting and allow Massachusetts to truly contribute toward global GHG reductions.

6. **Ensure High-Integrity Carbon Sequestration to Balance the Most Difficult-to-Eliminate Emissions**
   It is imperative that carbon sequestration used to achieve Net Zero is sufficient to balance out any remaining GHG emissions and does not replace necessary emissions reductions in the Commonwealth or elsewhere. Net Zero in Massachusetts requires an 85% reduction in gross emissions relative to the 1990 level. Carbon sequestration will be leveraged to balance residual emissions in areas of the economy that are particularly difficult to decarbonize but will not be used in lieu of effective emissions reduction strategies. Any approach to sequester and store carbon must provide additional benefits and minimize harm.

Ongoing Parallel Planning Efforts

Climate change and the transition to clean energy touch almost every area of public policy in the Commonwealth. This Plan incorporates work being done by various state agencies and municipal partners, including, but not limited to, the 2022 Massachusetts Climate Change Assessment, the 2020 Massachusetts Department of Transportation Rail Vision report, the 2019 Statewide Bicycle Transportation Plan (updated in 2021), the MBTA's Better Bus Project, the Independent System Operator New England's (ISO-NE's) 2050 Transmission Study, and the Massachusetts Solid Waste Master Plan (SWMP). [14,15,16]

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[14] Massachusetts Bay Transportation Authority, "Rail Vision," https://www.mbta.com/projects/rail-vision.

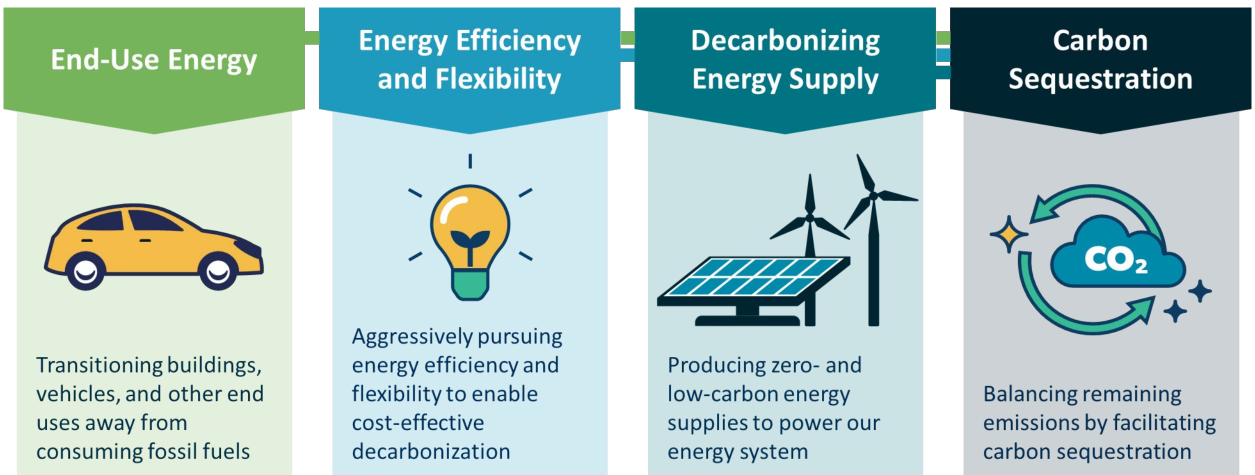
[15] Massachusetts Department of Transportation, "Massachusetts Bicycle Transportation Plan" (May 2019), https://massdot.maps.arcgis.com/apps/MapJournal/index.html?appid=c80930586c474a3486d391a850007694

[16] Massachusetts Bay Transportation Authority, "Better Bus Project," https://www.mbta.com/projects/better-bus-project.

Envisioning Massachusetts in 2050

Standing in 2022, the main components of the path to Net Zero are clear to Massachusetts, with four key priorities. The first priority is reducing emissions from energy "end-uses," such as vehicle transportation or building heating, via electrification or fossil-free alternatives. The second priority is maximizing the efficiency and flexibility of energy use to ensure electric grid reliability and cost-effective decarbonization. Third, the electricity supply must transition to low-emitting sources. Fourth and finally, in a 2050 future where some emissions are likely to remain, Massachusetts must balance residual GHG emissions with carbon sequestration approaches. These tenets are the guiding pillars of the Commonwealth's 2050 planning process, illustrated in Figure 1-1.

FIGURE 1-1. FOUR KEY PILLARS OF DECARBONIZATION



The Commonwealth can achieve its 2050 emission limits with technologies that are already known and largely commercialized. Massachusetts in 2050 will look different from today, but it will not be entirely foreign. The Commonwealth's electric power supply will be both bigger and cleaner as it accommodates the electrification of buildings and vehicles while also meeting increasingly stringent emissions standards. Offshore wind will be a cornerstone of the Commonwealth's electricity generation alongside solar PV and energy storage, with a portfolio of additional clean energy technologies to balance variable resources on the grid. Several high-voltage transmission lines throughout the Northeast will allow the sharing of low-cost, clean energy among Massachusetts and its neighbors.

Nearly all passenger vehicles and most medium- and heavy-duty vehicles will be zero-emissions vehicles, which include both battery and hydrogen fuel-cell options. Commuters using public transit will board electric buses and, in some areas, electric trains. Charging stations will be available across the Commonwealth, with charging technologies and business models that meet the needs of all drivers. There will be more housing near public transit to ensure that people have ample access to transport where they live and work.

The majority of residential and commercial buildings will have tight building envelopes, be weatherized to optimize energy efficiency, and be heated and cooled by efficient electric heat pumps or other zero-emitting technologies. The Commonwealth's natural and working lands are well-protected, providing urban shade, clean air, wildlife habitat, durable and sustainable wood products, and carbon storage. Massachusetts will balance any residual GHG emissions with carbon sequestration in-state and/or sequestration resources from other jurisdictions.

The Massachusetts workforce will reflect this transition. For instance, the deployment of the offshore wind industry over the coming decades will create tens of thousands of jobs spanning engineering, planning, construction, and operations needs. Experts in efficient heating system installation and maintenance will be in high demand over the next few decades. The Commonwealth will remain an innovation powerhouse, drawing on its educational wellspring to commercialize innovative decarbonization solutions for the world-at-large.

The Role of Climate Science and Resilience

Massachusetts, along with the rest of the world, is already experiencing the impacts of climate change. The latest climate science suggests temperatures will continue to rise, precipitation patterns will change, and conditions that enable coastal flooding will increase. Safeguarding environmental, social, and physical resources while preparing for the intensifying impacts on communities are necessary components of the Commonwealth's forward-looking climate plan.

The 2022 Massachusetts Climate Change Assessment[17] evaluates the impacts of climate change on the Commonwealth, including public and private assets, natural resources, and human health. The Climate Assessment will inform the 2023 Massachusetts State Hazard Mitigation and Climate Adaptation Plan, which represents the Commonwealth's plan to comprehensively integrate climate change impacts and adaptation strategies with hazard mitigation planning. The Climate Assessment evaluates the effects of increasing temperatures, changing precipitation patterns, rising sea levels, and more powerful coastal storms across five components of society: human, infrastructure, natural environment, governance, and economy. It identifies the most urgent impacts based on the estimated magnitude of

[17] Massachusetts Executive Office of Energy and Environmental Affairs, "MA Climate Change Assessment," https://www.mass.gov/info-details/ma-climate-change-assessment.

consequence, the disproportionality of exposure, and gaps in adaptation action. Figure 1-2 below outlines the overall findings.

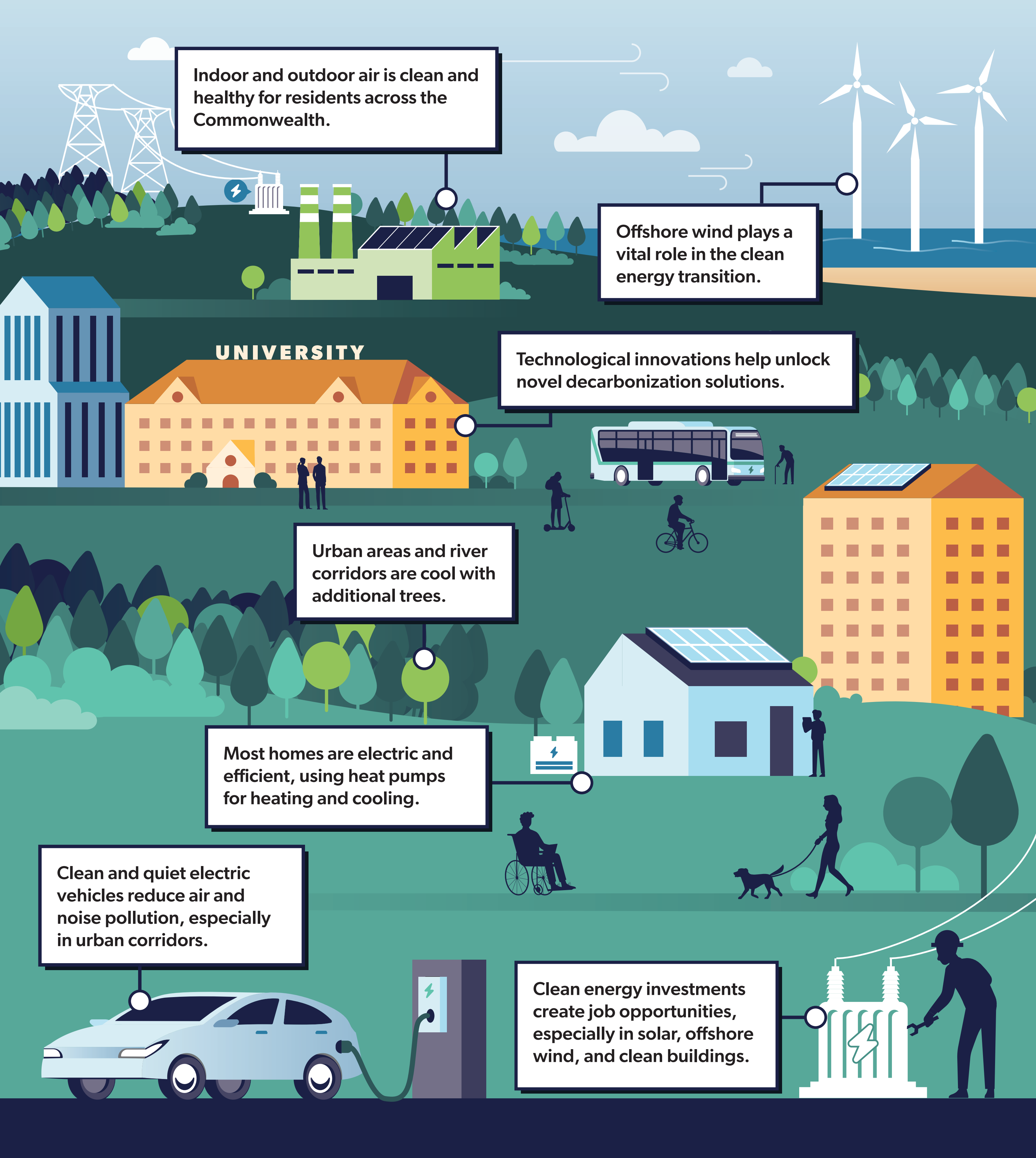
FIGURE 1-2. MOST URGENT IMPACTS OF CLIMATE CHANGE ON MASSACHUSETTS

Human	Infrastructure	Environment	Governance	Economy
Health and cognitive effects from extreme heat, including premature death and learning loss. **Health effects from degraded air quality,** including childhood asthma cases and premature death due to climate impact on particulate matter and ozone air quality. **Emergency service response delays and evacuation disruptions** from extreme storms, leading to injuries, loss of life, and requiring health, safety, and traffic first responders.	**Damage to inland buildings** from heavy rainfall and overwhelmed drainage systems. **Damage to electric transmission and utility distribution infrastructure** associated with heat stress and extreme events. **Damage to rails and loss of rail/transit service,** including flooding and track buckling during high heat events.	**Freshwater ecosystem degradation** due to warming waters, drought, and increased runoff. **Marine ecosystems degradation** because of warming, particularly in the Gulf of Maine, and ocean acidification. **Coastal wetland degradation** from sea level rise and storm surge. **Forest health degradation** from warming temperatures, changing precipitation, increasing wildfire frequency, and increasing pest occurrence.	**Increase in costs of responding to climate migration,** including planning for abrupt changes in local populations. **Increase in demand for state and municipal government services,** including emergency food assistance, and state-sponsored health care.	**Reduced ability to work,** particularly for outdoor workers during extreme heat, as well as commute delays due to damaged infrastructure. **Decrease in marine fisheries and aqua-culture productivity** from changing ocean temperatures and acidification, which leads to decreased catch and revenues and impacts related industries. **Reduction in the availability of affordably priced housing** from direct damage (e.g., flooding).

In addition to informing how Massachusetts will need to adapt to climate change, the Climate Change Assessment also informs the Commonwealth on strategies needed for the management and restoration of natural and working lands, and ongoing clean energy and infrastructure development. Massachusetts will continue to update the assessment in the coming years to stay at the forefront of integrating the best available climate science into statewide planning and advancing equitable resilience strategies.

See yourself in 2050

The transition to Net Zero has benefits across all aspects of society.



Chapter 2: Centering Environmental Justice

Vision for Environmental Equity

Environmental justice (EJ) is rooted in the principle that all people deserve protection from environmental pollution and the ability to live in and enjoy a clean and healthy environment, regardless of race, color, income, class, handicap, gender identity, sexual orientation, national origin, ethnicity or ancestry, religious beliefs, or English language proficiency. Achieving EJ requires:

1. Meaningful involvement of all people with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies, including climate change policies; and
2. Equitable distribution of energy and environmental benefits and environmental burdens.[18]

These principles will guide and ensure a just transition and be used to develop policies that achieve environmental equity. EEA's Environmental Justice Task Force (EJTF), made up of staff representing each EEA agency,[19] has been developing Massachusetts' EJ strategy, which each agency will follow to enhance environmental, energy, and climate justice across the Commonwealth. Many initiatives identified in this 2050 CECP will be implemented through actions that agencies have outlined in the EJ strategy.

Numerous studies have shown that communities of color, low-income neighborhoods, indigenous populations, and neighborhoods with high percentages of residents with limited English proficiency face disproportionately higher exposure to pollution, public health, and climate risks, and bear a higher energy burden when compared with other

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[18] *See* Mass. Gen. Laws Ch. 30, § 62, definition of "environmental justice principles."

[19] Commonwealth of Massachusetts, "About the EEA Environmental Justice Task Force," https://www.mass.gov/service-details/about-the-eea-environmental-justice-task-force.

neighborhoods.[20,21,22,23] Such disproportionate burdens often stem from the cumulative impacts of many factors, including historical implementation of housing, transportation, environmental permitting, and energy infrastructure siting policies; lack of economic opportunities or educational resources; and consequent public health vulnerabilities.

The 2021 Climate Law defines an "environmental justice population" in Massachusetts based on percentage threshold levels of racial minority,[24] low-income, or limited English proficiency residents living in a particular "block group" as delineated by the United States Census Bureau.[25] Massachusetts' Environmental Justice Policy, updated in 2021 to align with the 2021 Climate Law, seeks to ensure environmental, energy, and climate benefits for Environmental Justice populations while minimizing harm to the most vulnerable populations throughout the Commonwealth.[26]

This chapter discusses how Massachusetts will prioritize equity in the transition to a clean energy economy. As the state works to achieve Net Zero with clean and advanced technologies, Massachusetts' central goal is that EJ populations are not left behind.

Ensuring Equitable Investments

One core component of Massachusetts' strategy to prioritize equity is to set a minimum threshold for investments that benefit EJ populations and low-to-moderate-income residents. EEA will ensure that, by the end of 2024, a certain number of clean energy and climate investments go to disadvantaged communities and that, within this amount, a specified portion

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[20] Maria De Moura, Cecilia Pinto et al., "Inequitable Exposure to Air Pollution from Vehicles in Massachusetts: Who Bears the Burden?" *Union of Concerned Scientists* (2019), http://www.jstor.org/stable/resrep24098.

[21] Robert D. Bullard, et al., "Toxic Wastes and Race at Twenty 1987–2007," *United Church of Christ*, (2007), https://www.ucc.org/wp-content/uploads/2021/03/toxic-wastes-and-race-at-twenty-1987-2007.pdf.

[22] A. Jbaily, X. Zhou et al., "Air pollution Exposure Disparities Across U.S. Population and Income Groups," *Nature* 601 (January 2022): 228–233, https://doi.org/10.1038/s41586-021-04190-y.

[23] Christopher W. Tessum et al., "Inequity in consumption of goods and services adds to racial–ethnic disparities in air pollution exposure," *Proceedings of the National Academy of Sciences of the United States of America* 116, no. 13 (2019): 6001–06, https://www.jstor.org/stable/26696656.

[24] The EEA Environmental Justice Policy defines "minority" as "individuals who identify themselves Latino/Hispanic, Black/African American, Asian, Indigenous people, and people who otherwise identify as non-white." *See* Massachusetts Executive Office of Energy and Environmental Affairs, "Environmental Justice Policy of the Executive Office of Energy and Environmental Affairs" (June 24, 2021), https://www.mass.gov/doc/environmental-justice-policy6242021-update/download.

[25] 2021 Climate Law § 56 (codified at Mass. Gen. Laws Ch. 30, § 62).

[26] EEA Environmental Justice Policy (updated June 2021).

will target EJ populations.[27] This strategy is harmonious with the federal Justice40 Initiative,[28] which requires at least 40% of the benefits of climate investments go toward disadvantaged communities. The approach will also be consistent with the steps taken by other jurisdictions to specify a set percentage of investments for disadvantaged communities or targeted low- to moderate-income consumers.[29]

Specifying a set portion of clean energy and climate investments to be in EJ neighborhoods will require an open and transparent process that ensures that the voices of EJ populations are at the forefront of policy deliberations. In addition to consulting with EJ residents, EEA will also work with the EJ Council, GWSA IAC, and the EEA EJ Task Force to secure a certain level of benefits to flow to EJ populations that historically have been marginalized, underserved, and overburdened by pollution.

In developing an investment goal, EEA's first step will be to define clean energy and climate investments and gather a baseline of existing investments in disadvantaged communities, EJ neighborhoods, or benefitting EJ populations. Starting in 2023, EEA will identify the best metric to track clean energy and climate investments to disadvantaged communities and EJ populations, whether it be a percentage-based investment or a total funding requirement.

EEA will conduct the assessment with a substantial stakeholder process that will include input from (1) the EJ Council, (2) stakeholders, and (3) the EJ populations that will receive these investments. This process will improve how the Commonwealth ensures equitable distribution of the benefits, including the availability of jobs and workforce development, associated with clean energy programs and policies. Following the public process, EEA will announce new metrics that will best track clean energy and climate investments and set goals for a portion of these investments to go to disadvantaged communities and EJ neighborhoods or populations. These metrics and goals will be added to EEA's Clean Energy and Climate Plan Dashboard, launched with this plan, to increase transparency and provide the public with the best available data to track progress toward climate mitigation in Massachusetts.

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[27] The Commonwealth recognizes the distinction between EJ populations and other disadvantaged residents of the Commonwealth, such as children, elders, moderate-income households with a high energy burden, and those with disabilities or mobility issues.

[28] U.S. Department of Energy, Office of Environmental Management, "Justice40 Initiative," https://www.energy.gov/em/justice40-initiative.

[29] E.g., California's Environmental Justice Law, which requires at least 35% of investments from California's cap and trade auction proceeds to benefit disadvantaged communities or low-income residents. *See* California EPA, "California Climate Investments to Benefit Disadvantaged Communities," https://calepa.ca.gov/envjustice/ghginvest/.

Community Engagement

Massachusetts will continue to use best practices for enhanced community engagement efforts in all aspects of this CECP, particularly when implementing programs that could affect EJ populations. Public engagement is the best process by which to gain an understanding of the circumstances and needs of EJ populations and ensure that programs and policies can best channel the proper resources and attention to the residents of Massachusetts.

A clear example of this effort is the EEA-hosted EJ focus group sessions in 2021. Over 200 stakeholders attended the focus group sessions in addition to the EJTF members. The focus group sessions centered the discussions on: (1) urban and rural land preservation and use; (2) protection, use, and stewardship of natural resources; (3) energy and the green transition; and (4) urban water quality, air quality, and toxics.[30] The crucial first-hand knowledge conveyed during these discussions helped inform policy decisions in this Plan.

In response to public comments, and to reflect the recommendations provided by the Commission on Clean Heat (discussed in more detail in Chapter 5b), the Commonwealth will launch a Climate Campaign in 2023 to raise climate awareness across the Commonwealth. The statewide Climate Campaign will aim to accomplish the following: (1) build awareness, understanding, and interest in climate action; (2) educate the public about the actions that each resident can take to save energy and minimize climate impact; and (3) increase people's receptivity to clean energy technologies. Centered around EJ, the Climate Campaign will provide information in languages accessible to EJ populations.

As part of the Climate Campaign, EEA will increase engagement with cities and towns across the Commonwealth to help communities build and implement town-specific climate mitigation plans while ensuring that available data and implementation approaches are consistent across the Commonwealth. Working with each city and town, EEA will build up "toolkits" that will help each community access financial and technical assistance support from the state, with a focus on ensuring inclusion and a just transition for all communities while being particularly attentive to the unique needs of EJ populations.

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[30] *See* Environmental Justice Stakeholder Focus Group Session comments: Commonwealth of Massachusetts, "Environmental Justice Public Involvement," https://www.mass.gov/info-details/environmental-justice-public-involvement.

Reduce Impacts of Air Pollution and Infrastructure Siting on Environmental Justice Populations

Existing air pollution (from NO_x, SO_x, ozone, and particulates) is often worse in EJ neighborhoods for several reasons. Large point-source emissions, such as power generators and industrial facilities, are disproportionately located in and near EJ communities. Many EJ communities face severe air pollution from fuel-burning heating systems and exhaust from vehicles, particularly from nearby traffic congestion and proximity to highways. To change historical patterns and advance EJ principles across Massachusetts, the Commonwealth will leverage the opportunities presented through the energy transition to significantly improve air quality and increase the economic benefits to EJ populations.

MassDEP is working to expand its air monitoring network in EJ populations by establishing new monitoring stations (e.g., in Chelsea in 2021 and planned for the Chinatown neighborhood of Boston in 2023) and providing air sensors to municipalities. The data will increase public understanding of air quality and guide actions to reduce air pollution, especially in EJ populations. MassDEP has also received funding under the American Rescue Plan Act (ARPA) to upgrade and expand particle pollution monitoring in and near EJ populations and will seek additional funding for community-based air quality monitoring under the federal IRA.

In addition, starting in 2023, EEA will work with public health professionals to increase coordination on how to ameliorate existing air pollution conditions while reducing GHG emissions across the Commonwealth. Engaging public health professionals in the planning process will help identify communities experiencing energy-related health impacts, design solutions to strategically invest in these communities, and provide air pollution monitoring to ensure that these investments have a positive health impact on EJ populations.

New clean energy technologies, including solar, wind, electric vehicles, and heat pumps, will reduce exposure to pollution that harms human health. However, these new technologies will require Massachusetts to site and build significant new energy infrastructure, including the transmission and distribution upgrades necessary to ensure a strong and reliable electricity grid. Collaborating across secretariats, the EJ Council, and a public participation process, the Commonwealth will seek to develop a holistic state-wide plan for siting energy infrastructure, kicking off the process in 2024. This substantial undertaking will require a coordinated effort between key personnel at state agencies and a well-constructed and implemented public involvement plan.

Chapter 3: 2050 Economy-Wide and Sector-Based GHG Limits

To achieve Net Zero in 2050, Massachusetts must reduce statewide GHG emissions by at least 85% relative to the 1990 level and balance any residual emissions with carbon sequestration attributable to the Commonwealth. Net-zero emissions accounting is presented in a conceptual diagram in Figure 3-1, with terminology explained in Table 3-1.

The first part of this chapter discusses the requirement to reduce statewide emissions to 85% below the 1990 level, the emission categories to which this requirement applies, the sector-specific sublimits, and the analytical approach behind setting the statewide emissions limit and sector-specific sublimits. The second part of this chapter discusses the approach to achieve net-zero emissions such that any residual emissions are equivalent to carbon sequestration attributable to the Commonwealth, which includes accounting for biogenic emissions and carbon sequestration.

FIGURE 3-1. NET-ZERO GREENHOUSE GAS EMISSIONS ILLUSTRATED

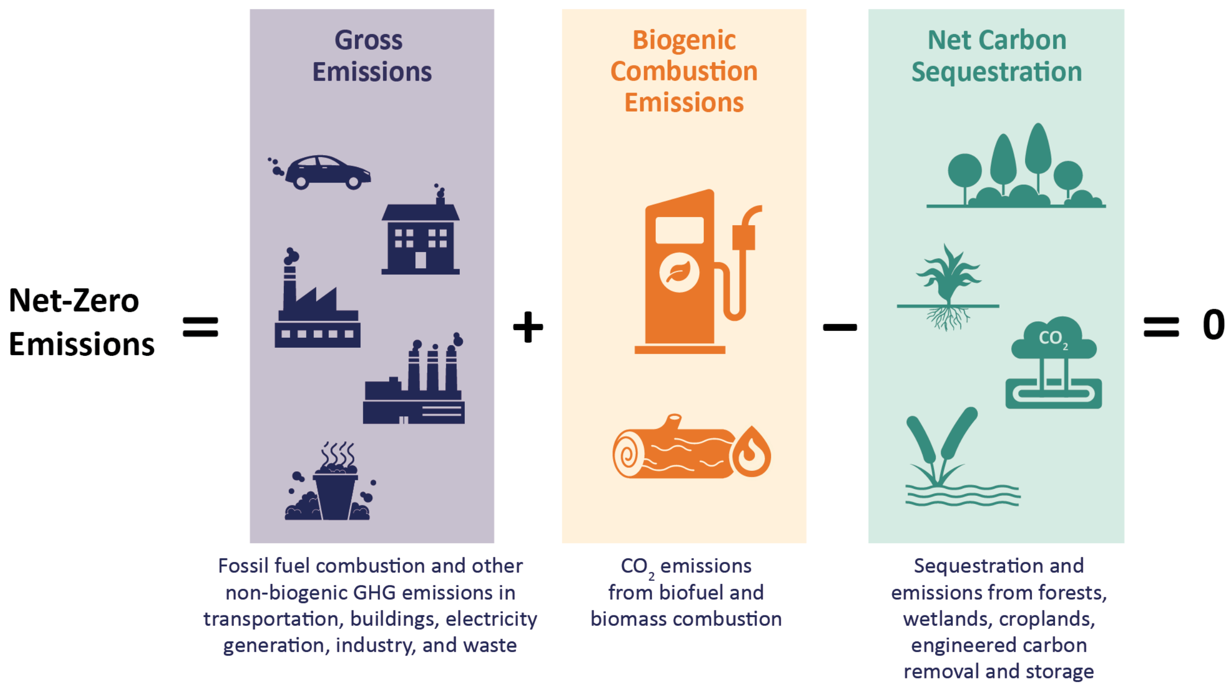

TABLE 3-1. NET EMISSIONS, NET-ZERO EMISSIONS, AND RELATED TERMS

Term	Explanation in Massachusetts Context
Net Emissions	"Net emissions" refers to the difference between all GHGs released into the atmosphere and those removed from the atmosphere on an annual basis from all sources and sinks in or attributable to MA. *Net Emissions = Gross Emissions + Biogenic Combustion Emissions – Net Carbon Sequestration*
Net-Zero Emissions	"Net-zero emissions" refers to a level of statewide GHG emissions that is equal in quantity to the amount of carbon dioxide or its equivalent that is removed from the atmosphere and stored annually by, or attributable to, the Commonwealth. *Net-Zero Emissions = Gross Emissions + Biogenic Combustion Emissions – Net Carbon Sequestration = 0*
Net Zero	"Net Zero" refers to the established statewide GHG limit for 2050, requiring net-zero emissions, provided that in no event shall the level of gross emissions be greater than a level that is 85% below the 1990 level. The requirement includes: *Net Emissions = 0* <u>and</u> *Gross Emissions* ≤ 15% of *Gross Emissions* in 1990
Gross Emissions	"Gross emissions" consist of all GHG emissions categories included in Massachusetts' 1990 Baseline,[31] including emissions from the combustion of non-biogenic materials, non-CO_2 GHG emissions from the combustion of biogenic materials, and leakage of other GHGs in Massachusetts, and emissions from out-of-state generation of electric power consumed in Massachusetts. *Examples:* Carbon dioxide (CO_2) emissions from the combustion of fossil fuel and non-biogenic waste; methane (CH_4), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6) leaks
Biogenic Combustion Emissions	"Biogenic combustion emissions" include CO_2 emissions resulting from the combustion of biologically-derived materials (excluding material of ancient biological origin such as fossil fuels). These emissions are not included in gross emissions but are reported separately in the Massachusetts GHG inventory. *Examples*: Carbon dioxide emissions from the combustion of biofuels for use in transportation and heating, and biogenic waste combustion CO_2 emissions in waste-to-energy plants
Net Carbon Sequestration (or Carbon Sequestration)	"Net carbon sequestration" refers to the difference between GHG emissions and carbon sequestration occurring annually on Massachusetts' natural and working lands, and any additional carbon sequestration attributable to Massachusetts. *Net Carbon Sequestration = MA NWL Carbon Sequestration – MA NWL GHG Emissions + Additional Carbon Sequestration* In general, carbon sequestration refers to the removal of carbon dioxide from the atmosphere and the long-term storage of the carbon in terrestrial, oceanic, geological, or durable product reservoirs. In the context of this Plan and Massachusetts GHG accounting, carbon sequestration means *net* carbon sequestration and is expressed as negative emissions. Additional carbon sequestration attributable to Massachusetts may include procured out-of-state sequestration, as discussed in Chapter 7. *Examples of NWL carbon sequestration*: biomass growth in forests and other ecosystems *Examples of NWL GHG emissions:* emissions from deforestation or development on organic soils
Residual Emissions	"Residual emissions" refers to the remaining gross and biogenic combustion GHG emissions in 2050 that must be balanced by net carbon sequestration to achieve Net Zero.
Natural and Working Lands (NWL)	Lands within the Commonwealth that: (1) 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; (2) produce forest products; (3) consist of forests, grasslands, freshwater, and riparian systems, wetlands, coastal and estuarine areas, watersheds, wildlands or wildlife habitats; or (4) are used for recreational purposes, including parks, urban and community forests, trails, or other similar open space lands.

31 As defined and updated by MassDEP. *See* Massachusetts Department of Environmental Protection, "MassDEP Emissions Inventories," https://www.mass.gov/lists/massdep-emissions-inventories.

85% Statewide GHG Emissions Reduction in 2050 and Sector-Specific Emissions Sublimits

As a component of achieving Net Zero, the Commonwealth must reduce gross GHG emissions to at least 85% below the 1990 baseline level in 2050. Baseline gross emissions include GHGs from the combustion of fossil fuels serving Massachusetts' transportation, building heating, electricity production, and industry demands, along with other sources like leaks from natural gas pipelines, hydrofluorocarbon (HFC) leaks from refrigeration systems, and sulfur hexafluoride (SF_6) leaks from gas-insulated switchgear. Consistent with international inventory convention, the current Massachusetts GHG inventory separately tracks biogenic emissions and non-biogenic (gross) emissions.[32] Biogenic emissions include GHG emissions from natural and working lands (NWL) and carbon dioxide (CO_2) emissions from the combustion of biofuels and biomass. Biogenic combustion and NWL emissions are not included in the 1990 baseline gross emissions from which compliance with Massachusetts emission limits and sublimits is determined.

The Commonwealth has set sector-specific emissions sublimits. These sublimits, shown in Table 3-2, are based on simulations of Massachusetts' energy usage to achieve the necessary GHG emission reductions in 2050 most cost-effectively and based on technologies and the relative costs of various necessary transitions known today or projected based on the best available information to date. The economy-wide modeling supporting this 2050 CECP has been updated with the best available data as of the fourth quarter of 2022.

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[32] IPCC GHG inventory guidelines allocate CO_2 emissions from the combustion of biogenic feedstocks to the NWL sector in the jurisdiction where the feedstock was grown (e.g., emissions from corn ethanol grown in Iowa), even when the emissions physically take place in other sectors (e.g., combustion in vehicle engines in the transportation sector) or jurisdictions (e.g., in Massachusetts). In the sector and jurisdiction where biogenic combustion physically occurs, only the CH_4 and N_2O emissions are attributed to that sector and jurisdiction, while the CO_2 emissions are recorded as an information item that is not included in the sectoral or jurisdictional total emissions, as these emissions should already be included in the NWL sector of the jurisdiction where the feedstock was grown (assuming the feedstock-producing jurisdiction is tracking and reporting emissions following IPPC guidelines). For further details, *see* E. Calvo Buendia et al., eds., *2019 Refinement to 2006 IPCC Guidelines for National GHG Inventories Volume 2: Energy* (Switzerland: Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme, 2019), https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol2.html.

TABLE 3-2. EMISSIONS LIMIT AND SECTOR-SPECIFIC SUBLIMITS FOR 2050

Emissions Limit & Sublimits	Emissions Limit as a % Reduction from 1990	Emissions Limit Expressed in $MMTCO_2e$*
Statewide Limit	**85%**	**14.0**
Sector-Specific Sublimits		
Transportation	86%	4.1
Residential Heating and Cooling**	95%	0.8
Commercial & Industrial Heating and Cooling**	92%	1.2
Electric Power	93%	2.0
Natural Gas Distribution & Service	72%	0.5
Industrial Processes	-27%	0.8

*These numbers represent the $MMTCO_2e$ based on the statewide GHG emissions inventory, published December 2022. If the inventory methodologies change, the equivalent $MMTCO_2e$ numbers will change.

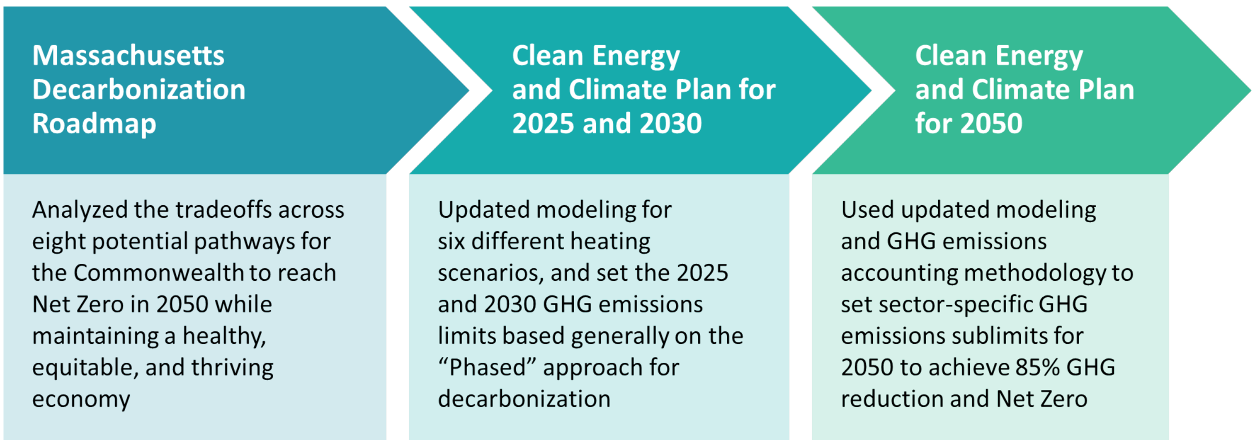
**Due to how emissions are tracked in the statewide GHG inventory, emissions associated with electricity usage in cooling residential, commercial, and industrial buildings are covered under the electric power sublimit.

Notes: Table does not include the agriculture and waste categories in the statewide GHG emissions inventory by MassDEP. These categories have projected total emissions of approximately 1.1 $MMTCO_2e$ in 2050 and are not subject to a sublimit. With the emissions from agriculture and waste included, the sublimits jointly would aggregate up to roughly 89% reduction from the 1990 level, which is more than the economy-wide 85% reduction required.

The ability and the pace of transformation will face uncertainties around technological developments and adoption rates of decarbonization solutions. Future improvements in data accuracy, potential discoveries of new GHGs, and other breakthroughs in atmospheric and earth science may result in changes in GHG reporting methods and accounting practices. Since the limit and sublimits are set as percentages of the Massachusetts 1990 baseline emissions, changes in how the 1990 baseline GHG emissions are calculated would affect the required reductions in tonnage. Due to the above-mentioned uncertainties, the 2050 sector-specific sublimits are set at levels slightly more stringent than necessary to achieve the 85% economy-wide GHG reduction requirement. Setting the sublimits with a slightly greater stringency would allow for some margins for error in meeting each of the sector-specific sublimits. If necessary, EEA can update the 2050 sublimits in subsequent CECPs to reflect updated information.

The analysis informing the 2050 emissions limit, sublimits, and this Plan is based on the Commonwealth's prior clean energy and decarbonization analyses and reports, as summarized in Figure 3-2. The 2050 Roadmap Study, published in December 2020, highlights that electrification and the "All Options" pathway meet the 2050 emissions reduction targets with the least cost while achieving deep decarbonization. Analysis for the 2025/2030 CECP, presented in detail in that publication's Appendix A,[33] highlights the need to immediately install heat pumps for those wanting efficient cooling and replace heating systems at the end-of-life of the equipment. That additional analysis shows a stock turnover of over half a million residential heating systems and over 300 million square feet of commercial space with electric heat by 2030. The 2050 CECP sublimits are based on the same analysis that was conducted for the 2025/2030 CECP, extended through 2050, with some minor refinements.

FIGURE 3-2. OVERVIEW OF PROCESS FOR SETTING GHG EMISSIONS LIMIT & SUBLIMITS



The GWSA identifies discrete sectors that require sublimits as components of the statewide GHG emissions limit: transportation, residential heating and cooling, commercial and industrial heating and cooling, electric power, industrial processes, and natural gas distribution and service. The Massachusetts' GHG emissions inventory is the primary method of tracking compliance with the GWSA. To account for the emissions reductions required by the GWSA in a way that comports with current emissions tracking, EEA has organized statewide emissions into the following policy sectors, consistent with the 2025/2030 CECP: transportation, buildings, electric power, non-energy and industrial, and natural and working lands.

An integrated energy and economic model supports this Plan. It is designed to simulate various sectors of the economy and energy systems simultaneously to meet the 2030, 2040, and 2050 statewide GHG emissions limits. The modeled emissions that remain in each sector—along with the non-energy and industrial emissions—sum to ~10.5 million metric tons of carbon dioxide equivalent (MMTCO_2e) in 2050, which is ~89% below the 1990 level. The industrial process, natural gas distribution & services, and other (waste and agricultural practices) sector

[33] Appendices to the 2025/2030 CECP are available at: Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (June 30, 2022), https://www.mass.gov/doc/appendices-to-the-clean-energy-and-climate-plan-for-2025-and-2030/download.

analyses were not part of the integrated energy and economic simulations. Instead, these emission projections were estimated first to determine the remaining emission allotment for the other sectors.

Table 3-3 below shows the modeled residual emissions in 2050 for the transportation, buildings, power, and non-energy & industrial sectors. Along with the remaining emissions are benchmarks from the modeling results and the policies being pursued to achieve the simulated outcomes. Achievement of the benchmarks will require successful implementation of the policies, and the remaining emissions from each sector are slightly lower than necessary to ensure that the Commonwealth achieves the 2050 requirement of 85% below 1990 levels.

The relationships across the sectors in the simulations are not linear. The model simulates the least-cost pathway to achieve Net Zero in 2050 using the best available assumptions. Sector-specific emissions sublimits are based on the most economic allocation of emissions across the sectors over the time period through 2050. The resulting emissions level from one sector is sensitive to various assumptions used in the model, including assumptions related to other sectors.[34] Because of the interdependencies and the fact that some policies are designed to be bundles of policies, this Plan does not focus on the targeted emissions reduction per *individual* policy. Instead, this Plan provides targeted benchmarks for each sector-specific bundle of policies discussed in Chapter 5.

[34] For example, if technological improvements lead to significant cost reductions for long-duration energy storage sooner than expected, the model will select to build more storage and renewable energy and thus decarbonizing the power sector sooner, and change the allocation of emissions among other sectors.

TABLE 3-3. 2050 RESIDUAL EMISSIONS AND BENCHMARKS BY MAJOR SECTORS

Transportation Sector

SECTOR SUBLIMIT: 86% EMISSIONS REDUCTION BY 2050 FROM 1990 LEVELS

Residual Emissions Sub Category	Residual Emissions in 2050 ($MMTCO_2e$)	Benchmarks to Enable Emission Reductions		Policy Drivers or Enablers
Light-Duty Vehicle Fuel Use	**<0.1**	**# EVs**	~5 million light-duty EVs	• Vehicle emission standards (Advanced Clean Cars 2) • MOR-EV incentives • Land use reform and increased housing near transit • Rideshare regulation • Electric vehicle infrastructure programs
		% EVs	97% of all light-duty vehicles	
		VMT	Reduce VMT per household to ~19,400 miles/year	
Medium/Heavy Duty Vehicle Fuel Use	**<0.1**	**# EVs**	~353,000 medium and heavy-duty EVs (battery electric and hydrogen fuel cell)	• Advanced Clean Truck standards • Federal medium and heavy-duty efficiency standards • MOR-EV Truck • Clean Fuels Policy
		% EVs	93% of all medium- and heavy-duty vehicles	
		Alternative fuel use	Diesel emission intensity down to 1 kg/mmBtu from 74 kg/mmBtu	
Marine and Aviation Fuel Use	**4.1**	**Alternative fuel use**	Emission intensity down to 60 kg/mmBtu from 70 kg/mmBtu	• Federal Aviation Climate Plan • International Maritime Organization GHG Strategy • Clean Fuels Policy

Buildings Sector Overview[35] (Residential and Commercial)

SECTOR SUBLIMIT: 93% EMISSIONS REDUCTION BY 2050 FROM 1990 LEVELS

Residual Emissions Sub Category	Residual Emissions in 2050 ($MMTCO_2e$)	Benchmarks to Enable Emission Reductions		Policy Drivers or Enablers
Residential Fuel Use	**0.8**	**# of whole-home air source heat pumps**	Over 2 million homes	• Clean Heat Standard • Building Decarbonization Clearinghouse • Climate Finance Accelerator • Joint Utility Plan • Public Education Campaign • Stretch Energy Code and Specialized Municipal Opt-in Energy Code
		# of ground source heat pumps	~195,000 homes	
		Energy efficiency envelope retrofits	1.3 million homes	
		Alternative fuel use	Heating oil contains only 1.5% fossil blend; pipeline gas contains 80% fossil blend	
Commercial Fuel Use	**0.9**	**Sq. ft. heated by air source heat pumps**	~1,500 million sq. ft., of which 140 million has back-up fuel	
		Sq. ft. heated by ground source heat pumps	~140 million sq. ft. of commercial space	
		Alternative fuel use	Heating oil contains 1.5% fossil blend; pipeline gas contains 80% fossil blend	

[35] The "buildings sector" includes both residential and commercial heating. This differs from Table 3-2, which combines the emissions from commercial and industrial heating.

Power Sector Overview

SECTOR SUBLIMIT: 93% EMISSIONS REDUCTION BY 2050 FROM 1990 LEVELS

Residual Emissions Sub Category	Residual Emissions in 2050 ($MMTCO_2e$)	Benchmarks to Enable Emission Reductions		Policy Drivers or Enablers
In-state Emissions[36]	**1.6**	**Offshore wind capacity**	23 GW	• Procure authorized OSW and advance development of floating OSW • Support wholesale market reforms, including the use of FCEM for future clean energy procurements • Implement Portfolio Standards (RPS, CES, CES-E, CPES) • Implement generator emission limit (310 CMR 7.74) • Implement Massachusetts CO_2 Budget Trading Program (310 CMR 7.70) • Modernize distribution infrastructure • Advance solar industry • Enable load flexibility and demand management
		Onshore wind capacity	1 GW	
		Solar capacity	27 GW	
		Storage capacity	5.8 GW	
Out-of-state Emissions[37]	**0.4**	**Total transmission import capacity**	34 GW	• Develop and use FCEM to support large-scale regional clean energy resources • Implement Portfolio Standards (RPS, CES, CES-E, CPES) • Implement Massachusetts CO_2 Budget Trading Program (310 CMR 7.70) • Advance regional transmission planning • Reform wholesale markets to facilitate growing need for flexible generation and load
		Transmission emissions intensity	0.23 $MMTCO_2e$/TWh	

36 In-state electric sector GHG emissions are determined from data on the fuels used to produce electricity in-state, including United States Energy Information Administration data on the use of natural gas, oil, and wood, and data reported by or to the United States Environmental Protection Agency for municipal waste combustors.

37 Out-of-state electric sector GHG emissions are determined by estimating the amount of power Massachusetts imports from neighboring states and provinces (and associated emissions), including the effects of MassDEP's Clean Energy Standard (CES) and DOER's Renewable Portfolio Standard (RPS). For details, see the MassDEP GHG inventory spreadsheets and narrative documents: Massachusetts Department of Environmental Protection, "MassDEP Emissions Inventories," https://www.mass.gov/lists/massdep-emissions-inventories.

Non-Energy & Industrial Sector[38]

SECTOR SUBLIMIT: 76% EMISSIONS REDUCTION BY 2050 FROM 1990 LEVELS

Residual Emissions Sub-Category	Residual Emissions in 2050 ($MMTCO_2e$)	Benchmarks to Enable Emission Reductions		Policy Drivers or Enablers
Industrial Energy	**0.3**	**Energy efficiency**	1% energy efficiency increase year over year	• Mass Save® commercial and industrial programs in both energy efficiency and electrification
		Electrification	52% of total final energy electrified; over 90% of final energy in industrial HVAC, lighting, and machine drive applications is electrified	
Industrial Process	**0.8**	**HFC**	Nationwide, 85% phasedown of HFC production and consumption by 2036	• EPA regulations to implement Kigali Amendment to Montreal Protocol ratified by U.S. Senate
		SF_6	No increased emissions	• MassDEP regulations limiting SF_6 leaks in new equipment • MassDEP determines schedule for phasing out SF_6 use in the electric transmission and distribution system
Natural Gas Systems	**0.5**	**Gas pipeline emissions**	DOER analyzes implications and makes recommendations to inform future legislative changes	• Gas System Enhancement Plans (GSEP) Working Group to propose legislative reform regarding gas pipelines
Other: Agricultural and Waste	**1.2**	**Waste disposal**	Reduce waste disposal by 90% in 2050 to 570,000 tons	• Prepare and implement 2030, 2040, and 2050 Solid Waste Master Plans

In developing the 2050 sector-specific emissions sublimits and this Plan, EEA consulted with other departments, agencies, and regional authorities, as well as engaged with advisory groups, other stakeholders, and with members of the public during a public comment period. Equity and EJ principles were observed throughout this process and will remain at the center of policy commitments and implementation in this Plan.

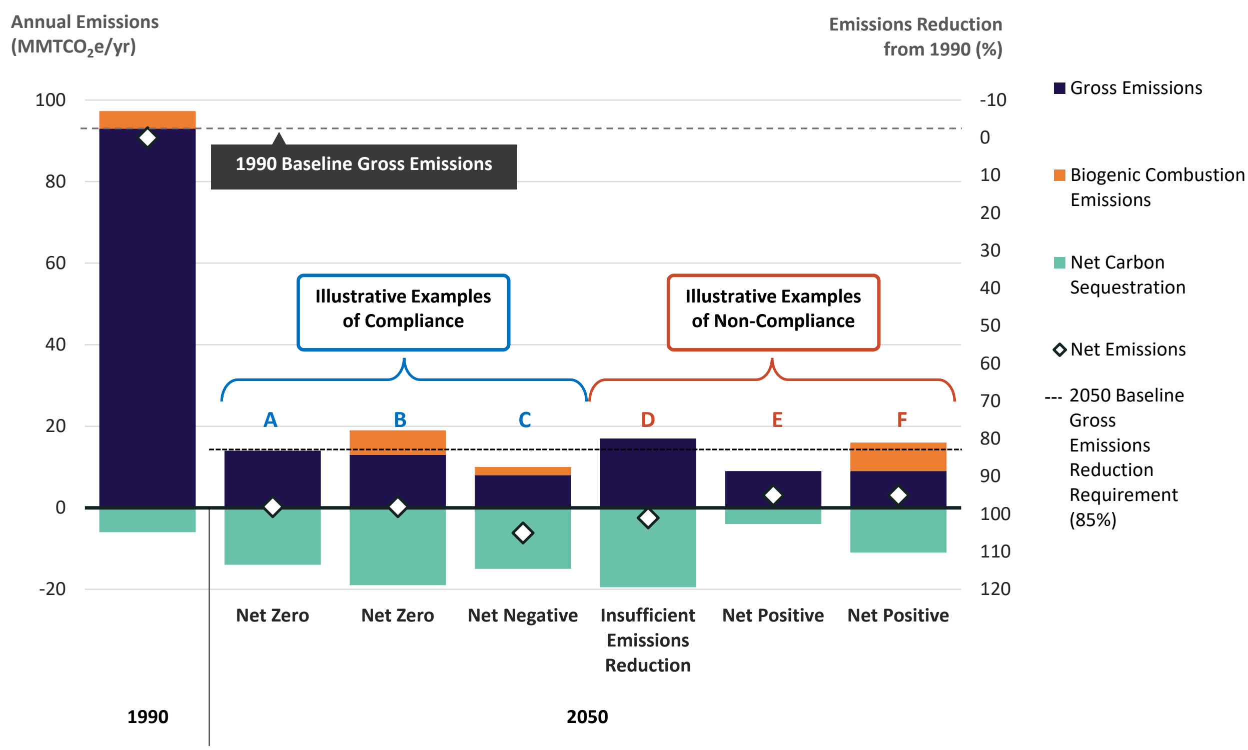
[38] The non-energy and industrial sector includes four main categories of emissions, three of which are included in Table 3-2: industrial energy (which is combined with commercial heating in Table 3-2), industrial process, and natural gas systems. The non-energy and industrial sector also includes other emissions from agriculture and waste which do not have specific sublimits even though their emissions are included in the state-wide Net Zero limit.

Achieving Net Zero

Achieving Net Zero in 2050 requires accounting for (1) the combustion of biogenic fuels and (2) the carbon sequestration and GHG emissions occurring on natural and working lands. Achieving Net Zero will likely require the Commonwealth to procure additional carbon sequestration from nature-based and/or engineered solutions beyond Massachusetts' NWL carbon sequestration capabilities.

Figure 3-3 below illustrates how the Commonwealth can comply with the Net Zero emissions limit. Compliance can be achieved in different ways but requires that the gross emissions are reduced by at least 85% relative to the 1990 level, and that gross and biogenic combustion emissions together are balanced by equal or greater quantities of net carbon sequestration (shown in illustrative examples A, B, and C in Figure 3-3). Illustrative examples of non-compliance include (1) the gross emissions are not reduced by at least 85% relative to the 1990 level (shown in Figure 3-3, example D), or (2) the gross and biogenic combustion emissions together exceed net carbon sequestration (shown in Figure 3-3, examples E and F).

FIGURE 3-3. ILLUSTRATIVE EXAMPLES OF COMPLIANCE AND NON-COMPLIANCE WITH NET ZERO EMISSIONS LIMIT

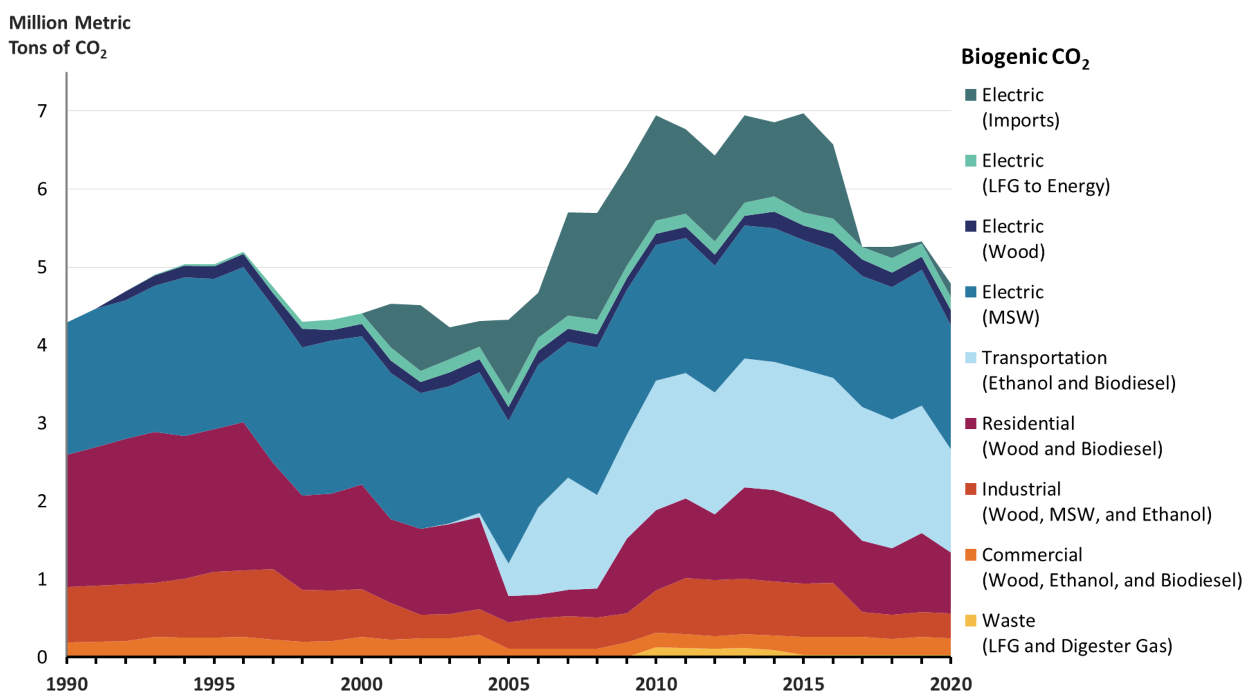


Biogenic Combustion Emissions

Biogenic combustion emissions include the carbon dioxide released from the combustion of biologically-derived feedstock serving Massachusetts' transportation, building heating, and electricity demands. In the Commonwealth today, most of these emissions result from the combustion of biogenic municipal solid waste for electricity production, biofuels for transportation, and wood for residential heating, as indicated in Figure 3-4 below.

Based on the methodology used by and the emissions factors from the U.S. Environmental Protection Agency's State Inventory Tool, these emissions are estimated to be 4.8 $MMTCO_2$ in 2020, up from 4.3 $MMTCO_2$ in 1990, primarily due to the increased use of ethanol as a transportation fuel. Massachusetts' biogenic combustion emissions (and non-biogenic emissions) will need to be reduced and/or offset by net carbon sequestration in or attributable to the Commonwealth. As more and different types of advanced biofuels are developed, current emissions inventory conventions or methodologies may not adequately account for the emissions and carbon sequestration associated with their feedstock, production, and use. Chapter 6 further discusses biofuels (and other alternative fuels) and the potential need for updates to the emissions to account for future advances in biofuel production and delivery.

FIGURE 3-4. MASSACHUSETTS BIOGENIC COMBUSTION EMISSIONS



Note: LFG refers to landfill gas. MSW refers to municipal solid waste.

Net Carbon Sequestration

Carbon sequestration includes processes that remove carbon dioxide from the atmosphere and transfer the carbon into long-term storage. This occurs primarily via photosynthesis and carbon accumulation on natural and working lands, particularly in forest lands in Massachusetts (see Chapter 5e). NWL ecosystems include natural processes, often under human influence, that both sequester carbon and emit GHGs. While it is possible to separate out emissions from sequestration in some cases, NWL carbon sequestration (expressed as negative emissions) is typically estimated and reported on a *net* basis, reflecting annual carbon accumulation or loss in ecosystems (e.g., in biomass or soils) simultaneously.

While NWL carbon sequestration and emissions are not subject to sector-specific sublimits, EEA set goals in the 2025/2030 CECP to decrease net NWL emissions (i.e., increase net sequestration) relative to the 1990 baseline of -5.8 $MMTCO_2e$. The amount of carbon that could be sequestered by Massachusetts' NWL in 2050 is uncertain, but the 2050 Decarbonization Roadmap Land Sector Report[39] and subsequent assessments indicate a strong likelihood that net NWL sequestration could be less than the 6.9 $MMTCO_2e$ estimated for 2020.

As discussed in Chapter 5e, climate-intensified ecological disturbances, the conversion of forests to other land uses, and a slowdown in the growth of Massachusetts' aging forests present considerable risks and challenges to maintaining current levels of carbon sequestration through 2050. NWL protection, management, restoration, and improved resource utilization could help mitigate this risk and maintain or grow the Commonwealth's carbon sequestration capacity, but further analysis will be needed to make a complete assessment of the impacts of these strategies.

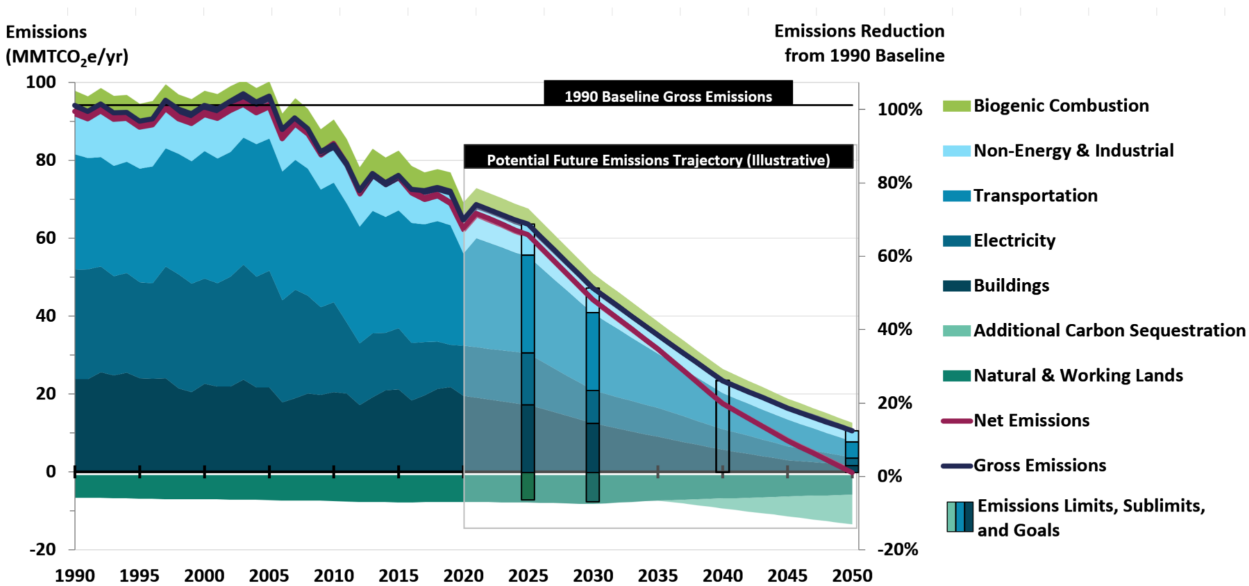
Looking to 2050, even with the strategies in this plan, Massachusetts' NWL will not likely have the necessary capacity to sequester all the residual emissions attributable to the Commonwealth. Thus, additional carbon sequestration capacity will be needed to reach net-zero emissions. These additional carbon sequestration resources may include out-of-state NWL sequestration and/or engineered carbon dioxide removal technologies. Prospects for and policy considerations of these additional resources are discussed further in Chapter 7.

[39] Jonathan Thompson et al., *Land Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study*, Harvard Forest: Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs (2020), https://www.mass.gov/doc/land-sector-technical-report/download.

Emissions Trajectories to Achieve Net Zero in 2050

Figure 3-5 below shows the historical GHG emissions from Massachusetts and the statutory 2030 and 2040 emissions limits at 50% and 75% reductions from 1990 baseline emissions. This figure also shows the sector-specific emissions sublimits and net NWL carbon sequestration goals for 2025 and 2030. Collectively, these limits, sublimits, and goals show a plausible future emissions trajectory for achieving Net Zero in 2050.

FIGURE 3-5. PAST EMISSIONS THROUGH 2020, EMISSIONS LIMITS AND SUBLIMITS, AND ILLUSTRATIVE POTENTIAL EMISSIONS TRAJECTORY THROUGH 2050



Chapter 4: Cross-Sector Strategies

Climate policy in Massachusetts has traditionally been divided into the major sources of global warming emissions: the combustion of fossil fuels in our vehicles, furnaces and boilers that heat our homes and businesses, power generators, and industrial applications and waste management. As we look to 2050, some of the policies and programs needed to mitigate GHG emissions begin to merge across economic sectors and sources of emissions. Across the sectors, reducing emissions to achieve Net Zero requires education, workforce, innovation, and other springboards necessary to carry out emissions-reduction strategies over time.

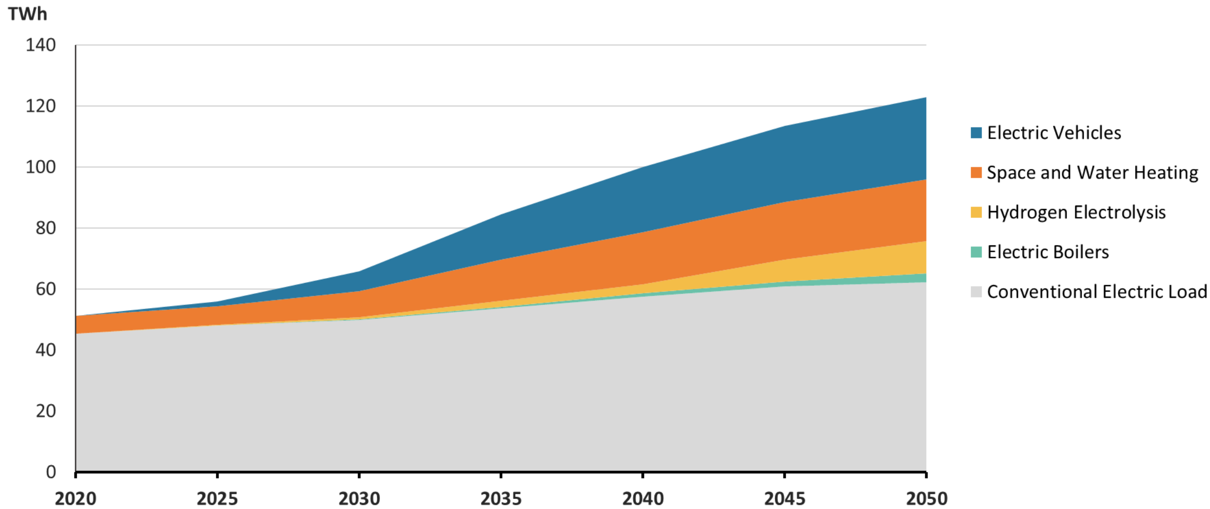
This 2050 CECP recognizes those points of intersection. For example, buying an EV is an individual automobile purchase, but it may also involve a home renovation project, as some EV owners will install a charging station at home. Some residents who use heat pumps for cooling and heating may choose to install solar PV on their roofs to power the heat pumps and charging station. Across the board, implementing the clean energy transition will require a robust workforce to build and install the necessary technologies and infrastructure. Some decarbonization strategies require additional electric infrastructure, which in turn may face challenges related to optimal land use and siting decisions. As more of our economy becomes powered by electricity, it becomes increasingly critical to ensure system resiliency with efficient buildout and management of our electricity system.

This chapter discusses some of the cross-sector considerations that will continue to guide climate policies in Massachusetts. In particular, this chapter discusses strategies aimed at: (1) coordinating electrification efforts across sectors; (2) building a robust and diverse workforce to support the transition to clean energy; (3) establishing best practices for land-use planning that balances development and sequestration capacity; (4) enhancing Massachusetts' role as a global leader in clean energy innovation; and (5) leveraging state resources to illustrate Net Zero viability and assist municipalities in transitioning to a Net Zero future.

Coordinated Electrification: Adapt Electricity Planning and Consumer-Facing Programs to Integrate Cross-Sectoral Electricity Loads

Massachusetts' path to economy-wide decarbonization relies on an expanded role for the power system. Most future electricity load growth will come from new sources of electricity demand: transportation, residential and commercial buildings, industrial energy needs, and possibly even the production of hydrogen and/or synthetic fuels. As Figure 4-1 below illustrates, anticipated final electricity demand in Massachusetts more than doubles from around 50 TWh in 2020 to over 120 TWh in 2050. Load growth from electric vehicles, space and water heating, hydrogen production, and electric boilers accounts for 55 of those 70 TWh of growth, as estimated via simulations.

FIGURE 4-1. PROJECTION OF MASSACHUSETTS ELECTRICITY LOAD



Note: Excluding line losses, battery storage, and net transmission exports.

These new loads will increase overall dependence on the electricity system, requiring accelerated investment in expanded generation, transmission, and distribution infrastructure. Electric utilities, the Independent System Operator of New England (ISO-NE), and regulatory agencies will need to adapt load forecasting and system planning practices to respond to accelerated load growth.[40]

New sources of electricity demand also introduce opportunities to increase load flexibility to minimize the total cost of decarbonization. Load from EV charging and electric space and water heating can be shifted throughout the day to minimize distribution peaks, thereby reducing the investment required to increase electricity system capacity. Hydrogen production through electrolysis, while still under research and development, may be helpful in the future to store energy when costs are low. Capturing the potential value of flexible load will require new demand-side management and pricing programs so that consumers can maximize their ability to adjust their electricity use patterns when the system is constrained (see further discussion of electric power sector policies in Chapter 5c).

The policies driving decarbonization in one area can have cross-cutting effects on another part of the economy. For example, this Plan includes policies and programs that will help consumers

[40] Such electricity load forecast will require new tools and methodologies because historical data will not be sufficient in estimating, for example, consumers' EV charging and the electric heating patterns.

navigate the energy transition with a particular focus on equity and inclusion. Those policies need to be applied across the board. In another example, the buildings section of Chapter 5 discusses new ways to inform and engage consumers about the electrification of residential and commercial heating and cooling. The outreach will inform how to best conduct a climate campaign to educate consumers on all the other opportunities. The buildings section also discusses setting up a climate finance mechanism to help facilitate the financing of many decarbonization efforts, with a focus on attracting private investments. Successes in using a climate finance mechanism can be applied across many public-private investment opportunities, including investing in climate resilience.

Build a Robust and Diverse Clean Energy Workforce to Meet the 2030 and 2050 Goals

To reach the Commonwealth's 2030 goals, Massachusetts' clean energy sector will need to add approximately 22,580 new full-time jobs. Looking ahead to 2050, that number increases to more than 66,000.[41] Today, occupations like electricians, plumbers, pipefitters, carpenters; heating, ventilation, and air conditioning (HVAC) technicians; and construction/trades managers already face significant supply shortages, such that clean energy employers face significant competition for the talent needed.[42]

Some clean energy sectors are growing quickly, such as offshore wind. Estimates conducted by BWR[43] show that, by 2030, Massachusetts will need to grow the offshore wind workforce by seven times, which in turn requires increased training capacity to align with project timelines and employment needs.

The path forward will require Massachusetts to expand the clean energy labor pool by prioritizing attracting diverse candidates, bolstering industry awareness, scaling up workforce and education programs, and improving alignment with employers' and participants' needs. Just as the growth of the biotech industry reshaped the statewide economy in the last decade, clean energy will play an equally transformative role in the state's economy going forward.

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41 *See* Figure 8-2, Change in Employment from 2030 by Value Chain. Also, these numbers represent net full-time equivalent jobs, so the number of total new workers who will need to be attracted and trained is likely higher.

42 Preliminary data from the *Massachusetts Clean Energy Workforce Needs Assessment.*

43 Massachusetts Executive Office Energy and Environmental Affairs, *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (June 30, 2022), https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download.

Massachusetts is poised to train the future clean energy workforce, and a scaled-up effort must begin immediately and be sustained through the next several decades.

Prioritizing Diversity, Equity, and Inclusion

With 95% of the new clean energy jobs between now and 2030 projected to be middle- and high-wage jobs, an inclusive approach to growing the workforce can significantly reduce historical income inequalities and provide tremendous opportunities for residents.[44] While the unemployment rate in Massachusetts is relatively low compared to other regions of the country, many cities and towns where large percentages of the population live in EJ Block Groups have higher unemployment rates.[45]

PICTURE 4-1. WORKER ON SOLAR ROOF ATOP THE WIND TECHNOLOGY TESTING CENTER

Massachusetts' commitment to equitable access to clean energy benefits includes access to high-quality job opportunities. Using the $12 million in annual funding for Equity Workforce Development programming administered by MassCEC, Massachusetts will continue to provide clean energy occupational training for priority populations[46] and support minority- and women-owned small business enterprises (MWBEs).[47] The programs will

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

[45] For example, in Lawrence, where 100% of the population lives in EJ neighborhoods, the average unemployment rate in 2022 is 7.75%—more than double the statewide rate during the same period. Springfield, New Bedford, and Fall River—where 95.8%, 78.3%, and 77.1% of the population, respectively, live in EJ communities—all have unemployment rates 70–80% greater than statewide rates. Data are retrieved from Massachusetts Department of Economic Research, "Labor Force and Unemployment Data," https://lmi.dua.eol.mass.gov/LMI/LaborForceAndUnemployment#. Included monthly rates through August 2022.

[46] Priority populations identified in the legislation include small business enterprises that are minority and women-owned, other businesses or communities underrepresented in the clean energy workforce or clean energy industry, individuals residing within an EJ or low-income community, current and former workers from the fossil fuel industry, and federally recognized and state acknowledged tribes within the commonwealth.

[47] In September 2022, the Baker-Polito Administration announced $3.6 million in Minority- and Women-Owned Business Enterprises Support Implementation and Planning Grants and Equity Workforce Training Grants administered through MassCEC. *See* Massachusetts Clean Energy Center, "Baker-Polito Administration Announces $3.6M in Funding to Equity Workforce Training and Minority- and Women-Owned Business Enterprises in Climate-Critical Fields" (September 23, 2022), https://www.masscec.com/press/baker-polito-administration-announces-36m-funding-equity-workforce-training-and-minority-and#.

yield an increasingly diverse bench of highly trained workers and develop a wider array of thriving MWBEs to lead climate-critical work.

The forthcoming Massachusetts Clean Energy Industry Need Assessment report will inform program design and funding priorities to ensure that these resources address gaps and prepare trainees for careers in high-demand areas as the Commonwealth works toward our 2030 and 2050 goals. A significant amount of additional effort will be needed to prepare the workforce for the future. Thus, additional funding in this area will be critical to achieving Massachusetts' decarbonization targets.

Providing increased opportunities for unemployed and underemployed individuals and members of historically marginalized communities requires training programs that include robust support services, transparent communication about career fit considerations, and solid employer partnerships to enable strong post-training placements and inclusive work environments. In 2022, MassCEC made initial awards to 16 grantees that will plan and expand comprehensive training approaches focused on climate-critical occupations.[48] Going forward, Massachusetts will continue to prioritize increasing the participation of underrepresented populations.

These efforts align with a broader statewide commitment to increasing equity in the workforce. The Executive Office of Labor and Workforce Development (EOLWD) recently released Interactive Equity Dashboards designed to provide integral data to close job and equity gaps.[49] Additionally, increased funding for the Senator Kenneth J. Donnelly Workforce Grants for Expanded Training Capacity and Employment Program Performance provides a proven avenue for positive employment and wage outcomes across programs that serve diverse populations, many of whom also have barriers to employment.[50]

To amplify the impacts of these public investments, employers can partner with community-based organizations and training providers to develop more apprenticeship and pre-

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[48] Massachusetts Clean Energy Center, "Baker-Polito Administration Announces $3.6M in Funding to Equity Workforce Training and Minority- and Women-Owned Business Enterprises in Climate-Critical Fields" (September 23, 2022), https://www.masscec.com/press/baker-polito-administration-announces-36m-funding-equity-workforce-training-and-minority-and#.

[49] Massachusetts Executive Office of Labor and Workforce Development, "Executive Office of Labor and Workforce Development Releases Interactive Equity Dashboards" (September 16, 2022), https://www.mass.gov/news/executive-office-of-labor-and-workforce-development-releases-interactive-equity-dashboards.

[50] Commonwealth Corporation, *2021 Annual Report: Workforce Competitiveness Trust Fund*, https://commcorp.org/wp-content/uploads/2022/02/WCTF-2021-Annual-Report.pdf.

apprenticeship programs that include effective mentoring supports focused on increasing diversity and inclusion across all genders and racial-ethnic backgrounds.[51] Clean energy industry organizations can serve as connective tissue by facilitating awareness and peer learning across companies that have expanded their workforce development strategies to include coordination with training programs and apprenticeship opportunities.[52] Increased public and private collaboration to drive equitable access to clean energy employment benefits will also more strongly position Massachusetts to access federal funding opportunities of the IIJA and the IRA, many of which tend to align with the goals of the Justice40 Initiative.[53]

Increasing Coordination to Scale Workforce Capacity

Developing the necessary clean energy workforce will require greater awareness, high-quality training, employer coordination, and support services—all of which underscore the importance of increased collaboration with key partners across the Commonwealth. Partners include the Workforce Skills Cabinet,[54] the MassHire workforce system,[55] two and four-year colleges, high schools, vocational and technical schools, community-based organizations, EJ advocates, organized labor, and clean energy employer consortiums.

The forthcoming Workforce Needs Assessment and network of clean energy employers can inform these collaborations to focus on developing and scaling programs that align with in-demand clean energy jobs. For instance, the Regional Workforce Skills Planning Initiative was launched in 2017 to fuel job growth and address employer demand for talent across the Commonwealth. Originally, that initiative involved developing in-state regional priorities and strategies across seven regions throughout the Commonwealth. The seven Regional Workforce Teams continue to update the Regional Blueprints and Plans and, therefore, present opportunities to include the projected growth of the clean energy industry to ensure that the

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51 Building Pathways, "If You Can See It, You Can Be It: Pipelines for Women into the Trades," https://tradeswomenbuild.files.wordpress.com/2022/06/bpi-case-study_final-2.pdf.

52 Massachusetts Executive Office of Labor and Workforce Development, "Division of Apprentice Standards," https://www.mass.gov/orgs/division-of-apprentice-standards.

53 The White House, "Justice40: A Whole-of-Government Initiative," https://www.whitehouse.gov/environmentaljustice/justice40/.

54 Please see information about the Massachusetts Workforce Skills Cabinet, set up by the Baker-Polito Administration in 2015 via Executive Order, at Office of Governor Charlie Baker and Lt. Governor Karyn Polito, "Workforce Skills Cabinet," https://www.mass.gov/orgs/workforce-skills-cabinet.

55 Please see information about MassHire at MassHire Department of Career Services, "About MassHire," https://www.mass.gov/about-masshire.

clean energy training needs are addressed by future programs that support the Commonwealth's workforce and education systems.[56]

In addition to the focus on higher education, Massachusetts can grow qualified clean energy workers through the expansion of existing vocational and training programs. Currently, the demand for seats in vocational high school programs exceeds the existing capacity by a factor of 1.75. Among oversubscribed vocational schools, 95% identified the capacity of their space as a key constraint.[57,58] In December 2021, the Baker-Polito Administration devoted over $200 million to capital grants and skills training for vocational high schools and career technical education programs.[59] Through the initial grants awarded in 2022, programs are already planning to modernize and expand capacity in carpentry, HVAC, electrical, and advanced manufacturing programs—all of which will contribute toward building a qualified clean energy workforce.[60] The opportunity to increase capacity extends beyond the regular school day as more vocational schools and programs open second and third-shift offerings through the Career Technical Initiative (CTI), which links support from MassHire Career Centers to provide additional services, career readiness, and job placement support.[61]

Additionally, Massachusetts' 15 community colleges, all of which recently received American Rescue Plan Act (ARPA) funds devoted to workforce development, offer an essential avenue to building the required workforce, especially as employers collaborate to clarify the value of

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[56] More information about the Regional Workforce Blueprints can be found at Executive Office of Labor and Workforce Development, "Regional Workforce Skills Planning Initiative," https://www.mass.gov/regional-workforce-skills-planning-initiative. One ongoing challenge is that the blueprints utilize the two-digit North American Industry Classification System (NAICS) industry codes, and clean energy occupations cross multiple official industries, including, but not limited to, utilities (22), construction (23), manufacturing (31–33), and professional, scientific, and technical Services (54).

[57] Massachusetts Department of Elementary and Secondary Education, "Massachusetts Career Vocational Technical Education Waitlist Report for 2020–2021 (FY21)" (February 2021), https://d279m997dpfwgl.cloudfront.net/wp/2021/06/DESE_spec-item1.2-cvte-waitlist-report.pdf.

[58] Shaun M. Dougherty and Isabel Harbaugh, "Policy Brief: Understanding Excess Demand for High-quality Career and Technical Education in Massachusetts," Massachusetts Department of Elementary and Secondary Education (July 2019), https://www.doe.mass.edu/ccte/cvte/programs/2019-07policy-brief.pdf.

[59] Office of Governor Charlie Baker and Lt. Governor Karyn Polito, "Governor Baker Signs $4 Billion Federal COVID-19 Relief Funding Spending Bill" (December 13, 2021), https://www.mass.gov/news/governor-baker-signs-4-billion-federal-covid-19-relief-funding-spending-bill.

[60] Office of Governor Charlie Baker and Lt. Governor Karyn Polito, "Baker-Polito Administration Awards $24 Million in Skills Capital Grants to High Schools" (September 28, 2022), https://www.mass.gov/news/baker-polito-administration-awards-24-million-in-skills-capital-grants-to-high-schools.

[61] The CTI program is relatively new, and additional information can be gleaned from the first annual report. *See* Commonwealth Corporation, *2021 Annual Report: Career Technical Initiative*, https://commcorp.org/wp-content/uploads/2022/08/CTI-2021-Annual-Report.pdf).

stackable credentials.[62] With most of the job growth projected in occupations that do not require a four-year college degree but call for specialized training, both the associate degree programs and the non-degree workforce development offerings from community colleges will contribute to supplying Massachusetts' next generation of HVAC workers, Smart Building Technicians, Municipal Construction and Building Inspectors, and more. The Senator Kenneth J. Donnelly Workforce Success Grants and the over 30 joint apprenticeship training centers (JATCs) operated by the Building Trades unions are also workforce programs that, with intentional coordination, can expand the number of trained, clean energy workers.[63,64]

The Workforce Training Fund, which provides resources for employers to increase incumbent worker training, reached almost 13,000 trainees in 2021 and is a powerful resource for small businesses and companies looking to develop career pathways for employees, increase retention rates, and provide employees with advancement opportunities. The clean energy industry could learn from the successful efforts of the manufacturing industry: despite employing just 6.6% of the Commonwealth's total workforce, it accounted for 47% of the funds awarded through the general training fund program and 36% of the funds from the Express grant program in fiscal year 2021.[65,66] Through coordination with clean energy employers, labor unions, Mass Save®, and training providers, this strategic utilization of the Workforce Training Fund could address many key incumbent workforce needs.

Throughout this clean energy transition, collaborating with labor unions to help transition and/or provide skills training for the existing workforce, particularly those currently working in oil and gas industries, will be essential as increased decarbonization efforts reduce the demand for fossil fuel workers. The opportunities for skills training will begin immediately, with transition-based training to take place over time through the 2030s and 2040s. Similarly, many workers across trade occupations will need to learn how to apply their existing skills to new

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62 "Baker-Polito Administration Awards $15 Million in Workforce Training Grants to the Commonwealth's 15 Community Colleges," Executive Office of Education (July 11, 2022), https://www.mass.gov/news/baker-polito-administration-awards-15-million-in-workforce-training-grants-to-the-commonwealths-15-community-colleges.

63 Commonwealth Corporation, *2021 Annual Report: Workforce Competitiveness Trust Fund*, https://commcorp.org/wp-content/uploads/2022/02/WCTF-2021-Annual-Report.pdf.

64 Building Trades Training Directors Association of Massachusetts, *Directory of Joint Apprenticeship Training Centers in Massachusetts*, https://www.mass.gov/files/2017-07/building-trades-training-book_0.pdf.

65 "2020 Massachusetts Manufacturing Facts," National Association of Manufacturers, https://www.nam.org/state-manufacturing-data/2020-massachusetts-manufacturing-facts/.

66 Commonwealth Corporation, *2021 Annual Report: Workforce Competitiveness Trust Fund*, https://commcorp.org/wp-content/uploads/2021/09/WTFP-2021-Annual-Report.pdf.

equipment and building techniques, and the professional development opportunities from their unions can help transform these skill sets.

Building the Next Generation Through Early Awareness

To build the long-term workforce needed to achieve the 2050 goals, the Commonwealth must significantly expand the pipeline of new workers. Attracting more students to clean energy careers requires increased awareness of climate-critical career opportunities. Several existing programs provide strong avenues for fostering clean energy career awareness, but additional efforts will be necessary so that the information reaches a broader set of residents.

The Department of Elementary and Secondary Education (DESE) supports early career awareness and exploration through several important existing programs. The My Career and Academic Plan (MyCAP) tool and implementation guides emphasize career exploration and planning alongside academic and social-emotional development.[67] MassCEC will seek to partner with DESE to include relevant resources, such as MassCEC's Clean Energy Careers Training and Education Directory, in their implementation guides and professional development sessions to expand awareness.[68]

DESE's Connecting Activities (CA) program, which has operated for over two decades, is coordinated through the 16 MassHire Workforce Boards. Each year, it provides students from over 200 public high schools with work-based learning and career development opportunities, including 1,200 events a year, many of which feature employer partners at career panels or career fairs.[69] MassCEC will connect clean energy employers and industry associations with local Connecting Activities staff to reach the public high schools involved in DESE's program.

DESE's Early College and Innovation Pathways programs, which yield positive student outcomes, prioritize career exploration and planning and could offer another way to increase student awareness of the clean energy sector.[70] The Innovation Pathway programs are industry-aligned. They are developed based on predetermined industry sectors, which have

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67 Massachusetts Department of Elementary and Secondary Education, "My Career and Academic Plan (MyCAP)," https://www.doe.mass.edu/ccte/ccr/mycap/.

68 Massachusetts Clean Energy Center, "MassCEC Clean Energy Careers Training & Education Directory," https://cleanenergyeducation.org/.

69 Massachusetts Department of Elementary and Secondary Education, "Connecting Activities," https://www.doe.mass.edu/connect/.

70 Massachusetts Department of Elementary and Secondary Education, *Massachusetts Innovation Pathway & Early College Pathway Program Evaluation Impact Report* (June 2020), https://www.doe.mass.edu/research/reports/2020/06impact-evaluation.docx.

included manufacturing and environmental and life sciences—both of which offer clear opportunities to integrate connections to the clean energy sector. Additionally, the findings of the forthcoming Clean Energy Workforce Needs Assessment will provide the information to coordinate with the Workforce Skills Cabinet (or future equivalent body), DESE, and the MassHire workforce boards to explore the viability of building a dedicated Clean Energy Industry Innovation Pathway option.

In addition to the Connecting Activities, Early College, and Innovation Pathways programs that it administers, many of DESE's Chapter 74 and Non-Chapter 74 Career and Technical Education (CTE) programs provide direct training pipelines to climate-critical occupations like electricians, HVAC technicians, plumbers, and auto technicians. Some of these CTE programs have already started to increase student access through MassCEC-supported programming and subsidized clean energy internships. Further coordination with these programs can support greater integration of clean-energy specific training content and increase student awareness of all the relevant clean energy opportunities connected to their emerging technical skills.

The 2022 Climate Act requires DESE to work with EOLWD to develop an offshore wind career training pilot program, and the findings from this effort will inform how best to expand broader clean energy career training and awareness into the K-12 curriculum.[71] With further coordination between DESE, the Workforce Skills Cabinet, EEA, and MassCEC, Massachusetts will seek to establish "clean energy" as a priority industry sector and explore the benefits of creating a 17th Career Cluster focused on the energy industry and the associated career opportunities across clean energy.[72] The efforts to establish this priority industry sector will begin in 2023.

Finally, the Commonwealth can learn from early efforts underway in other jurisdictions, such as Michigan, to launch a Climate Service Corps in coordination with the national AmeriCorps programs.[73] Developing a Massachusetts Climate Service Corps for young adults would drive awareness and adoption of clean energy technologies and expand the pipeline of new entrants into climate-critical occupations. Components of the Climate Service Corps would build off MassCEC's long-standing internship program and emerging Equity Workforce Training implementation programs. Investing in this effort would scale the impact and extend the

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71 Mass. Acts 2022, Ch. 179, https://malegislature.gov/Laws/SessionLaws/Acts/2022.

72 Virginia has added a 17th career cluster focused on Energy; more information is described here: Henrico Workforce & Career Development, "CTE Classes," https://henricocte.com/career-classes/.

73 Michigan Labor and Economic Opportunity, "MI Climate Corps Funding," https://www.michigan.gov/leo/boards-comms-councils/mcsc/nfr/mi-climate-corps-funding.

engagement period with residents crucial to developing a growing and inclusive pipeline for climate-critical occupations.

Develop Proactive Land-Use Strategy to Site Housing and Clean Energy

Achieving the 2050 Climate Limits will require significant changes in how land is used in the Commonwealth. The 2050 CECP calls for an enormous number of technologies, infrastructure, and solutions that will have to be implemented here in Massachusetts: heat pumps, electric vehicles, charging stations, solar panels, wind turbines, energy storage, transmission and distribution infrastructure, multimodal transportation infrastructure, electrified bus facilities and rail lines, and housing near public transportation, among others. Much of the infrastructure needed to support these solutions will have to be permitted and built in Massachusetts. At the same time, the strategy to conserve natural carbon sinks requires minimizing the impact of development on natural and working lands.

Aligning these complex objectives, with responsibilities spread between state, regional, and local governments, requires a proactive approach. Massachusetts will work across secretariats, with local partners, and with stakeholders to develop a holistic, long-term land use strategy to support the implementation of this 2050 CECP. This strategy will include recommendations on programs and incentives that can help the state achieve its goals for housing and transit-oriented development by removing regulatory barriers to siting new housing units in transit-rich neighborhoods. Massachusetts agencies will work together to consider how to balance the location of housing and jobs so that people can live closer to where they work. In collaboration with the EJ Council, Massachusetts' land use strategy will consider how to efficiently and equitably site the energy infrastructure that will be necessary as the state transitions to electrified heating and transportation. Going forward, Massachusetts will consider approaches to maximize land protection when greenfield projects are being developed in the state, discussed in more detail in Chapter 5e.

The land use plan will be developed in collaboration with stakeholders and local partners, with multiple opportunities for public input over the course of 2023 and 2024, with a goal of delivering recommendations to the Legislature, local government, and executive branch agencies by the end of 2024.

Innovation: Scaling the Commonwealth's Innovation Ecosystem

Widespread electrification, smart grid management, and a surge in renewable generation will help Massachusetts achieve the 2050 requirements. However, meeting the state's own requirements is only a small piece of the solution to global climate change. Massachusetts is uniquely positioned to be at the forefront of delivering and "exporting" new climate solutions and technologies to the world-at-large.

The vibrant academic institutions, research partnerships, and entrepreneurial networks that have made Massachusetts a wellspring of ideas for healthcare and education will need to take center stage in providing climate solutions worldwide. Start-ups incubated at local universities that tackle direct air capture, long-duration energy storage, nuclear fusion, and other climate-critical innovations are already aiding mitigation and adaptation efforts across the globe. MassCEC, the state's main engine for clean energy innovation, has attracted roughly $5 of private capital for each public dollar invested, driving roughly $2.7 billion toward clean energy efforts since 2010.[74] From its support for various companies and organizations, MassCEC has helped seed a lively ecosystem for climate solutions in Massachusetts (see Figure 4-2 below).

Across the next two to three decades, Massachusetts will need to continue its leadership role in working with its academic and research institutions to develop future technologies that will help accelerate decarbonization efforts across the world. This means that, through the next decades, the state government will need to continue to invest, partner, mobilize, and inspire climate solutions by accelerating the clean energy innovation ecosystem.

74 Massachusetts Clean Energy Center, "About," https://www.masscec.com/about.

FIGURE 4-2. SNAPSHOT OF THE MASSACHUSETTS INNOVATION ECOSYSTEM

These efforts will include maintaining a robust pace of innovation by streamlining the process for sound ideas to scale. Bold solutions require bold support, and Massachusetts is considering ways to build upon its grant-based programs and strategic investments and toward partnerships that leverage the state's strength and scope. To ensure ideas emerging from academia find commercial footing, the Commonwealth is using its reach across state universities to identify the growth potential of "tech-transfer" programs. Such programs, of which there are several successful models in Massachusetts,[75] help bring new knowledge created by researchers to private industry (both new and existing enterprises), primarily by assisting in the disclosure and licensing of intellectual property.[76] Massachusetts plans to assess the performance of in-state technology transfer programs and facilitate the exchange of best practices through a consortium of universities.

Over the next few years, Massachusetts will consider administering competitive grants to those looking to expand or establish such programs with resources such as investments in laboratories, legal resources, and entrepreneurial curricula. As an example, one of the near-term technological innovations that will be needed across the globe and in Massachusetts is

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[75] Maryann Feldman et al, "Research to Renewal: Advancing University Tech Transfer," *Heartland Forward* (May 2022), https://heartlandforward.org/wp-content/uploads/2022/05/ResearchToRenewal.pdf.

[76] Massachusetts Institute of Technology, "Ad Hoc Faculty Committee: MIT Technology Transfer in the 21st Century," https://web.mit.edu/provost/techtrans/index.html#.

long-duration storage. DOER and MassCEC will join efforts in developing programs that invest in additional research and development of long-duration storage.

Climate Leadership: Continue to Leverage State Resources to Demonstrate Net Zero Solutions and Work with Municipalities in Achieving Climate Goals at the Community Level

The Commonwealth has recognized the value of advancing GHG reduction efforts by addressing energy use across state-owned or state-funded facilities. The Leading by Example (LBE) program, administered by DOER, is one example of such efforts. The program works with state agencies, quasi-public authorities, and public colleges and universities to advance clean energy and sustainable practices that reduce the environmental impacts of state government operations. Further, the Green Communities program, also administered by DOER, extends such efforts to the municipal level, providing tools and resources to advance energy efficiency and renewable energy projects at municipal and public school facilities. As the Commonwealth sets itself up to comply with the 2050 emissions limit, these programs will scale up to exemplify the "2050 ready" solutions at state-owned facilities and empower residents and businesses to take collective action.

Leading by Example: Toward Rapid Electrification

Executive Order 484: Leading by Example – Clean Energy and Efficient Buildings[77] directed the public sector to reduce the environmental impacts of state government operations and set targets for energy efficiency and GHG emission reductions across 80 million square feet of public buildings, as well as an expansion of government's use of renewable energy. With the support of the LBE program and through dozens of clean energy projects overseen by the Division of Capital Asset Management and Maintenance (DCAMM) and others, significant progress has been made. As of 2020, state government saw an 85% reduction in oil consumption, the installation of more than 25 MW of on-site solar PV, and a 25% reduction in overall GHG emissions from a 2004 baseline.

In 2021, the new Executive Order 594: Leading by Example: Decarbonizing and Minimizing Environmental Impacts of State Government[78] set a goal to increase the focus across state facilities to rapidly electrify buildings' heating systems and organizations' transportation fleets.

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[77] Executive Order No. 484: Leading by example – clean energy and efficient buildings, https://www.mass.gov/executive-orders/no-484-leading-by-example-clean-energy-and-efficient-buildings.

[78] Executive Order No. 594: Leading By Example: Decarbonizing and Minimizing Environmental Impacts of State Government, https://www.mass.gov/executive-orders/no-594-leading-by-example-decarbonizing-and-minimizing-environmental-impacts-of-state-government.

Comprehensive efforts to identify the technologies and strategies that will be necessary to meet these ambitious energy and emissions goals across new construction, existing buildings, and fleets are already underway. The LBE program is designed to be flexible and will evolve with advances in technology and innovative solutions over time. Ongoing LBE efforts moving forward will include:

- Primarily through DCAMM, requiring all new state government construction and substantial building renovation projects to be high performance, virtually or completely fossil fuel free, resilient, and, where possible, meet net-zero emissions energy standards.
- Development of facility decarbonization studies and incorporation of decarbonization goals into existing master planning processes.
- Prioritization of fossil fuel-free solutions in existing building retrofits and energy projects.
- In collaboration with the Office of Vehicle Management and other state fleet managers, ramping up the electrification of the state's fleet, including the deployment of necessary charging infrastructure.
- Continued development of on-site renewable resources and, to achieve long-term net-zero emissions goals, procurement of clean electricity for state government operations.
- Implementation of other sustainability efforts and practices in support of statewide emissions reductions, including but not limited to conserving water, increasing recycling, and using collective procurement power to reduce the environmental and public health impact of state government purchases.

BOX 4-1. CHELSEA SOLDIERS’ HOME

In its final construction phase, the new 247,000-square-foot Chelsea Soldiers’ Home will be a state-of-the-art long-term care facility for veterans, with 154 rooms organized around shared community spaces and generous courtyards. The project, managed by the Division of Capital Asset Management and Maintenance, has been designed with 2050 climate goals front and center: ground source heat pumps will heat and cool the building; natural ventilation, coupled with an advanced heat recovery system, will reduce energy use substantially; along with a high-performance envelope, energy consumption is projected to be 71% below code, while ensuring that temperatures remain comfortable and constant; and the 594 kW DC solar array will generate a significant amount of the energy used by the facility. This significant infrastructure investment will also result in ongoing operational savings for the Soldiers’ Home. This high-efficiency, mostly electric building is just one of many similar projects that are or will be part of the state government’s building portfolio, a clear demonstration of how the Commonwealth is truly leading by example.

Green Communities: A New Approach

DOER’s Green Communities program provides funding opportunities to reduce municipal energy use and costs via investments in clean energy projects in municipal buildings, facilities, and public schools, along with guidance and technical assistance. The Green Communities

Designation and Grant Program provides a roadmap along with financial and technical support to municipalities that pledge to reduce municipal energy use and set ambitious climate goals.

Participation in the Green Communities program has grown steadily since July 2010 to include over 80% of cities and towns across the Commonwealth, representing 87% of the population. The benefits of designation extend beyond the program itself, inspiring cities and towns to undertake additional energy-saving and energy-transition initiatives, improve coordination between municipal staff and departments, and increase messaging with the public at large about energy and climate-related issues and actions.

In 2023, DOER plans to launch a new Green Communities program that will align with the GHG emissions reduction requirements articulated in this Plan and the 2025/2030 CECP. This effort will increase coordination with municipal and regional entities on net-zero planning, capacity building, and implementation. The new and expanded program will encourage municipalities to demonstrate climate leadership by:

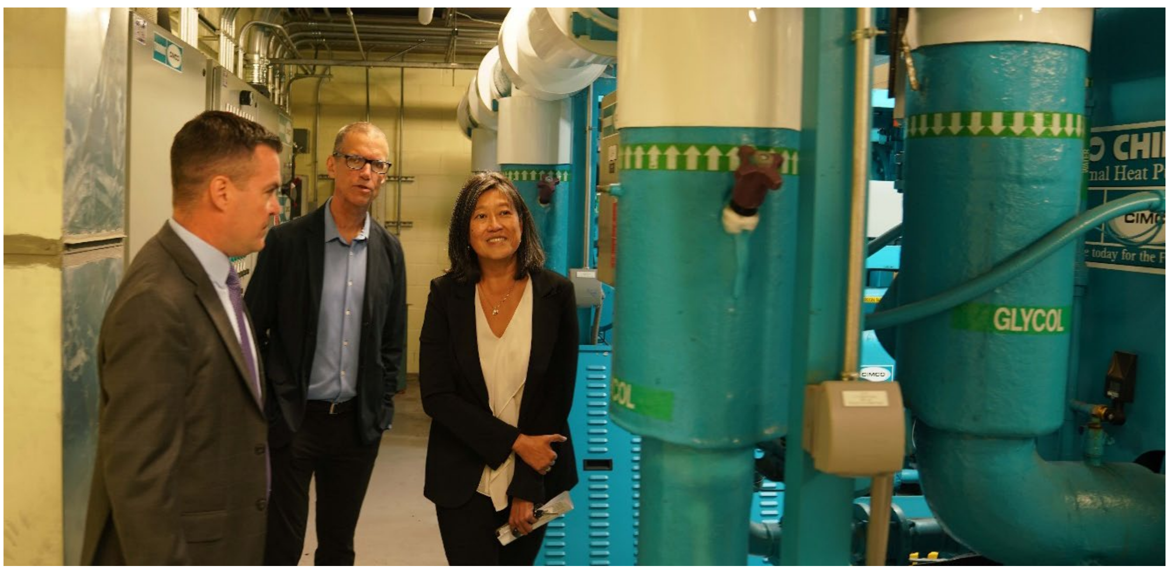
- Creating a plan for eliminating onsite use of fossil fuels in municipal buildings and fleets by 2050
- Ensuring new construction will be net-zero or net-zero ready by adopting the Specialized Stretch Energy Code
- Accelerating the transition to zero-emission municipal fleets
- Promoting clean energy opportunities to residents and businesses, particularly those that have been traditionally underserved by Mass Save® programs
- Support EEA's climate campaign by "touching" every resident from every community

A Broader View of State Resources

Beyond efforts at state-owned facilities within LBE and voluntary participation from municipalities in the Green Communities program, Massachusetts has the opportunity to ensure that "state-aided buildings"—those that receive state funding but are not owned by the Commonwealth—also align with the 2050 Net Zero limit and climate resilience goals. State-aided, publicly owned buildings such as K-12 schools, public libraries, or local housing authorities are prime opportunities to demonstrate climate-leading designs within our communities. State-aided, privately owned buildings also offer an avenue to demonstrate construction that exemplifies climate leadership. Starting in 2023, EEA will work with funding agencies to explore establishing application criteria that incorporate decarbonization goals, prioritizing projects that exceed applicable code requirements or are designed to minimize GHG emissions in support of the Commonwealth's decarbonization goals. The state recognizes that the expectations for each project will depend on its size and the amount of state financial assistance it receives.

BOX 4-2. REILLY MEMORIAL RINK

The need for constant cooling makes indoor ice rinks some of the most energy-intensive facilities in the Massachusetts Department of Conservation & Recreation's (DCR) portfolio, making them a focal point for DCR's Net Zero plan. In recent years, DCR upgraded refrigeration systems in 11 of its ice rinks, improving their energy efficiency and reducing energy costs by an average of about 40%. In certain locations, DCR's upgrades went even further. Reilly Memorial Rink—a DCR property in Brighton, MA, that was upgraded in 2018—has solar panels installed on its rooftop to help offset the facility's electricity usage. Below, Undersecretary Chang (right) and Commissioner Rice (left) are pictured touring the facility.

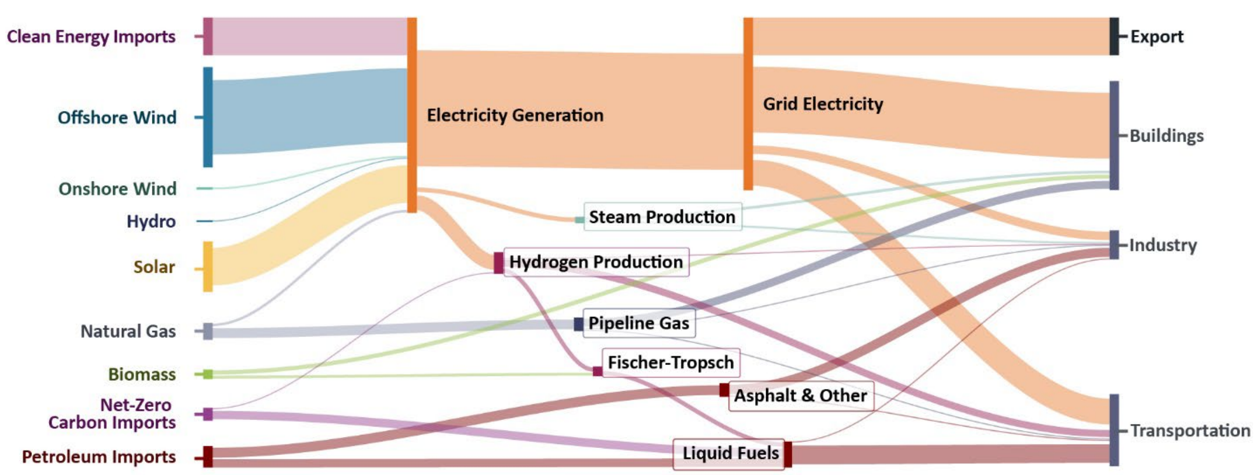


Chapter 5: Sector Strategies

This 2050 CECP builds on strategies and policies outlined in the 2025/2030 CECP by setting sector-specific GHG emissions reduction targets for transportation, buildings, electricity generation, industrial emissions, and non-energy sources such as leaks of natural gas and refrigerants. The Commonwealth will invest in improving and expanding a public transportation system that runs on clean energy while accommodating bike, pedestrian, and electric vehicle (EV) infrastructure. The Commonwealth will also work towards promoting building electrification and deploying distributed energy resources to cut heating emissions and long-term energy costs.

Accommodating transportation and building electrification will require a power sector with more clean electricity generation resources as well as new and upgraded transmission and distribution systems. The Commonwealth will also focus on minimizing leaks of potent GHGs in industrial applications. In addition to sector-specific sublimits, the Plan includes goals and commitments to reduce GHG emissions and increase carbon sequestration on in-state natural and working lands (NWL), which will play an important role in achieving net-zero emissions. Figure 5-1 below provides a snapshot of Massachusetts' energy flow in 2050, when the Commonwealth expects to achieve Net Zero.

FIGURE 5-1. MASSACHUSETTS ENERGY USE IN 2050



Chapter 5a: Transportation

TABLE 5A-1. TRANSPORTATION SECTOR SUBLIMITS FOR 2050

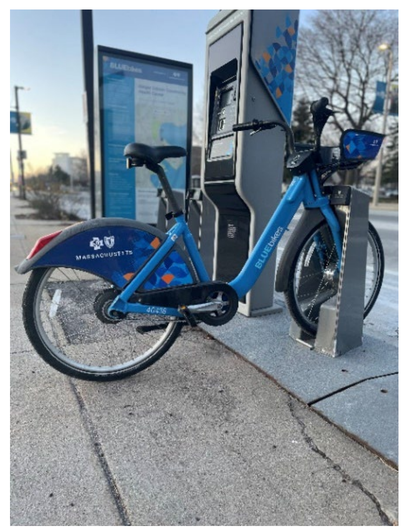
Transportation Sector Gross Emissions (MMTCO_2e)	1990	2020	**2050**
Gross Emissions (MMTCO_2e)	29.6	23.7	**4.1**
% Reduction (Increase) from 1990			**86%**

Note: GHG emissions for 2020 are based on preliminary estimates from MassDEP.

Overview

For many decades, transportation in the United States has been dominated by personal vehicles powered by internal combustion engines, delivering people from residences to their jobs in the urban core and back again. Today, changes in technology and practice, together with smart investments being made across Massachusetts, are creating new possibilities for a future transportation system that will work better for the Commonwealth—a transportation system in which people will be able to get around while driving less, producing less global warming emissions, and spending less money.

The 2025/2030 CECP outlined strategies that the Commonwealth will pursue to promote alternatives to personal vehicle travel. The Commonwealth aims to invest in and improve the public transportation system so that it can accommodate additional ridership and uses clean energy. The Massachusetts Department of Transportation (MassDOT) will continue to be a national leader in investments in multimodal transportation infrastructure, building upon a bike and pedestrian network that is among the strongest in the U.S. The Commonwealth will work with employers to consider how changing work and commuting patterns can help improve congestion and emissions.



PICTURE 5A-1. BLUEBIKES STATION IN BOSTON

MassDOT started to prepare its 2050 Statewide Long Range Transportation Plan, entitled Beyond Mobility, in October 2021, and the Plan is set to be complete by December 2023. Beyond Mobility will serve as a strategic plan for MassDOT and inform future capital planning and programming activities. The Plan will set a vision for the future of transportation in Massachusetts and document a set of goals based on extensive public and intergovernmental input. Thus far, public engagement activities have included two electronic surveys with over 3,000 total responses received, focus groups, a series of community activations held in Massachusetts' Gateway Cities, and external stakeholder interviews. Based on input received through these public engagement activities, preliminary goal areas include promoting equity, encouraging car-free travel, keeping the transit system in a state of good repair, improving access and connectivity, and making transit services safe and reliable.

One important component of the Commonwealth's strategy to reduce reliance on personal vehicles, and increase access to and use of public transportation, is to encourage the construction of housing near public transit stations. A recent change to the Massachusetts Zoning Act requires all cities and towns that host MBTA service must have at least one zoning district of reasonable size in which multi-family housing is permitted "as of right"[79] and meets other criteria set forth in the statute, including districts to be located within one-half mile of a transit station, where applicable. This program is called "MBTA Communities."

Widespread adoption of these zoning districts should result in more transit-oriented housing production over time, but fully addressing the housing needs of the metro Boston region will require decades of effort and the full participation of local government. The Commonwealth and its 351 cities and towns need to respond to the current housing crisis and continue to site housing near transit in such a way that will alleviate congestion on roadways. Beyond MBTA Communities, cities and towns throughout the Commonwealth can improve quality of life and reduce emissions by prioritizing transit-oriented development and smart growth strategies for all development.

PICTURE 5A-2. EV CHARGING STATION

While there are some trends toward reducing car ownership among younger generations, it is most likely that in 2050 there will still be millions of vehicles on the roads. Thus, the primary strategy to achieve deep decarbonization in the transportation sector is to make sure that the vehicles that are driving those miles are being powered by clean energy. Consistent with decarbonization studies for other jurisdictions, transitioning the vehicles operating in Massachusetts to EVs will be the most effective decarbonization strategy for reaching Net Zero in 2050.

79 *See* Mass. Gen. Laws. Ch. 40A, § 3A, definition of "as of right," https://www.mass.gov/info-details/section-3a-guidelines.

The primary policy that Massachusetts has in place to ensure this transition happens is the vehicle emission standards implemented by the California Air Resources Board and followed by Massachusetts and 11 other participating states. These standards will ensure all new light-duty vehicles for sale in Massachusetts, beginning in 2035, will be either zero-emission vehicles or plug-in hybrids. Separate standards for medium- and heavy-duty vehicles will ensure that Massachusetts achieves rapid growth in zero-emission vehicles in these sub-sectors simultaneously.

PICTURE 5A-3. BAKER-POLITO ADMINISTRATION CELEBRATES PROGRESS ON SOUTH COAST RAIL PROJECT

To support the transition to EVs, Massachusetts will continue to provide financial incentives to accelerate EV adoption through the MOR-EV and MOR-EV Truck programs until EVs are no longer significantly more expensive than their internal combustion equivalents. Massachusetts recently increased the statewide electric vehicle incentive to $3,500 in accordance with the 2022 Climate Act and is currently taking additional steps to make the rebates available at the point of sale and provide increased incentives for low-income drivers.

To reduce range anxiety associated with using EVs, Massachusetts is developing a detailed plan for building out the public charging infrastructure, with support from the federal government. Massachusetts was among the first states to complete its electrification plan, making the Commonwealth eligible for federal discretionary funds from the IIJA. Clean transportation programs will provide targeted incentives and grant funding opportunities for low- and moderate-income residents and EJ communities.

The Commonwealth will also transition its own vehicle fleet to EVs. Electrification of public transportation will require rapid modernization of the bus facilities. The Commonwealth will continue to explore electrification of the commuter rail network as laid out in the MBTA Rail Vision report.[80] In addition, Massachusetts has set ambitious goals to electrify state vehicles through the Leading by Example program. Success on these projects will require sustained federal and state funding to support electrification.

The policies set out in the 2025/2030 CECP will help the Commonwealth achieve over one million EVs on the road in Massachusetts by 2030, with EVs being over 50% of all new vehicle

[80] *MBTA Rail Vision* (Boston, 2020), https://cdn.mbta.com/sites/default/files/2021-07/2020-02-rail-vision-report.pdf.

sales at that time. Battery EVs likely will be at price parity with internal combustion engine equivalents for most vehicle types by 2030, in addition to cheaper operating costs and potentially eliminating the need for upfront subsidies. However, estimates show that EVs will still be only roughly 19% of light-duty vehicles and 10% of medium and heavy-duty vehicles on the Commonwealth's roads in 2030.

PICTURE 5A-4. BAKER-POLITO ADMINISTRATION HIGHLIGHTS PROGRESS OF IMPROVEMENTS AT UNION STATION IN WORCESTER

After 2030, the Commonwealth will maintain policies to expand EV infrastructure and support low- and moderate-income residents in purchasing EVs. Importantly, new policies will be set to promote the retirement of legacy internal combustion vehicles and address emissions from difficult-to-electrify transportation modes. As the share of EVs grows, the Commonwealth will ensure that EV charging supports responsible grid management and that the transition to EVs will not impose high electricity costs. When internal combustion vehicles are replaced by EVs, the Commonwealth will need to decide how and when drivers of EVs would help fund transportation infrastructure to replace the funding that comes from the current gasoline tax.

Retirement of Internal Combustion Vehicles

The slow pace of technology turnover represents one of the enduring challenges to achieving rapid decarbonization in transportation and other sectors. By 2030, EVs likely will be established as the superior technology in terms of performance and cost and will begin to dominate the new vehicle market, but many existing internal combustion engine vehicles will still be on the road.

To encourage retirement and further accelerate electrification, Massachusetts will set incentives to permanently retire combustion vehicles. Massachusetts' vehicle retirement program will focus on helping low- and moderate-income residents retire old vehicles and high-emission vehicles and help them acquire cleaner alternatives, including EVs, transit passes, e-bikes, or alternative modes of transportation.

Encourage Smart Charging

Vehicle electrification will increase electric load. The policies for the power sector account for this increased electric load and recognize the need for additional grid infrastructure, particularly local electric distribution system enhancements. The extent of the required additional infrastructure and associated investments will be location-specific and will depend on when Massachusetts residents charge their EVs. If residents charge during peak electricity events (e.g., during the critical summer evenings or winter evenings when heat pumps are operating), the impact on electric grid infrastructure could be considerable. Thus, the Commonwealth will need load-control programs and/or pricing approaches to shift electric vehicle charging to times when other electricity usage is low or during times when the production of renewable energy is high. Shifting charging behaviors will require EV charging to be flexible and help transition to renewable energy with affordable costs.

A 2016 analysis conducted by M.J. Bradley and Associates demonstrates that the potential savings for ratepayers from smart charging are considerable, in the range of $500 million through 2050.[81] The deployment of bi-directional charging could further unlock the ability of electric vehicles to provide additional benefits, including power outage protection for residents and businesses. Thus, the Commonwealth will require the participation of all incentive recipients in demand management programs starting in 2025, when EV adoption is expected to reach close to 5% of all light-duty vehicles. Massachusetts will work with utilities to develop programs that will require smart charging approaches to be the default choice for EV owners.

Massachusetts is also working with the U.S. Department of Transportation and partners to be poised to receive the federal funding available to help achieve our emissions goals. Maintaining federal partnerships and being ready to apply for additional federal electrification funds is a primary strategy for the Commonwealth.

Address Hard-to-Electrify Modes of Transportation

While battery EVs should meet most of the Commonwealth's transportation needs, electrification may not be feasible for all areas of the transportation sector. Airplanes, ships, and long-haul trucks will be challenging to electrify, primarily because the greater energy density of liquid fuels may prove essential to operating these modes of transportation effectively. Massachusetts' ability to achieve significant emission reductions in these areas is limited by jurisdictional issues: most long-haul trucks and ships operating in Massachusetts are registered out-of-state, and federal law limits state regulation on air travel.

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[81] Dana Lowell, Brian Jones, and David Seamonds, *Electric Vehicle Cost-Benefit Analysis*, M.J. Bradley & Associates LLC (2016), https://mjbradley.com/sites/default/files/MA_PEV_CB_Analysis_FINAL_17nov16.pdf.

Massachusetts' strategy to reduce emissions in these parts of the sector will necessarily rely on the deployment of clean fuels. Today, advanced biofuels are one of the few low-emission technologies capable of achieving the energy density necessary to power airplanes over long distances, making air travel a priority use case for limited stocks of biofuels. Massachusetts will not be driving the future market for biofuels, nor will it be in the position to set fuel policies for all air travel, and therefore will rely on national policies such as the U.S. Aviation Climate Action Plan to reduce emissions from air travel.[82]

The deployment of hydrogen, renewable natural gas, or renewable diesel could be components of a national strategy to transition long-haul trucks and ships away from the use of oil. There, too, Massachusetts will be following national and international trends and implementing policies to reduce emissions from trucks and ships. For example, Massachusetts is closely monitoring the International Maritime Organization's GHG strategy that aims to reduce GHG emissions from international maritime shipping.[83] Additionally, the Commonwealth will work with the airline, cruise, and shipping industries to electrify non-travel-related equipment. Investments in electric Ground Service Equipment (GSEs), as well as ship-to-shore power, are two examples of non-travel related equipment that, when electrified, go a long way to help the Commonwealth meet its climate goals. Accordingly, starting in 2030, the Commonwealth will explore market-based mechanisms, such as clean fuel standards, for the portion of the transportation sector that will be difficult to electrify.

Contribute to Commonwealth Transportation Fund

Gasoline taxes represent an important source of revenue for transportation infrastructure in Massachusetts, contributing approximately $750 million per year (pre-COVID pandemic) to the Commonwealth Transportation Fund. Together with vehicle taxes and registration fees, the gasoline tax represents a fair bargain for Massachusetts drivers: transportation infrastructure is funded by a tax that approximates use of transportation resources. From the perspective of 2022, the fact that the users of EVs do not pay gasoline tax is not a major problem, as EVs are currently a small percentage of vehicles on the road and the high price of EVs means that EV owners contribute disproportionately to state sales taxes. Starting in 2030, as sales numbers grow and EV costs decrease over time, Massachusetts will identify ways to replace the existing sources of transportation infrastructure funding with new sources.

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82 Federal Aviation Administration (FAA), *United States 2021 Aviation Climate Plan* (November 9, 2021), https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf.

83 International Maritime Organization (IMO), "Initial IMO GHG Strategy," https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx.

Chapter 5b: Buildings

TABLE 5B-1. BUILDINGS SECTOR SUBLIMITS FOR 2050

Buildings Sector Gross Emissions ($MMTCO_2e$)	1990	2020	**2050**
Residential Heating	15.3	12.2	**0.8**
Commercial (without Industrial) Heating	8.4	7.3	**0.9**
Total Gross Emissions ($MMTCO_2e$)	23.8	19.5	**1.7**
Total Percent Reduction from 1990			**93%**

Note: Cooling of residential and commercial buildings primarily uses electricity. Thus, the emissions from cooling are covered in the electric power sector (in Chapter 5c).

Overview

Massachusetts' building stock will require a dramatic transition to achieve the necessary GHG emissions reduction shown in Table 5b-1 above. The gross emissions sublimits for the Residential and Commercial heating sectors sum to 1.7 $MMTCO_2e$ in 2050, representing a reduction of approximately 93% from the 1990 level. In 2050, on average, buildings will be more efficient than they are today, and they will use cleaner, mostly electrified, heating systems. Some buildings will be equipped with distributed energy resources (such as solar PV and battery storage). As a result of these changes, Massachusetts residents and businesses will benefit from more comfortable spaces to live and work, better air quality, favorable health impacts, and lower and less volatile long-term energy costs. To achieve these changes on the scale and at the pace required to meet 2050 emission reduction requirements, the Commonwealth will need to implement new policies and investments.

In September 2021, Governor Baker signed Executive Order No. 596, establishing the Massachusetts Commission on Clean Heat ("Commission") to produce a set of policy recommendations to sustainably reduce the use of heating fuels and minimize the GHG emissions from buildings while ensuring the costs and opportunities arising from such reductions are distributed equitably.[84] The Commission met regularly throughout 2022 and explored options for strategies to meet Massachusetts' GHG reduction requirements through the 2020s to 2050.

The 2025/2030 CECP discussed four key strategies for the buildings sector that are consistent with preliminary recommendations from the Commission on Clean Heat. The first strategy

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[84] Massachusetts Commission on Clean Heat, *Final Report* (November 30, 2022), https://www.mass.gov/info-details/commission-on-clean-heat-issues-final-report.

established a cap on heating emissions for 2025 and 2030.[85] The second strategy recommended performance benchmarks and standards, including the creation of a uniform and consistent energy performance reporting approach and the adoption of new building codes,[86] including the Specialized Municipal Opt-in Energy Code and the Stretch Energy Code, which increase the efficiency requirements for new buildings. The third strategy focused on delivering electrification results at scale, including (1) the use of a climate finance mechanism (i.e., a "green bank") and (2) providing technical assistance through a suggested Clean Heat Clearinghouse while building upon the nation-leading energy efficiency programming through the existing Mass Save® program. The fourth strategy recognized that major natural gas and electricity infrastructure planning will be needed as residents and businesses transition from using fossil fuel-based heating systems to electric heat pumps.

This 2050 CECP builds on the 2025/2030 CECP by adopting final recommendations developed by the Commission. Electrification is the economically and practically preferred methodology to reduce GHG emissions in the buildings sector. This 2050 CECP focuses on the strategies necessary to deploy electrification at the scale and pace required to meet the Commonwealth's GHG emission reduction goals by 2050. The strategies herein will ease logistical and financial burdens for customers, facilitate joint planning between electric and natural gas utilities, and make EJ and equity a central focus of the long-term transition strategy. Through coordinated efforts with various state and local agencies, including EEA and EOHED, Massachusetts will support these strategies with a wide range of policies and programs to address market barriers, stimulate private investments, and ensure that electrification is scaling at the pace necessary to achieve Net Zero in 2050.

Establish a Clean Heat Standard to Promote Electrification and Adoption of Clean Heat Solutions

To achieve the 2050 buildings sector sublimit, the 2050 CECP adopts the framework for a Clean Heat Standard (CHS) as laid out in the Commission on Clean Heat's Final Report. The CHS is a

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85 Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (June 30, 2022), 51–52, https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download.

86 The 2021 Climate Law amended the statute governing the Board of Building Regulations and Standards (BBRS) to include a specialized stretch energy code, developed and promulgated by the Department of Energy Resources. The 2021 Climate Law also required the development of a new Municipal Opt-in Specialized stretch energy code. These codes appear as new regulations in 225 CMR 22.00 (covering residential low-rise construction) and 225 CMR 23.00 (covering commercial and all other construction), which will be filed with the Secretary of State in December 2022. More information on the new Stretch Codes can be found here: https://www.mass.gov/doc/summary-document-explaining-stretch-energy-code-and-specialized-opt-in-code-language/download.

regulatory construct that is similar to other clean energy standards such that clean heat solutions will receive credits that are valued in the marketplace. In the CHS framework, fuel suppliers will be the obligated parties who must create or own clean heat credits to comply with the regulation. Appendix B of the 2025/2030 CECP has a preliminary explanation of a CHS concept, developed by the Regulatory Assistance Project. Like other environmental standards that use marketable credits, the CHS will be used to reduce GHG emissions from building heat, with a focus on encouraging electrification and energy efficiency.

The standard would require obligated parties to demonstrate a reduction in emissions by deploying applicable clean technologies or purchasing clean heat credits from parties that have successfully implemented solutions. The standard encourages competition while reducing emissions, minimizing homeowner transaction costs, and sharing the burden of the transition widely and equitably. The Commonwealth agrees with the Commission on Clean Heat that the standard should make credits available for implementing GHG reduction strategies with a preference for electrification and energy efficiency measures.

The Massachusetts Department of Environmental Protection (DEP), in consultation with DOER and EOHED, will conduct a regulatory process, including public stakeholder sessions, as it develops the CHS and will implement it as early as 2024.

Develop and Implement a Commonwealth-Wide Building Benchmarking and Labeling Program

To increase the transparency of building emissions and encourage building owners to improve the performance of their buildings, the Commission on Clean Heat recommends that DOER develop and implement a state-wide building benchmarking and labeling program. The program would help increase awareness among building owners, prospective buyers, and renters on the relative emissions performance and costs of comparable buildings. The program will allow for increased transparency on building retrofit needs, enable potential buyers and renters to make more informed decisions, create market demand for high-performing properties, as well as encourage building owners to invest in energy efficiency upgrades.

The benchmark and labeling program will be developed with input from stakeholders, including representatives from municipalities and low-to-moderate income (LMI) and EJ communities, and be integrated with existing programming to support necessary building upgrades in a way that will not create undue burdens to LMI and EJ populations. Buildings in LMI and EJ communities that receive lower than average scores should be prioritized for various incentive programs through Mass Save® and the Building Decarbonization Clearinghouse, funding and financing through the green bank, as well as CHS credits.

Following the recommendations from the Commission on Clean Heat, DOER, in consultation with EOHED, will develop a labeling system, building upon the existing U.S. Department of Energy building scorecard program and DOER's pilot scorecard programs (that have been rolled out in conjunction with Mass Save® in certain communities) and roll out a program for all building types across the Commonwealth by 2025. DOER should assess and determine the frequency of updates required for different use types, such as every 10–12 years or at the time of certain events, such as undergoing a major retrofit project or upgrading to a more efficient electric heating system, whichever comes first.

Develop a Building Decarbonization Clearinghouse to Streamline Consumer Needs

PICTURE 5B-1. RESIDENTIAL HOUSE WITH ROOFTOP SOLAR PANELS

As shown in Table 5b-1, the gross emissions sublimits for residential and commercial heating systems are set at 1.7 $MMTCO_2e$ in 2050. This is a reduction of approximately 22.1 $MMTCO_2e$ from the 1990 level, which the Mass Save® programs would need to support through energy efficiency and electrification services under the current design. The existing Mass Save® programs have been delivering energy efficiency and electrification, helping Massachusetts achieve its buildings sector's sublimits and solidifying its reputation as a nation-leading program in energy efficiency investments. However, it is not yet a comprehensively customer-centered program that integrates clean energy solutions for all consumers interested in upgrading their home and office systems. The 2022 Climate Act included updates to the mandate of Mass Save® programs to better align with the state's decarbonization goals, including a requirement to phase-out incentives for fossil fuel-based heating systems.

The Commission on Clean Heat, through many months of detailed deliberations and discussion, recommends that the Commonwealth create a new centrally-managed, customer-focused Building Decarbonization Clearinghouse to connect customers (including building owners, developers, residents, contractors, and consultants) with available clean energy opportunities. Such a Clearinghouse would serve as the central hub for a variety of decarbonization-focused programs, including Mass Save®, various incentive-based programs for assisting customers in decarbonizing heating systems, solar incentive programs, storage incentive programs, other funding opportunities, and technical support services.

Massachusetts recognizes that many customers may need a combination of technical assistance, financial assistance, and building decarbonization solutions. Developing a centrally-managed Clearinghouse would connect customers with necessary installation experts and logistics managers. Access to funding will be a top priority, and once set up, the staff at the Clearinghouse would coordinate with those providing resources at the Climate Finance Accelerator (discussed below) and other funding sources to ensure financial support is accessible.

As conceptualized by the Commission on Clean Heat, the Building Decarbonization Clearinghouse would provide support for the installation of clean energy equipment that customers need and want, such as EV charging stations and solar plus energy storage systems, providing Massachusetts residents and businesses with a one-stop shop for full decarbonization solutions. Setting up such a Clearinghouse would streamline offerings, assistance, and funding to help the Commonwealth drive decarbonization of the building stock as quickly as possible.

Overall, the Clearinghouse would play a central role in communicating the Commonwealth's progress toward the buildings sector's emissions reduction requirements. Accordingly, after the Clearinghouse has had a chance to operate for a few years, the staff at the Clearinghouse, in consultation with DOER, should recommend improvements to future programs, including but not limited to enhancements and/or revisions to the Mass Save® program.

PICTURE 5B-2. INSTALLATION OF RESIDENTIAL HEAT PUMPS

The Commission on Clean Heat's Final Report stresses the importance of the Clearinghouse in ensuring equitable access to the clean energy program offerings across all communities, with a particular focus on ensuring energy and EJ. This means that the Clearinghouse would implement targeted outreach to engage with LMI and EJ community members, and design program attributes to meet their needs. Most importantly, the Commission on Clean Heat recommends that the Clearinghouse needs to be set up and operated in a way that LMI and EJ populations do not bear a significant cost increase.

In response to the Commission on Clean Heat's recommendations, EEA, DOER, and MassCEC, in consultation with EOHED, will evaluate the best model for setting up the Clearinghouse, including considerations for whether Massachusetts will be best served by an independent third-party model or whether the Clearinghouse should be housed within existing Executive Offices or agencies. This determination will be made by 2024.

Create a State-Wide Climate Finance Mechanism to Accelerate the Financing of Decarbonization Projects

The Commission on Clean Heat has recommended that Massachusetts set up a state-wide "green bank" to help attract private capital into financing decarbonization solutions. According to the Coalition for Green Capital, green bank is a term used to describe "mission-driven institutions that use innovative financing to accelerate the transition to clean energy and fight climate change."[87] A green bank would have the mission of addressing climate change and other related objectives, such as improving resiliency or serving low-income or EJ populations.

Accordingly, to implement this recommendation from the Commission on Clean Heat, Massachusetts will be setting up a Climate Finance Accelerator (a state-wide "green bank") with the first step to accelerate the clean energy transition for buildings. Such a Climate Finance Accelerator will use innovative financing techniques such as credit enhancements and diversification of risk to help scale up the scope of building decarbonization projects.

Following the recommendation from the Commission on Clean Heat, in 2023, EEA, in partnership with MassCEC and MassDevelopment, will assess how the Climate Finance Accelerator would provide an array of financing options across various market segments, including residential, commercial, and industrial buildings, working with developers, owners, and private financiers. This effort will build upon the various existing financing mechanisms available through MassDevelopment and the clean energy expertise of MassCEC.[88] Effectively developing, bundling, and communicating available financial tools in partnership with the private sector will allow the Commonwealth to scale up the necessary building retrofits to achieve the buildings sector's 2050 sublimit. Massachusetts is currently evaluating the options, the financing mechanisms, and the structure of those services in the Climate Finance Accelerator and aims to have an implementation plan in place by the end of 2023.

Conduct Joint Energy System Planning

The Commission on Clean Heat discussed in great detail the needed coordination or joint system planning between the electric and gas systems to support the electrification of heating. Such a recommendation signifies the importance of addressing the joint challenges associated with (1) the needed scale and pace of upgrading the electricity system to ensure reliable

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[87] Coalition for Green Capital, "What is a Green Bank," https://coalitionforgreencapital.com/what-is-a-green-bank/.

[88] MassDevelopment, "Massachusetts Financing Solutions," https://www.massdevelopment.com/what-we-offer/financing/.

electric service and (2) the needed caution around making additional investments into the natural gas system when every million spent will need to be paid back by a diminishing number of gas users or the gas utilities' shareholders. Thus, as the members of the Commission on Clean Heat recognize and emphasize, as building heating transitions from the use of natural gas to electricity, utility companies will need to coordinate to secure a smooth transition.

The Commission on Clean Heat recommends that the DPU and DOER work together to establish a framework for conducting joint energy system planning. This joint energy system plan should be developed through a robust stakeholder engagement process, which includes collaboration with an advisory committee of select key stakeholders, including the utilities, municipal representatives, building owners, and residents, and representatives of LMI/EJ communities and those whose heating systems are hard to comprehensively electrify, such as hospitals and laboratories that may need high-temperature heating sources. Such a joint energy system plan should provide clear guidance to policy makers, developers, regional planners, and community members about the anticipated infrastructure transitions necessary for accelerated electrification as well as strategic gas system retirement.

As the overall demand for natural gas decreases due to increasing efficiency and electrification, the economics of the gas delivery infrastructure becomes extremely important for consumers. As throughput decreases, the gas distribution system's largely fixed costs will fall more heavily onto a decreasing number of remaining customers or uses. Such cost impact may be exacerbated by higher-cost biomethane or synthetic natural gas to replace natural gas if they are used and assuming their costs do not decrease dramatically over the next two decades. The remaining customers may include disproportionate numbers of LMI customers who may be renters unable to choose their heating system and/or find it hardest to afford the upfront costs of electrification.

On the electricity system side, Massachusetts recognizes that the electric transmission and distribution system upgrades needed to support electrification require identifying geographic regions where the accelerated deployment of clean heating is possible, as well as identifying regions where there are currently electric capacity constraints that would need to be resolved prior to expanded electrification. Locations where accelerated deployment is possible will be top candidates for initial strategic gas infrastructure retirement. This is particularly true of areas that will soon require expensive gas system upgrades and therefore may create opportunities to avoid those gas system costs if electrification can be pursued promptly. Regions in Massachusetts that are subject to electricity system constraints will be candidates for electric system infrastructure upgrades or perhaps alternative clean heating technologies to electrification, followed later by gas infrastructure retirement as appropriate.

The analyses of the needs and opportunities for gas and electric infrastructure upgrades will need to be done in a coordinated way to best guide the deployment of clean heating systems. In addition, the electric infrastructure upgrades will need to be planned to accommodate the growing demand from various other decarbonization technologies, including the deployment of EV charging. Such electricity distribution (and, in some areas, transmission) upgrades will necessarily consider the potential ability to implement load flexibility associated with the deployment of distributed solar and energy storage or price-based demand response. System planning that takes these factors into account will be at the center of the effective transition of electric and natural gas uses across the Commonwealth to achieve the 2050 emissions limit.

Beginning in 2023, EEA will work with DOER and DPU on defining long-term policy directions to manage the future of the natural gas distribution system. As discussed above, the necessary reductions in natural gas throughput will require changes in how the gas system is operated and regulated and may require decommissioning significant parts of the gas system. Massachusetts will consider mitigating the risks to customers where possible, with policies to help facilitate the coordination of natural gas and electric distribution planning and to limit large new investments to contain overall gas system costs. In the near term, the gas utilities need to develop gas demand response programs and help advance electrification efforts to protect remaining customers from shouldering the entire remaining system costs as the gas system contracts.

The Commonwealth will also monitor the safety and reliability of the natural gas distribution system, which could face challenges on both dimensions if throughput and revenues fall significantly. The Commonwealth will strengthen policies to ensure continued monitoring of gas system performance and protection against deterioration, ensuring that the gas distribution companies remain capable of managing the system through the duration of the transition. Additional policies may be needed for the gas system during the transition to ensure that it remains reliable and safe, as some portions of it may gradually contract while other parts are still being relied upon by remaining customers. Please see additional discussion of this topic in Chapter 5d.

To ensure that all relevant voices are heard, the Commonwealth will follow the Commission's recommendation to encourage stakeholder engagement throughout the joint planning process, including working with an advisory committee of select stakeholders (including municipal representatives, building owners and residents, and LMI/EJ community members). Once the effort is set into motion, DOER will report on key metrics associated with the joint energy system plans, such as the potential financial, environmental, and equity impacts on the residents and businesses across the Commonwealth. DOER should use these results to make recommendations to adjust the joint energy system plan as necessary.

As a part of the recommendation from the Commission on Clean Heat, the joint energy system plan should first analyze existing building stock and the existing gas and electric infrastructure to identify areas suitable for accelerated deployment of electric heat pumps. This initial analysis should include an analysis of the age and quality of the electricity infrastructure, substation capacity, housing characteristics, and LMI/EJ communities. Using such an analysis, the plan would include geospatial information that can guide planners, developers, and policymakers on where to expect infrastructure upgrades. Further, the joint plan can actively employ targeted electrification to avoid incremental gas infrastructure investments. Opportunities (and the potential costs) associated with new energy infrastructure projects, such as district geothermal, should also be identified in the plan.

Further, following the Commission's recommendation, the DPU will examine both natural gas and electric utility rates to ensure that they align with the cost of service and that opportunities to reduce the cost of operating electric heating systems are considered. Specifically, any cost allocation of the electricity system should consider the impact on customers' ability to switch to electric heating systems that will be needed to reduce GHG emissions from the buildings sector. Rate design should also take into consideration ways to protect ratepayers who are most sensitive to cost increases, particularly as the usage of the gas distribution system decreases over time. This may mean that when the gas distribution rate increases to a certain level, a substantial amount of protection will be needed for those who still remain on the system to ensure that LMI and EJ populations are not left on a system whose costs are likely to rise steeply.

Develop a Climate Campaign and Public Education Efforts

To achieve the desired buildings sector transition (and other decarbonization requirements), all decision-makers need to be aware of and engaged in adopting decarbonization strategies. When the Commonwealth requires a specific action due to regulation or code, ensuring that Massachusetts residents are informed and aware of changes will accelerate customer adoption and build momentum.

Starting in 2023, Massachusetts will be developing a statewide climate campaign that targets and engages specific audiences, including building owners, landlords, renters, architects, developers, and installers. The messaging should be clear, concise, and adapted to the experience and knowledge level of each audience. Existing public outreach and awareness, such as MassCEC's Clean Energy Lives Here and the existing Green Communities program, can serve as the foundation of new public education work. Outreach will include various forms of community engagement, local media, and social media. The Commonwealth will use local success stories to build momentum.

PICTURE 5B-3. BILLBOARD OF CLEAN ENERGY CAMPAIGN

Public climate campaigns and outreach in LMI and EJ communities will be a priority from the very beginning, with a focus on collaboration with trusted community-based organizations and leaders. In addition, when working with municipalities, the Commonwealth will explore its ability to use designated liaisons to assist community organizations with climate-related reporting and service delivery, as well as communications concerning new regulations, including opportunities provided by existing and new programs.

Chapter 5c: Electric Power

TABLE 5C-1. POWER SECTOR SUBLIMIT FOR 2050

Electric Power Gross Emissions ($MMTCO_2e$)	1990	2020	2050
Gross Emissions ($MMTCO_2e$)	28.2	12.8	**2.0**
% Reduction from 1990			**93%**

Overview

While the power sector in Massachusetts (and New England) has already achieved significant GHG emissions reductions in the past two decades, further reductions will require building clean energy generation resources, new transmission projects, and in some cases, upgraded distribution systems. A part of this growth is required to meet the anticipated load increase from the electrification of Massachusetts' transportation and building heat.

In 2020, the GHG emissions from the power sector were about 50% less than the 1990 level. These reductions were attributable to the state moving away from coal- and oil-fired power plants and replacing them with less emitting energy resources. The deployment of customer-side energy efficiency and distributed energy resources (DERs) has helped counter the load growth on the electricity system.

The 2025/2030 CECP articulated the roles of offshore wind and solar PV resources, hydroelectricity imports from Canada, and regional collaboration in further decarbonizing the state's electricity sector over the next five to ten years. Policy tools such as the Renewable Energy Portfolio Standard (RPS), the Alternative Energy Portfolio Standard (APS), the Clean Peak Standard (CPS), and the Clean Energy Standard (CES) will continue to promote clean energy adoption. Massachusetts will optimize siting of solar PV installations based on environmental, economic, and land-use trade-offs.[89] The 2025/2030 CECP maps a trajectory for clean energy deployment through the end of this decade, laying the groundwork for electric sector decarbonization beyond 2030.

Procuring and deploying clean electricity generation to meet electricity demand in 2050 will require a new way of thinking. The simulations conducted in support of the 2050 Roadmap, the 2025/2030 CECP, and this Plan show that, in 2050, Massachusetts will likely need approximately 27 GW of solar PV and 24 GW of wind resources. Likewise, the New England region will need

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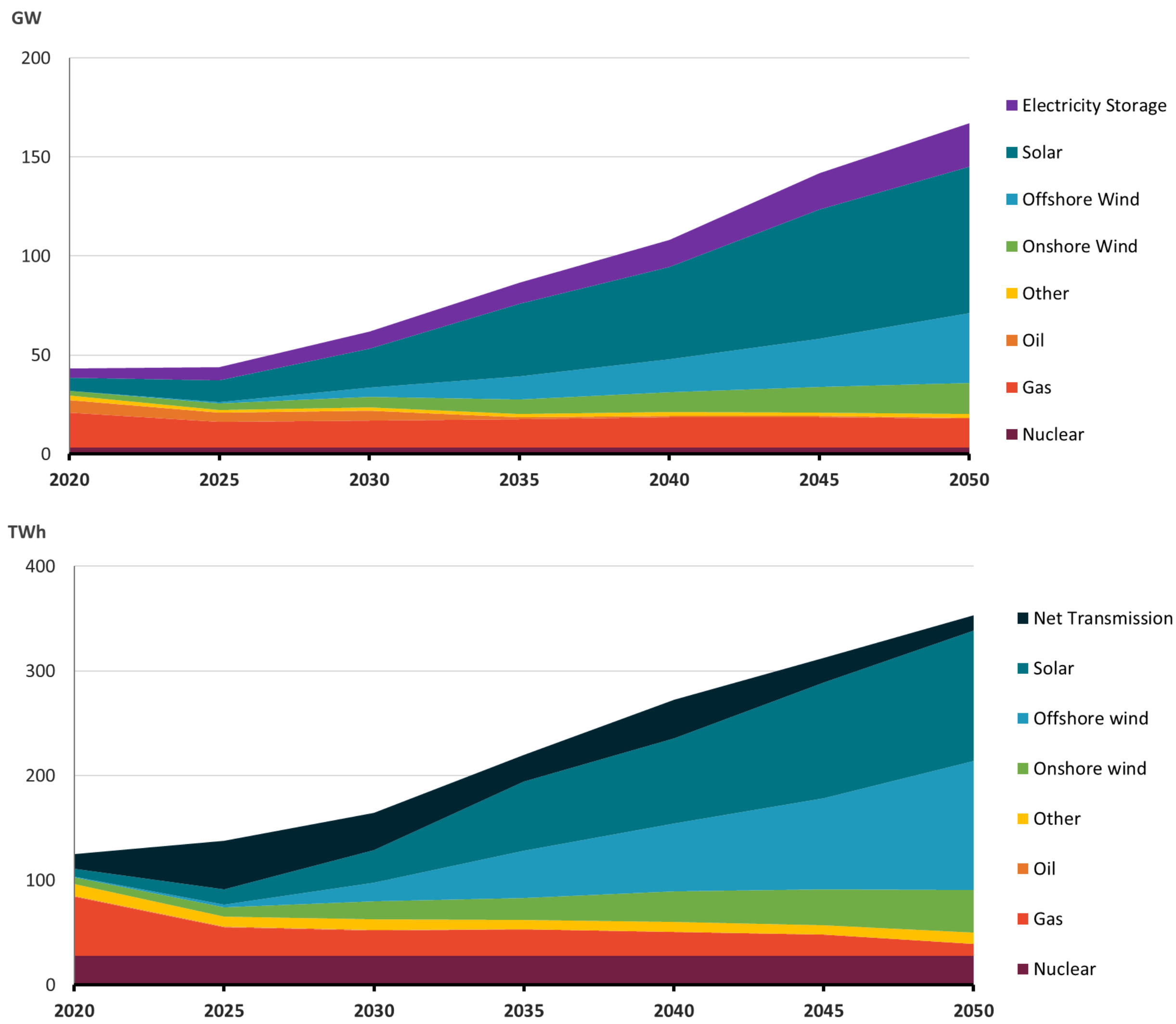
89 Commonwealth of Massachusetts, "Technical Potential of Solar Study" (November 22, 2022), https://www.mass.gov/info-details/technical-potential-of-solar-study.

significantly more clean energy resources to achieve decarbonization goals and targets by 2050. Figure 5c-1 below shows the projected GW of installed capacity for various power generation resources (top panel) and the TWh of energy production by type (bottom panel) that will be needed to serve New England, including imported energy via high voltage transmission system from other regions (termed "net transmission"). This reflects the simulation of the "Phased" scenario, by which the electrification of buildings is "phased-in" over the next three decades. A detailed description of the "Phased" approach is in the 2025/2030 CECP, Chapter 3.

FIGURE 5C-1. NEW ENGLAND'S INSTALLED CAPACITY (TOP PANEL) AND ELECTRICITY GENERATION (BOTTOM PANEL) BY ENERGY SOURCE



Note: "Other" includes both biomass and municipal solid waste electric generation units.

Integrating a large amount of clean energy into New England will require efforts on multiple fronts. First, Massachusetts will need to go beyond contract procurements as the main deployment strategy and consider approaches that better capture market pricing, quickly achieve scale, and are technology neutral. Second, the transmission system must be more robust. Third, the entire electricity system must be able to integrate clean energy resources while maintaining system reliability and resilience, particularly in the face of more severe weather events due to climate change. All of these will require continued coordination between New England Power Pool (NEPOOL), Independent System Operator New England (ISO-NE), New England States Committee on Electricity (NESCOE), the Federal Energy Regulatory Commission (FERC), and other stakeholders involved in clean energy resource procurement, electricity market reforms, transmission planning, and cost allocation.

In addition, significant advancement and investments will be needed for the electric distribution system. The Commonwealth will modernize the distribution system to integrate distributed energy resources and allow for and encourage load flexibility. Further, Massachusetts is committed to EJ such that all regulatory processes, including and particularly siting decisions, will be as inclusive as possible, engaging all stakeholders in the decision-making process. Below are descriptions of the strategies in more detail.

Develop and Deploy Successor to Procurements of Large-Scale Clean Energy Projects

Through 2024, Massachusetts will continue to rely on procurements as the main strategy for securing clean energy resources. However, beyond 2024, the Commonwealth will need a new approach to finance clean energy resources at the scale and pace needed to meet Net Zero. The current model of individual state procurements for clean energy projects occurs outside of existing wholesale market structures, requires a lengthy solicitation and regulatory review process, and places financial risk on ratepayers through long-term contracts.

Although state-funded procurements have been necessary to jump-start the deployment of large-scale renewable energy, Massachusetts will lead the region's shift away from traditional procurements and toward alternative methods for funding further renewable development. A Forward Clean Energy Market (FCEM) is a centralized forward auction in which buyers and sellers can voluntarily exchange clean energy attribute credits (CEACs). An FCEM model, in contrast to procurements,

PICTURE 5C-1. BAKER-POLITO ADMINISTRATION ANNOUNCES OFFSHORE WIND INDUSTRY PORTS INVESTMENT CHALLENGE IN NEW BEDFORD

would allow for better integration with existing competitive wholesale market structures and could be technology-neutral, conducted regularly, and enable each New England state to secure necessary clean energy resources.

Massachusetts is leading an effort to design a preliminary approach for a New England FCEM. The proposal will include details such as the products that can be traded in the FCEM, potential buyers and sellers, financial structures, regulatory integration, and the tracking of clean energy attributes. DOER is releasing a straw approach in late 2022 and sharing it with stakeholders across the New England region to seek comment. In general, an FCEM model allows generators and developers to submit offers of clean energy supply and allows energy distribution companies, states, or other entities to purchase a commitment to deliver clean energy. The purchases help to secure revenues in the marketplace to finance the development of clean energy resources. An FCEM would allow states to submit offers in the auctions to purchase clean energy resources consistent with their decarbonization targets, while municipalities, corporations, or retail suppliers can go above and beyond state targets to purchase CEACs.

Further work will be necessary to refine how the FCEM can integrate with existing energy markets (wholesale energy, capacity, and ancillary services markets), regulations (e.g., RPS, CES), and existing legal authorities. The preliminary work that Massachusetts has taken on can serve as a launching pad for the rest of the New England region to carefully evaluate the design of an FCEM. This will require close consultation with all New England states, ISO-NE, and other key stakeholders, with the aim to advance the design to a full market implementation, subject to the approval of the relevant state or federal agencies (such as FERC if implemented by ISO-NE). As an initial commitment, Massachusetts would consider developing a MWh target when using the FCEM for future clean energy procurement, such as the amount of renewable energy that is qualified under RPS Class I.

Support Offshore Wind Development

As the integrated energy and economic simulations show, offshore wind will be a cornerstone of the Massachusetts energy supply in the next three decades, through to 2050, enabling the Commonwealth to meet its decarbonized energy demand while sustaining economic growth. For that vision to become a reality, Massachusetts needs to invest in infrastructure, particularly ports, workforce, and supply chain, to support the industry’s growth. The Commonwealth will continue to work with federal entities and other states to expand the offshore wind industry, including working with the Bureau of Ocean Energy Management (BOEM) to identify new renewable energy areas in federal waters and auction lease areas for offshore wind in the Gulf of Maine. This effort will help create future development opportunities and engage with fishing interests to ensure that offshore wind and fisheries can share the valuable natural resources of the East Coast. Further, Massachusetts is working with industry experts to develop floating offshore wind technologies that could be deployed in deep waters.

PICTURE 5C-2. BAKER-POLITO ADMINISTRATION ANNOUNCES 2022 OFFSHORE WIND WORKS AWARDS

To facilitate the integration of offshore wind, Massachusetts has been working with other New England states in crafting a vision for developing an offshore grid, called the "Multi-state Modular Offshore Wind Integration Plan." That vision has been articulated in a white paper issued in September 2022, which underscores New England's effort to improve the integration of offshore wind resources, improve overall system reliability, and meet state decarbonization mandates while avoiding significant and costly reliability system upgrades.[90]

The Commonwealth will continue to work with other states and federal partners in mobilizing the financial resources and know-how to develop an offshore transmission system that could allow future offshore wind projects to "plug and play" into a system that serves the region and the country. Deploying offshore wind and offshore grid systems according to this vision will require a substantial amount of stakeholder engagement, including leadership from Massachusetts officials, offshore wind developers, transmission developers, environmental advocacy organizations, other state governments, and the federal government. Thus, EEA will continue to work on advancing a long-term transmission plan to integrate offshore wind at the regional level throughout the next three decades.

Simultaneously, the Commonwealth will leverage federal support to reform transmission planning in New England, catalyze innovative transmission projects, and construct transmission projects that integrate offshore wind and other clean energy for Massachusetts and New England as a whole. Regional coordination lowers development risks, reduces costs, improves grid resilience, and increases overall benefits across the Northeast.

The Commonwealth will continue to explore how offshore wind might help decarbonize other hard-to-electrify sectors. To that end, the state is collaborating with New York and other

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[90] New England Energy Division, "Regional Transmission Initiative: Notice of Request for Information and Scoping Meeting" (September 1, 2022), https://newenglandenergyvision.files.wordpress.com/2022/09/transmission-rfi-notice-of-proceeding-and-scoping.pdf.

neighboring states on a regional clean hydrogen hub that may be powered by electricity generated from offshore wind resources (see the future of fuels discussion in Chapter 6).

Reform Transmission Planning and Cost Allocation

PICTURE 5C-3. WIND TESTING CENTER

A robust and expanded transmission network will be critical to the Commonwealth's clean electricity future, ensuring that energy can be delivered from where it is produced to the New England grid (see Figure 5c-2 below for a map of the needed transmission capacity from Massachusetts to neighboring areas in 2050). Planning and developing transmission projects can take many years to decades. Thus, immediate and urgent action is needed to ensure the Commonwealth's goals can be achieved.

Massachusetts has been working with regional partners, including ISO-NE, to reform long-term transmission planning to capture the trends and policy directions and integrate large-scale renewable and clean energy for the region. This effort will set the groundwork necessary to define and estimate the regional benefits associated with various transmission projects to and within New England. In turn, those benefits will help inform how the costs associated with the regional transmission projects will be shared across electricity users in New England. While it is often controversial and difficult to settle, reaching an agreement across stakeholders on what regional transmission projects are needed to meet the region's needs and how the associated costs will need to be shared will be critical in advancing the electrification of transportation and building heat via the deployment of clean energy across the region and through imports.

The New England states have actively advanced transmission planning reforms necessary for the clean energy transition, including extending planning horizons and providing states an opportunity to request planning efforts. As a result of that work over the past three years, at the request of NESCOE, ISO-NE initiated the 2050 Transmission Study and, more recently, developed an approach to identify future transmission system needs over the longer-term planning horizon, which uses information made available through the New England states' decarbonization analyses.[91] The states also are working with ISO-NE to develop tariff changes for a long-term transmission planning process that reflects states' priorities. Fully aligned with

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[91] ISO Newswire, "FERC accepts ISO-NE proposal for state-requested, longer-term transmission planning process" (March 7, 2022), https://isonewswire.com/2022/03/07/ferc-accepts-iso-ne-proposal-for-state-requested-longer-term-transmission-planning-process/.

reforms that New England has taken on, in the second half of 2022, the New England states responded to FERC's Notice of Proposed Rulemaking on the future of transmission planning, cost allocation, and generation interconnection, highlighting the need for regional flexibility, a state-centric approach, and consumer protection.[92]

The IIJA and the IRA provide substantial funding to support transmission planning and construction, as well as specific support for offshore wind transmission development.[93] Massachusetts will leverage these funds to modernize its transmission network, maximizing the potential of clean energy resources while minimizing adverse impacts to ratepayers. To prepare for receiving the federal funding, in September 2022, Massachusetts, with four other New England states, issued a joint Request for Information (RFI) seeking comment on how to leverage new federal funding opportunities from the IIJA and IRA to upgrade the regional transmission system to integrate renewable and clean energy resources.[94]

Massachusetts will continue to work with other states, ISO-NE, and FERC to design and implement changes in the way the region conducts transmission planning and cost allocation. This effort is critical to the future of decarbonization. Without a well-planned regional transmission system that integrates clean energy, Massachusetts will not be able to realize the electrification and decarbonization necessary to achieve Net Zero in 2050. The Commonwealth will evaluate the results from the 2050 Transmission Study and other ISO-NE transmission planning efforts to continue to meet system reliability requirements as Massachusetts and other states move through the clean energy transition.[95] Massachusetts will continue to actively engage with FERC, ISO-NE, other New England states, and all stakeholders to ensure that transmission planning, cost allocation, and interconnection processes and principles align

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92 Initial Comments of the New England States Committee on Electricity, FERC Docket No. RM21-17-000, Building for the Future Through Electric Regional Transmission Planning and Cost Allocation and Generator Interconnection (August 17, 2022), https://www.iso-ne.com/static-assets/documents/2022/08/rm21-17_iso_initial_comments_transmission_nopr.pdf.

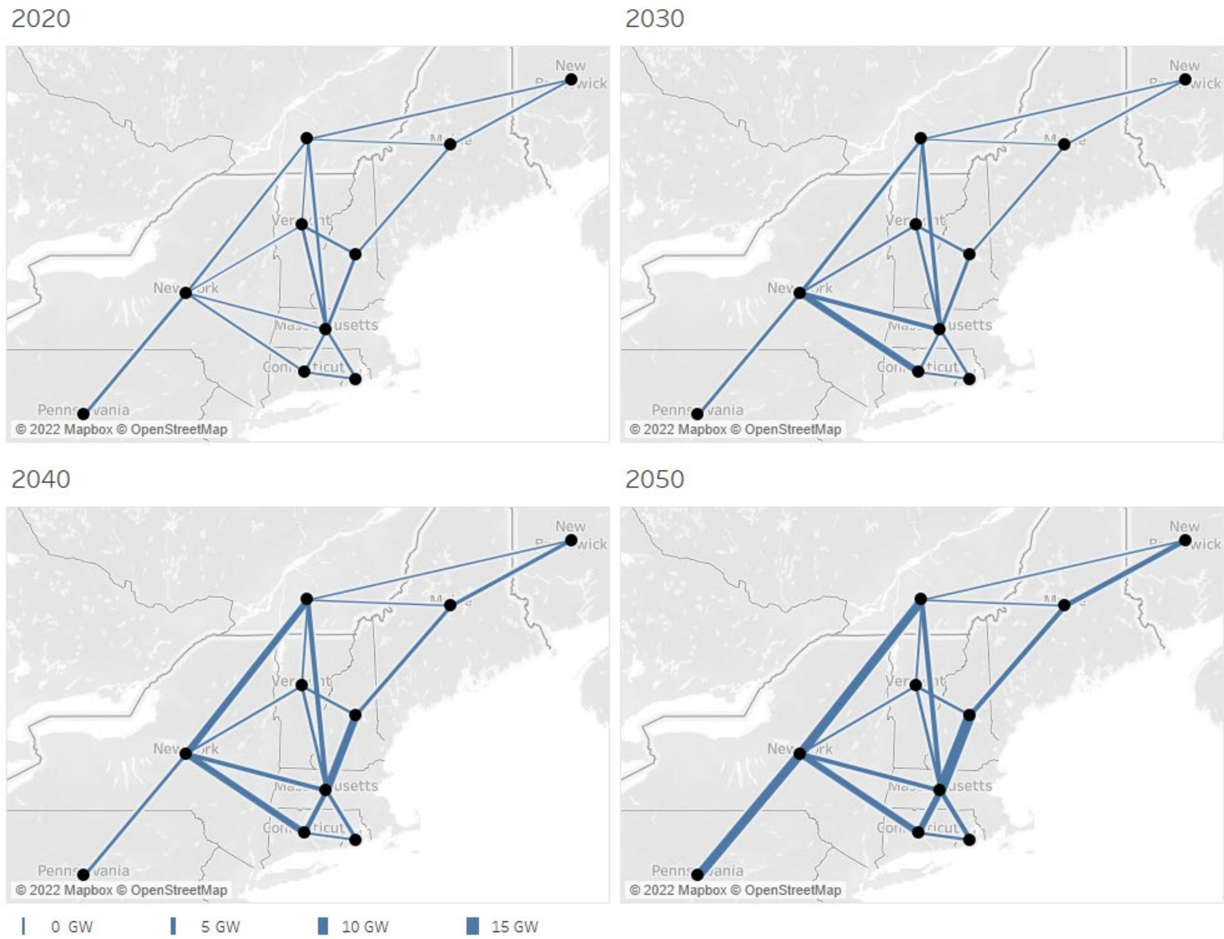
93 The IIJA establishes a $2.5 billion Transmission Facilitation Program (TFP) for the U.S. Department of Energy (DOE) to develop transmission lines. In addition, the IRA provides $2 billion to DOE for direct loans to non-federal borrowers to construct new high-capacity transmission lines and upgrading interties and $760 million in grants to assist siting authorities in evaluating interstate transmission lines. The IRA also provides $100 million for transmission planning, modeling, and analyses for the development of OSW transmissions projects and for convening stakeholders to address transmission project development.

94 New England Energy Vision, "New England States Transmission Initiative," https://newenglandenergyvision.com/new-england-states-transmission-initiative/.

95 ISO New England, "Longer-Term Transmission Studies Materials," https://www.iso-ne.com/system-planning/transmission-planning/longer-term-transmission-studies/.

with the Commonwealth's decarbonization priorities and provide cost-effective, reliable electricity in the years to come.

FIGURE 5C-2. ILLUSTRATIVE MAP OF TRANSMISSION CAPACITY NEEDED BETWEEN MASSACHUSETTS AND NEIGHBORING AREAS



Reform Wholesale Electricity Markets

The pace and level of new clean energy deployment needed to achieve at least an 85% reduction in gross GHG emissions and net-zero emissions in 2050 will require careful and strategic restructuring of the region's wholesale electricity market. Massachusetts will continue to support ISO-NE's implementation of its Future Grid Reliability Study[96] and Future Grid Initiative Key Project[97] to ensure the reliability and safety of the grid while minimizing costs.

One key finding of the 2050 Massachusetts Decarbonization Roadmap[98] and subsequent analyses is that a power system dominated by variable renewable energy resources will need to retain certain existing dispatchable thermal generators to ensure reliability while minimizing the costs of balancing the grid. This is particularly important for meeting the peak power demand, which will increasingly shift from summer to winter due to electric heating. Some natural gas generators will continue to be necessary in 2050 to operate during times of low wind and solar availability. However, those gas generators are expected to produce a small share of annual electricity generation and, thus, GHG emissions.

Recognizing the importance of flexibility in a deeply decarbonized grid, Massachusetts will continue to design incentives for energy storage to help maintain system reliability, reduce curtailment of renewable energy resources, and shift load to match supply patterns. Specifically, research and development of long-duration energy storage will be particularly valuable in the future. Massachusetts has been a leader in incorporating short-duration electric storage into our state energy policies, and a potential opportunity exists for developing the policies to support the development and, ultimately, the cost-effective deployment of clean long-duration storage in Massachusetts. Thus, Massachusetts commits to working with universities, research and development entities, and innovators to invest in technologies that would likely increase the options and decrease the costs of long-duration storage.

Modernize and Utilize the Distribution System to Accommodate Decarbonization Goals

Equipping the electric distribution system to be able to monitor and control power flows based on changes in load and generation will help keep distribution flexible, reduce overall system costs, and integrate renewable energy. Starting in 2023, DOER will lead the newly created Grid Modernization Advisory Council (GMAC), which will work on holistic distribution system planning in coordination with electric distribution companies (EDCs). The state has begun

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96 ISO New England, *2021 Economic Study: Future Grid Reliability Study Phase 1* (July 29, 2022), https://www.iso-ne.com/static-assets/documents/2022/07/2021_economic_study_future_grid_reliability_study_phase_1_report.pdf.

97 ISO New England, "New England's Future Grid Initiative Key Project," https://www.iso-ne.com/committees/key-projects/new-englands-future-grid-initiative-key-project/.

98 Commonwealth of Massachusetts, "MA Decarbonization Roadmap," https://www.mass.gov/info-details/ma-decarbonization-roadmap.

modernization planning, with a focus on investing in grid-facing technologies and systems that enhance the operation, communication, and control of the distribution system while maintaining reliability and integrating DERs. Going forward, Massachusetts will continue to collaborate with utilities and other stakeholders on modernization efforts such as installing advanced metering infrastructure (AMI). AMI can provide real-time energy consumption information valuable in planning and designing customer programs that lower both system costs and GHG emissions.[99] To maximize the benefits of AMI while balancing privacy concerns, as a part of the holistic distribution planning effort, DOER will consider a uniform data access strategy and ensure that all electric distribution utilities maximize their monitoring and control capabilities using the best data analytics.[100] In addition to investing in AMI, utilities must increase the acquisition and use of state-of-the-art data analytics to fully enable load flexibility.

Such distribution modernization efforts will include ensuring that the electric distribution system is capable of integrating DERs (both in front of and behind customers' meters). These efforts will also involve streamlining the generator and load interconnection process and enabling load flexibility in a cost-effective manner. The Commonwealth will track distribution system developments as well as clean energy and decarbonization efforts across the state to ensure that the individual utilities' plans, when combined, align with state goals.

The Commonwealth will continue to consult with stakeholders that use grid services to better understand what investments are necessary. The GMAC, established by the 2022 Climate Act,[101] will engage with stakeholders representing the diverse energy communities across the state, including environmental advocacy and EJ communities, to encourage efficient investments in the electric distribution systems that will facilitate the achievement of the statewide GHG limits and sublimits, and increase transparency and stakeholder engagement in the grid planning process. The GMAC will review and provide recommendations on the abovementioned electricity distribution modernization plans to maximize benefits to customers; demonstrate that efficient investments can help increase system flexibility; facilitate electrification of buildings, transportation, and other sectors; improve grid reliability and resiliency; minimize or mitigate impacts on ratepayers; and reduce impacts on and provide benefits to low-income ratepayers.

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[99] For example, AMI is essential for the implementation of time-varying rates and load flexibility measures to. AMI also provide utilities and third-party aggregators with improved visibility of DER assets, facilitating better planning of the distribution system.

[100] Customers could opt to authorize utilities or third-party vendors to securely access aggregated, regional data to more effectively incentivize energy efficiency, load shifting, and GHG reductions.

[101] Mass. Acts 2022, Ch. 179, https://malegislature.gov/Laws/SessionLaws/Acts/2022.

As described in the Buildings chapter, as customers increasingly electrify their heating systems, natural gas local distribution companies (LDCs) and electric distribution companies will need to coordinate planning efforts, especially on the location and pace of expanding the electric distribution system to meet the demand from increasing electricity load. The Commission on Clean Heat recommended a framework to enable and conduct statewide joint utility planning across the Commonwealth's gas and electric utilities.[102] Coordinated utility planning could examine existing characteristics of the electric and gas infrastructure, building stock, and community demographics to identify locations for electrification efforts to prioritize the deployment of clean heat technologies and strategic retirement of gas infrastructure. Coordinated planning may identify expected capacity constraints so that near-term actions can ensure adequate and reliable electric supply, including infrastructure upgrades and alternative technology integration.

Implement Innovative Load Flexibility Measures to Promote Clean Energy Use

As described above, there will need to be significant investment in the Commonwealth's distribution system to support decarbonization policies. Massachusetts will prioritize policies and programs that ensure efficient infrastructure investments. The Commonwealth will continue to prioritize greater deployment of energy efficiency and load flexibility measures to minimize necessary distribution system expansion (see Box 5c-1 for more information on load flexibility potential). Starting no later than 2024, DOER will work with the EDCs to design effective time-varying rates (TVR) and other load flexibility measures utilizing appropriate data from modern grid technologies as low-cost and efficient tools to encourage optimal consumption choices for customers.

To meet the 2030 and 2050 goals, the EDCs should submit effective TVR and modern load management programs to the DPU no later than 2026 and implement approved measures to reduce the impact of electrification costs. Massachusetts will consider sponsoring or supporting pilot projects that test innovative, under-researched demand flexibility program options, with a focus on methods that increase customer engagement or provide a broader range of value streams. Utilities around the country have deployed TVRs on an opt-out basis and provide valuable insight for Massachusetts' implementation. Unlocking additional

[102] Massachusetts Commission on Clean Heat, *Final Report* (November 30, 2022), https://www.mass.gov/info-details/commission-on-clean-heat-issues-final-report.

flexibility may require new participation and business models as well as innovative regulatory frameworks (e.g., performance-based regulation).[103]

Further, to ensure that flexible electricity load can participate in the wholesale electricity market and contribute toward providing system flexibility and reliability, Massachusetts will work with ISO-NE to implement FERC policies (including those required under FERC Order 2222[104]) to align state policies and regulatory requirements that would support the use of distributed resources, including energy storage and various forms of demand response in the wholesale markets.

Finally, Massachusetts will develop or revise appliance codes and standards in support of demand flexibility deployment. For example, appliances with significant energy footprints may be required to have two-way communication with the grid.[105] As appliances and the "internet-of-things" evolve, Massachusetts will set policies to enable devices to be programmed to automatically adjust operations based on signals from the grid to stabilize the grid and reduce the likelihood of reliability failures (e.g., blackouts or brownouts). Encouraging electric load to respond to distribution and transmission needs will be increasingly important as most of Massachusetts' transportation and heating/cooling systems rely on the electricity system.

BOX 5C-1. LOAD FLEXIBILITY POTENTIAL

Increasing flexibility in electricity demand and timing will be a key strategy for maintaining a reliable decarbonized grid. A U.S. Department of Energy study shows that opportunities to optimize the timing of residential and commercial building loads can help save up to $18 billion/year in power system costs and $100–$200 billion between 2020 and 2040 nationally.[106] By reducing and shifting the timing of electricity consumption, load flexibility measures could decrease CO_2 emissions by 80 million tons per year by 2030, or 6% of total power sector CO_2 emissions. This reduction is greater than the annual emissions of 50 medium-sized coal plants, or 17 million cars.

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[103] Performance-based regulation mechanisms can explicitly link successful deployment and utilization of energy efficiency and demand response resources with financial incentives and encourage their use by strengthening cost-containment incentives.

[104] Federal Energy Regulatory Commission, "FERC Order No. 2222: Fact Sheet" (September 17, 2020), https://ferc.gov/media/ferc-order-no-2222-fact-sheet.

[105] Washington State currently requires all electric storage water heaters sold in the state to have ports compliant with the CTA-2045 standard, allowing the appliances to have two-way communication with the grid.

[106] U.S. Department of Energy, *A National Roadmap for Grid-Interactive Efficient Buildings*, Office of Energy Efficiency and Renewable Energy (May 17, 2021), https://gebroadmap.lbl.gov/A%20National%20Roadmap%20for%20GEBs%20-%20Final.pdf.

Incorporate Environmental Justice into Decarbonized Electricity Systems

Environmental justice and equity have been and will continue to play a central role in the siting and permitting of power sector infrastructure. Thus, conducting public outreach in an inclusive manner will be critical in providing information and data transparently. Going forward, it is imperative that the siting and permitting processes for new energy facilities holistically consider environmental burdens and equity impacts on communities. Construction and upgrades of new energy infrastructure must uplift—and not hinder—EJ communities. Massachusetts, the EDCs, and developers will work with local community leaders and organizations to minimize burdens related to power system infrastructure. Massachusetts will continue to incorporate the voices of those that have traditionally been underrepresented in policy and regulatory processes and decisions. Currently, the DPU and the Energy Facilities Siting Board (EFSB) are developing EJ Strategies and a Public Involvement and Community Engagement Plan (PIP) to promote meaningful involvement by all peoples and communities.[107] Massachusetts will build on these efforts to amplify the voices of EJ Communities in future proceedings, working groups, and stakeholder discussions in a way that is consistent with the Massachusetts Environmental Justice Policy.[108]

In addition to ensuring diverse viewpoints are heard and considered in siting and permitting processes, the Commonwealth will consider requiring the electric and natural gas utilities to report the current and forecasted number of facilities that may need to be located in EJ communities, particularly those facilities that may present a significant impact on certain communities.[109] Starting in 2024 and in collaboration with government agencies, the EJ Council, and a public participation process, the Commonwealth will re-evaluate the approaches used in siting and permitting energy infrastructure projects. The aim would be to allow for a more inclusive and equitable approach to assess how energy infrastructure is deployed across the state.

Separately, to build a diverse workforce in the energy and climate fields, as a part of its cross-sector strategy, the Commonwealth is committed to training and growing an inclusive workforce to construct, operate, and maintain the clean energy system. The Commonwealth will lean on the training and workforce development efforts to present opportunities to further enhance the inclusiveness of the Commonwealth's economic growth, particularly with EJ

[107] DPU 21-50 and EFSB 21-01.

[108] Commonwealth of Massachusetts, "Environmental Justice Policy," https://www.mass.gov/service-details/environmental-justice-policy.

[109] Such facilities may include generators, compressor stations, transmission lines, and substations, among others.

populations. As explained in Chapter 4, the Commonwealth will invest in job training and placement programs for communities that are traditionally underrepresented in the clean energy field to ensure that the well-paying jobs and economic benefits associated with the transition flow to communities that have previously not benefited from those investments. In addition, future contract and project solicitations will prioritize locally-sourced materials and contracting opportunities with minority-, women-, and veteran-owned businesses.

Chapter 5d: Non-Energy & Industrial

TABLE 5D-1. NON-ENERGY & INDUSTRIAL SECTOR SUBLIMITS AND TARGETS FOR 2050

Non-Energy & Industrial Gross Emissions ($MMTCO_2e$)	1990	2020	**2050**
Industrial Energy	5.6	3.2	**0.3**
Industrial Process	0.7	3.2	**0.8**
Natural Gas Distribution & Services	1.9	0.7	**0.5**
Agriculture & Waste	3.4	1.0	**1.1**
Total Gross Emissions ($MMTCO_2e$)	11.5	8.3	**2.8**
Total Percent Reduction from 1990			**76%**

Note: GHG emissions for 2020 are based on preliminary estimates from MassDEP.

Overview

This Plan, following the methodology of the 2025/2030 CECP and Decarbonization Roadmap, includes industrial energy and industrial process emissions within the non-energy and industrial section even though the sublimit for industrial energy is combined with commercial buildings. Massachusetts' industrial sector contributes a relatively small part of the state's emissions, and it includes the manufacturing of products as varied as pencil boxes to seltzer. Industries in Massachusetts currently rely on fossil fuels for various applications in addition to heating and cooling their buildings. Fossil fuels are also used to produce steam and heat, operate production lines, power air compressors, run pumps, operate emissions control devices, cool refrigeration units, and perform numerous other activities.

Non-energy-related emissions consist of anthropogenic emissions other than those created by burning fossil fuels. Most Massachusetts' emissions in this category are fluorinated gases (F-gases),[110] which fall into the industrial process emissions category. These F-gases include hydrofluorocarbons (HFCs)—used in refrigeration, air conditioners, and heat pumps—and sulfur hexafluoride (SF_6), used in gas-insulated electrical infrastructure switchgear. Also included in industrial processes are the direct emissions of CO_2 as a result of lime production.

Other contributors to the non-energy category, as of 2020, include the emissions associated with natural gas distribution and services (via leakage),[111] solid waste management, and

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110 United States Environmental Protection Agency, "Overview of Greenhouse Gases," https://www.epa.gov/ghgemissions/overview-greenhouse-gases#f-gases.

111 The methodology for natural gas distribution emissions accounting has recently been changed in accordance with EPA improvements by adding post-meter natural gas leak emissions. The 2025 and 2030 sublimits were based on the February 2022 version of the 1990 baseline, which does not include the update. The 2050 sublimit is based on the December 2022 version of the 1990 baseline, which does include the update.

agricultural-related emissions. The latter two sources do not have emissions reduction sublimits but round out the statewide inventory of total emissions.

As outlined in the 2025/2030 CECP, the Commonwealth's policies aimed at reducing non-energy and industrial emissions primarily focus on eliminating and replacing the non-energy emissions with the highest global warming potential, such as HFCs and SF_6, and actively managing best practices around the processes that produce them, such as waste disposal. These policies remain in place over the 2050 timeframe.

Reduce Industrial Energy Emissions

Reductions in industrial energy emissions over the next three decades will likely stem from substantial electrification, energy efficiency measures, opportunistic use of bio- and synthetic fuels, and, if and when economic, selective use of carbon capture technologies. Electrification and energy efficiency efforts are already underway, with Mass Save® offering specialized technical expertise to help manufacturing facilities identify energy-saving measures. From 2011–2020, the Mass Save® Energy Efficiency Program resulted in energy savings of over 1,000 GWh of electricity and more than 23 million therms in the manufacturing segment.[112] As the market for alternative fuels continues to develop, low- and no-emission fuels may be able to replace fossil fuel use in some of the industrial processes and facilities that remain difficult to electrify. Carbon capture technology may be appropriate at certain facilities if the technology matures to a low-cost point. Figure 5d-1 below shows how carbon capture and other strategies, such as energy efficiency, electrification, and clean fuels, can help lower emissions from the industrial sector.

[112] Detailed information can be found by obtaining a free account at https://insight.dnv.com/MACustomerProfile and viewing C&I Electric and Gas summaries and Manufacturing data.

FIGURE 5D-1. MODELED 2050 DECARBONIZATION PATH FOR THE INDUSTRIAL SECTOR

Energy Efficiency	Electrification	Clean Fuels	Carbon Capture & Storage
Increases in efficiency in the sector average 1% total energy savings year over year. Efficiency remains a cost-effective way to reduce GHG emissions.	Nearly all HVAC and manufacturing machinery and about 50% of all process heat and steam production are electrified. Electricity use nearly doubles in the entire sector.	Total fuel use decreases by roughly 75%. Hydrogen and advanced bio-based fuel blends enable lower emissions from continued fuel use.	Carbon capture and storage technologies can be deployed at certain difficult-to-decarbonize industrial facilities as technologies improve and become more economic.

Target Non-Energy Emissions That Can Be Abated or Replaced

F-gases like HFCs and SF_6 have high global warming potentials (GWP) compared to CO_2 and last a long time in our atmosphere. The American Innovation and Manufacturing (AIM) Act of 2021 directs EPA to phase down production and consumption of HFC refrigerants to 15% of their baseline levels in a stepwise manner by 2036 through an allowance allocation and trading program. AIM is consistent with the Kigali Amendment to the Montreal Protocol, which was ratified by the U.S. Senate on September 21, 2022, further obligating the U.S. to reduce the production and use of HFCs, which in turn would reduce the use of HFCs in Massachusetts.[113]

The main use of SF_6 is as an insulating gas in electric transmission and distribution systems. MassDEP's Reducing Sulfur Hexafluoride Emissions from Gas-insulated Switchgear regulation (310 CMR 7.72) requires newly purchased electrical transmission and distribution equipment to have a low SF_6 leak rate. The largest electric utilities in Massachusetts are pursuing phasing out the use of SF_6. National Grid has indicated it will eliminate SF_6 from its equipment by 2050,[114] and Eversource is working with industry partners to research and test innovative solutions to replace SF_6.[115] MassDEP will stay abreast of research and development to determine when SF_6 use in the electric transmission and distribution system can be phased out and will update its regulation accordingly, based on national trends and the economics of the alternatives.

Regarding natural gas distribution emissions, the option for Gas System Enhancement Plans (GSEPs) to be submitted to DPU by local distribution companies (LDCs) was created in 2014 and

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113 U.S. Department of State, "U.S. Ratification of the Kigali Amendment" (September 21, 2022), https://www.state.gov/u-s-ratification-of-the-kigali-amendment/.

114 National Grid, "National Grid's 2021 Net Zero Plan Update" (November 4, 2021), p. 10, https://www.nationalgridus.com/media/pdfs/our-company/net-zero/cm8610-net-zero-sm.pdf.

115 Eversource, "Carbon Neutral by 2030," https://www.eversource.com/content/wma/residential/about/sustainability/carbon-neutrality.

made mandatory in 2021 to accelerate the replacement of leak-prone gas pipelines owned and operated by the Commonwealth's six investor-owned gas utility companies. GSEP's intention is to improve safety and reduce emissions from gas leaks. Pursuant to the 2022 Climate Act,[116] the DPU will convene a stakeholder working group to develop recommendations for regulatory and legislative changes that may be necessary to align GSEPs with GHG limits and sublimits and consider the plans' impacts on and implications for a number of areas. These include public health, safety, equity, affordability, reliability, reductions in GHG, and cost recovery for the repair and replacement of pipeline infrastructure—which may include, but are not limited to, embedded costs, potentially stranded assets, and opportunity costs and benefits. The stakeholder work group will also evaluate opportunities to advance utility-scale renewable thermal energy and will ensure that any change recommended will enable natural gas LDCs to maintain a safe and reliable gas distribution system during the Commonwealth's transition to Net Zero.

The Massachusetts gas LDCs' current GSEPs include significant anticipated investments through 2039 to upgrade the gas infrastructure to reduce methane leakage and safety risks. Simultaneously, the policies in the 2025/2030 CECP and this 2050 CECP that are necessary to reduce GHG emissions from the buildings sector will substantially reduce natural gas and other fossil fuel usage for heating. The GSEP time frame for increasing investments in the natural gas system is similar to the timeframe in which natural gas use will be reduced significantly. This means that all new investments in the gas distribution system will need to be recovered over an economic life of one to three decades or less, far shorter than the four to six decades life that is typical for such assets. Thus, the joint system planning for the natural gas and electric systems discussed in Chapter 5b will need to be put into place as soon as possible to minimize the risks of creating additional stranded assets.

The gas LDCs have been and will continue to be responsible for ensuring the orderly management of the gas delivery system so that remaining customers can be served reliably and safely until they can transition off the natural gas system and that no customers will face undue financial burdens. To reduce the emissions from the buildings sector, the Commonwealth needs to reduce the use of natural gas and ensure the gas system continues to be viable as long as necessary while protecting consumers from overpaying for investments that may not be needed beyond 2050. A reform to the GSEP will be needed such that, in the longer term, the transition to clean heating will involve the retirement (both financially and physically) of some gas assets. Additional gas investments made going forward will add to the challenges

[116] Mass. Acts 2022, Ch. 179, § 68, https://malegislature.gov/Laws/SessionLaws/Acts/2022.

associated with the gas transition, so they must be made judiciously. Otherwise, those costs will need to be borne by gas ratepayers or gas utility shareholders. To the extent that some of the new GSEP investments can be avoided (such as using "repair or retire" strategies), their added costs may be significantly reduced, thereby reducing the burden on remaining gas customers and reducing the magnitude of a problem that may ultimately need to be addressed by the Commonwealth.

The costs of the existing natural gas delivery system must be mitigated wherever possible. For example, the gas LDCs may need to implement natural gas demand response or manage customers' departure from the gas system to enable the retirement of some selected parts of the system to save some ongoing avoidable operating and/or capital investment costs. If stranded costs are significant because the move away from gas is faster than the financial and operational retirement of the gas system, it may be necessary to protect remaining customers from shouldering the entire remaining system costs by requiring the shareholders of the natural gas companies to share in paying for the stranded costs.

The 2022 Climate Act has allowed ten cities or towns to adopt and amend general or zoning ordinances or bylaws that require new building construction or major renovation projects to be fossil fuel-free. Such buildings or condominium units will not utilize coal, oil, natural gas, or other fuel hydrocarbons, including synthetic equivalents, or other fossil fuels. This is a demonstration project to begin to move away from the use of the natural gas system for heating. The electric and gas distribution companies that serve the cities and towns in the demonstration project will collect and report to DOER information regarding the monthly electricity and gas consumed, and corresponding electricity and gas costs, for each consumer in each municipality participating in the demonstration and contrast them with non-participating comparable municipalities. DOER will make the data publicly available annually and compile a report every two years summarizing the data and analyzing the net reduction in emissions in each municipality participating in the demonstration and in several comparable municipalities.

The report shall also analyze impacts on housing production; housing affordability, including electric bills, heating bills, and other operating costs; housing affordability for persons of low and moderate-income, including electric bills, heating bills, and other operating costs; and other matters set forth by DOER after consultation with municipalities and with individuals, organizations, and institutions knowledgeable about issues of housing and emissions reductions; and include recommendations for the continuation or termination of the demonstration project. DOER, in consultation with EEA and the EOHED, will promulgate regulations to implement the demonstration project no later than July 1, 2023.

The findings associated with the ten-municipality demonstration project will help inform future policies and regulatory approaches to gradually reduce the reliance on natural gas while maintaining system safety and reliability during the transition to clean energy.

Execute Recommendations from Solid Waste Master Plan Produced Every Decade

MassDEP is required to develop and maintain a comprehensive statewide master plan for reducing and managing solid waste, which the agency updates on a 10-year planning cycle. The Massachusetts 2030 Solid Waste Master Plan: Working Together Toward Zero Waste[117] committed to the longer-term goal of reducing the Commonwealth's solid waste disposal by about 90% (to 570,000 tons) by 2050 and diverting recoverable material from disposal to higher uses. Reduction in waste can minimize the need for municipal waste combustors, and the 2030 Solid Waste Master Plan commits to "make a concerted effort to improve the performance of existing combustion capacity and, in the 2025 program review, explore the potential to establish a declining cap on carbon dioxide emissions from municipal waste combustors." MassDEP will continue to align with the 2030 Solid Waste Master Plan and execute recommendations from future Solid Waste Master Plans produced each decade.

[117] Commonwealth of Massachusetts, "Solid Waste Master Plan," https://www.mass.gov/guides/solid-waste-master-plan.

Chapter 5e: Natural and Working Lands

Overview

Natural and working lands (NWL) and the ecosystem services they provide must continue to be protected as Massachusetts pursues actions to achieve the Net Zero limit. Carbon sequestration from the growth of trees and the accumulation of organic matter in healthy soils and wetlands provide valuable and cost-effective removal of carbon dioxide emissions and storage of carbon, as well as many other valuable ecosystem services. While usually a net carbon sink, NWL can be a source of GHG emissions when disturbed, cleared, or developed. This section details the Commonwealth's ambitious goals, strategies, and commitments to protect and enhance in-state NWL carbon sequestration for the period between 2030 and 2050, building and expanding upon those described in the 2025/2030 CECP. Policies to procure additional carbon sequestration to achieve net-zero emissions in 2050 are discussed in Chapter 7.

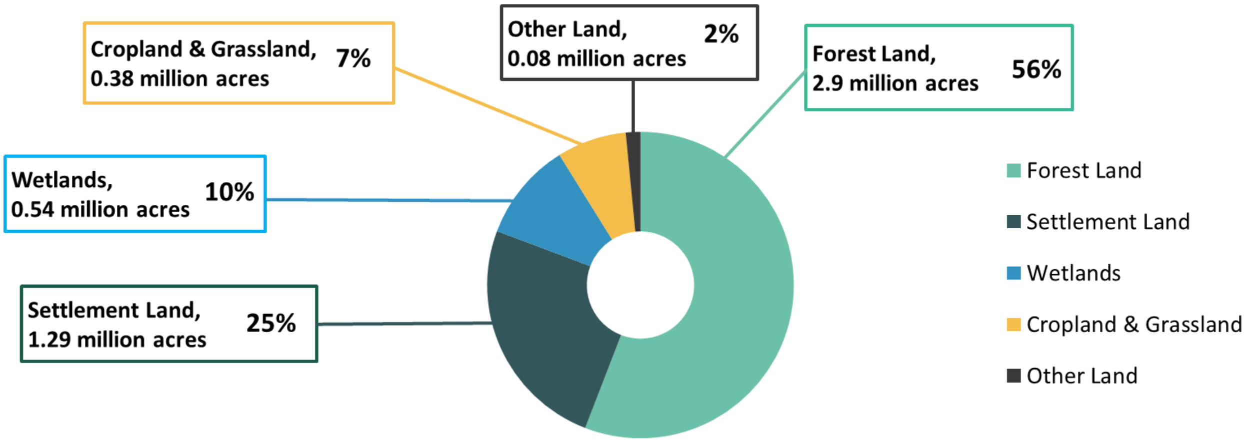
NWL Sequestration, Emissions, and Accounting

Massachusetts NWL GHG fluxes include both carbon sequestration and emissions occurring on forest land, settlement land, wetlands, and croplands and grasslands, as shown in Figure 5e-1 below. [118] Net emissions on NWL are estimated to have been -6.9 MMTCO_2e (i.e., positive carbon sequestration) in 2020, as shown in Table 5e-1,[119] with approximately 85% occurring on forest land that makes up around 56% of total land area in Massachusetts.

[118] EEA reclassification of U.S. Geological Survey's Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.2. LCPRI and LCSEC land cover products, available at https://www.usgs.gov/special-topics/lcmap/collection-12-conus-science-products. For further details, see Chapter 8 and Appendix C of Massachusetts Clean Energy and Climate Plan for 2025 and 2030 at https://www.mass.gov/2030CECP.

[119] The methodology, data, limitations, and uncertainty of the NWL GHG emissions inventory are discussed in detail in Chapter 8 and Appendix C of Massachusetts Clean Energy and Climate Plan for 2025 and 2030 at https://www.mass.gov/2030CECP. Since the publication of the 2025/2030 CECP, Massachusetts' NWL GHG inventory has been updated to include 2020 emissions and modified to include additional reporting categories: Inland Wetlands – Flooded Land CH_4 Emissions, Settlement Soil N_2O Emissions, and Landfilled Food Scraps Carbon Stock Change. The inclusion of these additional categories results in an estimate of 2019 NWL net emissions of -6.9 MMT CO_2e, rather than -7.0 MMTCO_2e, as reported in the 2025/2030 CECP. Several emissions categories have also been further disaggregated for greater consistency with national and international reporting standards: Land Converted to Crop/Grassland Ecosystem Carbon Stock Change is now reported separately for Croplands and Grasslands; Coastal Wetland Ecosystem Carbon Stock Change is now reported separately for CO_2 and CH_4 emissions.

FIGURE 5E-1. MAJOR NATURAL AND WORKING LAND CLASSES IN MASSACHUSETTS IN ACRES AND AS A PERCENTAGE OF ALL LAND AREA STATEWIDE[120]



Positive net NWL carbon sequestration (i.e., negative net emissions) means that carbon is accumulating in Massachusetts' NWL ecosystems, which collectively store over 2,000 MMTCO$_2$e in soils, biomass, and dead organic matter.[121,122] The rate of net carbon sequestration was growing consistently during the 1990s and 2000s and has been relatively stable for the past decade. However, the Commonwealth has seen a steady loss of forests and other NWLs to development and other uses in recent decades (~5,000–7,000 acres of forest loss per year),[123,124,125] meaning that sequestration could be higher were it not for these losses. Recent NWL carbon sequestration, GHG emissions, and land use dynamics are discussed further in Massachusetts' 2025/2030 CECP (Chapter 8 and Appendix C).

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120 Footnote 118.

121 Brian F. Walters et al., *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*, Forest Service Research Data Archive (2021), https://doi.org/10.2737/RDS-2021-0035.

122 Jonathan R. Thompson et al., *Land Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study*, Harvard Forest (2020), https://www.mass.gov/doc/land-sector-technical-report/download.

123 Walters et al. (2021).

124 Christopher A. Williams et al., *Avoided Deforestation: A Climate Mitigation Opportunity in New England and New York*, Clark University (2021), https://www.nature.org/content/dam/tnc/nature/en/photos/Avoided-Deforestation-Report-NE-NY.pdf.

125 Heidi Ricci et al., *Losing Ground: Nature's Value in a Changing Climate*, Massachusetts Audubon Society (2020), https://www.massaudubon.org/our-conservation-work/policy-advocacy/local-climate-resilient-communities/losing-ground.

TABLE 5E-1. ESTIMATED GHG EMISSIONS (POSITIVE VALUES) AND CARBON SEQUESTRATION (NEGATIVE VALUES) ON MASSACHUSETTS' NWL IN 2020[126]

Land Classes / Reporting Categories			2020 Net Emissions ($MMTCO_2e$)
Forest Land			**-5.8**
Forest Land Remaining Forest Land		**-5.23**	
Forest Ecosystem Carbon Stock Change	-4.57		
Harvested Wood Products Carbon Stock Change	-0.66		
Land Converted to Forest Land		**-0.60**	
New Forest Ecosystem Carbon Stock Change	-0.60		
Cropland & Grassland			**0.3**
Crop/Grassland Remaining Crop/Grassland		**0.23**	
Cropland Soil Carbon Stock Change	0.22		
Grassland Ecosystem Carbon Stock Change	0.01		
Land Converted to Crop/Grassland		**0.08**	
New Cropland Ecosystem Carbon Stock Change	0.09		
New Grassland Ecosystem Carbon Stock Change	-0.01		
Wetlands			**-0.1**
Wetlands Remaining Wetlands		**-0.11**	
Coastal Wetlands Ecosystem Carbon Stock Change	-0.20		
Coastal Wetlands CH_4 Emissions	0.01		
Inland Wetlands - Flooded Land CH_4 Emissions	0.08		
Land Converted to Wetlands		**0.00**	
New Wetland Ecosystem Carbon Stock Change	0.00		
Settlements			**-1.3**
Settlements Remaining Settlements		**-1.81**	
Biomass Carbon Stock Changes	-2.68		
Soil Carbon Stock Changes	0.88		
Settlement Soil N_2O Emissions	0.08		
Landfilled Food Scraps Carbon Stock Change	-0.08		
Land Converted to Settlements		**0.53**	
New Settlement Ecosystem Carbon Stock Change	0.53		
Other Land			**0.0**
Total Net NWL Emissions			**-6.9**

For the purposes of meeting its Net Zero Limit in 2050, the Commonwealth considers the net negative emissions reported in its NWL GHG emissions inventory to be net positive carbon sequestration attributable to Massachusetts (see Chapter 3 for further explanation of the Net Zero Limit and net emissions accounting). This inventory-based, biophysical accounting

126 Footnote 119.

approach includes all estimated GHG fluxes to and from the atmosphere on all NWL in Massachusetts, irrespective of cause and land ownership (see Chapter 7 for further discussion of carbon sequestration accounting). Some categories and activities are not currently well-captured in the NWL GHG inventory (e.g., small-scale land clearing, inland wetlands), and while most important emissions categories are included and estimated to a reasonable approximation, these estimates have considerable uncertainty and may change with improved monitoring and methods. To be in the best position to achieve Net Zero in 2050, the Commonwealth is pursuing policies to enhance and secure NWL carbon sequestration in Massachusetts and to reduce major risks of carbon loss, as discussed below.

Net Carbon Sequestration Potential in 2050

Current levels of NWL carbon sequestration in Massachusetts are driven largely by forest land use, particularly by natural forest regrowth and land conservation following a history of forest clearing for agriculture and unsustainable logging practices in the 19th and early 20th centuries. This has led to increasing rates of forest carbon sequestration in recent decades due to an abundance of young, fast-growing trees. However, statewide sequestration has leveled off in recent years (see discussion in Chapter 8 and Appendix C of the 2025/2030 CECP) and is likely to decline at some point in the future. Looking to 2050, there are considerable uncertainties and risks pertaining to carbon sequestration in Massachusetts' forests due to forest demographic shifts, ecological disturbances, and land use change. Nevertheless, forest land and overall NWL carbon stocks (i.e., stored carbon) are likely to continue growing, even if at a slower rate.

NWL and forest carbon sequestration are expected to decline in Massachusetts because most of the state's forests are in the 60–100 year age range,[127] a stage when carbon accumulation tends to start slowing down. This slowdown occurs as maturing forests experience increasing competition for finite resources, declining overall growth rates, elevated mortality, and more limited opportunities for tree regeneration.[128] It is not presently clear when statewide carbon sequestration in Massachusetts' forests might begin to decline—they may be able to maintain

[127] USDA Forest Service, Forests of Massachusetts, 2019, Resource Update FS-239 (2020), https://doi.org/10.2737/FS-RU-239.

[128] Chadwick Dearing Oliver and Bruce A. Larson, *Forest Stand Dynamics* (New York: John Wiley & Sons, Inc., 2016).

high rates of net carbon accumulation for some time,[129,130] potentially aided by intervention.[131] However, results from the Land Sector Technical Report of the 2050 Decarbonization Roadmap[132] indicate that the shift is likely to occur in the next few decades and could lead to a decline in annual statewide net carbon sequestration of over 1 $MMTCO_2e$ by 2050.

In addition to demographic factors, carbon sequestration and carbon stocks in Massachusetts' forests face considerable risk from ecological disturbances. These disturbances include insect outbreaks, pathogens, wind, ice, wildfire, and periodic hurricanes. While many of these disturbances are natural, and forests in this region can recover relatively quickly, intensification of disturbances from climate change and the introduction of exotic insect pests present additional stress that could increase emissions and decrease net sequestration.[133]

Massachusetts has historically experienced a high-impact hurricane approximately every 40 years,[134,135] and the frequency and magnitude of these events are expected to be intensified by climate change.[136,137] An intense hurricane would cause significant tree mortality and transfer forest carbon from live biomass to dead organic matter, as well as to harvested wood products to the extent that wood is salvaged. Much of this carbon would be released in subsequent years, increasing emissions, though natural forest recovery would lead to increased net carbon sequestration for a period as well. Carbon stocks in Massachusetts forests and other NWL are

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[129] Adrien C. Finzi et al., "Carbon budget of the Harvard Forest Long-Term Ecological Research Site: Pattern, process, and response to global change," *Ecological Monographs* 90(4) (2020), https://onlinelibrary.wiley.com/doi/10.1002/ecm.1423.

[130] Peter S. Curtis and Christopher M. Gough, "Forest aging, disturbance and the carbon cycle," *New Phytologist* 219(4) (2018): 1188–93, https://nph.onlinelibrary.wiley.com/doi/full/10.1111/nph.15227.

[131] Paul Catanzaro and Anthony D'Amato, *Forest Carbon: An Essential Natural Solution for Climate Change*, University of Massachusetts, Amherst (2019), https://masswoods.org/sites/masswoods.org/files/Forest-Carbon-web_1.pdf.

[132] Thompson et al. (2020).

[133] Massachusetts EEA, "Forest Health Degradation" impact assessment, pp. 89–97 in Appendix B of Massachusetts Climate Change Assessment (2022), https://www.mass.gov/info-details/ma-climate-change-assessment.

[134] Emery Boose et al., "Landscape and Regional Impacts of Hurricanes in New England," *Ecological Monographs* 71(2001): 27–48, https://doi.org/10.1890/0012-9615(2001)071[0027:LARIOH]2.0.CO;2.

[135] Chris Landsea et al., "The revised Atlantic hurricane database (HURDAT2)," United States National Oceanic and Atmospheric Administration's National Weather Service National Hurricane Center (2015), https://www.nhc.noaa.gov/data/hurdat/hurdat2-format-atl-1851-2021.pdf.

[136] Thomas R. Knutson et al., "Tropical cyclones and climate change: A Review," 243–284 in *Global Perspectives on Tropical Cyclones: From Science to Mitigation*, ed. Johnny C. L. Chan and Jeffery D. Kepert (World Scientific, 2010).

[137] Michael E. Mann and Kerry A. Emanuel, "Atlantic hurricane trends linked to climate change," *EOS, Transactions, American Geophysical Union*, 87(24) (2006), 233–241, https://doi.org/10.1029/2006EO240001.

likely to continue growing between now and 2050, but carbon sequestration could be significantly affected by the occurrence, timing, and severity of hurricanes and other ecological disturbances.

Another risk to Massachusetts forest's stored carbon is the conversion of forest land to developed uses. Development on forest land for settlement expansion or ground-mounted solar PV infrastructure removes a significant fraction of the area's carbon stocks and can significantly reduce or eliminate its future sequestration potential. While the Commonwealth will need to grow its solar generation capacity substantially to meet its 2050 clean energy goals (see Chapter 5c) and additional housing and urban development are needed to accommodate population growth, forest carbon losses can be minimized by prioritizing more efficient land use, non-forest solar siting, and development that follows smart growth practices and avoids deforestation.

Forest management, conservation, and resource utilization can also influence carbon sequestration and stocks, as well as forest health and resilience. Active forest management, including harvesting, can promote tree regeneration, growth, and carbon sequestration while also helping forests better mitigate or recover from the effects of stressors and disturbances in some cases (see discussion below). Moderate levels of harvesting can also provide Massachusetts with a sustainable, local source of carbon-storing wood products that are typically less emissions-intensive than alternatives. Harvesting does remove carbon from the forest, which leads to lower overall carbon stocks and increased net emissions for a period, so in some circumstances taking more passive management approaches with little or no harvesting can be appropriate.

The aforementioned Land Sector Report included an analysis of alternative management scenarios, finding relatively small differences in carbon sequestration and storage going out to 2050. But another recent study indicates the carbon sequestration benefits of improved forest management in Massachusetts could be more substantial, while also finding modest carbon benefits from the utilization of more wood for mass timber construction and from the establishment of passively-managed wildland forest reserves.[138] Ultimately, a mix of active and passive forest management, improved wood utilization, and holistic, long-term, landscape-scale

[138] Spencer R. Meyer et al., New England's Climate Imperative: Our Forests as a Natural Climate Solution, *Highstead* (2022), https://highstead.net/library/forests-as-a-natural-climate-solution/.

forest planning are likely to be most beneficial for forest carbon stocks, sequestration, and other ecosystem services.[139,140]

Collectively, forest demographic change, climate-intensified ecological disturbances, and the conversion of forests to other land uses present considerable risks, uncertainties, and challenges to maintaining current levels of carbon sequestration on Massachusetts' NWL through 2050. EEA is conducting a follow-up study to the Land Sector Report to examine the effects of hurricanes, exotic insect pests (hemlock woolly adelgid and emerald ash borer), and intensified disturbances on forest carbon dynamics. The study will also examine the potential impact of alternative land use and reforestation scenarios on Massachusetts' ability to sequester and store carbon. Finally, the follow-up study will further investigate the trade-offs and synergies between forest carbon sequestration, stocks, and resilience of a broader range of forest planning and management approaches, extending the analysis out to year 2100 and analyzing the interaction between management and ecological disturbances.

Results from the Land Sector Report update study—expected by the end of 2023—will help estimate the levels of net carbon sequestration that Massachusetts could expect through 2050 and beyond, including estimates of the potential impact of some of the policies and strategies outlined in the 2025/2030 CECP and this Plan. Together with other studies[141,142,143,144] and expert and stakeholder input, the Land Sector Report update will assist the Commonwealth in assessing the potential carbon sequestration, storage, and resilience implications of various ecological disturbances and land use policies. Future CECPs will be informed by the findings of

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139 Catanzaro and D'Amato (2019).

140 Charles H.W. Foster and David R. Foster, *Thinking in Forest Time: A Strategy for the Massachusetts Forest,* Harvard Forest (1999), https://harvardforest1.fas.harvard.edu/sites/harvardforest.fas.harvard.edu/files/publications/pdfs/foresttime.pdf.

141 Williams et al. (2021).

142 Meyer et al. (2022).

143 U.S. State Natural Climate Solutions Mapper, Nature4Climate, https://nature4climate.org/nature-in-action/united-states-ncs-mapper/. *See also:* Bronson W. Griscom et al., "Natural climate solutions," *Proceedings of the National Academy of Sciences*, 114(44) (2017), 11645–11650. https://doi.org/10.1073/pnas.1710465114.

144 Reforestation Hub, The Nature Conservancy and American Forests, https://www.reforestationhub.org/. *See also:* Susan C. Cook-Patton, "Lower cost and more feasible options to restore forest cover in the contiguous United States for climate mitigation," *One Earth* 3 (2020), 739–752, https://doi.org/10.1016/j.oneear.2020.11.013.

this and related assessments, and will also incorporate any NWL sequestration and emissions goals, as deemed appropriate.

This CECP sets discrete policy goals and details specific no-regrets strategies and actions that will reduce NWL emissions and enhance net NWL carbon sequestration to put Massachusetts on a pathway to net-zero emissions by 2050, as described in the following sections. These efforts will be implemented while considering opportunities to maintain and enhance the full range of ecosystem services that NWLs provide and ensuring these benefits are shared equitably, particularly by EJ communities. Additionally, as an ongoing effort, the Commonwealth will continue to improve the monitoring, reporting, and analysis of NWL in the coming decade to better understand and assess relevant GHG fluxes and policy options. In addition to the Land Sector Report update, the NWL GHG inventory will be improved in 2023, including a more complete, spatially explicit accounting of land use and land use change, new emissions factors, and additional land use classes and emissions categories.[145] Following publication of the updated Land Sector Report and NWL GHG inventory, EEA will continue to assess opportunities to improve data and analytical approaches to meet the Commonwealth's needs in the NWL sector in subsequent years.

Goals and Strategies

The Commonwealth aims to permanently conserve at least 40% of Massachusetts lands and waters (up from 27% in 2022 and the 30% conservation goal for 2030) and to plant at least 64,400 additional acres of riparian and urban trees by 2050 (compared to 2022). These goals—and the strategies and policies to achieve them—build on the goals, strategies, and policies in the 2025/2030 CECP. The Commonwealth's focus is to expand the protection, management, and restoration of NWL and their capacity to remove and store carbon now through 2050 and beyond. These efforts will be implemented while balancing other ecosystem services that natural and working lands can provide. The Commonwealth will also implement selected strategies and policies in ways that provide equitable benefits to EJ communities, such as increasing tree canopy in EJ neighborhoods, ensuring that lands managed by state agencies or with public funding are accessible to everyone, including EJ populations, and increasing incentives and technical assistance to underserved and underrepresented landowners and farmers. Below includes a more detailed description of each strategy.

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[145] For example, a more complete estimate of GHG fluxes from inland (non-tidal) wetlands will be included, as the only inland wetland category in the current NWL GHG inventory is Flooded Land CH_4 emissions. Harvested wood product carbon stock change estimates will be updated based on more recent data sources.

Expand NWL Conservation

PICTURE 5E-1. MASSACHUSETTS LANDSCAPE

Conservation is the most important strategy for the Commonwealth to retain as much NWL carbon sequestration resources and long-term ecosystem resilience as possible by protecting forests and other natural land cover types from land clearing for development. Currently, approximately 27% of land and waters in Massachusetts are legally protected in perpetuity.[146] To conserve at least 40% of Massachusetts by 2050, the Commonwealth and its conservation partners will need to permanently protect an additional 685,000 acres, averaging an additional 25,000 acres annually between 2023 and 2050. To accomplish this ambitious pace of conservation, the Commonwealth will need to leverage recent federal funding sources; provide additional incentives for landowners; expand support to municipalities, land trusts, and regional entities in land acquisitions; and explore options to channel private investments to NWL conservation.

Passage of the Inflation Reduction Act in August 2022 has earmarked significant federal funding for NWL conservation, including:

- $75 million for the Forest Legacy Program, which is administered by the U.S. Forest Service in partnership with state agencies, to encourage the protection of privately owned forest lands through conservation easements or land purchases;
- $1.4 billion for the Agricultural Conservation Easement Program, which is administered by the Natural Resources Conservation Service, to protect agricultural lands through the acquisition of easements, limit non-agricultural uses of croplands and grasslands on working farms and ranches, and protect, restore, and enhance wetlands that have been previously degraded due to agricultural uses.

Guidance from the federal government on the timeline and process for funding disbursement is forthcoming. Once the funding becomes available, the Commonwealth will seek funding and work with landowners, municipalities, land trusts, and other land conservation partners to acquire conservation easements on privately owned lands of interest.

[146] Estimate based on the Protected and Recreational OpenSpace datalayer: "MassGIS Data: Protected and Recreational OpenSpace," Commonwealth of Massachusetts, https://www.mass.gov/info-details/massgis-data-protected-and-recreational-openspace.

Increasing the pace of NWL conservation requires not only additional funding but also expanding the staffing capacity of state, municipal, and land trust stakeholder organizations. Conservation funding from the state and federal governments is typically in the form of grants made available to municipalities, land trusts, and other partners. Municipalities with large tracts of NWL suitable for conservation often have a small staff, and they rely heavily on volunteers. By providing technical assistance and funding for consulting support—along with a Payment in Lieu of Taxes (PILOT) from the state to municipalities as proposed in the 2025/2030 CECP—the Commonwealth can empower municipalities to keep more lands in their community as natural and working lands. The Commonwealth can also support municipalities through working with regional planning agencies and land trusts, consolidating resources to help communities with similar interests and needs. By 2024, EEA will establish a program to provide technical assistance and expanded grant support to municipalities, regional entities, and land trusts for NWL conservation.

PICTURE 5E-2. BAKER-POLITO ADMINISTRATION LAUNCHES MASSACHUSETTS OFFICE OF OUTDOOR RECREATION

While increased federal funding provides some of the needed capital to ramp up NWL conservation, a sustained funding stream is necessary to maintain the expanded pace of conservation over the next 28 years and beyond. The Commonwealth will need to explore options to increase state funding and channel private investments to NWL conservation. One such option is to attract pledges and contributions to NWL conservation from socially responsible companies and entities. Another option is using compliance payments from regulatory programs and/or mitigation funds from the Massachusetts Environmental Policy Act (MEPA) review of land-clearing projects. By 2025, EEA will assess innovative ways to bring additional investments into NWL conservation.

Limit NWL Loss

To allow natural and working lands to continue functioning as such and to protect future nature-based carbon sequestration potential, the Commonwealth will need to reduce any incentives for land and forest clearings, including those associated with ground-mounted solar and buildings. DOER is currently conducting the Technical Potential of Solar Study to further assess solar siting considerations for environmental, land use, and economic factors. The study and resulting recommended policy guidance will help indicate where and how much solar could be sited in the Commonwealth while protecting critical lands and habitats. Regarding land use impacts from the built environment, the Commonwealth will need to carefully balance the preservation of undeveloped land with the need to accommodate housing production and other new development. The Commonwealth's focus on promoting Smart Growth with Natural Resource Protection Zoning and Transit-Oriented Development will help to meet the critical need for housing production in locations close to public transit, bike trails, and other alternatives to personal vehicles, while recognizing that, if unconstrained, green-field development may result in excessive conversion of some forested and agricultural lands to other uses. The Commonwealth will continue to explore land use policies and incentives to encourage redevelopment of under-utilized sites, steer new development to infill locations, and minimize the loss of natural and working lands.

Additionally, the MEPA Office began deliberations in 2022 with the MEPA Advisory Committee regarding the potential to add a review threshold in MEPA regulations, which would require development projects engaging in a certain level of forest clearing to undergo an environmental impact review process. Although no new review thresholds were proposed as part of the 2022 regulatory changes, the MEPA Office may revisit that issue in its future regulatory changes, and plans to develop methodologies by 2024 for quantifying the GHG emissions implications of large-scale land clearing and potential options for mitigation, including the use of wood in long-lived wood products and contributions to tree planting and land conservation efforts. Future CECPs will provide any updates to the regulatory approaches to protect more land from deforestation.

Scale Up Reforestation and Tree Planting Efforts

To increase the carbon sequestration capacity of Massachusetts NWL, the Commonwealth will significantly scale up tree planting by leveraging recent federal funding sources, such as the $1.5 billion in grants from the IRA for increasing tree equity and community tree canopy. Such an increase in funding will be necessary to achieve the ambitious goal of 64,400 acres or more of new riparian and urban trees in Massachusetts by 2050. Urban tree plantings will be implemented as part of the Greening the Gateway Cities program, which targets EJ neighborhoods in gateway cities that have less tree canopy, older housing stock, higher wind speeds, and a larger renter population. Increasing tree canopy in EJ neighborhoods and other urban areas has the added benefit of mitigating urban heat islands and related energy costs, as well as improving air quality, stormwater management, neighborhood aesthetics, and property values. The new Riparian Tree Planting program will be implemented as discussed in the 2025/2030 CECP. The program will work with local land trusts, conservation districts, and watershed associations to find appropriate locations in EJ communities, institutional lawns, developed areas, low-production farm fields, and other unforested open spaces that would have the best water filtration and habitat benefits.

PICTURE 5E-3. 1,000TH TREE PLANTED IN CHICOPEE WITH THE GREENING THE GATEWAY CITIES PROGRAM

Scaling up tree planting will need adequate resources. The Department of Conservation and Recreation (DCR) currently purchases trees for urban planting projects from in-state growers and nurseries. To cost-effectively scale up tree planting efforts, the Commonwealth will explore options such as contracting with local nurseries and/or developing additional nurseries within Massachusetts to meet the tree planting targets. Both of these options provide the added benefits of supporting in-state employment and carbon sequestration. Additionally, the Commonwealth will expand tree planting efforts to include additional partners, such as non-government organizations, schools, and youth groups. The DCR's Urban and Community Forestry Program has planting crews of up to 100 staff every planting season, with a significant need for more assistants to plant and maintain thousands of additional trees in riparian areas and cities annually to meet the goal of 64,400 newly planted acres by 2050.

Manage Forests and Farms for Changing Climate

Strong windstorms damage forests and erode soils; persistent droughts increase the risk of forest fires and impact soil microbial activity; and outbreaks of invasive species further stress trees and lead to increased tree mortality. Each of these events—projected to increase in severity and frequency due to global climate change and examined in detail in the 2022 MA Climate Change Assessment—results in the release of carbon from impacted trees and soils into the atmosphere and a decrease in annual carbon sequestration until recovery can occur. Climate-smart management practices can help Massachusetts forests and farms become more resilient carbon sinks by promoting healthy soils and well-spaced, multi-age, and species-diverse forest lands established under natural regeneration.

At appropriate sites, climate-smart forestry can enhance carbon sequestration by (1) planting climate-adapted tree species in forests with limited species diversity or in areas that have failed to produce sufficient natural regeneration to replace desired canopy trees; (2) managing invasive and native herbaceous, fungal, and insect species, as well as deer browsing, to maintain the productive capacity of the forest; (3) extending the time between timber harvests in healthy forests to grow larger trees; (4) removing trees to create openings of adequate size to perpetuate a range of plant and animal species in overstocked stands; and/or (5) designating a portion of lands to be excluded from commercial timber production, similar to the Landscape Designation process DCR has used.[147,148]

As outlined in the 2025/2030 CECP, the Commonwealth will continue its commitments to climate-smart forest management and support the marketing of long-lived, durable wood products as a complement to this forest management approach. This includes assessing workforce needs and development opportunities as part of a study to be commissioned by DCR in 2023 on the common end uses of timber harvested in Massachusetts and the barriers and opportunities associated with wood markets.

Utilizing more of the harvested timber for long-lived, durable wood products not only ensures continued carbon storage but can displace the use of carbon-intensive materials (such as cement, steel, and plastic) in buildings, furniture, and products. Executive Order 594 *Leading by Example: Decarbonizing and Minimizing Environmental Impacts of State Government* requires research on various carbon policies that "shall include recommendations on whether and how agencies may incorporate the following elements into their emissions calculations and programs: carbon sequestration, embodied carbon, carbon offsets, negative carbon emissions, internal cost of carbon..."[149] Following the completion of the research, the Commonwealth will explore incorporating embodied carbon standards into the evaluation of new state facilities.

The Commonwealth will continue to encourage climate-smart, healthy soil practices on croplands, as outlined in the 2025/2030 CECP. Practices such as no- or low-tillage, cover cropping, and improved nutrient management can help retain carbon in the soils and decrease emissions from farming. These practices will be incentivized, potentially using federal funding recently made available, including $16.7 billion from the IRA for conservation practices that improve agricultural soil health and carbon storage while reducing agricultural emissions.[150]

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[147] Laura Marx et al., "Healthy Forests for our future: A management guide to increase carbon storage in Northeast forests," The Nature Conservancy and Northern Institute of Applied Climate Science (2021), https://www.srs.fs.usda.gov/pubs/63533.

[148] Massachusetts Department of Conservation and Recreation, "Caring for Your Woods: Managing for Forest Carbon," https://www.mass.gov/doc/caring-for-your-woods-managing-for-forest-carbon/download.

[149] Commonwealth of Massachusetts, Executive Order No. 594, Section 8. "Leading by Example: Decarbonizing and Minimizing Environmental Impacts of State Government" (April 22, 2021), https://www.mass.gov/executive-orders/no-594-leading-by-example-decarbonizing-and-minimizing-environmental-impacts-of-state-government.

[150] $8.45 billion for the Environmental Quality Incentives Program, $3.25 billion for the Conservation Stewardship Program, and $4.95 billion for the Regional Conservation Partnership Program.

When coupling healthy soil practices with dual-use solar PV development (also known as "agrivoltaics"), farms are in a unique position to contribute to renewable energy deployment, carbon sequestration, and food security. Dual-use systems are solar PV installations on farmlands that allow for simultaneous electricity and food production, including animal grazing. When properly designed and constructed, dual-use systems can shield crops growing underneath from extreme heat and help retain soil moisture. Additionally, agrivoltaics financially help farmlands remain as farmlands.

PICTURE 5E-4. FARM WITH ROOFTOP SOLAR PANELS

Over the past few years, DOER has been working with the Department of Agricultural Resources (MDAR) to begin allowing certain types of dual-use systems to qualify for financial incentives under the SMART program as Agricultural Solar Tariff Generation Units (ASTGU). DOER updated the ASTGU definition in April 2022 to clarify the sunlight requirement, prohibit the clearing or conversion of forest land, and establish other requirements focusing on agricultural production in agrivoltaics. DOER and MDAR also set a program goal of 80 MW of AC capacity for ASTGU, after which the agencies will reassess the program design. As the Commonwealth scales up renewable energy deployment in the next three decades, EEA agencies will continue to improve dual-use policies, carefully balancing electricity, food production, and NWL carbon sequestration on qualified farmlands.

Limit Methane Emissions from Wetlands

With rising sea levels from climate change, Massachusetts' coastal wetlands are at risk of degradation and loss if their soil accretion rates are unable to keep up with the sea level rise and/or migrate due to restricted tidal flow, development, or naturally steep inland elevation. Coastal wetlands, especially salt marshes, are a carbon sink, but their degradation and loss can release the stored carbon into the atmosphere as methane emissions. The Commonwealth will pursue proactive wetland restoration that restores tidal wetlands, removes tidal flow restrictions, and restores salt marsh functionality, as discussed in the 2025/2030 CECP. By removing a tidal restriction, the natural tidal flow will be

PICTURE 5E-5. SALT MARSH

able to reach the upper portions of an estuary, providing valuable tidal water to support increased salt marsh acreage where land elevations are appropriate.

EEA state agencies and offices will continue to collaborate with MassDOT in identifying appropriate bridges and culverts for upsizing or replacement, as well as to help target infrastructure funding. In other locations where salt marshes are limited by human-built structures such as seawalls, funding could be used to purchase properties impacted by storm damage to allow for inland migration of salt marshes and/or restoration of coastal habitat.[151] State agencies will pursue federal funding to support tidal wetland restoration and migration.

The Commonwealth will continue to improve the protection and health of inland wetlands, as outlined in the 2025/2030 CECP. These dynamic ecosystems and their GHG flux are highly sensitive to soil and hydrologic conditions, as well as water quality. Minimizing their disturbance, degradation, and loss, particularly those wetlands with organic soils (peatlands) that store more carbon than those with mineral soils, is an important strategy to ensure inland freshwater wetlands function as more of a carbon sink than a carbon source.

[151] This may have the added benefit of reducing storm damage to buildings. There are approximately 517 properties in Massachusetts currently classified as "Severe Repetitive Loss Properties" by the Federal Emergency Management Agency.

Chapter 6: The Future of Fuels – Alternatives to Fossil

Overview

While electrification will be Massachusetts' primary decarbonization strategy and overall fuel use will decline substantially in a Net Zero economy, there will be some residual need for fuel combustion in 2050 for hard-to-electrify applications. These uses will be served primarily by "alternative fuels" that may be available to aid the Commonwealth in achieving its decarbonization goals. These alternative fuels will not be produced from fossil sources but instead from biological feedstocks or synthesized using clean electricity. Standing in 2022, future markets and pricing of these alternative fuels are quite uncertain and will be influenced by the availability of biomass feedstocks, technological progress, and supply-demand interactions. Like current fossil fuel markets, the markets for alternative fuels are likely to be national or global in scope, and Massachusetts' supply, demand, and policies will not likely be a major driver of these markets (biomass that is used directly for fuel, such as wood waste, may be more local in nature due to the costs of transporting bulky biomass).

This chapter introduces several key types of alternative fuels: biofuels, hydrogen, and synthetic fuels. It reviews how they are produced and some of the common topics that arise with their use and with the transition from fossil fuels. This includes future availability and likely economics, associated GHG emissions, and uncertainties around potential supply and uses. It closes with an outline of proposed policies to ensure the Commonwealth is pursuing an equitable and sustainable strategy regarding its long-term use of fuels.

Some alternative fuels are derived from biological sources—biogases created by the natural decomposition of biological matter, or liquid biofuels such as bio-diesel and ethanol that can be extracted or produced from plant materials. Currently, hydrogen is primarily produced by steam methane reformation (SMR), which separates natural gas (methane) into hydrogen, carbon monoxide (CO), and carbon dioxide (CO_2), releasing the CO_2 into the atmosphere. This type of hydrogen is referred to as gray hydrogen.[152] If the CO_2 is instead captured during production, then this type of hydrogen is referred to as blue hydrogen.[153] In the future, it may be cost-effective to produce hydrogen by separating water into hydrogen and oxygen using electrolysis. If renewable electricity is used, this type of hydrogen is referred to as green

[152] U.S. Department of Energy, "Hydrogen Production: Natural Gas Forming," https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming.

[153] National Renewable Energy Laboratory, "Hydrogen 101," https://www.nrel.gov/docs/fy22osti/82554.pdf.

hydrogen.[154] Synthetic fuels are gaseous or liquid fuels that are often chemically similar to fossil fuels and can be synthesized from raw materials such as green hydrogen and CO_2 (e.g., derived from direct air capture or biological sources).[155] Some of these alternative fuels can be "dropped in" as a direct substitute for natural gas and petroleum fuels, requiring little or no modification of existing end-use equipment, while others have different characteristics and may require equipment changes. To the extent that green hydrogen and some synthetic fuels are produced from electricity in the first place, they may be viewed as ways to transform or store energy rather than primary energy sources. Most of these alternative fuels are not used at a significant scale today, and some are not yet commercially available.

To provide context, current fossil fuel use in Massachusetts includes gaseous fuels like natural gas and propane that come from natural gas extraction, and liquid fuels like gasoline, diesel, heating oil, and aviation fuel that come from oil wells and refineries; there is little remaining coal use.[156] Figure 6-1 below shows the Commonwealth's 2020 fuel use, including the amount of major fuels used in each sector and identifying the primary sectors: transportation, buildings (residential and commercial), electricity generation, and industrial uses.

Current fuel use is dominated by natural gas, used for heating, electricity generation, and industrial uses, and by petroleum products: gasoline and diesel for transportation and fuel oil for heating.[157] With the current electrification strategies and policies, within two decades, many of these applications will be largely electrified (e.g., light-duty vehicles and space heating), relying on mostly renewable and clean electricity rather than fuels. Total fuel use will fall significantly, with some hard-to-electrify sectors, such as aviation, heavy transportation, and high-temperature industrial uses, continuing to rely on fuels. However, about half of that fuel usage will likely be alternative fuels rather than fossil, as illustrated in the right panel of Figure 6-1.

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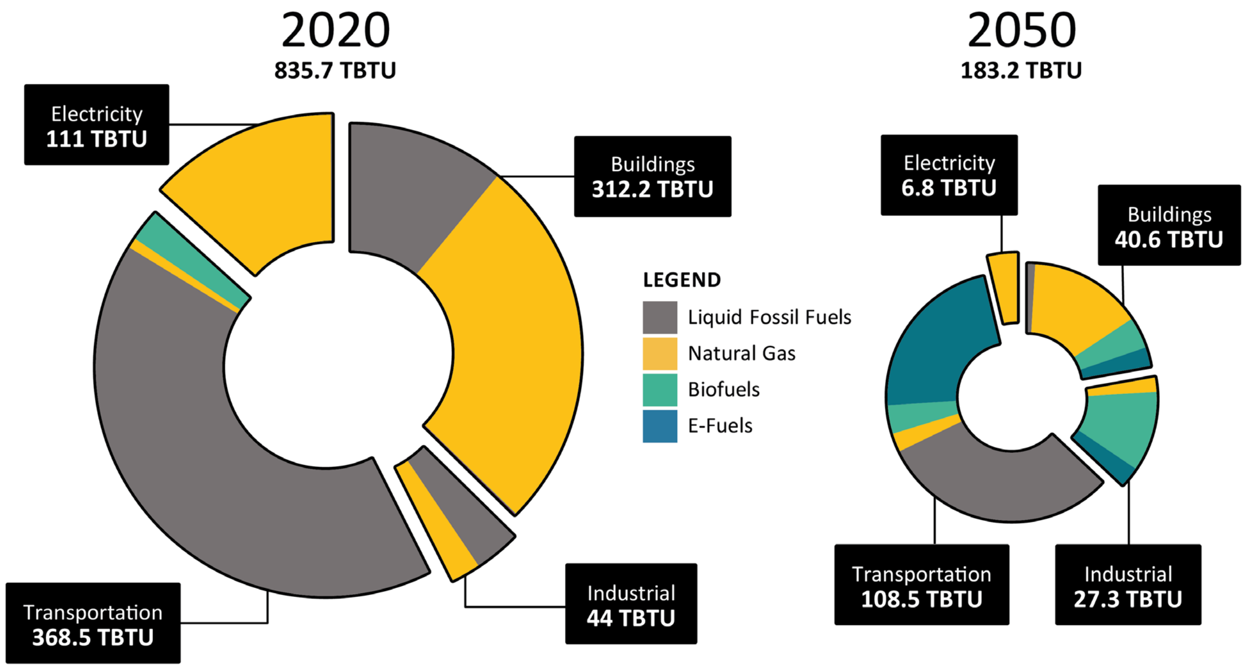
[154] U.S. Department of Energy, "Hydrogen Production: Electrolysis," https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis.

[155] Synthetic fuels should not be confused with synfuels, which are produced from fossil sources such as oil sands and coal.

[156] U.S. Energy Information Agency, Massachusetts State Profile and Energy Estimates, https://www.eia.gov/state/?sid=MA.

[157] This chapter does not include a discussion of woody biomass use as it is anticipated that woody biomass will not play a major role in the long-term in Massachusetts. In addition, DOER, in collaboration with DEP, will be releasing a report on woody biomass in 2023.

FIGURE 6-1. FUEL USE IN MASSACHUSETTS, BY SECTOR AND FUEL, 2020 AND 2050[158]



Note: E-fuels or electrofuels refer to hydrogen, synthetic fuels, and ammonia.

When fossil fuels are combusted, they release GHG—primarily CO_2, and smaller amounts of methane (CH_4) and nitrous oxide (N_2O). Besides GHG, combustion emissions can also release criteria air pollutants like particulate matter and nitrogen oxides (NO_x) that contribute to ground-level ozone (smog). Burning alternative fuels instead of fossil fuels can reduce GHG emissions when evaluated on a lifecycle basis (though they, too, can emit criteria air pollutants).[159] For example, natural decomposition of some food and agricultural wastes can result in emissions of methane, a powerful greenhouse gas. While using these feedstocks to produce biofuels that are then combusted may reduce overall GHG emissions, such combustion will release GHG (even if not as great as in natural decomposition) and criteria air pollutants.

Many of these alternative fuels are currently quite costly and not widely available. Future prices and availability are difficult to predict. Technological progress and expanded production will likely push toward increased availability and cost reductions. However, feedstock limitations for biofuels and significant potential demands from other sectors transitioning away from fossil fuels (such as light-duty vehicles and space heating, if not electrified fast enough)

158 Data from simulations. In 2020, the electricity sector consumed 0.7 TBTU of coal.

159 U.S. Environmental Protection Agency, "Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels" (2009), p. 4, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100B3F8.txt.

may serve to limit the extent of any such price reductions or even push prices up. Thus, alternative fuels will likely be best suited for hard-to-electrify sectors that will find it easier to justify the higher price of alternative fuels. Massachusetts' policies must reflect this, encouraging the use of alternative fuels in the applications where they are most valuable.

Biofuels

As used here, the term "biofuels" includes both liquid and gaseous biologically-based fuels. The following sub-sections discuss liquid and gaseous biofuels, their markets, their availability, and emissions accounting.

Biogas and Biomethane

Gaseous biofuels are short-chain hydrocarbons derived from the breakdown of biological matter, such as cellulose, lignin, and sugars.[160] Biogas is a combination of methane, CO_2, and other gases that are produced when bacteria break down organic matter in the absence of oxygen. An anaerobic digester (biodigester) is a sealed vessel that facilitates and accelerates this decomposition in a controlled environment. These processes are mature and have been used for years—landfill gas is produced from municipal waste in landfills and accounts for about 90% of current U.S. biogas production; wastewater treatment plants have long used digesters to break down organic matter.[161] Recently, anaerobic digesters have been used more commonly to convert a wider variety of agricultural and other biological waste streams to biogas for use as fuel.[162]

The biogas feedstocks with the highest potential in the U.S. are food waste, crop residues, manure, and municipal waste, though these are still quite limited relative to the current scale of fossil fuel use.[163] Biogas can be burned directly to produce electricity or heat, or it can be upgraded by removing the CO_2 and other impurities to yield biomethane. Biomethane is often referred to as renewable natural gas (RNG). It is chemically the same as natural gas and can be

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[160] International Energy Agency, "An introduction to biogas and biomethane," https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane.

[161] International Energy Agency, "Outlook for biogas and biomethane" (2020), p. 17, https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth.

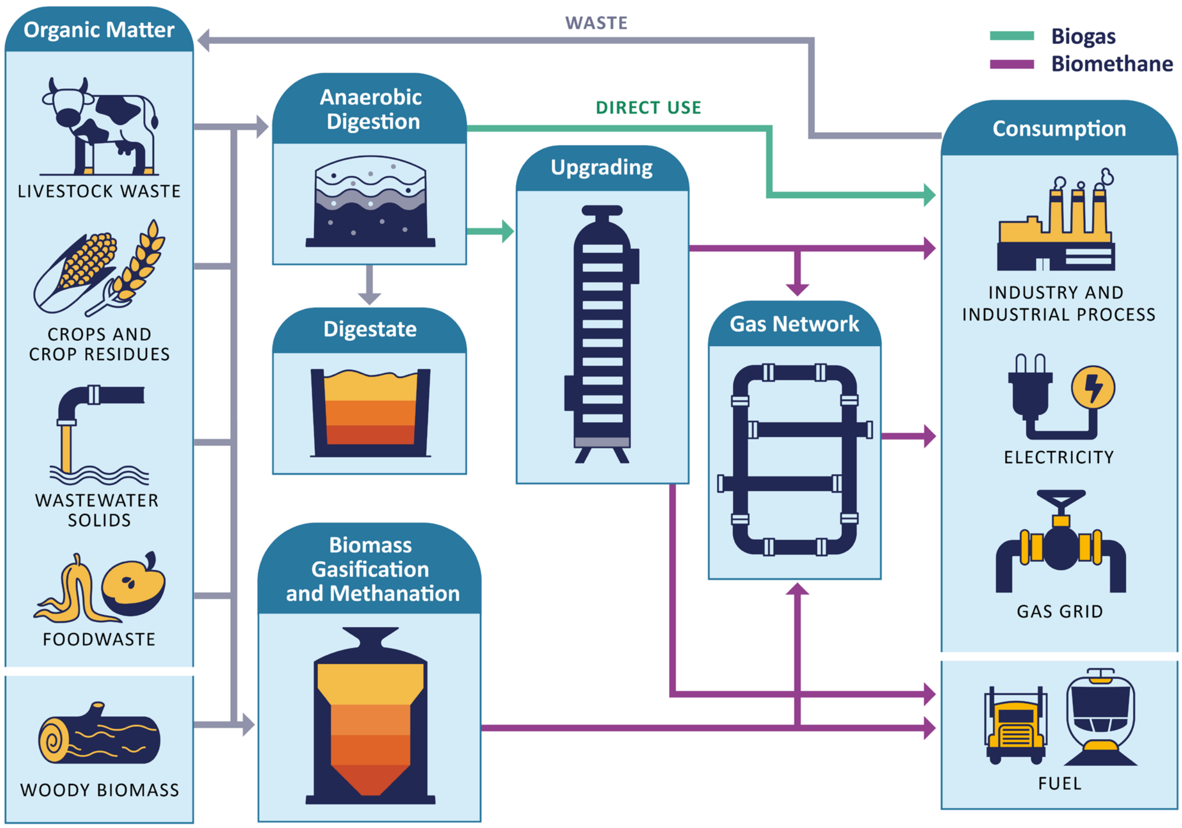
[162] U.S. Environmental Protection Agency, "AgSTAR Anaerobic Digester Database" (2022), https://www.epa.gov/agstar/livestock-anaerobic-digester-database.

[163] International Energy Agency, "Outlook for biogas and biomethane" (2020), p. 7, https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth.

injected into gas pipelines and used with existing gas-fired equipment.[164] Figure 6-2 illustrates several pathways for the production and use of biogas and biomethane.

Massachusetts currently has several sites that produce biogas: ten active landfill sites, eight agricultural waste sites, and several other biogas sites that utilize food waste and wastewater.[165,166] There are currently no RNG projects in Massachusetts, but RNG production is increasing across the country. As of 2021, 77 landfill gas facilities and 97 agricultural waste facilities were producing RNG in the U.S.[167]

FIGURE 6-2. BIOGAS PATHWAYS[168]



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[164] Ibid.

[165] U.S. Environmental Protection Agency, "LMOP Landfill and Project Database," https://www.epa.gov/lmop/lmop-landfill-and-project-database.

[166] U.S. Environmental Protection Agency, "AgSTAR: Biogas Recovery in the Agriculture Sector," https://www.epa.gov/agstar.

[167] U.S. Environmental Protection Agency, "Renewable Natural Gas," https://www.epa.gov/lmop/renewable-natural-gas.

[168] Adapted from International Energy Agency, "Outlook for biogas and biomethane" (2020), p. 14,

Most of today's RNG is procured for the transportation sector, often as compressed natural gas (CNG), to comply with the EPA's Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS) programs.[169,170] Some existing public transportation agencies use CNG for vehicle fuel. For example, the MBTA currently has 175 CNG buses in its fleet.[171] In addition, some natural gas utilities are considering blending RNG into the existing natural gas system.[172] The trade-offs between using RNG as a transportation fuel or a partial substitute for natural gas in pipelines versus using it for other high-value uses in hard-to-electrify sectors may evolve over time. The overall supply, demand, and cost for RNG over the next few decades will be highly dependent on several factors, including biological feedstocks and their GHG and land-use impacts, the overall availability and cost of RNG production, and competing uses for RNG, as well as policy and program designs in Massachusetts and other jurisdictions.

Liquid Biofuels

Liquid biofuels are longer-chain hydrocarbons produced from a variety of organic feedstocks via several methods. Oil from plants, organic byproducts, and waste materials, such as used cooking oil, can be separated and refined for use as liquid fuels.[173] Plant materials can be fermented to produce ethanol or methanol, and pyrolysis and gasification are thermochemical processes that convert biomass into bio-oils and synthesis gases (syngas), respectively, which can be upgraded to liquid fuels.

The two most common biofuels in use today are bioethanol and biodiesel, which are blended with motor fuels to comply with EPA's RFS and California's LCFS programs.[174,175] Produced from

https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth.

169 U.S. EPA, "Renewable Fuel Standard Program," https://www.epa.gov/renewable-fuel-standard-program.

170 California Air Resources Board, "Low Carbon Fuel Standard," https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard.

171 American Public Transportation Association, "Public Transportation Vehicle Database" (2020), https://www.apta.com/research-technical-resources/transit-statistics/vehicle-database/.

172 S&P Global Insights, "More US gas utilities launch renewable natural gas initiatives in 2022" (2022), https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/more-us-gas-utilities-launch-renewable-natural-gas-initiatives-in-2022-70551556.

173 See, for example, U.S. Department of Energy, "Biomass Resources," https://www.energy.gov/eere/bioenergy/biomass-resources.

174 U.S. Environmental Protection Agency, "Renewable Fuel Standard," https://www.epa.gov/renewable-fuel-standard-program.

175 California Air Resource Board, "Low Carbon Fuel Standard," https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard.

sugar, starch, or oilseed crops (e.g., corn, soybeans, or sugarcane), bioethanol and biodiesel are often referred to as first-generation biofuels.[176] Their feedstocks require intensive agricultural inputs (e.g., fertilizer and water) and can also be used as food for humans or livestock. Thus, the production of these first-generation biofuels can compete directly with food production and, if not carefully managed, can contribute to deforestation. Therefore, lifecycle GHG emissions from first-generation biofuels can be significant, though they are likely lower than those from combusting fossil fuels in some cases.[177,178,179,180]

Numerous potential second-generation biofuels (also referred to as advanced biofuels) can be produced from cellulosic biomass, such as perennial grasses and agricultural or forest waste, which can be grown on more marginal lands and may require less-intensive inputs.[181] The production of these second-generation biofuels may compete less directly with agriculture and food production and may be more sustainable than first-generation biofuels. However, they may still have a non-trivial amount of GHG emissions associated with their production and are farther from commercial availability.[182] Figure 6-3 below illustrates some ways that organic matter feedstock can be converted to various liquid biofuels.

In the long term, the Commonwealth does not expect to rely on the use of first-generation biofuels, which are used primarily in internal combustion engines. Most of the internal combustion engines will be phased out as the Commonwealth pursues the policies and programs that accelerate the adoption of light-duty electric vehicles. Instead, the 2050 supply of alternative fuels is projected to be mostly second-generation biofuels. In 2050, the Commonwealth anticipates that its total demand for liquid or gaseous fuels will be less than 200 trillion Btu, far below the current fuel use of almost 836 trillion Btu. Of this residual fuel

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[176] U.S. Department of Energy, "Biofuel Basics," https://www.energy.gov/eere/bioenergy/biofuel-basics

[177] Nida Khan et al., "Role of biofuels in energy transition, green economy, and carbon neutrality" MDPI, (2021), https://www.mdpi.com/2071-1050/13/22/12374/pdf?version=1636473664

[178] California Air Resources Board, "LCFS Pathway Certified Carbon Intensities," https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

[179] Argonne National Laboratory, "Corn ethanol reduces carbon footprint, greenhouse gases" (May 24, 2021), https://www.anl.gov/article/corn-ethanol-reduces-carbon-footprint-greenhouse-gases

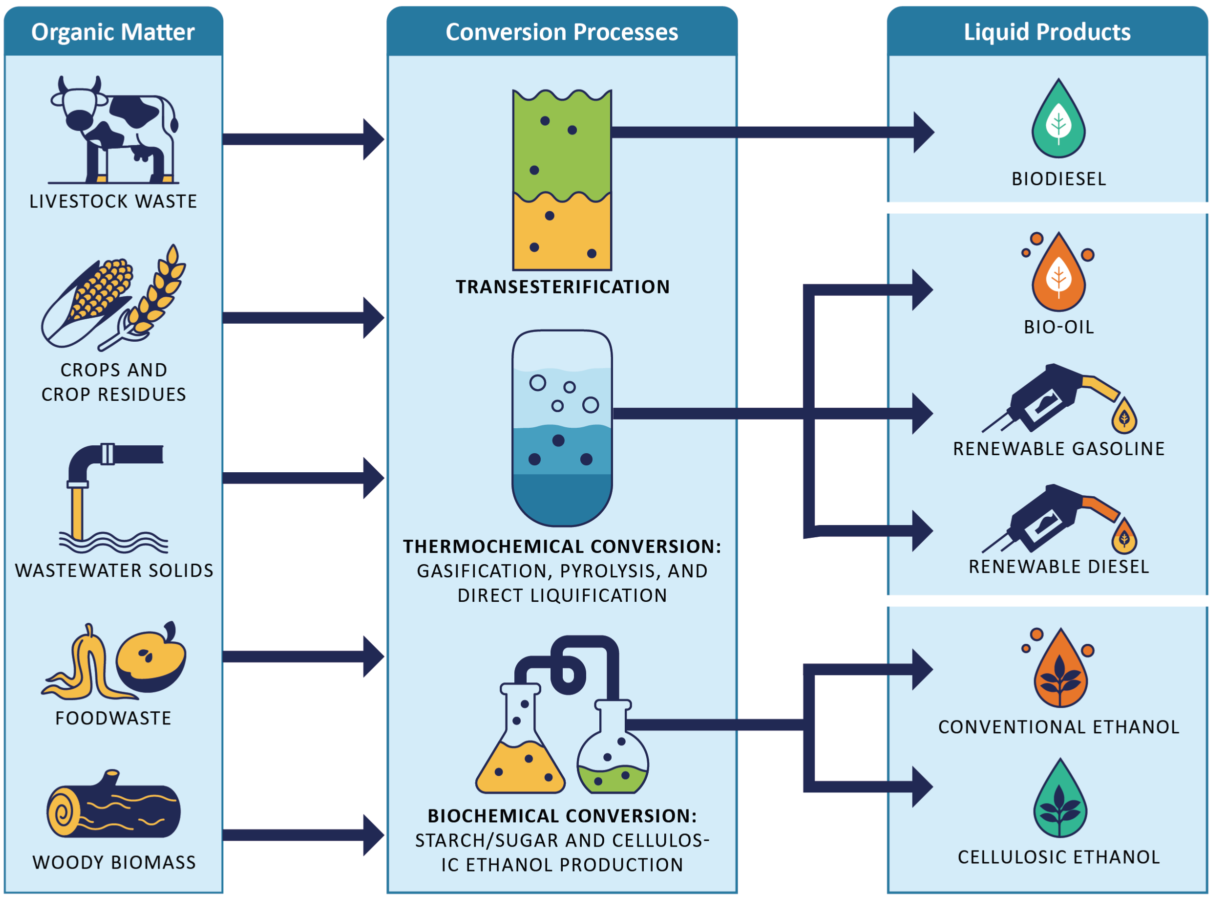
[180] U.S. Environmental Protection Agency, "Workshop on Biofuel Greenhouse Gas Modeling" (Feb. 28–March 1, 2022), https://www.epa.gov/renewable-fuel-standard-program/workshop-biofuel-greenhouse-gas-modeling

[181] Khan et al. (2021).

[182] Some nomenclatures combine second and third generation biofuels, referring to them together as advanced biofuels or next generation biofuels. For the purposes of this Plan, advanced biofuels will refer to second-generation biofuels.

use, about half (by energy) will need to be supplied by low-carbon or zero-emission fuels for Massachusetts to meet its emissions requirement set in this Plan. These residual fuels will be used in hard-to-electrify sectors such as the industrial sector, heavy transport, and aviation.

FIGURE 6-3. LIQUID BIOFUELS PATHWAYS[183, 184, 185]



Biofuel Availability

Some biofuels, like first-generation bioethanol and biodiesel, are readily available today, though current use may not reflect potential long-term availability.[186] Rather, the use of these

[183] U.S. Department of Energy, *Biodiesel Handling and Use Guide (Fifth Edition)*, DOE/GO-102016-4875 (2016), p. 3, https://afdc.energy.gov/files/u/publication/biodiesel_handling_use_guide.pdf.

[184] U.S. Department of Energy, *Design Case Summary, Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating, and Hydrocracking* (2009), https://www.energy.gov/sites/prod/files/2014/04/f14/pyrolysis_report_summary.pdf.

[185] Adapted from TotalEnergies, "BioTfuel: developing Second-Generation Biofuels," https://totalenergies.com/energy-expertise/projects/bioenergies/biotfuel-converting-plant-wastes-into-fuel.

[186] International Energy Agency, *Outlook for biogas and biomethane* (2020), p. 6,

fuels mostly mirrors current regulatory requirements and market conditions, such as EPA's RFS requirement that biofuels substitute a portion of petroleum-based fuels through blending. In 2020, biofuels accounted for about 5% of Massachusetts' total transportation energy use.[187]

Looking to 2050 and beyond, many types of liquid and gaseous biofuels will be produced from a variety of biomass feedstocks, with some flexibility regarding the feedstock used and the type of biofuel produced. Biomass waste, such as agricultural residues, animal manure, and forest waste, can be used to produce biofuels. While there is much more waste biomass than is currently being used for fuel, quantities are naturally limited by the amount of the primary products produced (see Box 6-1). Purpose-grown energy crops also can be used for biofuels, but they too face limits on the total amount of biomass that can be used for fuel production, primarily based on land availability, resource constraints (water, fertilizer), and competition with land use, agriculture, and food production. In addition, there are practical limits on how much and which biomass can be utilized because remote or thinly dispersed biomass may not justify the energy needed and cost to harvest, transport, and process it.

While biofuel production could expand from current levels, the studies above show limited biomass availability, which means that biofuels will likely be limited to high-value uses that are hard-to-electrify across the U.S., and perhaps as a backup fuel for electricity generation to provide peak energy for electric system reliability.[188] Overall, biofuels are likely to be a key resource for decarbonizing hard-to-electrify sectors, but because of availability limits, they will be able to replace only a small share of current fossil fuel use.

https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth.

[187] Data from simulations.

[188] The Royal Society, "Sustainable synthetic carbon based fuels for transport" (2019), p. 39, https://royalsociety.org/-/media/policy/projects/synthetic-fuels/synthetic-fuels-briefing.pdf.

BOX 6-1. BIOMASS AVAILABILITY

Several studies, including a few examples noted below, have looked carefully at the question of biomass availability. All have consistently shown that the total amount of biomass available is well short of what would be needed to support biofuel quantities approaching current fossil fuel consumption.

The U.S. Department of Energy's Billion-Ton Report (2016), which updates its 2005 Billion Ton Study, found that the U.S. has the potential to produce around 1.5 billion tons of dry biomass annually without adversely affecting the environment, which could be converted to about 15 quads of biofuels.[189] *While this is substantial, it is based on the study's High Yield scenario and is 22% of the recent annual U.S. combined petroleum and natural gas use of 66 quads.*

Similarly, Princeton's Net-Zero America Project found, in its High Biomass Potential case, that the U.S. has the potential to produce around 1.3 billion tons of dry biomass annually, which would equate to roughly 13 quads, or 20%, of recent U.S. combined petroleum and natural gas use.[190] *The alternative Delimited Biomass Potential scenario found values about half of this magnitude.*

In its Renewable Sources of Natural Gas study,[191] *the American Gas Foundation found significant renewable sources of methane are available, mostly from biological sources. The study's High Resource Potential Scenario found resources available to produce 4.5 quads of renewable methane annually in the long run at costs at or below $20/MMBtu. While the report states that this would satisfy 95% of U.S. residential gas demand, it is only about 14% of today's total U.S. natural gas demand.*

Green Hydrogen and Synthetic Fuels

Today, green hydrogen and synthetic fuels are generally more costly than biofuels. Compared to biofuels, they may have lower lifecycle GHG emissions if produced with clean electricity. Some of these resources may be produced locally if, for example, abundant renewable

[189] U.S. Department of Energy, "2016 Billion-Ton Report," p. 318, https://www.energy.gov/eere/bioenergy/2016-billion-ton-report.

[190] Princeton University," Net-Zero America Project Annex H," p. 7, https://netzeroamerica.princeton.edu/the-report.

[191] American Gas Foundation, "Renewable Sources of Natural Gas" (2019), https://gasfoundation.org/2019/12/18/renewable-sources-of-natural-gas/. The American Gas Foundation is the research arm of the American Gas Association, which advocates for natural gas utility companies.

electricity, a key input for green hydrogen and synthetic fuels, is available in New England. These alternative fuels are described below.

Hydrogen (H_2) has the potential to become an important component in the U.S. zero-emissions energy mix in the coming decades, though it faces some significant challenges. Green hydrogen is primarily produced via electrolysis, using renewable or clean electricity to drive a chemical reaction splitting water into hydrogen and oxygen.[192] The resulting hydrogen can release some of that energy again when it is burned or reacted in a fuel cell, recombining chemically with oxygen to reproduce H_2O. Figure 6-4 below illustrates the production pathway for green hydrogen.

Because hydrogen itself contains no carbon, its combustion does not emit CO_2 or other GHGs, though leaked hydrogen has indirect GHG impacts.[193] As with biofuel or fossil fuel combustion, burning hydrogen in the air results in the production of nitrogen oxides (NO_x), a criteria air pollutant. NO_x emissions can be reduced with emission controls, and Massachusetts has regulations to help reduce such emissions.[194,195,196]

Molecular hydrogen is a very small molecule and thus can leak easily. Hydrogen is corrosive and can embrittle steel pipes.[197] These two factors create challenges for using hydrogen with much of the existing natural gas pipeline and distribution infrastructure, including in-building gas piping and existing appliances on customers' premises.[198]

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192 There are several "colors" of hydrogen, such as gray hydrogen, produced from natural gas using steam methane reformation (SMR); blue hydrogen, produced from natural gas using SMR and carbon capture; and pink hydrogen, produced by electrolysis using nuclear power. *See* National Renewable Energy Laboratory, "Hydrogen 101," https://www.nrel.gov/docs/fy22osti/82554.pdf.

193 R. Derwent et al., "Global Environmental Impacts of the Hydrogen Economy," *Int. J. of Nuclear Hydrogen Production and Applications* 1(1) (2006): 57–67, https://agage.mit.edu/publications/global-environmental-impacts-hydrogen-economy.

194 U.S. Environmental Protection Agency, "Regulations for Emissions from Vehicles and Engines," https://www.epa.gov/regulations-emissions-vehicles-and-engines.

195 Mass. Gen. Laws Ch. 111, § 142K, https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXVI/Chapter111/Section142K.

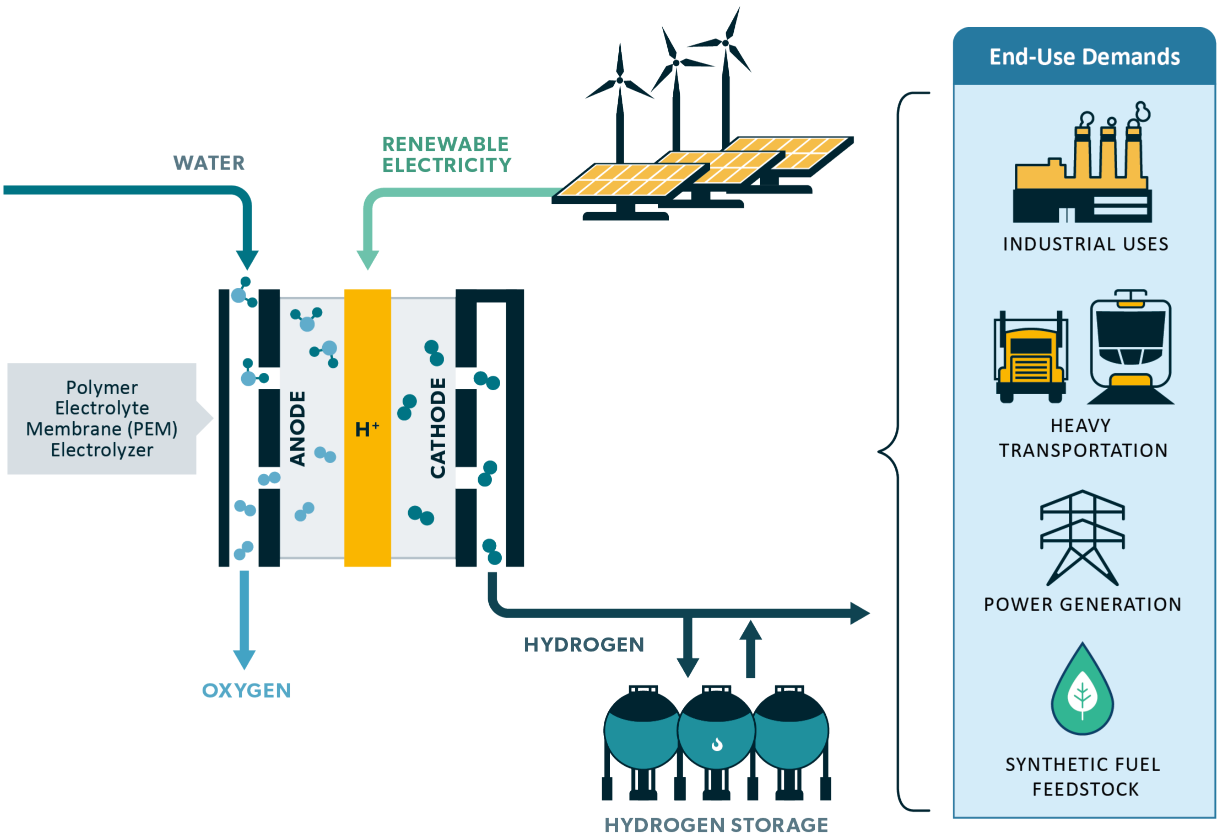
196 Massachusetts Department of Environmental Protection, "310 CMR 7.00: Air Pollution Control," https://www.mass.gov/regulations/310-CMR-700-air-pollution-control#recently-promulgated-amendments.

197 Energy Innovation, "Assessing the viability of hydrogen proposals" (2022), 7–8, https://energyinnovation.org/wp-content/uploads/2022/03/Assessing-the-Viability-of-Hydrogen-Proposals.pdf.

198 Id., p. 9.

Using dedicated infrastructure, hydrogen can be stored as a gas, liquid, or in chemical compounds and can be transported by hydrogen pipelines, ships, or trucks. Hydrogen has low energy density and an extremely low boiling point (far below the temperatures used for LNG, for instance) and therefore will face additional cost and technical requirements to compress or liquefy.[199, 200, 201]

FIGURE 6-4. GREEN HYDROGEN PATHWAY



Today, hydrogen is used as a chemical and industrial feedstock (for fertilizer and plastics) and for specialized high-temperature applications.[202] Green hydrogen can also be used as a form of energy storage, which is valuable in a decarbonizing economy as wind and solar energy are intermittent. For instance, hydrogen can be created from renewable electricity when there is a

199 IDEALY, "Liquid Hydrogen Outline," https://www.idealhy.eu/index.php?page=lh2_outline.

200 U.S. Department of Energy, "Liquid Hydrogen Delivery," https://www.energy.gov/eere/fuelcells/liquid-hydrogen-delivery.

201 U.S. Department of Energy, "LNG Basics," https://www.energy.gov/fecm/downloads/lng-basics.

202 U.S. Energy Information Agency, "Hydrogen Explained: Use of hydrogen," https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php.

surplus and used as a reliability fuel to cover periods of limited renewable electricity availability. However, current technologies have significant roundtrip efficiency losses with producing, storing, transporting, and utilizing green hydrogen, suggesting that green hydrogen energy storage is likely to be relatively costly and, therefore, best suited for long-duration and seasonal storage that is difficult to serve with batteries or other means.[203]

Because green hydrogen production is dependent on available clean electricity, siting large-scale green hydrogen production where clean electricity is abundant, cheap, and frequently available would reduce the cost of green hydrogen production. The high cost of electrolysis can be mitigated with cheaper electricity generation, which is associated with renewable facilities with higher capacity factors.[204] In this regard, New England's plans for large amounts of offshore wind, which has relatively high capacity factors, may make it an attractive region for hydrogen production in the long term. However, there are other regions in the U.S. (such as onshore wind in the Great Plains) and the world (such as abundant solar resources in Northern Territories, Australia) where renewable or clean energy can be produced at a much lower cost than in New England. The technology for producing green hydrogen is improving, with many researchers and companies working to develop more efficient, lower-cost electrolysis technologies and to improve the durability of catalysts.[205]

Synthetic carbon-based fuels can be produced via electrochemical and thermochemical processes. Electrofuels or e-fuels, sometimes referred to as power-to-gas or power-to-liquids, can be made by the synthesis of green hydrogen with CO_2 (or CO). The CO_2 can come from remaining emitting sources like power plants or industries, from direct air capture, or from biomass processes like biogas upgrading. Synthetic biofuels are produced through the chemical or thermal treatment of biomass or simpler biofuels.[206] These pathways may produce short-chain gaseous hydrocarbons like methane or longer-chain liquid fuels that are chemically similar to liquid fossil fuels like gasoline or diesel. They can be formulated as drop-in fuels compatible with existing infrastructure and end-use applications and are often easier to handle, store, and transport than hydrogen. Liquid synthetic fuels are particularly well suited for hard-to-electrify transportation applications such as aviation and heavy transport. These synthetic

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[203] NREL, "Energy Storage: Days of Service Sensitivity Analysis" (2019), Slide 4, https://www.nrel.gov/docs/fy19osti/73520.pdf.

[204] Genevieve Saur and Todd Ramsden, "Wind Electrolysis: Hydrogen Cost Optimization, *NREL* (2011), https://www.nrel.gov/docs/fy11osti/50408.pdf.

[205] The Royal Society, "Sustainable synthetic carbon based fuels for transport" (2019), p. 21. https://royalsociety.org/-/media/policy/projects/synthetic-fuels/synthetic-fuels-briefing.pdf.

[206] Ibid.

fuel production processes are at varying stages of technological readiness. Some of these fuels currently have high costs due to technological immaturity, small scale, and high input costs (including the cost of green hydrogen), though many technologies are under active development.

Since synthetic fuels can be made from captured CO_2 or biomass, they can displace the need for additional fossil fuel use. In using waste CO_2 as an input, synthetic fuels can help encourage a local market for emitting entities like industrial and manufacturing facilities to capture their CO_2 and reduce their emissions. Carbon capture for use often requires advanced emission controls, which can result in reducing other point-source air pollutants and, in turn, can improve air quality in pollution-dense areas. Carbon capture for use does not result in negative carbon emissions since the carbon is not being sequestered, but it can reduce GHG emissions while displacing fossil fuel uses. Synthetic fuels address some of the limitations associated with using pure hydrogen discussed above, such as lower energy density, difficulty to store and transport, and appliance and infrastructure compatibility concerns. Thus, using hydrogen as a feedstock for synthetic fuels can help to alleviate those limitations.

Green ammonia, a compound of nitrogen and green hydrogen (NH_3), is a carbon-free synthetic alternative that does not produce GHG emissions.[207] It is gaseous but can be compressed and cooled to a liquid for transportation or storage. It might have the potential to provide a useful vehicle for transporting and storing hydrogen, and it has been proposed for use directly as a fuel for shipping and heavy transport.

Markets for Alternative Fuels

Current markets for non-fossil fuels are dominated by liquid biofuels that meet federal and state blending requirements, but in the longer term, markets for sustainable, low-GHG alternative fuels may be quite different. Future uses of alternative fuels will require policies that discourage the use of fossil fuels and encourage sustainable, low-GHG alternative fuels in applications without other straightforward and lower-cost decarbonization options.

Projections regarding the future availability, production costs, and the market price of alternative fuels range widely, primarily due to different assumptions about government policies, technological improvements, transportation requirements, demand levels, feedstocks,

[207] Green ammonia production differs from most current ammonia production, which uses natural gas as a feedstock and is not emission-free.

and production technologies, among other factors.[208] Most projections agree that the cost of sustainable, low-GHG alternative fuels will be above historical fossil fuel prices, though technological improvements could reduce the costs of these advanced fuels. While the long-term prices and quantities of available alternative fuels are uncertain, alternative fuels (especially liquid fuels) can be easily stored, transported, and exchanged. Thus, future markets for alternative fuels will be broadly regional, national, or international in scope. Massachusetts entities will participate in those markets, but it is unlikely that the state will be able to drive the market dynamics significantly. Prices in these markets, like all effective markets, will be sensitive to demand levels and the costs of supply resources.

Further, state, national, and international policies can influence technological development and deployment over time, both through direct research, development, and demonstration (RD&D) and through policies inducing demand. Since production technologies are highly fungible, technical innovation or improvements around the world can readily affect U.S. markets.

Conventional biofuel use may not expand dramatically in part because of competition with agriculture and food production and because many conventional biofuels still have significant GHG emissions, making them less suited for deep decarbonization (assuming GHG emissions differences are accurately reflected in the policies that drive alternative fuel use in the first place) and the policies driving their use are being capped or phased down.

Hydrogen and biofuels cannot substitute for each other in all applications. For example, hydrogen may be well-suited for fertilizer and industrial feedstocks, backup electricity generation, and high-temperature industrial uses that may rely on dedicated hydrogen infrastructure.[209] Whereas, biofuels are likely used primarily in hard-to-electrify sectors such as heavy transportation, aviation, and industrial applications, as discussed above. Progress for hydrogen may be particularly responsive to policy support. In June 2021, the U.S. DOE announced its Hydrogen Shot initiative to bring hydrogen prices down to $1/kg (equivalent to

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[208] *See* IRENA, "Innovation Outlook: Advanced Liquid Biofuels" (October 2016), https://www.irena.org/publications/2016/Oct/Innovation-Outlook-Advanced-Liquid-Biofuels; International Energy Agency, "Energy Technology Perspectives" (2020), https://www.iea.org/reports/energy-technology-perspectives-2020; Bloomberg NEF, "Hydrogen Economy Outlook" (2020), https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf; and McKinsey, "Hydrogen Insights 2022" (September 2022), https://hydrogencouncil.com/en/hydrogen-insights-2022/.

[209] Michael Liebreich, "Separating Hype from Hydrogen – Part Two: The Demand Side," *Bloomberg NEF* (2020), https://about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-two-the-demand-side/.

about $8/MMBtu) within a decade.[210] The IIJA of 2021 allocated $8 billion from the DOE to establish at least four clean hydrogen hubs, meant to jumpstart the hydrogen economy by developing grid-scale hydrogen technology and infrastructure. The IRA established a federal hydrogen production tax credit of up to $3/kg and an investment tax credit of up to 30%, depending on the carbon intensity of the hydrogen produced.[211] Massachusetts is part of a coalition with New York, Connecticut, New Jersey, Maine, and Rhode Island to propose a hydrogen hub in the Northeast.

Due to the price dynamics discussed above, even with significant reductions in overall fuel use relative to today, available biomass supplies for low-cost advanced biofuels are likely to be exhausted. Hydrogen and synthetic fuels are likely to set a relatively high price for all alternative fuels (subject to adjustments for GHG differences, assuming policies accurately reflect emissions and that enough states' policies create widespread demand). Because alternative fuels are relatively scarce and likely to remain relatively expensive compared to fossil fuels, they are best suited for uses that are harder to decarbonize and can more easily justify the higher price. This dynamic and the resulting high prices will likely make alternative fuels less attractive for other sectors, such as light-duty vehicles and space heating, which have readily available clean alternatives like electrification.

Emissions Accounting for Alternative Fuels

One important consideration regarding alternative fuels is the extent to which they may affect the Commonwealth's GHG emissions. Many biofuels, especially first-generation biofuels, involve substantial indirect GHG emissions. Growing, harvesting, processing, and transporting biomass and biofuels can release significant GHG emissions—for example, via natural gas used in fertilizer manufacturing and diesel to fuel tractors and transportation. There can also be large indirect emissions and lost sequestration potential from land use changes.

Methane leakage may also play a role. For example, landfill gas facilities can leak substantial amounts of methane; anaerobic digesters offer a more controlled environment that enables capturing and burning methane that might otherwise be released to the atmosphere from some feedstocks and thus may result in significant overall GHG reductions from some sources.

Some synthetic fuels, particularly those utilizing biological feedstocks, may similarly involve indirect GHG emissions. As alternative fuels are produced and used, the Commonwealth will

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210 U.S. Department of Energy, "Hydrogen Shot," https://www.energy.gov/eere/fuelcells/hydrogen-shot.

211 Pub. L. No. 117-169 (Aug. 16, 2022), https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf.

evaluate the impacts of alternative fuels on GHG emissions and may consider changes in its emissions accounting methodologies and programs. Further, as alternative fuels become more prevalent, Massachusetts will determine how to optimize the standards that are used to qualify fuels for programs that encourage clean(er) fuel use. For example, Massachusetts' Alternative Energy Portfolio Standard (APS) is an alternative fuels program that requires fuels to have minimum GHG emissions reductions to be eligible. The Massachusetts APS is a complement to the state's Renewable Portfolio Standard program and applies to a variety of alternative energy technologies, including some biofuels. Under existing APS rules, biofuels must meet a 50% GHG reduction relative to the relevant fossil alternative (and be derived from organic waste feedstocks) to qualify for credits that serve as incentive payments.[212] As the Clean Heat Standard (discussed in Chapter 5b) is developed, approaches to qualify alternative fuels for the new policy will be needed.

Today, the California LCFS uses a market-based system to reduce transportation-related emissions. That program, administered by the California Air Resources Board, sets carbon intensity (CI) standards for qualified fuels, and these CI standards are reduced over time. Fuels are assigned a carbon intensity that considers both direct combustion and indirect emissions (that is, lifecycle GHG emissions). Fuels with a CI lower than the current standard generate credits, while fuels with a higher CI generate deficits. These credits and deficits are tradeable, and obligated entities must balance any deficits with offsetting credits. The LCFS differs from the RFS and APS in that crediting is based on the specific CI of the fuel rather than a simple threshold determination of whether a fuel qualifies or not, which may not fully distinguish the varying GHG emissions of different alternative fuels.

Since most current fuel use occurs in the transportation, buildings, and power generation sectors, many of the relevant policies for managing future fuel use and GHG emissions are discussed within the context of those sectors in their respective sections of this report. Several additional policies relating to the future of fuels as the Commonwealth pursues Net Zero are discussed below.

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[212] Massachusetts has historically supported selective alternative fuels to ensure the best environmental outcomes. The APS program's support for heating fuels derived from organic waste products, but not food crops such as soy, is one example. Similarly, in the electricity sector, the Renewable Portfolio Standard and Regional Greenhouse Gas Initiative regulations limit crediting for the use of solid biomass alternative fuels to feedstocks that do not compete with forest sequestration. In the transportation sector, corn ethanol is widely used as a substitute for gasoline, but the 2008 Clean Energy Biofuels Act's gasoline excise tax exemption only applies to ethanol produced from cellulosic feedstocks, not corn. Finally, policy support for the use of anaerobic digestion to manage waste and produce energy is based on analysis showing significant greenhouse gas emissions benefits compared to other waste disposal options.

Review Emission Accounting for Alternative Fuels

By 2024, MassDEP will consider whether changes are needed to the statewide GHG emissions inventory conventions, guiding principles and/or accounting methodologies for combustion emissions from conventional and advanced biofuels, hydrogen, and synthetic fuels, potentially including emissions impacts that occur outside the state (e.g., emissions and sequestration associated with out-of-state biofuel production). Considerations may include whether and how to include these emissions impacts in the 1990 baseline and in Net Zero emission accounting. It will be helpful to coordinate with other jurisdictions in accounting for out-of-state emissions, as consistent accounting may help align incentives to achieve reductions most efficiently on a regional basis. This inventory work can also help to inform the development of policies that reduce emissions on a lifecycle basis.

There are several accounting approaches in use by Massachusetts and other jurisdictions. California's approach may be particularly relevant because California already has a well-developed approach to managing a GHG emissions inventory and experience assessing a range of alternative fuels on a lifecycle emissions basis. Voluntary reporting standards like those put forward by the Intergovernmental Panel on Climate Change (IPCC) and the CDP (Carbon Disclosure Project) offer additional approaches for consideration. Massachusetts will review these approaches when considering changes to inventory conventions, guiding principles, and/or accounting methodologies.[213]

Accelerate Innovation

Greater innovation can provide a pathway to broader availability and lower prices for alternative fuels. Innovation can be encouraged by direct funding of RD&D or pilot projects or by stimulating demand, which will spur supply and yield experience with producing and delivering alternative fuels, though care must be taken to ensure that stimulating near-term demand does not inadvertently divert alternative fuels to lower-value sectors.

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[213] The *Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business as Usual Projection* states: "The Department recognizes that the science and practice of determining GHG emissions is changing rapidly and that Massachusetts, being at the cutting edge of this work, should avail itself of advancements in the science to the extent possible. Therefore, MassDEP will reevaluate the 1990 baseline as needed (e.g., significant new data becomes available). If amendment is necessary, a full public review process will be used." *See* Massachusetts Executive Office of Energy and Environmental Affairs, *Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business as Usual* (July 2009), p. 3, https://www.mass.gov/doc/statewide-greenhouse-gas-emissions-level-1990-baseline-2020-business-as-usual-projection/download.

Since Massachusetts will be only a small part of the overall demand for alternative fuels, policies for accelerating innovation or stimulating demand are likely to be most effective if coordinated with other states. This will help to amplify the impacts and ensure consistency in driving innovation while ensuring that aggregate regional or national demand does not unintentionally stress feedstock availability or the natural and working lands that provide those feedstocks. Coordination can also help to ensure that policy-driven demand does not compete unduly with high-value applications that lack substitutes.

Additional Considerations

Beyond these specific policies, the Commonwealth will actively work to develop and maintain a better understanding of the medium- and long-term supply of alternative fuels, the technologies that can produce them, and the potential demand for them across various end-use sectors, tracking these over time as new information and experience become available. Massachusetts' policies must acknowledge that overall fuel use across the economy will decline substantially in a net-zero economy, and any alternative fuels should be used selectively in the applications where they are most valuable. For example, policies that might influence future energy sources for heating should reflect the fact that space heating requires only low-grade (low temperature) heat energy, which can be provided by heat pumps from ambient air and water, and, as a result, is relatively easy to electrify. In contrast, some other fuel uses, such as aviation and high-temperature industrial applications, require high-grade heat energy that may be best provided by energy-dense liquid alternative fuels.

Finally, to the extent Massachusetts can continue to be a hub for clean energy innovation, including for alternative fuels, it may be able to amplify its impacts well beyond the direct effects of reducing GHG emissions from its own use of fuels. By stimulating the development of alternative fuel technologies and ways to use them effectively, the Commonwealth can improve the options that are available elsewhere, which can accelerate the adoption of clean energy technologies more broadly.

Chapter 7: Removing Carbon Through 2050 and Beyond

Overview

To achieve net zero in 2050, in addition to lowering gross emissions by at least 85%, Massachusetts will need to balance all residual emissions with carbon sequestration in or attributable to the Commonwealth. Residual emissions from difficult-to-decarbonize sectors of the economy will include both gross emissions and biogenic combustion emissions (see Chapter 3 for further discussion of net-zero emissions accounting, including a table defining terms used in this chapter).[214]

While the Commonwealth is pursuing policies to protect and enhance in-state carbon sequestration on natural and working lands (NWL), there will be limitations and risks to the Commonwealth's NWL sequestration capacity in the coming decades, as discussed in Chapter 5e. Therefore, some combination of engineered carbon dioxide removal (CDR) and out-of-state nature-based carbon sequestration will likely be necessary to meet Net Zero in 2050. In developing a carbon sequestration strategy, Massachusetts will need to evaluate various approaches and policy options on a range of considerations, including effectiveness, risks, environmental integrity, co-benefits, negative externalities, costs, and EJ implications.

This chapter will first outline the key considerations for achieving Net Zero with carbon sequestration. Then, it will discuss potential options for procuring additional carbon sequestration attributable to Massachusetts beyond the capability of in-state NWL. Finally, this chapter will outline the Commonwealth's timeline and process to develop an emissions accounting and policy framework for such additional carbon sequestration.

Guiding Principles and Key Considerations for Carbon Sequestration

Carbon sequestration strategies, methods, and policy mechanisms each carry distinct advantages and drawbacks that will require careful evaluation. Expanding on the guiding principles for achieving Net Zero emissions (discussed in Chapter 1), Box 7-1 describes key considerations and principles in developing the Commonwealth's overall carbon sequestration plan.

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214 Achieving 85% emission reduction equates to a gross emissions of ~14 MMTCO_2e in 2050 across the Massachusetts economy. As discussed in Chapter 6, advanced bioenergy likely to be in use in 2050 may have very low or zero emissions on a lifecycle basis, potentially avoiding the need to balance their biogenic combustion emissions with additional carbon sequestration.

BOX 7-1. KEY CONSIDERATIONS AND PRINCIPLES FOR DEVELOPING A CARBON SEQUESTRATION PLAN

Purpose: *Carbon sequestration is intended to balance only residual emissions in areas of the economy that are particularly difficult to decarbonize and will not replace necessary emissions reductions.*

Cooperation: *Look for opportunities to facilitate a more effective collective effort toward Net Zero. This includes work with other jurisdictions on standards that would enable the exchange of high-integrity carbon credits.*

Positive and Negative Externalities: *Weigh environmental, economic, and social co-benefits, including ecosystem services, local workforce and economic development, public health, and community-building opportunities. Mitigate potential risks and harms of both carbon sequestration activities and residual emissions, particularly to EJ communities.*

Distributional Effects: *Consider how investments and externalities are distributed among people, with particular attention to potential disparate impacts on EJ populations and other disadvantaged communities.*

Costs: *Consider the costs of carbon sequestration approaches to the Commonwealth and regulated entities and how those costs may be passed on to residents, particularly EJ populations.*

Prioritization: *Focus early carbon sequestration efforts on NWL and forest conservation, especially in-state, where benefits compound in the long term.*

Permanence: *The longevity and security of storage for removed carbon are important factors in carbon sequestration to minimize the risk of re-emitting. Consider distinct treatment of GHG emissions sources and carbon sinks with different longevity (e.g., biological v. geological carbon; CO_2 v. non-CO_2 GHGs).*

Real & Additional: *Ensure that Massachusetts' carbon sequestration actually leads to decreased atmospheric GHGs, avoids leakage of emissions to out-of-state sources, and contributes to achieving net-zero emissions globally.*

Enforceable: *Ensure that carbon sequestration is unambiguously attributable to Massachusetts and that ownership of credits is clearly established to avoid double-claiming with other jurisdictions.*

Quantifiable & Verifiable: *Consider the monitoring, reporting, and verification (MRV) methods that will be used to reflect the amount of carbon sequestered by any approach as accurately as possible.*

Transparency: *Ensure that methods, data sources, reporting, and accounting used are transparently reported and follow best practices.*

Carbon Sequestration Options

Sources of carbon sequestration include: (1) net carbon sequestration (i.e., negative emissions) occurring on Massachusetts' NWL, (2) out-of-state net carbon sequestration that is attributable to Massachusetts, and (3) engineered CDR approaches. Table 7-1 provides an overview of these different approaches and a high-level assessment of their risks; technology maturity; typical costs; monitoring, reporting, and verification (MRV) difficulties; sequestration potential; permanence; major co-benefits; and long-term feasibility outlook.

Carbon Sequestration on Massachusetts' NWL

Massachusetts' NWL sequestered approximately 6.9 MMTCO_2e in 2020 (the latest year with available data) and are unlikely to sequester more statewide in 2050, as discussed in Chapter 5e. Investing in carbon sequestration occurring on Massachusetts' NWL has some distinct advantages, most notably in delivering co-benefits (e.g., improved air and water quality, natural resources, biodiversity, climate resilience, water management, and economic and recreational opportunities) to the Commonwealth's residents. Strategies to maintain and enhance net carbon sequestration on Massachusetts' NWL include protection, management, and restoration, particularly of forest lands (described further in Chapter 5e).

While the Commonwealth plans to invest in and rely on carbon sequestration from Massachusetts' NWL, there are several risks and GHG emissions accounting questions associated with this strategy. Uncertainty about future land use change and ecological disturbances, both of which will be impacted by climate change, makes it difficult to estimate the amount of in-state NWL carbon sequestration that will be available in 2050. There are also questions about how much of this carbon sequestration should count towards Net Zero. There is an open question, to be decided as understanding evolves and through coordination with other jurisdictions, as to what portion of NWL sequestration will be considered a GHG removal *by or attributable to* Massachusetts, consistent with the Net Zero aim of stabilizing global temperatures.[215] Furthermore, to avoid double-counting and ensure the integrity of its carbon

[215] Specifically, the premise that global net zero emissions will stabilize global temperatures assumes that *anthropogenic* GHG emissions are balanced by *anthropogenic* CO_2 removals. Apportioning NWL emissions and sequestration to natural and anthropogenic causes is quite challenging, however, and different conventions are used in different contexts. The net sequestration reported in Massachusetts' NWL inventory is considered anthropogenic by U.S. and international GHG inventory convention, but this relies on a broader definition of anthropogenic than that used by the global climate modeling community and these may need to be reconciled in the future. *See* Giacomo Grassi et al., "Reconciling Global-Model Estimates and Country Reporting of Anthropogenic Forest CO_2 Sinks," *Nature Climate Change* 8(10) (2018): 914–20, https://www.nature.com/articles/s41558-018-0283-x. *See also* Myles R. Allen et al., "Net Zero: Science,

sequestration, the Commonwealth will need to determine the circumstances under which legitimate claims on Massachusetts' NWL sequestration from third parties would require deductions from the amount applied towards Net Zero compliance (e.g., if Massachusetts landowners sell carbon sequestration credits that are then applied towards another jurisdiction's emission reduction obligations). Cross-jurisdictional accounting for carbon sequestration credits and other climate mitigation actions are currently the subject of regional discussions with other New England states and international negotiations on Article 6 of the Paris Climate agreement.[216]

Because cross-jurisdictional carbon sequestration and net-zero emissions accounting standards are currently at an early stage of development, the Commonwealth will continue to use a simple state inventory-based accounting approach. For the near term, this means that all net carbon sequestration in Massachusetts' NWL GHG inventory will be considered applicable toward Net Zero, regardless of attribution to anthropogenic or natural causes, land ownership, or other jurisdictions' incentives. At the same time, EEA will continue to monitor and investigate accounting approaches that are aligned with net-zero emissions science and international best practices. When greater clarity and consensus are reached, the Commonwealth will look to adopt an improved accounting approach.

Carbon Sequestration on Out-of-State NWL

Given the environmental and accounting uncertainty and ecological limitations of carbon sequestration on Massachusetts' NWL, the Commonwealth will explore options for NWL sequestration outside the state that can be attributable to Massachusetts. In theory, this could involve investments anywhere in the world, employing any of the nature-based approaches described in Table 7-1 (forestry-based method, soil carbon sequestration, or wetland restoration). However, there are likely advantages to pursuing regional opportunities due to similar ecosystems, a regionalized economy, and a history of regional collaboration and cooperation across many energy and environmental issues. Many of the same strategies Massachusetts is pursuing for its NWLs (Chapter 5e) could be extended to other northeastern states, particularly those with greater capacity for additional carbon sequestration. Any arrangements the Commonwealth makes to ensure sufficient carbon sequestration in 2050 will

Origins, and Implications," *Annual Review of Environment and Resources* 47(1) (2022): 849–887, https://www.annualreviews.org/doi/10.1146/annurev-environ-112320-105050.

216 Axel Michaelowa et al., "Promoting Article 6 readiness in NDCs and NDC implementation plans," *Climate Focus* (2021), https://climatefocus.com/publications/article-6-readiness-ndcs-and-ndc-implementation-plans/.

require coordinating with other jurisdictions on accounting practices and exchange standards to ensure the integrity of the credits.

Engineered Carbon Dioxide Removal (CDR)

In addition to NWL-based carbon sequestration, there are a range of engineered CDR methods in various stages of development that could help Massachusetts meet its carbon sequestration needs in 2050. Nature-based carbon sequestration approaches remove CO_2 from the atmosphere by increasing the natural carbon stocks held in trees, soils, wetlands, and other natural areas. Alternatively, engineered CDR approaches rely on technological means to remove CO_2 from the air and ocean and store it in sediment, rock minerals, or geological formations.[217] Engineered CDR approaches include direct capture of atmospheric CO_2 via chemical reactions, accelerated mineralization (by binding and storing atmospheric CO_2 in rocks), bioenergy plus carbon capture and storage,[218] and various methods of inducing additional oceanic CO_2 uptake.

There is a growing scientific consensus that CDR solutions will be a critical piece in any net-zero emissions strategy, but CDR technology options all have relative advantages and drawbacks, including potential reductions, costs, feasibility, social acceptability, and broader environmental impacts, as shown in Table 7-1. CDR approaches are mostly still emerging technologies with relatively high costs, uncertain prospects for broad-scale deployment, and some risks. However, costs are likely to decrease over time, and these approaches offer some potential advantages, particularly with simpler MRV and greater security (permanence) of long-term storage.

Opportunities to deploy many of the engineered CDR methods in New England likely are limited because the region lacks geological formations suitable for long-term storage of captured carbon.[219] Thus, Massachusetts would likely procure CDR services from capture facilities located near sequestration sites in other jurisdictions. The Commonwealth can also contribute

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[217] CDR is sometimes used to describe natural, engineered, and hybrid methods of removing and storing carbon dioxide. In this Plan, however, "carbon sequestration" is used to broadly describe any of these approaches to generating net negative emissions, while CDR refers only to engineered and hybrid approaches.

[218] Carbon capture and storage (CCS) is generally distinct from CDR, as CCS involves capture of CO_2 at a point source (e.g., a smokestack) *before* it enters the atmosphere, and is thus an emissions reduction strategy, whereas CDR involves removal of CO_2 directly *from the atmosphere*, and is thus a negative emissions (i.e., carbon sequestration) strategy. In the case of bioenergy *with* CCS (BECCS), however, the carbon sequestration associated with bioenergy feedstock production plus the capture of emissions from feedstock combustion means that BECCS will generally have negative emissions and is thus considered a CDR approach. Accounting for bioenergy emissions more generally is discussed in Chapter 6.

[219] Deep, impervious structures that previously held fossil fuels are ideal for this type of long-term carbon storage.

to CDR technology development by providing dedicated research and development funding and proper policy support with the goal of decreasing the costs of engineered CDR solutions over time (see Box 7-2).

TABLE 7-1. OVERVIEW OF NATURE-BASED, ENGINEERED, AND HYBRID APPROACHES TO CARBON SEQUESTRATION

	Forestry-Based Methods	Soil Carbon Sequestration	Wetland Restoration	Bioenergy with Carbon Capture and Storage	Direct Air Capture and Storage	Enhanced Mineralization	Ocean-Based Methods
Approach Summary	Removes CO_2 through reforestation, afforestation, improved forest management, and agroforestry	Removes CO_2 through management of farmlands and pasturelands and soil amendment (e.g., storing or burying biochar)	Removes CO_2 through restored coastal wetlands and peatlands	Produce energy using biomass and capture emitted CO_2 for long-term storage or use in carbon-based products (e.g., concrete)	Removes CO_2 from the atmosphere via chemical reactions for long-term storage or use in carbon-based products (e.g., cement)	Accelerates natural weathering processes by binding and storing CO_2 in carbonate minerals	Enhances ocean CO_2 uptake by increasing alkalinity to dissolve CO_2 into bicarbonate and carbonate, or through fertilization to enhance phytoplankton photosynthesis[220]
Risks & Impacts	Requires significant land use and is vulnerable to ecological disturbances	Vulnerable to re-releasing carbon from changing management practices	Vulnerable to reversals due to land use changes and changing environmental conditions	Significant land use to produce biomass and impacts on food security; geological CO_2 storage may leak	Capture process is energy intensive; geological CO_2 storage may leak	Requires extensive mining; soil and water contamination	Long-term environmental impacts are uncertain
Technology Maturity	Mature	Mature	Mature	Mature	Emerging	Emerging	Emerging
Current Cost[221]	Low	Low	Low–Medium	High	High	Medium–High	Low–High
MRV Difficulty[222]	High	High	High	Low–Medium	Low–Medium	Medium	Medium

220 Other ocean-based methods include various coastal "blue carbon" approaches, such as producing seaweed and storing it in a carbon reservoir.

221 "Low" corresponds to technologies with estimated costs today between \$0–50/tCO_2, "medium" between \$50–100/tCO_2, and "high" >\$100/tCO_2. *See* Energy Transitions Commission, "Mind the Gap: How Carbon Dioxide Removals Must Complement Deep Decarbonisation to Keep 1.5°C Alive" (March 2022), https://www.energy-transitions.org/wp-content/uploads/2022/04/Mind-the-Gap-How-Carbon-Dioxide-Removals-Must-Complement-Deep-Decarbonisation-to-Keep-1.5C-Alive-1.pdf

222 "Low," "medium," and "high" correspond to technologies with relatively few, some, and significant MRV challenges, respectively. *See* Jennifer Wilcox, Ben Kolosz, and Jeremy Freeman (eds.), "The Building Blocks of CDR Systems," *Carbon Dioxide Removal Primer* (2021), https://cdrprimer.org/read/chapter-2.

TABLE 7-1 (CONTINUED). OVERVIEW OF APPROACHES TO CARBON SEQUESTRATION

	Forestry-Based Methods	Soil Carbon Sequestration	Wetland Restoration	Bioenergy with Carbon Capture and Storage	Direct Air Capture and Storage	Enhanced Mineralization	Ocean-Based Methods
Regional & Global Sequestration Potential[223]	High regional potential Medium–High global potential	Low regional potential Medium global potential	Low regional potential Low global potential	Very low regional potential Medium global potential	Very low regional potential Medium–High global potential	Low regional potential Medium global potential	Low regional potential Medium global potential
Permanence[224]	Low–Medium	Low–Medium	Low–Medium	High	High	Medium–High	Low–High
Major Co-Benefits	Promotes biodiversity, ecosystem services, and climate resilience	Promotes soil health and improves agricultural climate resilience	Promotes biodiversity, ecosystem services, and climate resilience	Offers fuel options for hard-to-decarbonize sectors	Produces pure CO_2 that can be reused for long-lasting products	Improves soil quality if carbonate minerals are added to soil for nutrients	Counters ocean acidification, which helps ocean ecosystems
Long-Term Outlook	Can scale now, but needs better MRV and preventative measures against forest losses	Can scale now, but needs improvement on MRV and permanence	Can scale now, but needs better MRV, more difficult to implement than forestry solutions	Needs greater biomass supply and improved technology to scale	Needs lower costs and improved energy efficiency to scale	Needs improved access to material and reaction techniques to scale	Needs improved access to material and technology to scale

[223] Regional potentials from Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts 2050 Decarbonization Roadmap* (December 2020) and, for wetland restoration, from Maine Department of Environmental Protection, Bureau of Air Quality, *Ninth Biennial Report on Progress toward Greenhouse Gas Reduction Goals*" (2022). Global potentials from M. Babiker et al., "Cross-Sectoral Perspectives," in *Climate Change 2022: Mitigation of Climate Change*, Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge, UK and New York, NY, USA: Cambridge University Press, 2022), https://report.ipcc.ch/ar6/wg3/IPCC_AR6_WGIII_Full_Report.pdf.

[224] "Low" corresponds to a sequestration potential of <10 years; "medium" 10–100 years; and "high" >100 years. Data from American University Institute for Carbon Removal Law and Policy, "Carbon Removal Fact Sheets & Resources," https://www.american.edu/sis/centers/carbon-removal/fact-sheets.cfm; Energy Transitions Commission, "Mind the Gap: How Carbon Dioxide Removals Must Complement Deep Decarbonisation to Keep 1.5°C Alive" (March 2022), https://www.energy-transitions.org/wp-content/uploads/2022/04/Mind-the-Gap-How-Carbon-Dioxide-Removals-Must-Complement-Deep-Decarbonisation-to-Keep-1.5C-Alive-1.pdf; and National Academies of Sciences, Engineering, and Medicine, "A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration" (2022), https://doi.org/10.17226/26278.

Policy Framework for Carbon Sequestration Procurement

The Commonwealth will need to develop a policy framework to enable the procurement of additional carbon sequestration as a critical step toward achieving Net Zero in 2050. This framework will be primarily oriented toward the acquisition of additional carbon sequestration beyond that provided by Massachusetts' NWL,[225] from either out-of-state NWL or engineered CDR. Some aspects of the framework could also apply to securing in-state NWL carbon sequestration. Procurement mechanisms might include a state sequestration investment fund, a compliance-based exchange for residual emitters, and/or partnerships with other jurisdictions to enable trade in sequestration credits or investment in NWL conservation, among other options. Basic components of the procurement framework that will need to be identified include:

> *Purchaser:* Who will be purchasing carbon sequestration services and credits? This could be an agency of the Commonwealth or a regulated emitting entity.
>
> *Seller:* From whom could the purchaser procure carbon sequestration credits? This could be from a private entity (e.g., business or individual landowner) or from another jurisdiction (e.g., another U.S. state). Sellers could be required to meet certain criteria. It is likely that there will be third-party aggregators and marketers.
>
> *Facilitator:* Who would facilitate the transaction? What infrastructure will be necessary to track and report transactions? Procurements could be conducted directly between buyer and seller or could be facilitated on a formal exchange or by a broker.
>
> *Standards:* What kind of standards or criteria would carbon sequestration credits and resources need to meet? The key considerations and principles for carbon sequestration (see Box 7-1) will play a role here.
>
> *Accounting:* How are purchased carbon sequestration credits applied to Massachusetts' net emissions accounting and Net Zero emissions limit?

One possible way of procuring additional carbon sequestration necessary to balance out residual emissions and achieve Net Zero in 2050 is to set a designated state entity responsible for such procurement. Key issues to consider include funding sources, qualifying criteria for

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[225] Carbon sequestration from NWL attributable to Massachusetts would reduce the needed offset sequestration amount.

purchases, and preferred MRV approach governing credits and transactions. Massachusetts could purchase carbon sequestration credits through an existing exchange or create a new exchange, likely in partnership with other jurisdictions, which would give the state a role in establishing the governance framework and setting standards. Under a multi-state framework, nature-based carbon sequestration procurements could occur through the purchase of conservation easements that include sequestration provisions on NWL. The Commonwealth could also take a diversified approach by creating a fund that would directly invest in any of a range of carbon crediting options, creating a portfolio of carbon sequestration investments. To amplify its procurement power, Massachusetts could pool resources with other jurisdictions to jointly procure sequestration services or invest in carbon sequestration credits.

Next Steps for Massachusetts' Carbon Sequestration Strategy

While residual emissions are not required to be balanced by net carbon sequestration until 2050, the Commonwealth will begin planning in this decade. In the next three years, as mentioned in the 2025/2030 CECP, the Commonwealth will develop: (1) an accounting framework for achieving Net Zero in-state and collectively with other jurisdictions outside of Massachusetts and (2) a framework for the necessary elements of a carbon sequestration procurement. Table 7-2 outlines preliminary topics to be addressed to help guide these planning efforts.

Develop Carbon Sequestration Accounting and Policy Frameworks

As a first step, a net-zero emissions accounting framework is needed, regardless of the carbon sequestration procurement approach that the Commonwealth ultimately pursues. The accounting approach discussed in Chapters 3 and 5e is the start of this effort. Massachusetts has begun discussions with Maine and Vermont about a shared emissions accounting framework for achieving net-zero emissions. As part of this process, a study has been commissioned by the states in partnership with the U.S. Climate Alliance to compare each state's GHG emissions inventory approaches for accounting as well as each state's respective legal obligations to achieve net-zero emissions. Differences will need to be reconciled or cross-walked to ensure consistency, compatibility, and mutual understanding. Following an agreement between the three states, the shared net-zero emissions accounting framework will be discussed with other U.S. states, particularly member states in the U.S. Climate Alliance. This process will include stakeholder and public engagement before finalization by the end of 2025.

With the development of the shared emissions accounting framework, the Commonwealth, in coordination with other jurisdictions, will develop a framework to inform the development of the policy mechanisms, including "market-based compliance mechanisms,"[226] and the infrastructure necessary for enabling the procurement of additional carbon sequestration. The framework will include a discussion of eligibility, registry, measurement, crediting, monitoring, and enforcement in the carbon procurement approach. The policy framework will be drafted by the end of 2025 and will go through a stakeholder and public process in 2026.

The Commonwealth will develop (or identify) its procurement mechanism(s) and infrastructure starting in 2030, allowing for the verifiable purchase of carbon sequestration credits, following the state's preferred approach. This includes setting up a transparent accounting and MRV system well before 2050 to ensure CO_2 removals are permanent, account for leakage, and appropriately address various risks while maximizing co-benefits.

Future 2050 CECP updates will include findings from the analyses and designs conducted in the 2020s, including any updates to the specific strategies for procuring carbon sequestration resources to achieve Net Zero in 2050. Some considerations that may be incorporated into future updates to the plan include:

- *Improved insight into NWL dynamics*: There is a clear need for a better understanding of NWL carbon sequestration capacity, risks, and strategies, including improved inventory, monitoring data collection, GHG flux estimation methods, modeling, and forecasting.
- *Early action for nature-based carbon sequestration*: The benefits associated with NWL carbon sequestration, particularly reforestation and avoided deforestation, can compound over time, and limited land availability, along with the expected increase in global demand for carbon sequestration resources, means that prices are likely to increase with time.
- *Patience for engineered CDR*: These approaches are currently in the early stages of technological development, so they are quite expensive and have only been demonstrated on small scales. But to the extent that they mature and become cost-competitive, they could offer some advantages, particularly in the security and longevity of geological storage.
- *Innovation:* The Commonwealth could consider ways of promoting innovation in carbon sequestration technology, business, and governance that would have broader effects than procurements alone (see Box 7-2 below).

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[226] Mass. Gen. Laws Ch. 21N, §§ 1, 4(e), and 7, https://malegislature.gov/Laws/GeneralLaws/PartI/TitleII/Chapter21N/Section1.

- *Diversified strategy*: Pursuing multiple carbon sequestration approaches is likely to be advantageous in terms of minimizing costs, risks, and impacts. This will also allow the Commonwealth to more easily learn and adapt from experience as the advantages and downsides of different approaches become more apparent over time.
- *Implementation timeline*: Massachusetts should begin building its carbon sequestration portfolio well before 2050 and plan to sustain or grow it well beyond. Thus, the Commonwealth will need to lay out a more specific timeline for future policies around the procurement of carbon sequestration resources.

TABLE 7-2. PRELIMINARY TOPICS FOR MASSACHUSETTS CARBON SEQUESTRATION STRATEGY AND POLICY FRAMEWORK

Topics	Description
Principles & Criteria	• Refine principles and considerations to guide Massachusetts' carbon sequestration strategies and policy framework (Box 7-1) • Develop specific criteria to evaluate various carbon sequestration approaches and methods (including those in Table 7-1)
Carbon Sequestration Accounting	• Identify what constitutes GHG removals in or attributable to the Commonwealth for the purpose of meeting Net Zero • Determine the accounting standards that would apply generally across various carbon sequestration options, consistent with Massachusetts' overall Net Zero limit and emission accounting framework; and with international best practices
Massachusetts' NWL Net Carbon Sequestration	• Estimate potential levels of net carbon sequestration that could be expected from Massachusetts' NWL in 2050 (as discussed in Chapter 5e) • Evaluate the portion of Massachusetts' NWL sequestration that could be counted towards Net Zero (i.e., whether and how it might differ from the NWL GHG inventory)
Out-of-State NWL Net Carbon Sequestration	• Evaluate the strengths and limitations of procuring various out-of-state NWL carbon sequestration resources compared to other options • Consider whether procurements for out-of-state NWL carbon sequestration resources would be best served by working with other states, regionally, or by pursuing national or global opportunities • Determine the accounting standards and other criteria for counting out-of-state NWL sequestration towards Net Zero in Massachusetts
Engineered CDR	• Evaluate the strengths and limitations of engineered CDR compared to other carbon sequestration options • Determine the accounting standards and other criteria for counting engineered CDR towards Net Zero in Massachusetts
Carbon Sequestration Procurement Approach	• Identify procurement options, including parameters of any potential procurements, such as who the purchaser, seller, and facilitator of carbon sequestration credit transactions would be, and the policy framework in which they would operate • Evaluate the strengths and limitations of the different procurement options and frameworks, and select a preferred approach • Determine the specific actions to implement the preferred approach, including a timeline for executing these actions
Promoting Innovation	• Determine what steps the Commonwealth can and should take to promote innovation in carbon sequestration technology, industry, and governance (Box 7-2)

BOX 7-2. CARBON SEQUESTRATION INNOVATION IN MASSACHUSETTS

Massachusetts is well-positioned to contribute to and benefit from innovation in carbon sequestration technology, industry, and governance, given the state's research institutions, technology industry, workforce, and climate and land use policies. By supporting in-state development of carbon sequestration approaches that could be broadly deployed, Massachusetts stands to benefit economically while also assisting both in-state and global movement toward net-zero emissions.

There is already considerable activity in the development of CDR technology in Massachusetts' academic and private sectors that could be further facilitated. The Commonwealth is home to many world-class universities and research centers that are endowed with the human capital necessary to accelerate CDR technology development. For example, Massachusetts Institute of Technology (MIT) has been a pioneer in carbon sequestration research, having first initiated its Carbon Sequestration Initiative in 2000, and its researchers continue to pursue research programs to improve the effectiveness and efficiency of CDR technologies. In addition, Massachusetts is a hotbed of technology-driven entrepreneurship that directly benefits from the state's robust research environment. Carbon Engineering, one of the first companies to scale direct air capture and storage (DACS) technology, benefits from partnerships with Harvard University researchers. Verdox, a CDR startup founded by MIT chemical engineers, developed an energy-efficient process to electromechanically remove carbon dioxide and raised more than $80 million in funding, including a grant from MassCEC. Scientific advances and technologies invented in Massachusetts can be deployed worldwide, pushing the CDR frontier farther while lowering implementation costs.

The Commonwealth could advance climate governance, playing an important role in assessing the viability of various carbon sequestration approaches, by specifying the quality standards Massachusetts would expect of credits that will count towards its Net Zero limit. These standards could be method-agnostic (e.g., nature-based, technological, or hybrid), as long as they meet strict thresholds for quality, integrity, and broader impacts outlined in Box 7-1 (e.g., permanence, EJ). The state could also play a role in accelerating growth in the carbon sequestration industry (see Chapter 4 – Innovation), including by sending clear signals of future demand for standard-meeting sequestration activity. The Commonwealth may have a particularly important role in promoting governance innovation for nature-based carbon sequestration that requires proactive land use planning and natural resource management. By working collaboratively across the state, local, and regional levels with state agencies, land trusts, private landowners, and the environmental science research community, the state could become a successful model for enhancing NWL carbon sequestration and promoting ecosystem services (see Chapter 4 - Develop Proactive Land-Use Strategy).

Chapter 8: Employment and Macroeconomic Impacts of Massachusetts' Decarbonization Policies Through 2050

This chapter of the 2050 CECP outlines the macroeconomic and employment impacts of Massachusetts' decarbonization goals from 2030 to 2050. This chapter begins by discussing the notable trends and changes that could shape the employment and macroeconomic impacts of decarbonization. The chapter then addresses the projected impacts through 2050, their notable drivers, and some policy considerations that are likely to play a crucial role in developing a robust clean energy workforce that can propel Massachusetts forward.

Overview of Impacts Through 2030

The 2025/2030 CECP outlined the employment and macroeconomic impacts of the Commonwealth's decarbonization goals through 2030. This section provides a brief overview of the findings of the employment and macroeconomic impact chapter within the 2025/2030 CECP. Please refer to that plan to examine the early impacts of decarbonization in greater detail.

The findings from the 2025/2030 CECP are substantial: by 2030, a net additional 22,600 full-time jobs will be created and supported relative to 2019 levels and will generate nearly $30 billion in Gross State Product.[227] The electricity and buildings sectors are the greatest forecasted sources of growth, adding 10,700 and 7,100 workers during this time, respectively. Within these larger sectors, EV chargers, solar PV, residential building envelope, transmission, and offshore wind subsectors will drive the greatest employment growth. Most (59%) of the jobs created will be in the construction industry, and the southeast and western portions of the state are projected to see the greatest concentration of additional jobs relative to their underlying economies, even though the metro region will see the greatest increase in jobs in absolute terms.

Long-Term Questions

Over the past 20 years, the pace of technological advancement and changes in federal policy have drastically reshaped what was thought to be possible across decarbonization efforts.

[227] This 2030–2050 analysis utilizes the same models and methodology devised for the 2025/2030 CECP. For more information about the methodology, please see the relevant chapters in the 2025/2030 CECP. *See* Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (June 30, 2022), https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download.

Given this new trajectory, it is possible that the 20 years spanning 2030–2050 will bring an even greater paradigm shift. There are several key long-term questions that will influence the speed of decarbonization in the future.

1. What impacts will the Inflation Reduction Act (IRA), the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act, and the Infrastructure Investment and Jobs Act (IIJA) have on the pace and scale of current climate initiatives underway? The IRA in particular offers substantial baseline incentives that are elevated by local procurement and production, as well as labor standards. It is likely that the resulting impact will be an acceleration of the timeline for decarbonization activities and that particular workforce structures will be preferred by developers.
2. How will technologies change and advance? How will these changes drive down costs, improve project feasibility, and push the frontier of what we thought was technologically possible?
3. How will society adjust to these changes? Changes in behavior will have significant impacts on employment and the economy. For example, the increased adoption of EVs may result in the decline of retail gasoline stations, or it may merely alter their business model to support longer intermissions in travel.
4. How will public perceptions of climate change and decarbonization efforts change? The increasing rate and severity of significant weather events may drive changes in public opinion, which may further affect policymaking.

The answers to these questions will have profound impacts on the speed and scale of decarbonization over the coming decades and, thus, its economic impacts.

Key Uncertainties Will Affect Employment and Economic Impacts in Massachusetts

Long-Range Transportation

Battery and battery-charging technologies continue to develop and evolve. Extended battery ranges and fast-charging technologies may alter transportation logistics and behavior, which may alter economic behavior and social patterns, including how much investment is needed in various types of EV charging infrastructure, and thereby affect the workforce needed.

Energy Storage

As research and innovation into battery materials continues, long-duration or even seasonal storage may change how electricity grids operate. Bi-directional electrical infrastructure at scale could also revolutionize grid operations, with thousands of EVs providing power to the grid during peak hours and charging during off-peak hours. These factors would significantly change the capacities and capabilities needed within the grid, therefore impacting the levels of new infrastructure investments and workforce needed.

Industrial Decarbonization; Hydrogen; and Carbon Capture, Utilization, and Storage (CCUS)

Some industries, such as industrial production, are more difficult to fully decarbonize than others. For instance, the production of cement releases CO_2 during the production process, as well as combustion-related emissions. To address these challenges, CCUS may play an important role in capturing and using or sequestering CO_2. These difficult-to-decarbonize industries could experience a spectrum of impacts, ranging from no changes—with CCUS fully utilized—to significant disruption if new technologies and accompanying skillsets are required. Hydrogen is also increasingly likely to play a role in industrial decarbonization. The extent to which hydrogen can be produced in an economically feasible and carbon-neutral way is another critical factor that can shape employment and economic opportunities around these technologies.

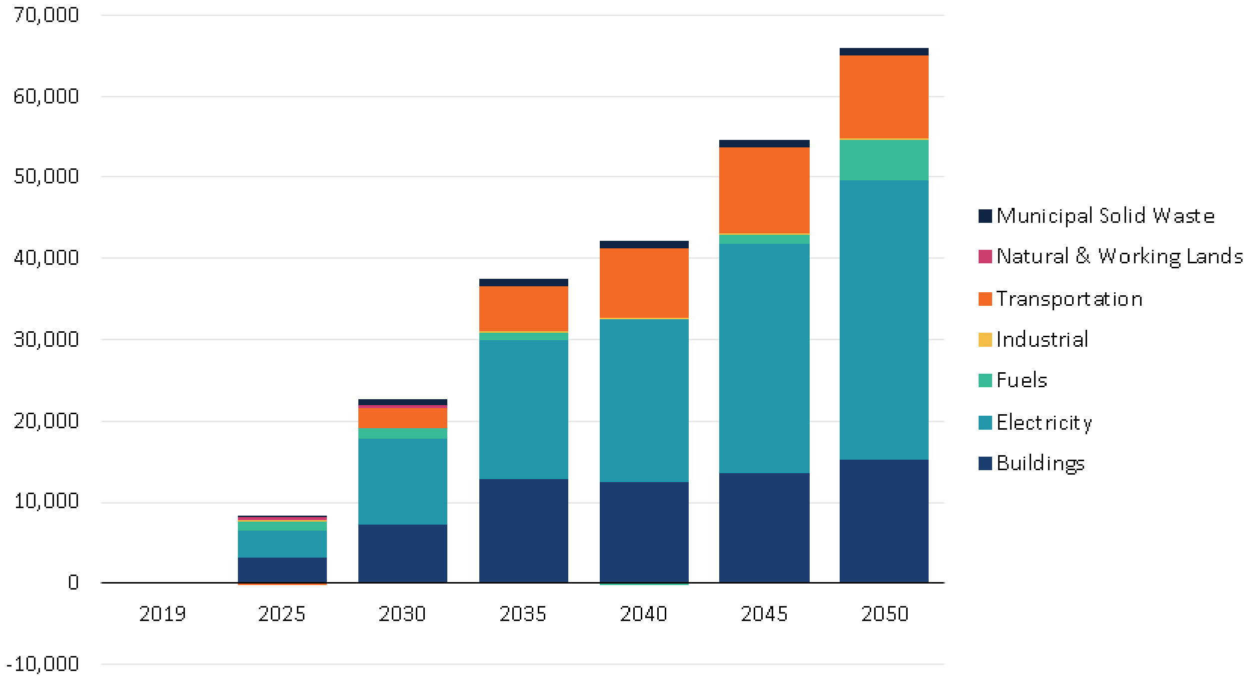
Alternative Fuels

Alternative fuels are necessary to decarbonize some of the hardest-to-electrify industries. The types of alternative fuels, where they are refined, and how they are deployed will all factor into employment and economic outcomes. It is also notable that the employment opportunities within biofuels and synthetic fuels (often including the transportation and sale of fuels) present an opportunity for similar roles that are displaced among more carbon-emitting fuels like natural gas and petroleum fuels.

Employment and Economic Impacts Through 2050

Beyond 2030, through to 2050, an estimated 11,000 full-time clean energy jobs will be added every five years. While most of this growth is driven by the electricity sector, the buildings and transportation sectors account for a significant share as well. It is also notable that the fuels sector goes from a net employment loss in 2040 to a net job gain of about 3,900 jobs in 2050 (Figure 8-1). This phenomenon in the fuels sector is driven by steady declines in fossil fuel-related employment that are offset by an estimated increase of biofuels and hydrogen in 2045 and 2050. The timing of fossil fuel employment displacement and offsetting biofuels and hydrogen employment gains is a trend worth further attention and consideration in the future. Such estimates should be refined in future 2050 CECP updates.

FIGURE 8-1. CHANGE IN EMPLOYMENT FROM 2019 BY SECTOR



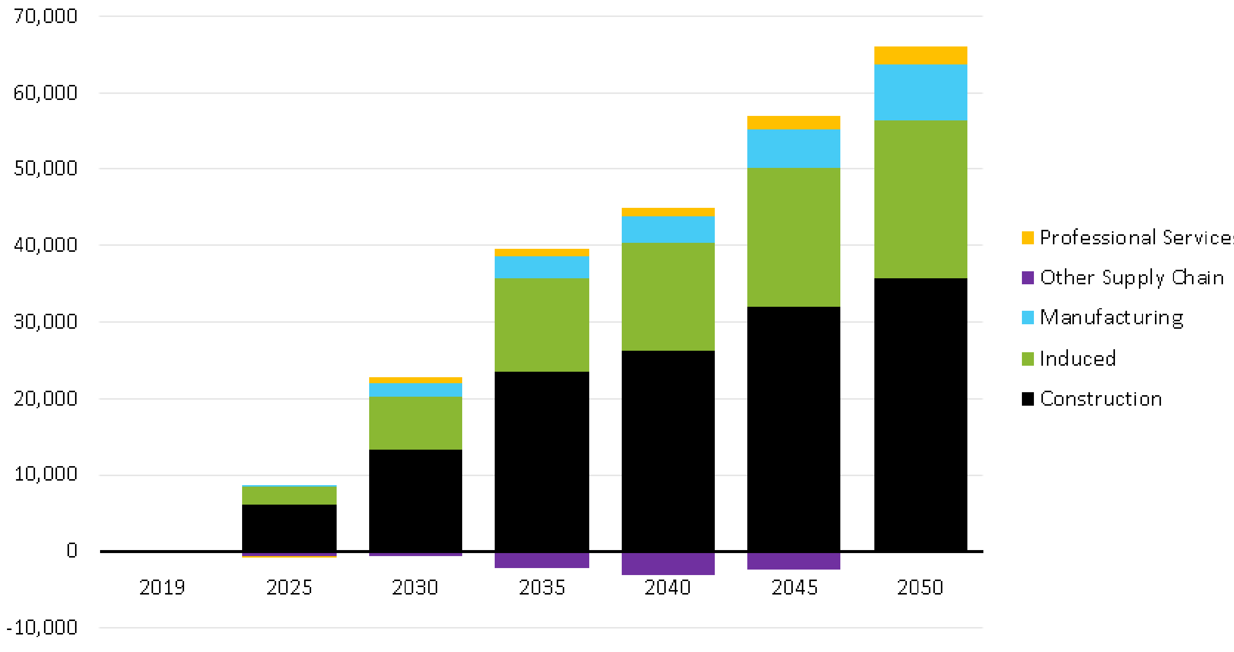
Note: The fuels sector goes from a net employment loss of about 300 in 2040 to a net job gain of about 3,900 jobs in 2050.

Most (51%) of the jobs added in 2050 are in construction, though nearly a third (31%) are induced[228] jobs. Employment losses in 2035–2045 in the fuels sector are likely to occur in specific parts of the value chain, namely wholesale and retail trade.[229] However, these losses are offset by the later growth in biofuels and hydrogen, resulting in a net gain in other supply chain employment by 2050 relative to the 2030 level (Figure 8-2).

[228] Induced jobs are economic impacts that occur throughout the economy as a result of the original "impact" activity. This means that, for roughly every two energy-related jobs created, one non-energy, economy-wide job will be created via the spending effects of the policies. For example, those who are paid to construct new offshore wind projects will increase their spending at restaurants, electronics stores, and other places throughout the economy, driving demand for new workers in these industries. For more information on induced effects, please refer to the 2025/2030 CECP. *See* Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (June 30, 2022). https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download.

[229] "Other supply chain" encompasses utilities, wholesale trade, repair, and maintenance.

FIGURE 8-2. CHANGE IN EMPLOYMENT FROM 2019 BY VALUE CHAIN



Major Drivers of Change

There are several sub-sectors that are responsible for most of the job gains and job losses as the economy transitions (Figure 8-3). These sub-sectors are discussed in greater detail below.

Charging Infrastructure

With more than 5 million vehicles registered on Massachusetts roadways, the electrification of transportation will be one of the most significant evolutions of the economy, and the need for robust charging infrastructure throughout the state will create an estimated 15,500 additional jobs between 2030 and 2050.

Electricity Distribution

Electrifying the Massachusetts economy requires a great deal of electrical infrastructure. Distribution of electric power from substations to homes and businesses is a crucial component of this process and subsequently is projected to add the second-greatest number of jobs (11,500) between 2030 and 2050.

Offshore Wind

By 2050, Massachusetts may have an estimated 23 GW of installed offshore wind capacity. The scale of labor and materials needed to assemble, install, and maintain these facilities cannot be overstated. Modeling suggests that as many as 9,500 additional full-time offshore wind workers will be needed by 2050 from 2030 levels.[230] Statewide employment gains could be even greater if there are higher rates of local manufacturing and production of these turbines.

Biofuels

The need to decarbonize hard-to-electrify industries means that biofuels will play an increasingly important role in Massachusetts' energy economy. Between 2030 and 2050, an additional 6,100 workers will be involved in the production, transportation, and delivery of biofuels.

Transmission

Running high-voltage electricity from generation sites to communities throughout the Commonwealth will require thousands of miles of transmission and distribution around the state. An estimated additional 4,900 workers will be needed for these efforts by 2050.

Residential Building Envelope

Making sure homes are insulated and energy efficient is an important strategy to minimize energy consumption while maximizing comfort. Between 2030 and 2050, an additional 3,600 workers will be needed to further support the installation of energy-efficient technologies and insulation of residences throughout the state.

Fueling Stations

The electrification of transportation will likely impact the ways that we travel. One important consideration is how vehicle charging behavior differs from the fueling of an internal combustion engine. Using the fastest current technology, a full charge can take 20 minutes to an hour or more, which is substantially different from the current fueling model. If vehicle refueling patterns change, the business models for fueling station retailers will also have to change, potentially displacing workers. While there are still unknowns on precisely how this will play out, the model assumed that the rise in EVs would result in a proportionate displacement of fueling station retail workers. If charging technology advances and becomes more comparable to the current fueling model, these employment displacements may be mitigated or never occur.

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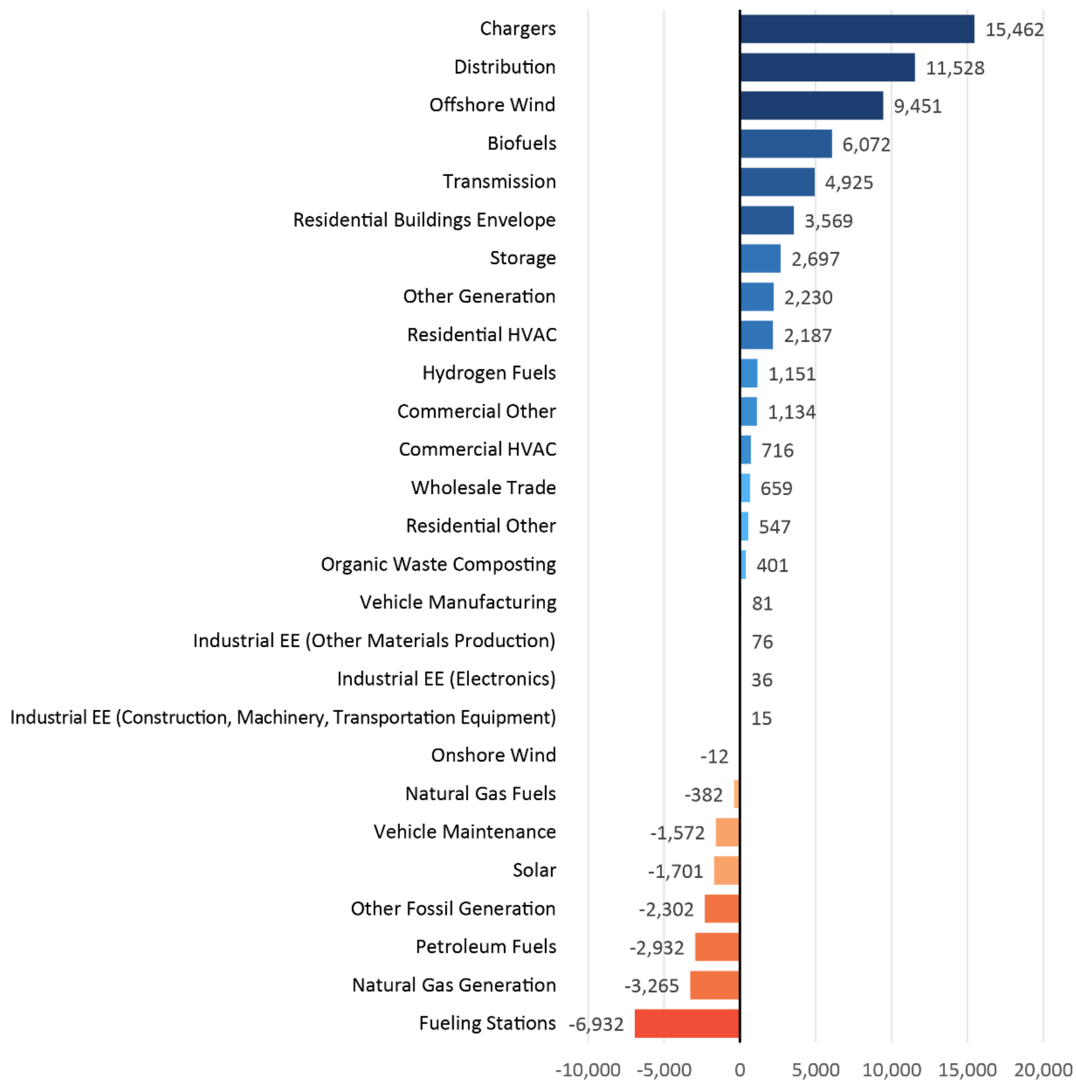
[230] For more information on the models and underlying assumptions developed around offshore wind in Massachusetts, please refer to the 2025/2030 CECP. *See* Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (June 30, 2022), https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download.

FIGURE 8-3. CHANGE IN EMPLOYMENT (2030–2050) BY VALUE CHAIN



Note: Job figures reflect the difference between full-time energy workers in 2030 and full-time energy workers in 2050.

Other Employment Losses

The other largest sources of worker displacement are in natural gas electric generation, petroleum fuels, other fossil fuel electric generation, solar, vehicle maintenance sectors, and natural gas fuels. The losses among fossil fuels employment are driven directly by the decreased need for these resources, while the declines in solar are driven by a slowing in distributed (residential) solar as the marketplace reaches a saturation point. Finally, declines in vehicle maintenance are driven by the fact that EVs have fewer moving parts and therefore require less routine maintenance and repairs, resulting in decreased demand for automotive repair workers.

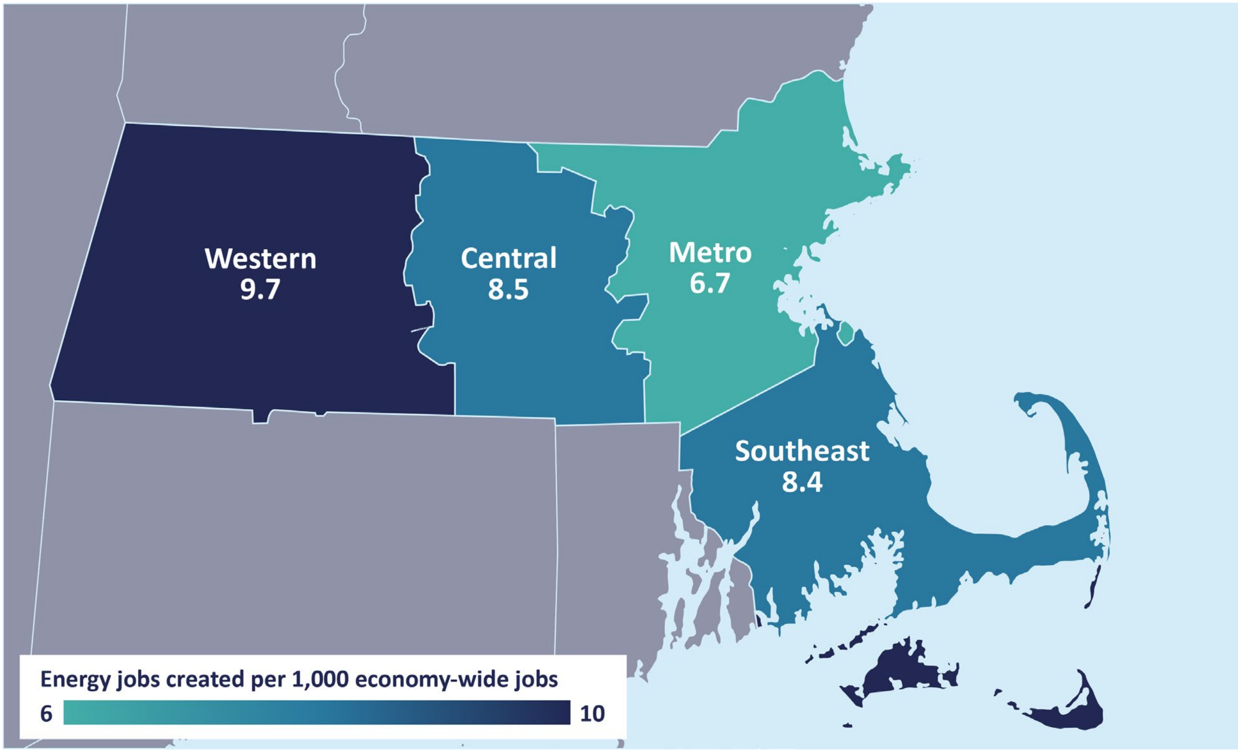
Secondary Employment Outputs

About eight in ten (79%) energy-related jobs[231] created between 2030 and 2050 will earn $26 or more per hour in 2021 dollars, roughly the median wage for Massachusetts workers in 2021. Most of the jobs added will be installation, maintenance, and repair (59%) roles, though management and professional roles will also account for a sizable portion of the jobs added (20%).

Like the trends anticipated between 2019 and 2030, new energy-related jobs created between 2030 and 2050 will be concentrated mostly in the western, southeast, and central portions of the state. The western part of the state is projected to see roughly 10 new energy-related jobs for every 1,000 existing economy-wide jobs (Figure 8-4). While the metro region is projected to see the greatest absolute increase in jobs, it sees the smallest impact relative to its underlying economy, adding 6.7 jobs for every 1,000 existing economy-wide jobs.

[231] These figures do not account for induced or economy-wide jobs previously noted.

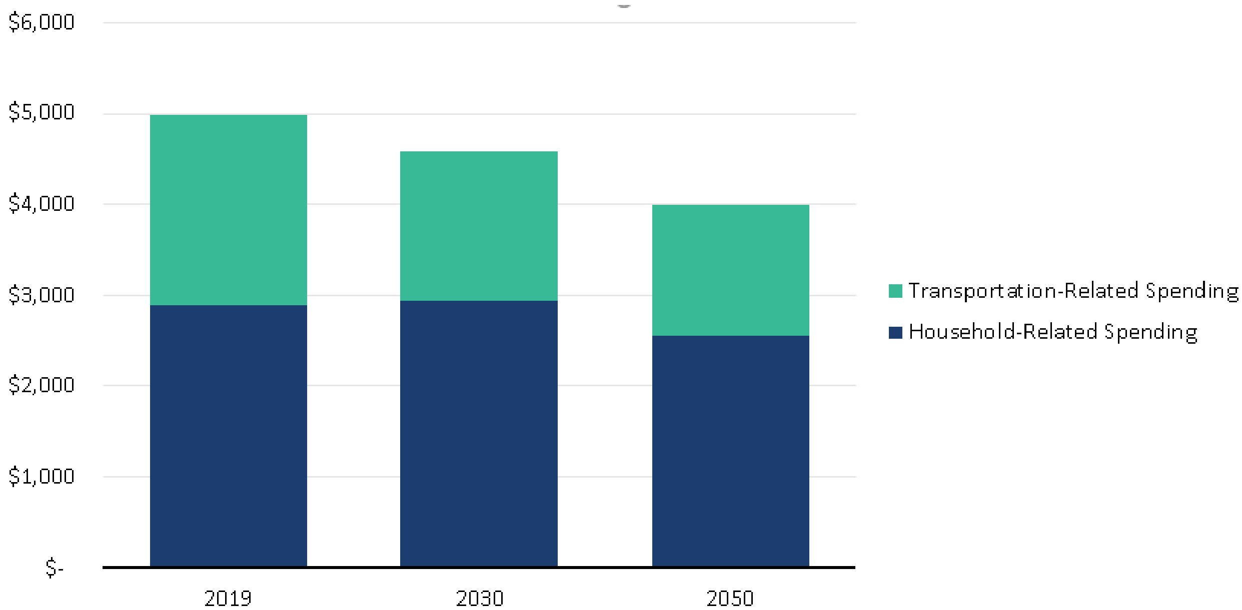
FIGURE 8-4. ADDITIONAL JOBS CREATED (2030–2050) FOR EVERY 1,000 ECONOMY-WIDE JOBS



Household Energy Expenditure Impacts

Like the trends projected between 2019–2030, the efficiency gains of electrification will result in lower household energy expenditures through 2050 (monthly bills for electricity and fuels). Transportation and household-related electricity and fuel expenditures are projected to decline by roughly 13% between 2030 and 2050, representing an average of nearly $600 (in 2021 dollars) in 2050 compared to 2030 (Figure 8-5, below). A household with greater adoption of efficiency and electric technologies will see greater savings than those highlighted below, while a household that implements little or no changes will see little or no benefits.

FIGURE 8-5. CHANGE IN HOUSEHOLD AND TRANSPORTATION-RELATED FUEL AND ENERGY COSTS ANNUALLY (2019–2050)



Our estimates also show that disadvantaged communities will likely see the greatest proportional decrease in energy expenditures relative to their income because lower-income households spend a greater share of their income on energy. While these models are useful, several policies and factors—including the upfront costs of electrification—will determine the distribution of financial impacts.

Environmental and Health Benefits for 2050

In addition to supporting the employment of thousands of workers across the Commonwealth, Massachusetts' decarbonization policies will result in significant improvements in air quality that enhance public health. As air quality improves, the incidence of several adverse health effects will decline. In 2050, this will include 181–409 fewer premature deaths, 20–185 avoided cases of non-fatal acute myocardial infarction, 214 avoided cases of acute bronchitis, and 21,700 fewer lost days of work, among other health benefits.[232] Altogether, improved air quality in 2050 will result in health benefits valued between $2.1 billion and $4.7 billion. Reductions in premature mortality account for approximately 98% of this total, reflecting the higher per-case value for mortality relative to other health outcomes.

[232] Estimates developed by Evolved Energy Research using the U.S. EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).

Policies That Can Play a Role in Improving the Massachusetts Clean Energy Economy and Workforce

Massachusetts' policies are projected to create significantly more new jobs and increase economic output statewide, yet deployment-related policies alone do not ensure that the jobs created will be high quality and accessible to all. Policies that require or incentivize project labor agreements (PLAs) lead to clean energy workers that are well-trained, supervised, and competitively paid. Labor unions are well-equipped to rapidly scale to meet the workforce needs of the fast-growing sectors. Community benefit agreements (CBAs) are critical to ensure that communities participate in the positive developments spurred by clean energy projects. CBAs invigorate communities and, when designed effectively, provide economic opportunities for residents and businesses in those communities. Policies that require and incentivize CBAs and PLAs can provide strong support for a more equitable and just approach that has a greater local impact.

Massachusetts has several important technology-oriented elements in this Plan. Several key technologies that are critical to achieving Net Zero are not currently at the level of maturity needed for wide-scale, immediate adoption. A combination of these technologies—such as green hydrogen, long-term battery storage, advanced and synthetic biofuels, carbon capture and storage, and others—will need to be implemented over the next 20–30 years. It is therefore imperative that the state continue to fund research, development, and deployment activities, including expanding the investments program and incubator and accelerator system across the Commonwealth. These efforts, combined with a focus on bringing opportunities to EJ and under-represented populations, can propel Massachusetts toward a stronger and more inclusive economy.

Appendix A: Policy Summary

The Commonwealth of Massachusetts set forth in the Clean Energy and Climate Plan for 2050 ("2050 CECP" or "Plan") a comprehensive set of specific strategies, policies, and actions to reduce statewide greenhouse gas emissions by at least 85% below the 1990 baseline level and achieve net-zero greenhouse gas emissions in 2050. The tables in this Appendix provide an overall summary of the approaches contained in the 2050 CECP for ease of reading, including a brief description of each, entities that would lead the implementation,[233] and the expected timeline.

Equity			
	Policy Summary	**Relevant Actors**	**Timeline**
1	Develop tracking metrics and set goals to commit clean energy and climate investments to disadvantaged communities and environmental justice populations. These goals will be communicated through the Clean Energy and Climate Plan Dashboard.	EEA	Starting in 2023
2	Launch a Climate Campaign to raise climate awareness across the Commonwealth	EEA	Starting in 2023
3	Seek to develop a holistic approach for siting energy infrastructure	EEA	Starting in 2024
4	Expand deployment of air monitoring network in environmental justice communities	MassDEP	Ongoing
5	Work with public health professionals to assess options to improve air quality, particularly in EJ neighborhoods	EEA	Starting in 2023

[233] Explanations of acronyms are available on page vi through page ix of the 2050 CECP.

Cross-Sector			
	Policy Summary	Relevant Actors	Timeline
1	Increase coordination with labor unions to assist in climate-critical training and retraining, especially for those who transition from other sectors and/or fossil fuel-based roles	MassCEC	Ongoing
2	Through coordination with Workforce Skills Cabinet, seek to establish clean energy as a statewide priority industry sector, with increased education/career programs and explore the benefits of creating a dedicated career cluster	MassCEC, EEA	Starting in 2023
3	Develop a plan for a "Climate Service Corps" to drive awareness, adoption, and the pipeline of workers for climate-critical solutions	MassCEC, EEA	2023–2025
4	Provide ongoing energy occupation training, including support for minority and women-owned small business enterprises, through Equity Workforce Development Programming	MassCEC	Ongoing
5	Develop a holistic, long-term land use strategy to support implementation of the 2050 Clean Energy and Climate Plan	EEA, EOHED, MassDOT, municipalities, regional planning authorities	2023–2024
6	Assess the performance of in-state technology transfer programs and facilitate the exchange of best practices for universities across MA	MassCEC	Starting 2023
7	Ramp up the Leading by Example program to promote the rapid decarbonization of state buildings and facilities	DOER	Ongoing
8	Increase coordination across municipal and regional entities on Net Zero planning, capacity building, and implementation	EEA, DOER	Starting in 2023
9	Identify capital projects that receive state funding and work with state funding agencies to explore establishing application criteria that incorporate decarbonization goals	EEA, EOHED, DOER	2023

Transportation			
	Policy Summary	**Relevant Actors**	**Timeline**
1	Implement advanced clean cars and truck standards to increase the number of zero-emissions vehicles	MassDEP	Ongoing regulation implementation
2	Install public charging infrastructure at a scale sufficient enough to support anticipated electric vehicle fleet	MassDOT, EEA	Ongoing
3	Develop 2050 statewide long-term transportation plan, with goals for increasing use of public transportation, reducing reliance on personal automobiles, investing in multimodal transportation infrastructure, and improving safety and reliability of our transportation system	MassDOT, MBTA	By end of 2023
4	Explore the electrification of public transit to meet standards of climate bill and MBTA Rail Vision	MassDOT, MBTA	Ongoing
5	Expand EV incentives and create incentives to retire old internal combustion engine vehicles	DOER	Ongoing
6	Require smart charging in all EV incentives	DOER	Starting in 2025
7	Adopt fuel standards to promote the use of biofuels and synfuels in hard-to-electrify areas	EEA	Starting in 2030
8	Identify ways to replace the existing sources of transportation infrastructure funding with new sources	MassDOT, EEA	Starting in 2030

Buildings			
	Policy Summary	**Relevant Actors**	**Timeline**
1	Develop a Clean Heat Standard	MassDEP, DOER, EOHED	Implementation as early as 2024
2	Establish uniform building performance reporting for all building types	EEA, DOER, EOHED	By 2025
3	Evaluate models for and develop a Clean Heat Clearinghouse	EEA, DOER, EOHED	Determination on model by 2024
4	Establish climate finance mechanisms to accelerate decarbonization financing	EEA, MassCEC, MassDevelopment	Implementation plan by end of 2023
5	Facilitate joint decarbonization planning between electric and natural gas utilities	EEA, DOER, DPU	Starting in 2023
6	Develop a public education and outreach Climate Campaign that centers environmental justice and equity	EEA	Starting in 2023

Electric Power			
	Policy Summary	**Relevant Actors**	**Timeline**
1	Develop Forward Clean Energy Market (FCEM) to support deployment of large-scale clean energy projects	DOER, regional partners	Ongoing development and implementation, operating no later than 2026
2	Support offshore wind development, including by advancing floating offshore wind technologies, securing needed long-term renewable energy lease areas, and developing offshore transmission system	EEA, DOER, MassCEC	Ongoing
3	Work with regional partners, ISO-NE, and FERC to reform regional transmission planning and cost allocation	DOER, regional partners	Ongoing
4	Reform wholesale electricity markets to incentivize reliable balancing of a highly renewable grid, including through the use of demand-side resources and long-duration energy storage	DOER, MassCEC, regional partners	Ongoing
5	Conduct holistic distribution system planning to ensure the distribution system enables controls of demand-side resources	DPU, DOER, EDCs	Starting in 2023
6	Enable load flexibility and demand management measures that promote clean energy and efficiency	DPU, DOER, EDCs	Ongoing
7	Assess and, if applicable, seek to develop a holisitic approach for siting energy infrastructure*	EEA	Starting in 2024

*Also highlighted in the Equity Policy Summary Table above

Non-Energy & Industrial			
	Policy Summary	**Relevant Actors**	**Timeline**
1	Promote energy efficiency upgrades and electrification in industrial sector	Mass Save®	Ongoing implementation
2	Reduce HFCs in line with federal regulation and target SF6 reductions with goal of phasing them out	EPA, MassDEP	Ongoing implementation
3	Determine whether changes are needed and, if so, develop a new approach to the Gas System Enhancement Plan (GSEP) to continue to reduce methane leaks while decarbonizing the natural gas system	DOER, DPU	Upon completion of the GSEP working group's report
4	Implement recommendations from Solid Waste Master Plans (SWMPs) in line with reducing solid waste disposal by 90% by 2050	MassDEP	As contained in 2030, 2040, 2050 SWMPs

Natural and Working Lands (NWL)			
	Policy Summary	Relevant Actors	Timeline
1	Establish a program to provide technical assistance and expanded grant support to municipalities, regional entities, and land trusts for NWL conservation	EEA	By 2024
2	Assess innovative ways to bring additional investments into NWL conservation	EEA	By 2025
3	Develop GHG emissions accounting of large-scale land clearing for development and options for mitigation	MEPA Office	By 2024
4	Explore options to scale up local tree supplies and planting and maintenance assistance	EEA, DCR	Starting in 2023
5	Continue incentivizing climate-smart forest management and assess opportunities for use of long-lived durable wood products to reduce GHG emissions in the built environment	DCR	Starting in 2023
6	Explore incorporating embodied carbon standards into the evaluation of new state facilities	DOER/LBE, DCR	Upon completion of E.O. 594's associated research
7	Continue incentivizing healthy soil practices	EEA, MDAR	Starting in 2023
8	Assess effectiveness of dual-use solar projects on farms and improve dual-use policies	DOER, MDAR	After reaching 80 MW of AC capacity for ASTGU
9	Proactively restore tidal wetlands, removing tidal flow restrictions, and restoring salt marsh functionality, as well as improving the protection and health of freshwater wetlands	DFG/DER, MassDEP, MassDOT	Starting in 2023

Future of Fuels			
	Policy Summary	**Relevant Actors**	**Timeline**
1	Consider whether changes are needed to the statewide GHG emissions inventory conventions, guiding principles, and/or accounting methodologies for combustion emissions from conventional and advanced biofuels, hydrogen, and synthetic fuels, potentially including emissions impacts that occur outside the state (e.g., emissions and sequestration associated with out-of-state biofuel production)	MassDEP	By 2024
2	As alternative fuels become more prevalent, Massachusetts will determine how to optimize the standards that are used to qualify fuels for programs that encourage clean(er) fuel use (e.g., Clean Heat Standard)	EEA, DOER, MassDEP	Ongoing
3	Support innovation by funding alternative fuel research and development and pilot programs. Coordinate with other states to amplify impacts, avoid stressing regional or national feedstocks or natural and working lands, and direct alternative fuels to high-value applications	MassCEC, EEA	Ongoing

Carbon Sequestration			
	Policy Summary	**Relevant Actors**	**Timeline**
1	Develop a Net Zero emissions accounting framework in coordination with other jurisdictions and stakeholders	EEA, MassDEP	By end of 2025
2	Establish a policy framework to guide the procurement of additional carbon sequestration in coordination with other jurisdictions and stakeholders	EEA	2025-2026
3	Develop (or identify) specific mechanism(s) and infrastructure for carbon sequestration procurement and exchange	EEA	Starting in 2030

Appendix B: Public Comments

Summary of Public Engagement

EEA solicited public feedback throughout the development of this Plan. EEA received stakeholder input and feedback through multiple public engagement and public comment processes, most recently with public hearings being held on October 6, 7, and 11, 2022. Three advisory groups held meetings that helped to provide input and feedback that informed development of this Plan:

- The Global Warming Solutions Act Implementation Advisory Committee (GWSA IAC) is a public body that advises EEA on GHG reduction measures. The IAC provided comments that included recommendations of policies for EEA's consideration in finalizing the scope of the 2025/2030 CECP and this 2050 CECP. The IAC held two meetings throughout the development of the 2050 CECP, on August 11 and October 5, 2022. In addition, the IAC held working group meetings to discuss sector-specific policies and consult on other topics related to this Plan. 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 Baker-Polito Administration established the Commission on Clean Heat to advise the Governor on the framework for long-term GHG reductions from heating fuels.[234] The Commission on Clean Heat held 19 meetings prior to and during the development of this 2050 CECP: January 12 and 26, February 9 and 17, March 9 and 23, April 6 and 27, May 18, June 10, July 7, August 10, September 15, October 6 and 18, November 3, 14, and 21, and December 7, 2022. In addition, four public webinars were held on March 1 and 24, 2022. Additionally, the public hearings on the 2025/2030 CECP and the 2050 CECP included a report on the progress of the Commission on Clean Heat, including the areas in which the Commission were likely to provide recommendations. The Commission's final recommendations were finalized and provided publicly on November 30, 2022.
- Governor Baker appointed members to the Environmental Justice Council to advise the state on policies to promote environmental justice. The Environmental Justice Council met four times prior to the release of this 2050 CECP to discuss the definition of "environmental justice" used in the Commonwealth's Environmental Justice Policy and policies and strategies in this Plan: July 28, September 15, September 27, and October 27,

[234] Massachusetts Executive Order No. 596: Establishing the Commission on Clean Heat (Sept. 21, 2021).

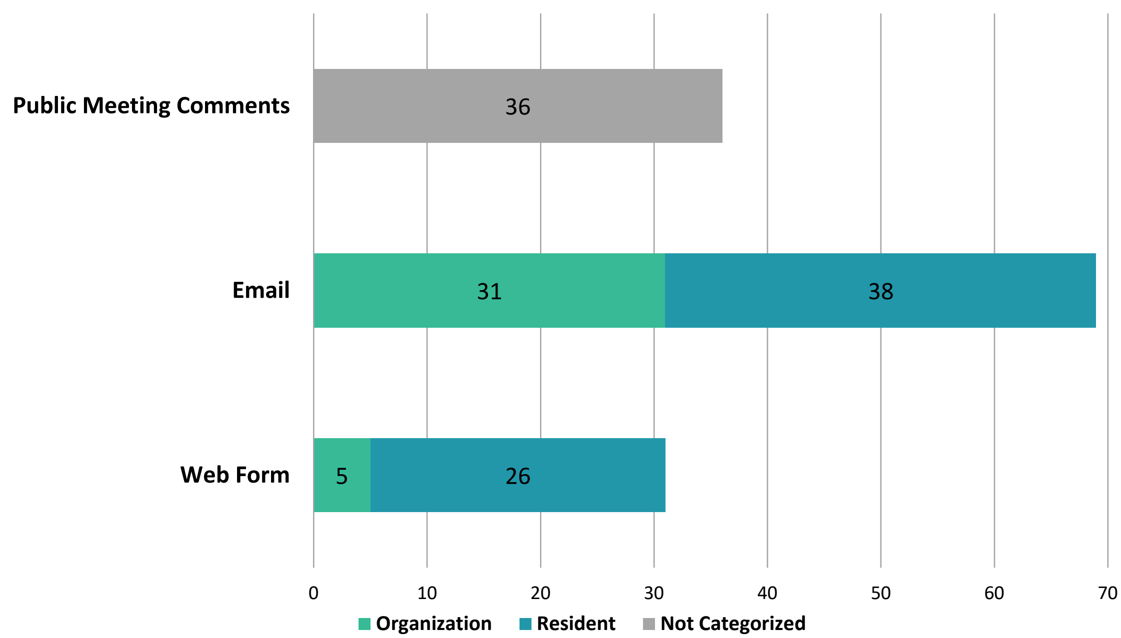
2022. Recommendations from the Environmental Justice Council helped shape the approach to equity in this Plan.

Comments Received

EEA received a total of 136 public comments on the proposal for the 2050 CECP. All comments were reviewed and considered in the development of the 2050 CECP. These comments came in the form of emails, web form responses, public meeting comments, and discussions with specific committees.

Figure B-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). IAC member organizations and non-IAC member organizations are not distinguished in Figure B-1 and are both counted under the Organization category. Participants who commented at the public hearings on October 6, 7, and 11, 2022 have not been categorized as resident or organization since not all commenters at public meetings stated whether or not they were speaking on behalf of an organization.

FIGURE B-1. TYPES OF COMMENTS RECEIVED DURING THE PUBLIC COMMENT PERIOD



The majority of the submitted comments were unique.

There were some responses that were phrased in a similar or identical fashion, based off form letters. There were nine submissions of a comment which asked for a breakdown of expected

GHG emissions by 2050, emissions reductions from large buildings, to increase the Clean Energy Standard to 100% by 2035, pollution tracking in EJ communities, and a reduction in vehicle miles traveled. There were 12 submissions of a comment organized by Green Energy Consumers Alliance. This comment included the same suggestions as the nine submissions (detailed above), and additionally advocated for maintaining a focus on workforce development and reconsidering the impact of federal developments resulting from the Inflation Reduction Act.

Thirty-six comments were identified as submitted by organizations. The types of organizations that submitted responses are shown in Table B-1. Non-governmental organizations (NGOs) and industry companies submitted the most organizational comments.

TABLE B-1. COMMENT BREAKDOWN BY ORGANIZATION TYPE

Organization Type	Number of Comments
Political or Municipal Groups	2
Industry	16
NGO	18
Total	**36**

Throughout the development of the 2050 CECP, committees, including the Environmental Justice Council and working groups of the GWSA IAC, provided feedback on this Plan. The comments received from these groups are not included in the above chart and table, but this feedback was reviewed and incorporated in the detailed summary of key comments in the next section.

Summary of Key Feedback and EEA Responses

Generally, most commenters broadly supported the 2050 CECP. EEA has reviewed all comments received and incorporated public input into the 2050 CECP where possible. Some comments received and suggestions made may not be reflected in this 2050 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 2050 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 2050 CECP;

B. Feedback that EEA has not incorporated into the 2050 CECP, but will consider for future CECPs; and
C. Feedback that EEA has considered, and has decided that the perspective provided or the approach suggested are not fitting for the 2050 CECP.

A. Feedback that EEA incorporated into the 2050 CECP

Feedback: Make the state's Plan clearer with specific targets, goals, and timelines.

- The 2050 CECP includes specific benchmarks and timelines of policies and commitments. The benchmarks are listed in Table 3-3 of Chapter 3. Policy and commitment timelines are included throughout the Plan and summarized in Appendix A.

Feedback: Improve transparency by making models public, stating assumptions, and clarifying implementation methods.

- The Commonwealth is committed to using the best available science, technology, and data. As noted in Chapter 3 of the 2050 Plan, the analysis informing the 2050 emissions limit, sublimits, and this Plan is based on the analyses conducted for the 2025/2030 CECP and the 2050 Decarbonization Roadmap Study (2050 Roadmap Study).[235] Please refer to Appendix A in the 2025/2030 CECP and the Energy Pathways to Deep Decarbonization Technical Report to 2050 Roadmap Study for detailed information on the energy pathways model as well as key assumptions and methods. Additionally, completed model outputs are available upon request.

Feedback: Provide clarity on how emissions sublimits were determined and the accounting methods used.

- Chapter 3 (see Figure 12 and Table 13) of the 2050 CECP discusses the process for setting GHG emission limit and sublimits.

Feedback: Consider the impact and funding opportunities from the federal Inflation Reduction Act (IRA).

- The 2050 CECP takes into consideration how the Inflation Reduction Act complements and reaffirms many of the policies and programs described in this Plan, especially in how funding from federal legislation can support the Commonwealth's programs.

[235] The 2025/2030 CECP is available at https://www.mass.gov/2030CECP and the 2050 Roadmap Study reports are available at https://www.mass.gov/2050roadmap.

Feedback: Prioritize investments and decarbonization efforts in environmental justice (EJ) communities. In addition, monitor and track progress.

- The Administration recognizes the need to prioritize clean energy and climate investments and decarbonization efforts in EJ neighborhoods and to benefit EJ populations. Starting in 2023, EEA will identify the best metric to track clean energy and climate investments to disadvantaged communities and EJ populations, whether it be a percentage-based investment or a total funding requirement. See Chapter 3 of the 2050 CECP for additional details.

Feedback: Take action to verify that the costs of electrification are not disproportionately affecting low- and moderate-income (LMI) communities.

- Through the discussion of the Clean Energy Clearinghouse and Climate Finance Accelerator in Chapter 5b of this 2050 Plan, Massachusetts will target outreach to LMI and EJ populations to provide information and logistics for decarbonization-focused programs, financing options, and technical support. The Commonwealth will evaluate mechanisms to mitigate risks to customers (including LMI and EJ customers) associated with the transition of the gas delivery system.

Feedback: Ensure community engagement.

- EEA will continue best practices for enhanced community engagement. As discussed in Chapters 2 and 4 of this 2050 Plan, Massachusetts will launch a Climate Campaign in 2023 to increase awareness, understanding, and receptivity of climate actions and clean energy technologies. EEA will increase engagement with cities and towns, including providing "toolkits" that will help each community access financial and technical assistance support from the state, with a focus on ensuring inclusion and a just transition for all communities, while being particularly attentive to the unique needs of EJ populations.

Feedback: Provide incentives and break down barriers to LMI consumers purchasing EVs.

- Massachusetts will continue to provide financial incentives to accelerate EV adoption through the MOR-EV and MOR-EV Truck programs. Additionally, clean transportation programs will provide targeted incentives for LMI residents.

Feedback: Protect EJ communities when siting energy facilities and infrastructure.

- Massachusetts will continue to promote regulatory processes that are inclusive to all stakeholders, particularly those who often host infrastructure in their communities. This includes being a part of siting decision-making processes. As discussed in Chapter 2 of the 2050 CECP, the Commonwealth will develop a holistic state-wide plan for siting energy infrastructure, kicking off the process in 2024.

Feedback: Consider needs of rural areas and ensure there are incentives and development opportunities in rural areas.

- The Administration recognizes the unique offerings of the rural economy and the needs of rural communities. As discussed in the 2025/2030, the Commonwealth will commission a study to identify potential opportunities (including workforce needs) to support the local durable wood market, which would benefit the rural economies of central and western regions of Massachusetts. Additionally, EEA will develop and seek to advance new legislation to support the goal of no net loss of forest and farmland, which would include a state Payment in Lieu of Taxes (PILOT) bonus to facilitate land protection in rural communities with a low tax base and high percentages of state conservation land. As the Commonwealth significantly scales up reforestation and tree planting efforts, state agencies will explore options to procure additional trees, potentially contracting with local nurseries and/or develop additional nurseries within rural regions of Massachusetts (see Chapter 5e of the 2050 CECP for more details).

Feedback: Involve the state government at all levels, including potentially creating new agencies to assist implementing the Plan. Municipalities, non-profits, and other actors should also be empowered.

- Development and implementation of the 2050 CECP was and will be a cross-agency and cross-secretariat-wide effort, led by EEA. EEA's outreach efforts will expand assistance to municipalities in achieving decarbonization objectives.

Feedback: Create employment and training opportunities for Plan implementation.

- Building a robust and diverse clean energy workforce is a core consideration towards meeting the 2050 climate goals. Massachusetts has already implemented multiple programs to prepare the clean energy workforce through educational and vocational training and is in the process of expanding workforce training efforts to provide increased opportunities for unemployed, underemployed, and historically marginalized communities.

The 2050 CECP discusses several such initiatives, including launching a Climate Service Corps and supporting the Equity Workforce Development program.

Feedback: The Plan should encourage transportation mode shift by investing in infrastructure for alternatives such as walking and biking.

- MassDOT will continue to invest in multimodal transportation infrastructure through MassDOT programs (Complete Streets and Shared Streets and Spaces) and work with employers to consider changing commuting patterns. Additionally, the Massachusetts vehicle retirement program will help low- and moderate-income residents replace old vehicles with alternatives including e-bikes.

Feedback: The Plan should have more emphasis on improving and electrifying public transit and increasing access to public transportation for low-income riders.

- Massachusetts will continue to implement the policies as laid out in the 2025/2030 CECP to improve, promote, and electrify public transit (e.g., MBTA Communities, MBTA Bus Modernization). MassDOT and the MBTA will continue to work to meet the goals for electrification of transit outlined in the 2022 Climate Act and detailed in the MBTA Rail Vision. Programs such as MBTA Communities will expand housing near transit stations to increase access to public transit. The Administration will continue to seek sustainable funding to provide affordable service to disadvantaged communities. MassDOT will continue working with municipalities and RTAs on pilot projects exploring fare-free bus service via the "Try Transit" grant program.

Feedback: Encourage smart charging.

- The Commonwealth recognizes the importance of encouraging smart charging and expects EV adoption to reach close to 5% of all light-duty vehicles by 2025. Massachusetts will work with utilities to develop programs that will require smart charging approaches to be the default choice for EV owners. The Commonwealth will also review incentive program rules and requirements to maximize EV owner participation in demand management program. The Commonwealth encourages load-control programs or pricing approaches to efficiently shift charging times.

Feedback: Expand EV charging quickly and equitably.

- The Commonwealth is currently developing a detailed plan for building out public charging infrastructure with support from the federal government and electric utilities.

Massachusetts was among the first states to complete its electrification plan, making the Commonwealth eligible for federal discretionary funds from the IIJA. The Administration will consider equity in this upcoming plan and ensure charging stations do not serve as a barrier to EV adoption in low- and moderate-income communities.

Feedback: Support solutions including hydrogen, renewable natural gas (RNG), or other biofuels for hard-to-electrify transportation applications such as airplanes, ships, and long-haul trucks.

- Chapter 6 of the 2050 CECP includes a detailed explanation of alternative fuels such as RNG and hydrogen and ensures that the policies are to use alternative fuels for hard-to-electrify applications until they are much more abundant and economical. Chapter 6 details the considerations regarding feedstock availability and costs of alternative fuels.

Feedback: Leverage Mass Save® to prioritize deep energy retrofits and weatherization.

- Following the change to the mandate of Mass Save® programs in the 2022 Climate Law, the 2050 CECP adopts the Clean Heat Commission's recommendation to create the Clean Energy Clearinghouse. The Clearinghouse will serve as the central hub for a variety of decarbonization-focused programs, such as Mass Save®. This streamlined approach will provide assistance and financing options for decarbonization solutions, including building retrofits and electrification.

Feedback: Support for a technology-neutral Clean Heat Standard.

- The 2050 CECP adopts the framework for a Clean Heat Standard, which, like other environmental standards that use marketable credits. The specific details of the Clean Heat Standard will be determined through a regulatory process led by the Department of Environmental Protection (MassDEP) in consultation with the Department of Energy Resources (DOER) and the Executive Office of Housing and Economic Development (EOHED) that includes stakeholder processes. The focus of the Clean Heat Standard will be on encouraging electrification and energy efficiency.

Feedback: Commit to joint utility planning to determine the best way to support electrification/decarbonization.

- The 2050 CECP includes a strategy for joint planning between electric and natural gas utilities. The Commission on Clean Heat has recommended that the Department of Public

Utilities and Department of Energy Resources establish a framework for conducting joint energy system planning. The 2050 CECP adopts this recommendation.

Feedback: Establish specific benchmarks and goals for building electrification.

- Following the recommendations from the Commission on Clean Heat, DOER will develop a labeling system, building upon the existing U.S. Department of Energy building scorecard program and DOER's pilot scorecard programs (that have been rolled out in conjunction with Mass Save® in certain communities) and roll out a program for all building types across the Commonwealth by 2025.

Feedback: Transition to a Forward Clean Energy Market (FCEM) while ensuring that customer bills are not adversely impacted.

- The Commonwealth is currently designing a proposal for a FCEM with a straw approach released at the end of 2022. Key stakeholders will be consulted, including neighboring states, customers, ISO-NE, and others. This will include investigating how an FCEM can integrate with existing wholesale electricity markets and how it will impact different stakeholders.

Feedback: Include more detail on how the Commonwealth will work across the region to ensure efficient transmission planning.

- The Commonwealth will continue to actively engage on the 2050 Transmission Study conducted by ISO-NE, the ongoing FERC regulatory proceedings related to transmission, the New England States Transmission Initiative, and other ongoing regional processes to advance transmission planning that will support the Commonwealth's decarbonization goals.

Feedback: Prepare the distribution system for electrification by streamlining the interconnection of renewables, emphasizing reliability and resiliency solutions, and coordinating with both electricity and natural gas utilities.

- The Commonwealth will initiate a Grid Modernization Advisory Council (GMAC) to consider holistic distribution system planning and review electric grid modernization plans submitted by the EDCs. GMAC feedback will seek to maximize customer benefits, ensure cost-effective investments, support state goals, and improve grid reliability and resiliency. Electric distribution companies and gas local distribution companies will coordinate across the state to ensure that strategies align with and accelerate state goals.

Feedback: Improve tree-planting efforts statewide.

- The Commonwealth is committing to planting at least 64,400 additional acres of riparian and urban trees by 2050. To reach this goal, the Commonwealth will leverage federal and state funding and will explore supply procurement options to meet tree planting demands.

Feedback: Limit deforestation going forward, in particular (1) protecting natural and working lands (NWL) from being cleared for solar installations and (2) siting solar on rooftops and built land instead.

- The Commonwealth aims to permanently conserve at least 40% of Massachusetts lands and waters by 2050, covering 685,000 acres. To reach this goal, the Commonwealth will leverage federal and state funding as well as explore innovative funding options for land acquisition and conservation easements. To mitigate NWL loss for solar installations, DOER is conducting the Technical Potential of Solar study to assess solar siting considerations for environmental, land use, and economic factors. Additionally, DOER recently prohibited the clearing or conversion of forest land for agrivoltaic systems eligible for financial incentives under the Solar Massachusetts Renewable Target (SMART) program.

Feedback: Partner with non-governmental organizations (NGOs), community organizations, etc. to maintain and manage NWL.

- The Commonwealth will continue partnering with land trusts, municipalities, NGOs, and community organizations for NWL conservation and management. As discussed in Chapter 5e, the Commonwealth will increase support to municipalities, land trusts, and private landowners to expand NWL conservation. To expand tree planting, the Commonwealth will enlist help from additional partners, such as NGOs, schools, and youth groups.

Feedback: Create a healthy soils program to support farmers adopting healthy farming practices.

- As discussed in the 2025/2030 CECP and again in the 2050 CECP, the Commonwealth will encourage climate-smart, healthy soils practices on croplands, and leverage federal funding for conservation practices that improve agricultural soil health and carbon storage while reducing agricultural emissions.

Feedback: Streamline permitting and siting for transmission and distribution facilities and strengthen exemptions in regulations for utilities.

- The Commonwealth will evaluate this issue as part of efforts to reform the transmission planning process and develop a holistic approach for siting energy infrastructure, as discussed in Chapters 2 and 5c.

Feedback: Emissions from biogas and biofuels should not be treated as carbon neutral or carbon negative resources.

- Depending on the feedstock, some alternative fuels can reduce GHG emissions, relative to fossil fuels, when evaluated on a lifecycle basis. However, alternative fuels involve direct combustion and indirect emissions. As alternative fuels become more prevalent in the Commonwealth, MassDEP will evaluate the impacts of alternative fuels' GHG emissions which may lead to changes in emission accounting methodologies and programs.

Feedback: Include increased support for Renewable Natural Gas (RNG) and hydrogen in the plan.

- Depending on the future availability, production costs, and market price of alternative fuels (such as RNG and hydrogen), they may be suitable for high-value, hard-to-electrify applications. As discussed in Chapter 6, the Commonwealth will fund alternative fuel research and development and pilot programs.

Feedback: Revisit assumptions regarding methane leaks and methane's global warming potential (GWP).

- MassDEP adopted a new methodology from the U.S. Environmental Protection Agency that added post-meter natural gas leak emissions to the most recent GHG inventory. MassDEP continues to monitor advances in methane emissions estimation, including the U.S. Environmental Protection Agency's expected update of methane's GWP in calendar year 2024 for calendar year 2022 emissions.

Feedback: Track and reduce methane leaks from the gas distribution system.

- The Department of Public Utilities' 220 CMR 114 requires gas operators to identify and repair Grade 3 significant environmental leaks. The regulation also requires gas operators with a GSEP to report the number of environmentally significant Grade 3 leaks on each length of GSEP-eligible pipe in its annual Gas System Enhancement Plan Reconciliation (GREC) filing. In addition, MassDEP's 310 CMR 7.73 *Reducing Methane Emissions from Natural Gas Distribution Mains and Services* regulation requires gas operators with a GSEP to meet declining annual limits on methane emissions from mains and services.

Feedback: Ensure that forthcoming accounting for biofuels and synthetic fuels in the Commonwealth's GHG inventory will fully and fairly account for the emissions reduction value of these fuels.

- Chapter 6 discusses that the Commonwealth will evaluate whether it may be necessary to update Massachusetts' GHG emissions accounting methodologies and programs to account for GHG emissions associated with alternative fuels.

Feedback: Ensure carbon sinks are real, verified, and permanent.

- As discussed in Chapter 7, these are among the key considerations that Massachusetts will weigh in developing its carbon sequestration strategies.

Feedback: Prioritize GHG emissions reduction over emissions offsets.

- As explained in Chapter 3, to comply with the 2050 Net Zero Limit, Massachusetts must reduce its GHG emissions by at least 85% below to the 1990 baseline level. Carbon sequestration can only help address the residual emissions, weighing the considerations outlined in Chapter 7.

B. Feedback that EEA has not incorporated into the 2050 CECP, but will consider in future CECPs because they serve longer-term goals

Feedback: Address the potential for future mechanisms to adjust emission sublimits, if needed, based on cost and feasibility of achievement.

- The Administration recognizes that EEA may need to update the 2050 sublimits in subsequent CECPs to reflect updated information, and has noted as such in Chapter 3 of the 2050 CECP.

Feedback: Provide clarification on why natural gas distribution emission reductions are lower in 2050 compared to 2030 (71% v. 82%). As distribution system leaks are repaired and customers transition off gas, leaks should decline.

- The methodology for natural gas distribution emissions accounting has recently been changed in accordance with EPA improvements by adding post-meter natural gas leak emissions. The 2030 sublimit is based on the February 2022 version of the 1990 baseline, which does not include the update. The 2050 sublimit is based on the December 2022 version of the 1990 baseline, which does include the update. Thus, the 2030 and 2050 sublimits are based on different 1990 baselines. Future CECPs will use the most recent 1990 baseline available.

Feedback: Require emissions reductions from large buildings instead of just energy reporting.

- The Clean Heat Standard will require obligated parties to demonstrate a reduction in emissions by deploying applicable clean technologies or purchasing clean heat credits from parties that have successfully implemented solutions.

Feedback: Set a more ambitious Clean Energy Standard (CES); increase it to 100% by 2035.

- MassDEP recently amended the CES so that the combined effect of Massachusetts' electricity standards is projected to reach approximately 90% in 2030 and approach 100% in 2050. A program review is required in 2031.

Feedback: Some commenters advocated for adding nuclear as part of the power sector strategy for meeting emission reductions targets.

- Beginning in 2021, both remaining nuclear power plants in New England are eligible for crediting under MassDEP's Clean Energy Standard (CES). This provides support for their continued operation and ensures that a portion of their output is credited to Massachusetts.

Feedback: End subsidies for and phase out high-heat waste facilities.

- The Commonwealth's 2030 Solid Waste Master Plan underscores a concerted effort "to improve the performance of existing combustion capacity and, in the 2025 program review, explore the potential to establish a declining cap on carbon dioxide emissions from municipal waste combustors."

Feedback: Reconsider timeline for phasing out SF_6 technology.

- MassDEP will stay abreast of research and development to determine when SF_6 use in the electric transmission and distribution system can be phased out and will update its regulation accordingly, based on national trends and the economics of the alternatives.

Feedback: Set more specific, quantitative goals, including on tree cover tracking, planting, and blue carbon.

- As outlined in Chapter 5e, the Commonwealth has set specific goals for tree planting and permanent conservation of NWL. EEA is developing a spatially explicit NWL inventory that, once completed in 2023, can be used to track tree canopy coverage over time and inform the setting of tree canopy goals. EEA is also monitoring developments related to blue carbon (which is carbon stored in coastal and marine ecosystems) and aims to have a better methodology for estimating and tracking annual GHG flux on wetlands.

Feedback: Set more ambitious goals for protecting NWL.

- The Commonwealth will continually evaluate its progress in conserving NWL and revise the goals as appropriate.

Feedback: Set specific, quantitative goals on carbon removal, especially for NWL.

- This CECP is not setting a specific 2050 NWL sequestration goal at this time, due to significant uncertainty and a wide range of possible outcomes related to natural processes. EEA will be publishing an update to the 2050 Roadmap Land Sector Report, which will better inform potential NWL sequestration levels in 2050 and enable better estimates of potential policy effects. An NWL sequestration goal may be set at that time and/or in future CECPs.

Feedback: Set air pollution reduction targets in environmental justice communities.

- The electrification of our energy systems, heat systems in buildings, and vehicles will dramatically reduce greenhouse gas emissions and air pollution throughout the Commonwealth, including EJ neighborhoods. To expand its air quality monitoring network, MassDEP is establishing new monitoring stations (e.g., in Chelsea in 2021, and planned for the Chinatown neighborhood of Boston in 2023) and providing air sensors to municipalities. The data will increase public understanding of air quality and guide actions to reduce air pollution, especially in EJ populations. MassDEP has also received funding under ARPA to upgrade and expand particle pollution monitoring in and near EJ populations and will seek additional funding for community-based air quality monitoring under the federal Inflation Reduction Act. The setting of air pollution reduction targets in EJ neighborhoods may be pursued for future CECPs.

Feedback: Clean Heat Standard should include renewable natural gas (RNG) and hydrogen.

- The 2050 CECP adopts the Clean Heat Standard (CHS) recommendation put forth by the Commission on Clean Heat. The details of the CHS will be set through a regulatory process conducted by MassDEP, in consultation with DOER and EOHED, and a stakeholder process.

The 2050 CECP finds that the future availability, production costs, and market price of alternative fuels (such as RNG and hydrogen) will determine their suitability for high-value, hard-to-electrify applications.

Feedback: Expand employer-led efforts to incentivizing decarbonization.

- The Commonwealth has been working towards encouraging employer collaboration with community-based organizations, labor unions, schools, and state programs in providing employment opportunities in clean energy. MassDEP currently implements the Massachusetts Rideshare Regulation (310 CMR 7.16), which requires certain facilities to implement and maintain measures designed to achieve a non-binding goal of reducing single-occupancy vehicle (SOV) commutes by 25% and to produce annual reports detailing steps taken to achieve that goal. Massachusetts will continue to expand on this initiative and consider how telework could play a role in reducing unnecessary commute travel.

Feedback: Set goal to track and reduce vehicle miles traveled (VMT).

- Policies in the 2050 CECP will decrease per capita VMT from the projected level for the future. However, modeling suggests that the decrease will be modest. Massachusetts will achieve this modest reduction by improving and encouraging public transit as well as other alternative modes, and building more housing near transit, which will help reduce emissions.

C. Feedback that EEA has considered, and has decided that the perspective provided or the approach suggested are not fitting for the 2050 CECP

Feedback: Decrease emphasis on electrification and examine the impacts and benefits for all decarbonization technologies.

- The 2050 CECP adopts the findings of the Commission on Clean Heat. Electrification is the economically and practically preferred methodology to reduce GHG emissions in the buildings sector. To achieve this, various clean technologies such as air-source heat pumps, ground-source heat pumps, or district geothermal systems could be used. If and when other clean resources become available and cost-effective, future CECP can update the plans based on new and best available information at that time.

Feedback: Impose sub-limits on the agriculture sector.

- As noted in Chapter 3, non-biogenic emissions from Agriculture are relatively small (have been 0.3-0.5 MMTCO_2e since 1990) and projected to continue to be small in 2050. Biogenic emissions from croplands and grasslands are also relatively small, estimated to be 0.3 MMTCO_2e in 2020 and likely not much more in 2050. While there are no specific sublimits on agricultural emissions, non-biogenic emissions from this sector are included in the 85% emissions reduction requirement of the state-wide Net Zero Limit.