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Statewide Greenhouse Gas Emissions Level: 1990 Baseline Update

Regulatory Authority: MGL Chapter 21N, Section 3

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Tables and Figures

Additional Appendices (Excel Spreadsheets)[2]

[1] See Appendix B "MassDEP Emission Reduction Programs for Mobile Sources" in https://www.mass.gov/doc/statewide-greenhouse-gas-ghg-emissions-baseline-projection-update-including-appendices-a-b/download.

[2] These Appendices can be found at: https://www.mass.gov/doc/statewide-greenhouse-gas-ghg-emissions-baseline-projection-update-including-appendices-a-b/download.

Introduction

The Massachusetts Global Warming Solutions Act (GWSA)[3] was signed into law in August of 2008 to address the challenge of climate change caused by the emissions of greenhouse gasses (GHG). GHGs accumulate in the atmosphere and trap heat that would otherwise be radiated back into space. This "greenhouse effect" is the primary cause of global climate change. There are a number of gases that are considered GHGs. The most prevalent GHG is carbon dioxide (CO_2), which is emitted when fuels are burned. Methane (CH_4), nitrous oxide (N_2O), and several other compounds primarily used as refrigerants are also GHGs of concern due to their potential to contribute to climate change.[4]

GWSA established the Climate Protection and Green Economy Act in Massachusetts General Law, which requires the Massachusetts Department of Environmental Protection (MassDEP) to, among other actions "*... triennially publish a state greenhouse gas emissions inventory that includes comprehensive estimates of the quantity of greenhouse gas emissions in the commonwealth for the last 3 years in which the data is available,*" and "*...determine the statewide greenhouse gas emissions level in calendar year 1990 and reasonably project what the emissions lever will be in calendar year 2020 if no measures are imposed to lower emissions other than those formally adopted and implemented as of January 1, 2009.*" [MGL chapter 21N, section 2, subsection (c) and section 3, subsection (a)]

Section 14 of GWSA further required MassDEP to establish the 1990 Baseline and 2020 Business as Usual (BAU) Projection by July 1, 2009. The 1990 Baseline and BAU Projection[5] were published July 1, 2009 and presented actual emissions from 1990 through 2008 for most sectors, and projected emissions to 2020 for all sectors. The 1990 Baseline is the emissions level against which Massachusetts' future GHG emissions reductions limits will be planned and measured.

GWSA required the Secretary of the Executive Office of Energy and Environmental Affairs (EEA), in consultation with other state agencies and the public, to establish a statewide limit on GHG emissions of between 10 percent and 25 percent below 1990 emissions level for 2020 along with a plan to achieve the 2020 limit [MGL chapter 21N, section 4, subsection (a)]. In December 2010, the Secretary of EEA set the 2020 limit at 25 percent below the 1990 Baseline level. The *Massachusetts Clean Energy and Climate Plan for 2020* (2020 CECP), also published in December 2010, contained strategies to meet that limit, and was updated December 31, 2015.[6]

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[3] See https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298

[4] Not all GHGs have the same heat-trapping capacity. For example, one ton of methane is equivalent to greater than 20 tons of CO_2 with respect to their heat trapping potentials. To account for these differences, a standard, known as the global warming potential (GWP), relating the heat trapping potential of each GHG to an equivalent quantity of CO_2 over a given time horizon, has been developed. Emissions shown in this document utilize this standard and are expressed in units of million metric tons of carbon dioxide equivalents ($MMTCO_2e$).

[5] *Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business As Usual Projection (2009)* at: https://www.mass.gov/doc/statewide-greenhouse-gas-emissions-level-1990-baseline-2020-business-as-usual-projection/download

[6] *2015 Update: Massachusetts Clean Energy and Climate Plan for 2020* see http://www.mass.gov/eea/docs/eea/energy/cecp-for-2020.pdf

On April 22, 2020, the Secretary of EEA published the 2050 Letter of Determination[7] setting the 2050 statewide emissions limit of "net zero greenhouse gas emissions 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."

On March 26, 2021, *An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy* was signed into law.[8] Some major requirements of this statute include:

- The adoption of interim statewide GHG emissions limits for 2025, 2030, 2035, 2040, and 2045;
- An interim 2030 statewide GHG limit that is at least 50% below the 1990 level, an interim 2040 GHG limit that is at least 75% below the 1990 level, and a statewide greenhouse gas emissions limit for 2050 that achieves at least net zero statewide greenhouse gas emissions provided that in no event shall the level of emissions in 2050 be higher than a level 85% below the 1990 level; and
- The adoption of sector-based statewide greenhouse gas emissions sublimits for electric power, transportation, commercial and industrial heating and cooling, residential heating and cooling, industrial processes, and natural gas distribution service.

Updating the 1990 Baseline

The *Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business as Usual Projection* (July 2009)[9] 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."

By 2016, significant new data had become available, so MassDEP sought public comment and subsequently published an updated 1990 Baseline in the *Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business as Usual Projection Update* (July 2016),[10] which supported the 2020 CECP update.

MassDEP is now proposing to update the methodologies and data used to estimate Massachusetts' 1990 GHG emissions a second time. These updates are described in Appendix A

[7] "*Determination of Statewide Emissions Limit for 2050*" see: https://www.mass.gov/doc/final-signed-letter-of-determination-for-2050-emissions-limit/download
[8] See Chapter 8 of the Acts of 2021 at https://malegislature.gov/Laws/SessionLaws/Acts/2021/Chapter8
[9] *Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business As Usual Projection (2009)* see: https://www.mass.gov/doc/statewide-greenhouse-gas-emissions-level-1990-baseline-2020-business-as-usual-projection/download
[10] *Statewide Greenhouse Gas Emissions Leve: 1990 Baseline and 2020 Business As Usual Projection Update (2016)* see: https://www.mass.gov/doc/statewide-greenhouse-gas-ghg-emissions-baseline-projection-update-including-appendices-a-b/download

to this *Statewide Greenhouse Gas Emissions Level: 1990 Baseline Update*. MassDEP is not proposing to update the *2020 Business as Usual Projection* since 2020 is now in the past.

- Part 1 of this document describes the update to the 1990 Baseline;
- Part 2 is a comparison of previous and updated GHG emissions levels; and
- Appendix A describes the sources of GHG emissions, data sources and methodologies used to determine the updated Massachusetts 1990 Baseline.

A public comment period is now open on the *Statewide Greenhouse Gas Emissions Level: 1990 Baseline Update.* MassDEP will accept written comments until 5:00 PM on Monday, June 28, 2021. Written comments must be submitted by email to climate.strategies@mass.gov or by mail to Sue Ann Richardson, MassDEP, One Winter Street, 6th Floor, Boston, MA 02108.

Part 1: Massachusetts 1990 GHG Emissions Baseline Update

What is the purpose of the 1990 Baseline? The *Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy* calls for the Commonwealth to adopt statewide GHG emissions limits for 2025, 2030, 2035, 2040, 2045 and 2050 expressed as percent reductions relative to the emissions level in the year 1990. The 1990 Baseline presented here will provide an updated emissions level against which these future limits will be set, and against which progress in achieving reductions will be measured.

Using the revised and updated data sources and methodologies described in Appendix A, MassDEP estimates that statewide GHG emissions in 1990 were 94.3 million metric tons of carbon dioxide equivalents ($MMTCO_2e$). Table 1, below, shows a breakdown of the updated 1990 Baseline GHG emissions by sector. Data and methodology updates were made to the following sectors: Residential, Industrial, Transportation, Wastewater, Natural Gas Distribution, Natural Gas Transmission & Storage, and Electricity Imports. (See Appendix A.) The tables in Parts 1 and 2 and the figures in Part 2 are based on the calculations in the spreadsheet in Appendix C.

Table 1: 1990 Baseline Update ($MMTCO_2e$)

Sector	1990 Emissions
CO_2e from Energy	88.0
Residential CO_2e from Fuel Combustion	15.3
Residential - CO_2	15.1
Residential - CH_4 & N_2O	0.2
Commercial CO_2e from Fuel Combustion	8.4
Commercial - CO_2	8.4
Commercial - CH_4 & N_2O	0.1
Industrial CO_2e from Fuel Combustion	5.8
Industrial - CO_2	5.6
Industrial - CH_4 & N_2O	0.0
Industrial - MSW (CO_2, CH_4 & N_2O)	0.1
Industrial - Nat Gas System (CO_2, CH_4 & N_2O)	0.1
Transportation CO_2e from Fuel Combustion	30.5
Transportation - CO_2	28.9
Transportation - CH_4 & N_2O	1.6
Electricity Total CO_2e from Fuel Combustion	28.0
Electric Generation - CO_2	25.1
Electric Generation - CH_4 & N_2O	0.1
Electric Generation - MSW (CO_2, CH_4 & N_2O)	0.9
Electricity Imports (CO_2, CH_4 & N_2O)	1.9
Natural Gas Systems (CO_2 and CH_4)	2.3
Natural Gas Distribution System	2.1
Natural Gas Transmission and Storage System	0.2
Industrial Processes	0.7
Lime, Dolomite, Soda Ash, Urea (CO_2)	0.2
ODS Substitutes, Semiconductor Manufacturing, Electricity Transmission (HFCs, PFCs, NF_3, SF_6)	0.5
Agriculture & Land Use (CO_2, CH_4 & N_2O)	0.4
Waste	2.9
Wastewater (CH_4 & N_2O)	0.7
Municipal Solid Waste - Landfills Only (CO_2, CH_4 & N_2O)	2.3
Gross Emissions	*94.3*

Note: Due to rounding to 1 decimal place, some totals appear higher or lower than the simple sum of the sectors. GHGs include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

Part 2: The Updated Massachusetts GHG Inventory

This updated 1990 Baseline contains complete GHG emissions through the year 2018, with partial emissions where data is available for 2019 and 2020, using the updated data, methodologies, and emission factors discussed in Appendix A. The following three figures show trends in GHG emissions.

Figure 1: Massachusetts 1990-2018 GHG Emissions with Updated 1990 Baseline

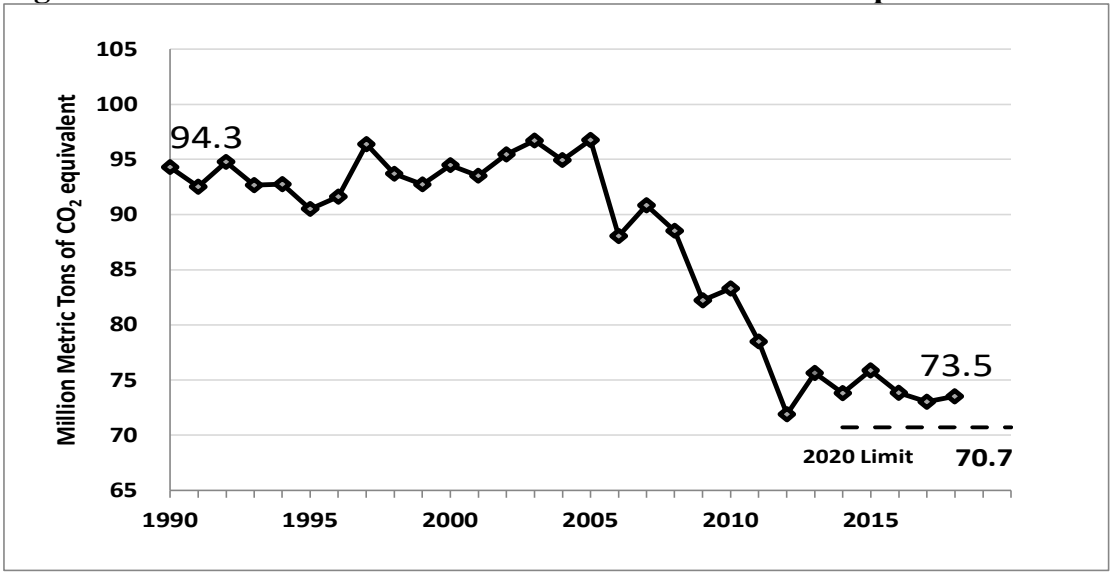

Figure 2A: Massachusetts 1990-2018 Fuel Combustion GHG Emissions by Sector

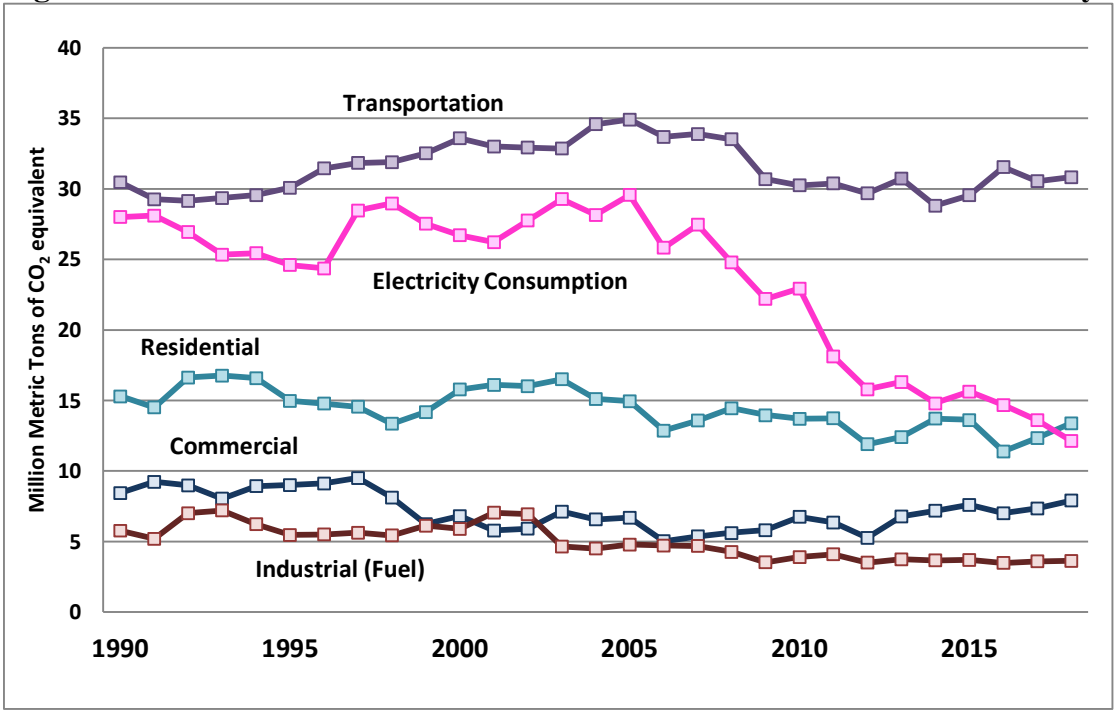

Figure 2B: Massachusetts 1990-2018 Non-Fuel Combustion GHG Emissions by Sector

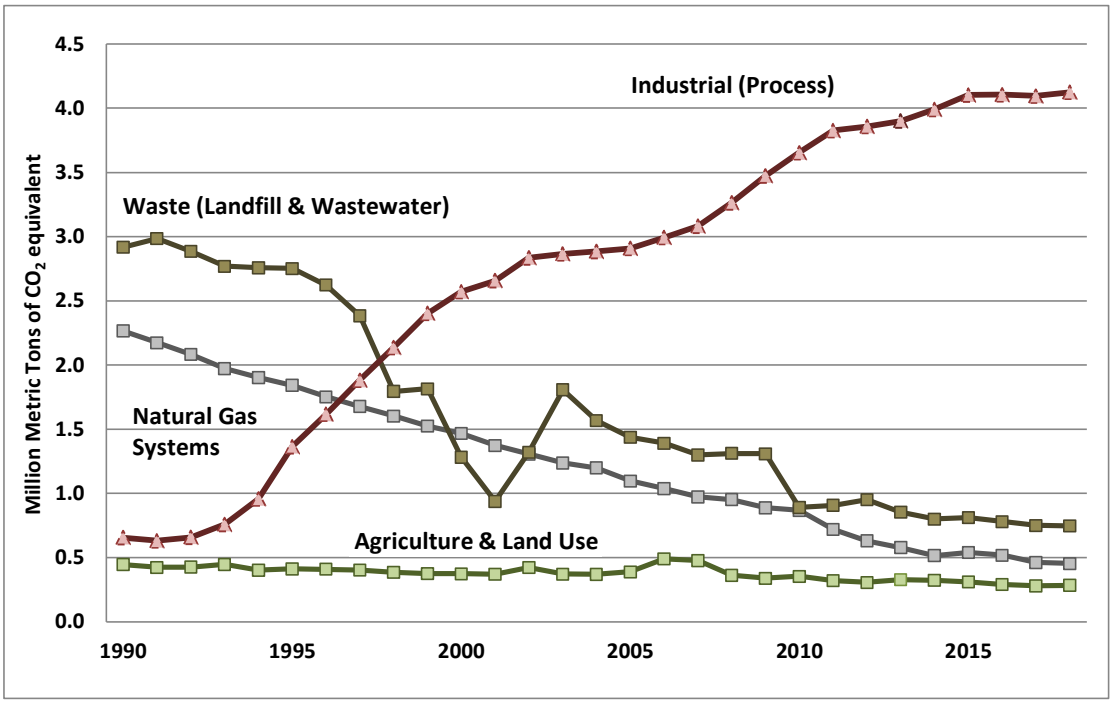

Table 2 presents a comparison of GHG emissions by year. GHG emissions are shown for: 1990, 2013 (the last year for which a complete inventory was developed in the 2016 update), the 2020 limit (25% below 1990) and the 2030 limit (at least 50% below 1990).[11] The middle column in the table shows GHG emissions which were published by MassDEP at the time of the last 1990 Baseline update in 2016 and the rightmost column in the table shows GHG emissions which have been updated using revised sector methodologies, updated data sources, and in some instances updated emission factors.

Table 2: Comparison of Massachusetts 1990 and 2013 GHG Emissions, and the 2020 Limit (MMTCO2e)

Year	2016 Published Values	2021 Published Values
1990 (Baseline)	94.4	94.3
2013 (Actual)	75.5	75.6
2020 Limit (25% below 1990)	70.8	70.7

MassDEP publishes a detailed GHG inventory at least every three years as required by MGL chapter 21N, section 2, subsection (c), usually annually, when major new data are released by the U.S. Energy Information Administration (EIA) for energy consumption in mid-summer and by the U.S. Environmental Protection Agency (EPA) for the remaining inventory sectors in early

[11] The 2025 and 2030 interim statewide GHG limits and sector-based GHG emissions sublimits must be adopted and published no later than July 1, 2022.

fall. Current GHG inventory spreadsheets, supporting appendices, and texts are available on MassDEP's website.[12]

Appendix A contains detailed information about the data sources and methodologies used to develop this updated GHG inventory and a comparison of those data sources and methodologies to those used for the 2016 update. The spreadsheet in Appendix C contains the GHG emissions upon which this inventory is based. The spreadsheets in Appendices D through U contain data upon which the 2001 through 2018 Electricity Import emissions are based.

GHG emissions are provided for the following years:

- 1990 through 2018: now with revised sector methodologies, updated data sources, and updated emission factors (see Appendix A below for details).
- 2019: partially complete for most sectors, and
- 2020: incomplete for most sectors.

[12] See https://www.mass.gov/lists/massdep-emissions-inventories#greenhouse-gas-baseline,-inventory-&-projection-

Appendix A: GHG Emission Sources, Data Sources and Methodology

This section describes the sources of GHG emissions data, the methodologies that MassDEP used to develop this updated Massachusetts GHG inventory, and the differences between the sources of GHG emissions and the methodologies used to determine the 1990 Baseline inventory in 2016 and this update. A section has been added to the Appendix C spreadsheet that allows the user to select the global warming potentials (GWPs) used to calculate most emissions.

1. Sources of GHG Emissions

Combustion of Fossil Fuels. The biggest contribution to CO_2 emissions comes from burning fossil fuels for heat, transportation, and electricity generation. Fossil fuel combustion also generates CH_4 and N_2O. Fossil fuels are combusted in the Residential, Commercial, Industrial, Transportation, and Electric Generation sectors. The non-energy consumption of asphalt, road oil, lubricants and waxes are excluded from reported emissions.

Industrial Processes. EPA has identified 15 specific United States industrial processes that emit significant quantities of GHGs: Cement Production, Lime Manufacture, Limestone and Dolomite Use, Soda Ash Manufacture and Consumption, Iron and Steel Production, Ammonia Manufacture, Urea Consumption, Nitric Acid Production, Adipic Acid Production, Aluminum Production, Hydrochlorofluorocarbon (HCFC)-22 Production, Consumption of Substitutes for Ozone-Depleting Substances (ODS), Semiconductor Manufacture, Electric Power Transmission and Distribution, and Magnesium Production and Processing. The industrial processes conducted in Massachusetts are Lime Manufacture, Limestone and Dolomite Use, Soda Ash Consumption, Urea Consumption, Consumption of Substitutes for ODS, Semiconductor Manufacture, and Electric Power Transmission and Distribution.

Natural Gas and Oil Systems. EPA identifies all phases of natural gas systems (including production, transmission, venting and flaring, and distribution) and petroleum systems (including production, refining, and transport) as sources of CH_4 and CO_2 emissions. Of these, only transmission and distribution systems of natural gas are present in Massachusetts with emissions coming from distribution sector leaks from pipelines, and services, customer meters, metering/regulating stations and venting, and transmission sector leaks from pipelines, compressor stations, and LNG import and storage facilities.

Waste Management. EPA has identified several waste management activities that produce significant GHG emissions: municipal solid waste combustion, landfill methane generation, and wastewater disposal and treatment. All of these occur in Massachusetts.

Agriculture and Land Use. EPA has identified several agricultural processes that are important GHG sources across the country: enteric fermentation (fermentation in the intestines of certain animals such as cows and sheep), manure management, management of plant residues retained in soil, legume cultivation, agricultural fertilizer use, rice cultivation, and burning agricultural residues. As with the industrial sources identified above, some of these activities are not found in Massachusetts or are at such *de minimis* levels that their contribution to GHGs in Massachusetts is negligible, if any (specifically, rice cultivation and agricultural residue burning are the two

processes that do not occur in Massachusetts). Land use means the application of fertilizer (as discussed in section 4 below) and is different from land use change (as discussed in section 6 below).

2. Data Sources and Methodologies

State and federal air pollution control programs have traditionally estimated air emissions of a wide variety of pollutants by applying pollutant-specific emission factors to measures of activities conducted by industrial sectors. EPA has developed a State GHG Inventory Tool (SGIT) which employs this methodology to estimate GHG emissions from sectors of concern in each state, based on the activities in key sectors in the state's economy. SGIT consists of a series of modules, or spreadsheets, which calculate emissions from the various sources of GHGs. Gases included in the inventory are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

The SGIT default data set provided the original basis for estimating and reporting annual GHG emissions by sector and is still the primary tool used for fossil fuel combustion. For example, one sector is electricity generation plants in Massachusetts. The EPA SGIT methodology uses Massachusetts electric generator fuel use data (from the U.S. Department of Energy's Energy Information Administration (EIA)'s State Energy Data System (SEDS)[13]) to calculate the electricity sector GHG emissions from fuel combustion. The SGIT is updated by EPA at least once per year. Each year, at the end of June, EIA releases updates of the data that SGIT uses to calculate CO_2, CH_4 and N_2O emissions from fossil fuel and some biomass combustion (except transportation sector CH_4 and N_2O, which SGIT calculates from other data). MassDEP continues to use SGIT's estimates of GHG emissions from fossil fuel combustion for most sectors of the inventory (as detailed below).

Data sources and methodologies for some sectors were updated with the 1990 Baseline/2020 BAU Projection Update in 2016. The EPA GHG Reporting program began collecting data with the 2010 emissions year. GHG emissions data from this reporting program can be obtained from the EPA *Facility Level Information on Green House Gases Tool* (FLIGHT).[14] FLIGHT provides some Massachusetts facility-specific data that the MassDEP inventory uses in place of SGIT defaults, particularly in the industrial processes and solid waste sectors where SGIT state level emissions were derived from national emissions apportioned to states based on population or sales. Another advantage of FLIGHT is that the data are available much sooner than SGIT.

The natural gas distribution system sector uses pipeline miles and services data from the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA)[15] and numbers of customers from EIA.[16] Starting in 2016, these data were combined

[13] See the EIA State Energy Data System (SEDS) at https://www.eia.gov/state/seds/

[14] See http://ghgdata.epa.gov/

[15] See https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-mileage-and-facilities

[16] See https://www.eia.gov/dnav/ng/ng_cons_num_a_EPG0_VN3_Count_a.htm for number of residential, commercial and industrial customer.

with updated emission factors to estimate CH_4 emissions from leaks in natural gas distribution system components.

3. Estimating GHG Emissions from Massachusetts Consumption of Electricity, including Imported Electricity

It is important to recognize that approximately half of the electricity used in Massachusetts in 2018 was imported from power plants located in other states and in Canada. In order to account for the net electricity imports into Massachusetts, as required by statute,[17] Massachusetts-specific generation and load data were utilized to develop an imported emissions estimate on the 'ElecImport' tab of Appendix C.

There are a variety of methods that can be used to estimate the emissions due to Massachusetts' consumption of electricity, including emissions associated with electricity generated out-of-state. MassDEP believes it is appropriate to consider GHG emissions associated with electricity consumption in both state-specific and regional contexts, since, due to the linked, regional nature of the New England electricity grid, electricity generated in a state is not necessarily consumed in that state, even if that state is a net importer of electricity. The "Massachusetts-based" approach discussed below is the method that Massachusetts uses in determining progress towards achieving GWSA limits.

Massachusetts-based emissions are determined by first assigning emissions associated with all electricity generated in Massachusetts to Massachusetts. Massachusetts is then assigned a portion of emissions from generation in the other New England states that generate more electricity than they use in a given year, plus a portion of the emissions from generation from the adjacent control areas (New York, New Brunswick, Quebec) in years that New England receives net imports[18] of electricity from each.[19] This approach apportions to Massachusetts a percentage of the megawatt-hours (MWh) of losses (and associated emissions) due to pumped hydro. This method also accounts for electricity generated in Massachusetts for which an energy-tracking certificate is used out-of-state.

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[17] From M.G.L. c. 21N, section 1, ""Statewide greenhouse gas emissions", the total annual emissions of greenhouse gases in the commonwealth, including all emissions of greenhouse gases from the generation of electricity delivered to and consumed in the commonwealth, accounting for transmission and distribution line losses, whether the electricity is generated in the commonwealth or imported; provided, however, that statewide greenhouse gas emissions shall be expressed in tons of carbon dioxide equivalents."

[18] The megawatt hours of imports and of losses associated with pumped hydro were found in ISO-NE "energy_peak_by_source.xlsx" report at http://www.iso-ne.com. The megawatt hours of losses associated with pumped hydro were apportioned to each New England state according to that state's fraction of total New England load.

[19] The New Brunswick and Quebec GHG emissions are based on a Canadian report, the 2020 version of which is the *National Inventory Report 1990–2018: Greenhouse Gas Sources and Sinks in Canada*, Environment Canada, April 14, 2020 at https://unfccc.int/ghg-inventories-annex-i-parties/2020. See Table A13-5 "Electricity Generation and GHG Emission Details for New Brunswick" and Table A13-6 "Electricity Generation and GHG Emission Details for Quebec"). MWh of electricity generated from wood combustion are obtained from Statistics Canada Table 25-10-0019-01 - Electricity generated from fuels, by electric utility thermal plants, annual (megawatt hour), Statistics Canada, CANSIM (database), at https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001901 (accessed November 2019).

An alternative, Regional-based emissions approach is also provided and is based on the fraction of New England electricity (in MWh) that is consumed in Massachusetts. Massachusetts is then assumed to be responsible for that same fraction of the GHGs emitted while generating that electricity. Thus, the Regional-based emissions approach is based on the total of New England GHG emissions from electricity generation plus GHG emissions associated with electricity imported from the adjacent control areas in years that New England receives net imports of electricity from those control areas; this total is multiplied by the ratio of Massachusetts to New England electricity consumption.

The 1990-2000 imported emissions are calculated on the 'ElecImport' tab of Appendix C and remain unchanged from the 2016 update. 2001-2002 were calculated in Appendices D and E spreadsheets and also remain unchanged from the 2016 update. In 2016, refinements were made to the methodology for the years 2003 onwards for determining emissions from imported power that addressed the Massachusetts Department of Energy Resources' Renewable Portfolio Standard, which requires an increasing amount of renewable power be sold each year. Other New England states have similar programs. These renewable power sales are documented through the use of certificates that are generated in one New England state or adjacent control area, but that may be used in another. Emissions from imported electricity for 2003-2016 (Appendices F through S) remain unchanged. The import emissions methodology underwent further refinements beginning with 2017 (Appendix T) as discussed below in section 4.

4. Updated Data Sources and Methodology Changes

Additional data sources have become available since the 2016 update and refinements have been made to the inventory as follows:

Fossil Fuel Combustion – Transportation and Industrial sectors. MassDEP now uses EIA's natural gas vehicle consumption data[20] to determine emissions from natural gas in the transportation sector. The EIA vehicle consumption value is subtracted from the SEDS natural gas transportation consumption value, to assign the remaining natural gas (used by the natural gas industry as heating fuel) to the industrial sector.

Fossil Fuel Combustion – Transportation and Residential sectors. State-level biodiesel consumption data became available from SEDS beginning in 2018 and extending back to 2010. SEDS considers biodiesel to be a transportation sector fuel; however, Massachusetts has a growing biofuel program for heating fuel, primarily for the residential sector. Therefore, MassDEP's inventory divides biodiesel equally between the transportation and residential sectors. Biodiesel is subtracted from distillate for the transportation and residential sectors as per EPA guidance, parallel to the way ethanol is subtracted from motor gas for the transportation sector.

Fossil Fuel Use by Fuel Cells – Commercial sector. MassDEP has moved the natural gas used by fuel cells from the fossil fuel combustion sector to this new category. Beginning with 2018,

[20] See https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_m.htm

energy tracking certificates are used to determine MWh generated by fuel cells. The MWh total is converted to a natural gas consumption value which is subtracted from the SEDS natural gas commercial consumption value. The CO_2 emissions from the fuel cell are calculated using the CO_2 emission factor discussed in section 5 and assigned to "Fossil Fuel Use by Fuel Cells – Commercial sector."

Wastewater. The SGIT Wastewater methodology calculates CH_4 and N_2O emissions from the disposal and treatment of municipal wastewater using state population to calculate the quantity of emissions. In the 2016 update, this methodology was revised to account for the Massachusetts Water Resources Authority's (MWRA) anaerobic digesters which capture and combust biogas for energy. Similar capability has come online at several smaller wastewater treatment facilities (WWTFs) in the state (Clinton, Greater Lawrence, Pittsfield and Rockland). The resulting reduction in CH_4 emissions is accounted for by subtracting the population served by these WWTFs from the Massachusetts state population beginning with the year 2000 for MWRA and 2014 for the others.[21] Starting with 2010 data, this update separates wastewater CH_4 emissions into CH_4 from WWTFs and CH_4 from septic systems using the percentages of the population on each (see below).

For N_2O, the 2016 update erroneously used only a portion of MA statewide population, while this update uses the entire state population to calculate N_2O emissions. Direct N_2O emissions are derived from the 72% of MA population not on septic based on a 2019 MassDEP survey[22] (updated from the 81% default used previously). For indirect N_2O emissions, the 'biosolids used as a fertilizer'[23] value has been updated from 30% beginning in 2010 to 38% beginning in 2017.[24]

Natural Gas Systems – Transmission and Storage. MassDEP now uses PHMSA as the data source for LNG import terminal and storage facilities, as well as for pipeline miles. Details on transmission compressor stations are gathered from EPA FLIGHT and from transmission companies directly. Emission factors for this update are obtained from *Annex 3.6: Methodology for Estimating CH_4, CO_2, and N_2O Emissions from Natural Gas Systems* of EPA's GHG Inventory (GHGI).[25] These CH_4 and CO_2 emission factors for leaks in natural gas transmission

[21] According to the MWRA, a small amount of biogas is flared. Flare data come from MWRA. The CH_4 and N_2O emissions from the combustion of this biogas are included in the non-biogenic portion of this inventory. See section 6 of this Appendix A for a discussion of flare biogenic emissions. Flare data and combustion data are not available for other smaller WWTFs.

[22] Survey results from May 2020 correspondence with MassDEP Water Utility Resilience Program (WURP) staff https://www.mass.gov/guides/water-utility-resilience-program

[23] See Figure 7 in "Tapping the Energy Potential of Municipal Wastewater Treatment: Anaerobic Digestion and Combined Heat and Power in Massachusetts," MassDEP, July 2011 at https://www.mass.gov/doc/tapping-the-energy-potential-of-municipal-wastewater-treatment-anaerobic-digestion-and-0/download?_ga=2.203127063.763941132.1614183000-1411992369.1612293920

[24] The Mass Sludge Survey 2018 v.1.1 *Wastewater Solids Generation and Management in Massachusetts Survey and Report* by North East Biosolids and Residuals Association (NEBRA) for the Massachusetts Clean Energy Center September 2019 which can be found at: https://files-cdn.masscec.com/NEBRA-MassCEC-MassSludgeSurvey2018-v.1.1-FINAL-30Dec2019.pdf

[25] See Annex 3.6 at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2019-ghg.

and storage systems are based on annual reporting to EPA's GHG Reporting Program and are more specific than the highly aggregated SGIT leak emission factors.

Natural Gas Systems – Distribution. Updated emission factors for leaks from the three types of customer meters were obtained from EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019: Updates for Natural Gas Customer Meter Emissions* memo.[26] Estimates of CO_2 emissions from natural gas distribution system leaks were added with this update. Emission factors for this update are obtained from *Annex 3.6: Methodology for Estimating CH_4, CO_2, and N_2O Emissions from Natural Gas Systems* of EPA's GHGI.

Imported Electricity. As described in section 3, the inventory includes emissions from electric power imported into Massachusetts. Appendices T and U for the years 2017 and 2018 make further refinements to the imported emissions methodology, particularly with respect to emissions imported into Massachusetts from other New England states. Details on these refinements are explained in the 2018 Retail Sellers Annual Emission Factor Technical Support Document.[27]

5. Global Warming Potential and Emission Factor Updates

Global Warming Potentials (GWPs). This 1990 Baseline update continues to use the Intergovernmental Panel on Climate Change (IPCC) AR4 100-year GWPs;[28] however, the Appendix C spreadsheet has been modified to allow the user to toggle between certain 100-year and 20-year GWPs from IPCC's Fourth and Fifth Assessment Reports on the 'Summary by Gas' tab.[29]

Combustion Emission Factors (EFs). MassDEP uses EFs from EIA, IPCC and EPA's GHG Reporting Rule[30] in calculating emissions from imported electricity and biogenic fuel sources. This inventory gives preference to EFs developed for areas most geographically proximate to Massachusetts (e.g., preference for U.S. EFs over international default EFs) and temporally recent (e.g., preference for more recent EFs over older EFs). This prioritization results in this inventory using: EIA's CO_2 EFs by fuel type where available to calculate CO_2 emissions; EPA's EFs by fuel type to calculate CO_2 emissions where EIA EFs were not available and to calculate CH_4 and N_2O emissions; and IPCC EFs by fuel type to calculate GHG emissions where EIA and EPA EFs were not available.

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[26] See https://www.epa.gov/sites/production/files/2021-04/documents/2021_ghgi_update_-_meters.pdf.
[27] The details of the import methodology can be found in steps 1 through 7 in the methodology and data sources section, beginning on page 7, of the *2018 Retail Sellers Annual Emission Factor Technical Support Document* at https://www.mass.gov/doc/technical-support-document-draft-2018-ghg-emission-factors/download.
[28] With the exception of substitutes for ozone depleting substances (ODS)/refrigerant gases which use a combination of AR4 and AR5 GWPs.
[29] It is not possible to toggle the GWPs for ODS substitutes since these include a combination of AR4 and AR5 GWPs which are not visible in the EPA SGIT Industrial Process module.
[30] EPA Table C-1 https://www.ecfr.gov/cgi-bin/text-idx?SID=871447586338f667584b9726666a00b3&mc=true&node=ap40.23.98_138.1&rgn=div9 and Table C-2 https://www.ecfr.gov/cgi-bin/text-idx?SID=871447586338f667584b9726666a00b3&mc=true&node=ap40.23.98_138.2&rgn=div9.

Fugitive Emission Factors. Emissions of CH_4 and CO_2 from natural gas systems come from leakage of the natural gas. The 2016 update revised the CH_4 fugitive EFs for the natural gas distribution sector to a combination of emission factors from SGIT, from an ICF report[31] for the Massachusetts Department of Public Utilities, and from an April 2015 study[32] that measured equipment emissions. See section 4 for a discussion of natural gas system CH_4 and CO_2 fugitive EF improvements with this update.

Fuel Cell Emission Factor. Emissions of CO_2 from fuel cells come from the process of reforming natural gas into a hydrogen gas stream which feeds the fuel cell. This inventory uses an average of the emission factors estimated for five different types of fuel cells, with and without heat recovery, obtained by ICF through a manufacturer data collection.[33]

6. Biogenic GHG Emissions from Combustion

Biogenic GHG emissions are the emissions of CO_2 that result from the combustion of biogenic materials (biogenic material means plant or animal material, excluding fossil fuels). Biomass fuels include ethanol (used in vehicles), biodiesel (used in vehicles and in heating fuel), wood (largely combusted at residences and electric generation plants), landfill gas (either flared or combusted for electric generation), biogas (from anaerobic digestion of sludge waste), and the biomass portion of municipal solid waste (combusted at waste-to-energy plants). This inventory uses the convention for biogenic sources adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and others, which report biogenic CO_2 emissions separately from other GHG emissions. Hence, Tables 1 and 2 do not include CO_2 released during combustion of biomass.[34]

Data for biogenic combustion sources come from EIA, EPA FLIGHT, and the MWRA. Updates to the biogenic inventory include the addition of CO_2 emissions due to biodiesel combustion in the transportation and residential sectors beginning with the year 2010, and improvements to the calculation of biogenic emissions from imported electricity beginning with 2001. The methodologies for these updates are discussed in section 4 above.

Biogenic GHG emissions for 1990 and 2018 are summarized in Table A1 and Figure A1 below. While there are more sources of data available for biogenic emissions now than there are for 1990, the data continue to present some limitations. For instance, to the extent that biomass harvested in Massachusetts is also combusted in Massachusetts, such emissions are double-reported as combustion and land use change emissions. Some additional limitations include: carbon sink data are only included for forestry; annual forest sink data points, for the years in between forest surveys, are based on interpolated rather than measured data; and municipal solid

[31] *Lost and Unaccounted for Gas*, December 23, 2014, see: https://www.mass.gov/doc/icf-international-report-lost-and-unaccounted-for-gas/download.

[32] *Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in the United States*, April 13, 2015 see: http://pubs.acs.org/doi/abs/10.1021/es505116p.

[33] Results from ICF manufacturer data collection can be found at: https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies_section_6._technology_characterization_-_fuel_cells.pdf.

[34] CH_4 and N_2O emissions associated with biomass combustion are included in emissions in Table 1. CO_2 emissions associated with biomass combustion are not included in Tables 1 or 2.

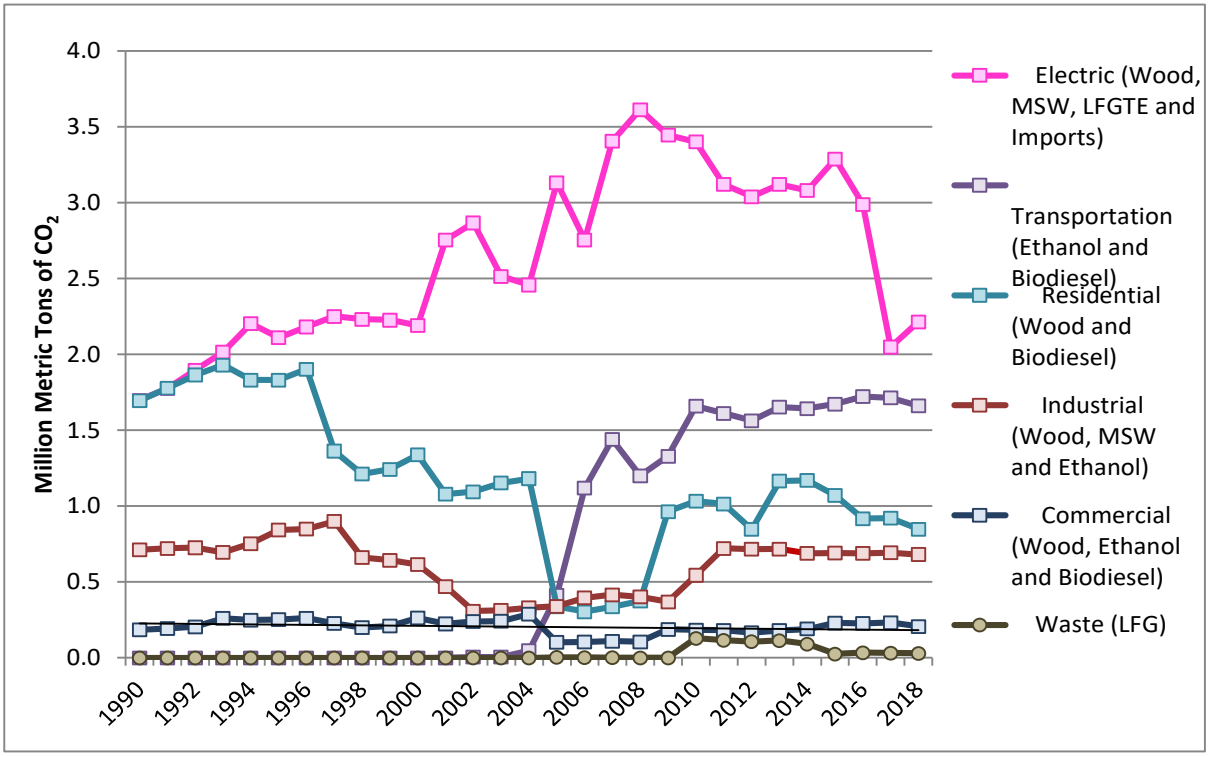
waste combustion whose biogenic fraction is estimated using the national fraction from 1990 to 2004.

Table A1: Biogenic GHG Emissions (MMTCO2e) from Combustion

Sector	1990	2018
Residential (Wood and Biodiesel)	1.7	0.8
Commercial (Biogas, Wood and Ethanol)	0.2	0.2
Industrial (Solid Waste, Wood and Ethanol)	0.7	0.7
Transportation (Ethanol and Biodiesel)	0.0	1.6
Electricity	1.7	2.2
Electric Power (Wood)	0.0	0.2
Electric Power (Solid Waste)	1.7	1.7
Electric Power (Landfill Gas to Energy)	0.0	0.2
Electricity Imports	-	0.1
Waste (Landfill Gas)	-	0.0
Landfill - Combustion in flares, engines & turbines	-	0.0
Wastewater - Combustion in flares	-	0.0
TOTAL Combustion	4.3	5.6

Notes: Due to rounding to 1 decimal place, some totals appear higher or lower than the simple sum of the sectors. Dashes represent a lack of data.

Figure A1: Estimated Massachusetts Biogenic CO2 Combustion Emissions 1990-2018 by sector



Note: To the extent that biomass harvested in Massachusetts is combusted in Massachusetts, associated CO_2 emissions are double-reported in combustion and land use change emissions.

7. Black Carbon

Black carbon is a short-lived climate pollutant. Black carbon is the most strongly light-absorbing component of particulate matter and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass. Over 50% of the black carbon emissions in the U.S. come from mobile sources, particularly diesel engines. MassDEP, in partnership with federal, state and private entities, has been working to reduce diesel emissions from on- and off-road sources, implementing many grant programs to support installation of diesel retrofit controls and replacements (e.g., diesel particulate filters, diesel oxidation catalysts, vehicle electrification, and wood stove change-out programs). Although MassDEP does not have black carbon emissions data for 1990 to include in the GHG inventory, diesel emissions reduction efforts in Massachusetts have been ongoing for many years.[35] See the Interim 2030 CECP for Massachusetts efforts to electrify transportation and heating, which will reduce black carbon emissions.

8. Issues for Future GHG Inventories

Technology changes, methodology changes, and data updates will inevitably affect future GHG emissions inventories. Methodologies and data sources are subject to revisions and improvements each year and MassDEP will continue to use the best data and approaches available. A few potential areas for change include:

Transportation – CH_4 and N_2O. EPA's SGIT Mobile module calculates CH_4 and N_2O emissions for vehicles based on a state's vehicle miles travelled (VMT) along with a national distribution of vehicle types and therefore does not account for Massachusetts' efforts to have all vehicles sold in Massachusetts be electric by model year 2035. Since there were no electric vehicles in 1990, this issue does not affect the 1990 Baseline. MassDEP will work with EPA and other states to address this issue in the future.

Industrial Processes – HFCs. The EPA SGIT Industrial Process module distributes the national emissions of ODS substitutes to the states based on a combination of population and semi-conductor sales and therefore will not account for MassDEP's regulation 310 CMR 7.76 *Prohibitions on Use of Certain Hydrofluorocarbons in Refrigeration, Chillers, Aerosol Propellants, and Foam End-uses*. MassDEP will work with EPA and other states to address this issue in the future.

Lifecycle and Embodied Emissions. Traditional emissions inventories are based on the production of emissions in a geographic area. But emissions are also generated by the manufacture of products elsewhere and the transportation of these products into Massachusetts (and thus "embodied" in these products). With the exception of electricity sector emissions (discussed in section 3 above), emissions that occur during the out-of-state manufacture of products used in Massachusetts are not included in this inventory. For example, in the case of

[35] For a list of mobile diesel reduction programs in Massachusetts see Appendix B "MassDEP Emission Reduction Programs for Mobile Sources" in https://www.mass.gov/doc/statewide-greenhouse-gas-ghg-emissions-baseline-projection-update-including-appendices-a-b/download.

gasoline, emissions from combustion in vehicles in Massachusetts are counted, but emissions from extracting and refining petroleum used in Massachusetts are not. This treatment of "lifecycle" or "embodied" emissions is consistent with the structure of GWSA. It also recognizes the difficulty in obtaining detailed information about how items imported into Massachusetts are produced and ensures that the same emissions are not double-counted in more than one jurisdiction.

Natural and Working Lands Carbon Flux. Achieving Net Zero in 2050 will require the ability to track and verify the annual removal from the atmosphere and storage of CO_2 by resources in, or attributable to, the Commonwealth. Currently, to the extent that biomass harvested in Massachusetts is combusted in Massachusetts, associated CO_2 emissions are double-reported in combustion and land use change emissions. In addition, the inventory does not currently acknowledge that some harvested wood is used to produce durable goods and materials that can maintain a portion of the removed carbon in storage for years (e.g., paper produced from pulp), to decades (e.g., furniture), to over a century (e.g., cross-laminated timber or insulation in buildings). Developing regionally consistent sequestration measurement, accounting, and market frameworks that will allow Massachusetts to purchase additional, least-cost sequestration services from its neighbors across the Northeast is critical to the Commonwealth's ability to achieve Net Zero in 2050.

An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy requires the 2025, 2030, etc. roadmap plans to include a carbon flux "baseline, goal and plan" to be "informed by a stakeholder process" and "integrated into the inventory." Any inventories published after the initial roadmap plans (required by July 1, 2022) will integrate an updated carbon flux methodology.