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2008-2010
Massachusetts Greenhouse Gas Emissions Inventory

Regulatory Authority:
MGL Chapter 21N, Section 2

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Introduction

In response to overwhelming scientific evidence that climate change is occurring as a result of human-created emissions of greenhouse gases (GHGs), and that these changes pose significant threats to public health and the environment, and because Massachusetts can seize significant economic benefits by moving to a clean energy economy, the Massachusetts Global Warming Solutions Act (GWSA)[1] was signed into law in August of 2008. The major requirements of this statute include:

- Adoption of statewide GHG emissions limits for 2020, 2030, and 2040 that will maximize the ability of the Commonwealth to meet the 2050 limit of at least 80% below 1990 emissions, as set by the Act,
- Implementation of plans to achieve these statewide GHG emissions limits, and
- Requirements for the mandatory reporting of GHG emissions by larger GHG emitting sources and retail sellers of electricity in the Commonwealth.

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 greenhouse gas 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.[2]

The 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.*" [MGL chapter 21N, section 2, subsection (c)]

Section 13 of the GWSA further states, "*The first inventory required pursuant to subsection (c) of said section 2 of said chapter 21N shall be published not later than December 31, 2010*." A preliminary GHG inventory for 2006, 2007 and 2008 was published by the required deadline. The Department used a similar approach to that used to develop the "Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business As Usual Projection,"[3] published on July 1,

[1] See http://www.malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298

[2] 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 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 equivalent (CO_2e).

[3] See http://www.mass.gov/eea/agencies/massdep/air/climate/global-warming-solutions-act-gwsa-implementation.html#2

2009, with the estimates for many sectors based on EPA's State GHG Inventory Tool (SGIT).[4] A final 2006-2008 GHG inventory was published in July 2012.[5]

Partial 2008 data were included in the original 3-year inventory in an attempt to get the most recent data possible to the public. Subsequently, due to the interest in understanding trends in Massachusetts GHG emissions more frequently than once every 3 years, MassDEP began posting an updated inventory spreadsheet more frequently. Therefore, the 3-year inventory is no longer the means by which MassDEP makes the most recent inventory data available to the public. In order to avoid the extra steps involved with issuing both a preliminary and final inventory, this 3-year inventory includes only the most recent 3 years for which we have complete data (2008-2010); hence, 2008 appears in two 3-year inventories.

MassDEP used the early 2012 version of EPA's SGIT to complete the final GHG inventory for 2006, 2007 and 2008 which was published in July 2012. MassDEP used March and September[6] 2013 releases of EPA's SGIT to complete this GHG inventory for 2009 and 2010.

This document describes the inventory. Appendix A describes any differences between the sources of GHG emissions, data sources and the methodologies used to determine the final 2006-2008 inventory and this inventory for 2009 and 2010. Appendices B, C and D are spreadsheets containing data upon which this inventory is based.

Massachusetts 2008, 2009 and 2010 GHG Emissions Inventory

Table 1 below shows non-biogenic GHG emissions data for 2008, 2009 and 2010 by economic sector. Table 2 below shows biogenic[7] CO_2 emissions data for 2008, 2009 and 2010 from biomass combustion, landfill gas oxidation, forest sequestration and land use change. Revisions to data sources or methodologies used to calculate the inventory are described in Appendix A below. The spreadsheet in Appendix B contains the data upon which Tables 1 and 2 are based. Spreadsheets in Appendices C and D contain data upon which the 2009 and 2010 Electricity Import values are based.

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[4] See http://www.epa.gov/statelocalclimate/resources/tool.html

[5] See http://www.mass.gov/eea/agencies/massdep/air/climate/global-warming-solutions-act-gwsa-implementation.html#2

[6] The September 2013 SGIT release included only the CO2FFC, Stationary and Mobile Combustion Modules.

[7] Biogenic greenhouse gas emissions means emissions of CO_2 that result from the combustion of biogenic (plant or animal) material, excluding fossil fuels. Biogenic emissions include CO_2 emissions from combustion of biomass, biofuels, landfill gas and the organic portion of municipal solid waste.

Table 1: Non-Biogenic GHG Emissions, Million Metric Tons of Carbon Dioxide Equivalents (MMTCO$_2$e)

	2008[8]	2009	2010
Energy Total	**80.1**	**75.8**	**73.1**
CO_2 from Fossil Fuel Combustion	77.4	71.0	72.8
Residential CO_2	14.2	13.9	13.6
Commercial CO_2	5.7	5.8	6.7
Industrial CO_2	4.1	3.2	3.7
Transportation CO_2	33.6	30.8	30.8
Electric Generation CO_2	19.8	17.3	18.0
Electricity Imports CO_2, CH_4, N_2O	3.0	2.2	2.0
Other Gases Total	2.8	2.6	2.5
Stationary Combustion	0.2	0.2	0.2
Electric Power	0.1	0.1	0.1
Other	0.2	0.2	0.2
Mobile Combustion	0.8	0.6	0.5
Natural Gas and Oil Systems	1.8	1.8	1.7
Industrial Processes	**3.2**	**3.0**	**3.2**
Agriculture	**0.3**	**0.3**	**0.2**
Waste	**2.4**	**2.9**	**2.9**
Gross Emissions	**89.0**	**82.0**	**83.6**

Note: due to rounding to 1 decimal place, some totals appear higher or lower than the simple sum of the sectors.

[8] Unchanged from 2006-2008 Inventory.

Table 2: Biogenic GHG Emissions (MMTCO$_2$e)

	2008	2009	2010
Energy Total	**4.6**	**6.1**	**6.4**
CO_2 from Biomass Combustion Total	3.9	4.7	4.9
Residential CO_2	0.4	1.1	0.9
Commercial CO_2	0.1	0.2	0.2
Industrial CO_2	0.3	0.3	0.3
Transportation CO_2	1.2	1.3	1.5
Electric Generation CO_2	2.0	1.9	1.9
Landfill - Combustion of LFG in flares, engines and turbines[9]	-	-	0.1
Electricity Imports CO_2	0.7	1.4	1.6
Landfill – Oxidation of LFG in landfill surface cover[9]	-	-	0.1
Forest Sequestration	**-10.8**	**-11.1**	**-11.3**
Land Use Change Emissions	**0.6**	**0.5**	**0.6**
Net Biogenic CO_2 Emissions	**-5.6**	**-5.8**	**-4.2**

Note: due to rounding to 1 decimal place, some totals appear higher or lower than the simple sum of the sectors.

To the extent that biomass harvested due to land use change in Massachusetts is also combusted in Massachusetts, such emissions are double-reported in Table 2 in Combustion and Land Use Change emissions.

[9] Added from MA GHG Reporting data first available in 2010.

Appendix A. GHG Emission Sources, Data Sources and Methodology

This section describes the sources of GHG emissions, the information available, and the methodology that the Department used to develop the 2008-2010 inventory.

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. Residential, Commercial, Industrial, Transportation and Electric Generation are the sectors in which fossil fuels are combusted.

Industrial Processes: The United States (US) Environmental Protection Agency (EPA) has identified 14 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 include Lime Manufacture, Limestone and Dolomite Use, Soda Ash Consumption, Urea Consumption, Consumption of Substitutes for ODS, Semiconductor Manufacture, and Electric Power Transmission and Distribution.

Agriculture: The US 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 the Commonwealth is negligible, if any (specifically, rice cultivation and agricultural residue burning are the two processes that do not occur in Massachusetts).

Waste Management: The US 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 are found in Massachusetts.

2. Data Sources and Methodology for Developing the Inventory

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. The US 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. Gases included in the inventory are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulfur hexafluoride (SF_6).

The SGIT was used to estimate emissions from 2008 to 2010. This section discusses data issues related to the SGIT.

The SGIT default data set provides a basis for estimating and reporting annual GHG emissions by sector. For example, one large sector is CO_2 emissions from fossil fuel electrical generation plants in Massachusetts. The EPA SGIT methodology uses Massachusetts electric generator fuel use data (the data is taken from the US Department of Energy's Energy Information Administration (EIA)) to calculate the electricity sector emissions from fuel combustion. The Department used SGIT's estimates of GHG emissions from fossil fuel electrical generation and other sectors to derive the inventory for Massachusetts.

Each year, by the end of June, EIA releases updates[10] of the data that SGIT uses to calculate CO_2, CH_4 and N_2O emissions from fossil fuel and biomass combustion (except transportation sector CH_4 and N_2O, which SGIT calculates from other default data). This 2008 to 2010 inventory used the June 2013 EIA data update for 2009 and 2010.

The Department made the following methodology changes between the final 2006-2008 inventory and the 2008-2010 inventory for years 2009 and 2010 only.

Methodology Changes to the Massachusetts GHG Inventory

The Massachusetts and EPA GHG Reporting programs provide some facility-specific data used in the inventory in place of SGIT values beginning with 2010. GHG emissions data from these reporting programs can be obtained from the Massachusetts *Climate Registry Information System* (CRIS)[11] and the EPA *Facility Level Information on GreenHouse Gases Tool* (FLIGHT).[12] This inventory replaces certain SGIT data with Massachusetts facility-specific data, particularly in the industrial processes and solid waste sectors where the SGIT state level emissions are derived from national values apportioned to states based on population or sales. In addition, the methodologies used in EPA SGIT are sometimes updated. Significant methodological changes begun with this inventory are noted below:

- Combustion of Municipal Solid Waste: Beginning with 2010, we use *Waste Characterization Studies*[13] that determine Massachusetts-specific plastics, rubber and fiber "Proportion of Discards" percentages instead of the SGIT default percentages. The Massachusetts percentages are state averages that are determined every three years as reported in Massachusetts Municipal Waste Combustor facility reports. The Massachusetts percentages are lower than the SGIT default percentages, resulting in a reduction in GHG emissions from the combustion of plastics, rubber and fiber.

[10] See the EIA State Energy Data System (SEDS) at http://www.eia.doe.gov/emeu/states/_seds.html
[11] See http://www.mass.gov/eea/agencies/massdep/air/climate/ma-greenhouse-gas-emissions-reporting-program.html#3
[12] See http://ghgdata.epa.gov/
[13] See http://www.mass.gov/eea/agencies/massdep/recycle/reports/waste-reduction-and-recycling.html

- Landfills: Landfills pose a difficult challenge in estimating GHG emissions. Massachusetts is one of the States for which EPA'S SGIT estimates negative landfill sector GHG emissions due to data gaps. Fortunately, Massachusetts landfills were required to report their GHG emissions to Massachusetts and EPA beginning with the 2010 reporting year. We have substituted the 2010 EPA SGIT landfill emissions data with EPA FLIGHT data rather than Massachusetts CRIS data, since more landfills report to EPA than to Massachusetts. CH4 data for industrial landfills are still obtained from SGIT since Massachusetts industrial landfills do not report GHG emissions to Massachusetts CRIS or EPA FLIGHT. We do not have Massachusetts-specific landfill data for 2009; however, rather than report a negative value from SGIT, we set the landfill CH4 avoided value (from CH4 destruction in flares, engines or turbines) equal to the landfill CH4 generated value (due to decomposing municipal solid waste), and the value nets to zero. Massachusetts GHG Inventories prior to 2009 are final, and therefore the landfill emissions values for prior years are not being changed.

- Industrial Processes: Data for lime manufacturing, historically absent for long stretches of time from the EPA SGIT inventory for Massachusetts, now come from the EPA FLIGHT data beginning with 2010 emissions.

- Electricity Use: Changes were made to the inventory to account for the use of electricity under the Commonwealth's Renewable Portfolio Standard, as discussed in the following section.

3. Estimating GHG Emissions from Imported Electricity Generation

It is important to recognize that approximately one third of the electricity used in the Commonwealth is imported from power plants located in other states and in Canada. In order to account for the net electricity imports into Massachusetts from other New England states and import areas, as required by statute,[14] Massachusetts-specific generation and load data were utilized to develop an imported emissions estimate. The New England Independent System Operator (ISO-NE), which manages the New England electricity grid, maintains generation and load megawatt hour data for each New England state. Data on electricity imported to New England from the adjacent New York, New Brunswick and Quebec control areas are also available from ISO-NE.

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 regional and more state-specific contexts, since, due to the linked, regional nature of the New England electric grid, electricity generated in a state is not necessarily consumed in that state, even if that state is a net importer of electricity.

[14] From GWSA, ""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."

Table 1 of this inventory presents emissions associated with electricity consumption using an approach that more directly accounts for emissions associated with electricity generated in Massachusetts, while an alternative regional approach is discussed further below. The approach used in Table 1 assumes that all electricity generated in Massachusetts is used in Massachusetts (with the exception of in-state generation for which a renewable energy certificate is used out-of-state, as discussed further below). Thus, electric sector emissions in this approach are based on emissions from Massachusetts power plants plus a portion of emissions from power plants in the other New England states that generate more electricity than they use in a given year and in the adjacent control areas (New York, New Brunswick, Quebec) in years that New England received net imports of electricity from those control areas.

Under this approach, emissions due to Massachusetts' consumption of imported electricity were determined by apportioning to Massachusetts a share of any excess generation (and associated emissions) from each New England state that generates more electricity than it uses. Thus, the inventory includes a share of the emissions associated with each electricity-exporting state's exported electricity, as calculated from EIA fuel heat content data. (These data are the basis of EPA's SGIT estimate of each state's CO_2, CH_4 and N_2O emissions from fossil fuel combustion and CH_4 and N_2O emissions from biomass combustion). Similarly, the inventory apportions to Massachusetts a percentage of the megawatt hours of losses (and associated emissions) due to pumped hydro and of the net annual imports into the ISO-NE grid from the New York, New Brunswick and Quebec grids.[15] Emissions from the Canadian Provinces were calculated using Environment Canada's National Inventory Report.[16]

A change integrated into this inventory addresses the Massachusetts Department of Energy Resources' Renewable Portfolio Standard that requires increasing amounts of renewable power be sold each year.[17] Other New England states have similar programs. These renewable power sales are documented through the use of Renewable Energy Certificates (RECs). While the electric-sector inventory methodology described above indirectly[18] accounts for the use of RECs, this inventory has been expanded to more explicitly and fully account for the purchase of RECs by Massachusetts retail electricity sellers. For example, if Massachusetts retail electricity suppliers buy RECs from a power plant in a state that is a net importer of electricity, the

[15] The megawatt hours of imports and of losses associated with pumped hydro were found in ISO-NE "Net Energy and Peak Load by Source" report at http://www.iso-ne.com/markets/hstdata/rpts/net_eng_peak_load_sorc/index.html. 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.

[16] The New Brunswick and Quebec GHG emissions are based on the *National Inventory Report 1990–2010: Greenhouse Gas Sources and Sinks in Canada*, Environment Canada, April 11, 2012 at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php. 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") and *Table 127-0006 - Electricity generated from fuels, by electric utility thermal plants, annual (megawatt hour),* Statistics Canada, CANSIM (database). http://cansim2.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&CNSM-Fi=CII/CII_1-eng.htm (accessed: May 5, 2010).

[17] See http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/rps-aps/

[18] The indirect accounting did not consider whether electricity was generated by RPS-qualified generators. To the extent that RPS-qualified generation occurred in a state that generated more electricity than it sold, a portion of the emissions of such generation were assigned to Massachusetts under the indirect accounting methodology.

inventory methodology to-date has not reflected emissions associated with such RECs. Likewise, if RECs associated with power generated at a Massachusetts in-state power plant are sold out-of-state, the inventory to-date has included the emissions (or lack thereof, if the facility is non-emitting) from such a plant, when they should more appropriately be credited to the state that purchased the RECs. Therefore, beginning with 2009, we have expanded the inventory electric-sector methodology to address RECs generated in one New England state or adjacent control area, but used in another.[19] The effect of this methodology change on Massachusetts 2009 "Electricity Imports" was a one third decrease in non-biogenic and a doubling of biogenic emissions. Since the RPS requires increasing amounts of renewable energy over time, it is possible that the previous methodology would have caused an increasingly less-accurate Massachusetts GHG inventory over time.

Massachusetts also considers electric sector emissions in a broader regional context, due to the linked nature of the New England electric grid, in which demand for electricity in one state influences electricity generation in other states. An alternative electricity consumption emissions approach, documented in Appendix B, involves first determining 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, electric sector emissions in this approach are based on the total New England GHG emissions from electricity generation plus GHG emissions associated with electricity imported from the adjacent control areas (New York, New Brunswick, Quebec) in years that New England received net imports of electricity from those control areas; this total was multiplied by the ratio of Massachusetts to New England electricity consumption. This approach is documented on the far right of the emission factors tab of the Appendices B, C and D spreadsheets for 2009 and 2010.

4. Biomass Biogenic CO_2 Emissions, Forest Sequestration and Land Use Change Emissions

Given the lack of annual data for biogenic sources and sinks, the Department has estimated biomass biogenic CO_2 emissions, forest sequestration and land use change emissions. Estimates of biomass combustion, forest sequestration and land use change are documented in Table 2. Despite the challenges in accurately calculating these data on an annual basis, it appears that other, non-annual, data available for the biomass sector are sufficient, and their magnitude is significant enough that it is important to track going forward. Some of the limitations associated with the data in Table 2 include: biomass emissions are double-reported when biomass harvested as a result of land use change in Massachusetts is also combusted in Massachusetts; carbon sinks are only included for forestry; and annual forest sink data points for years between forest surveys are based on interpolated rather than measured data.

Biogenic CO_2 emissions result from burning biomass, including: biofuels such as ethanol (used in vehicles and in the commercial and industrial sectors), wood and paper (largely combusted at residences and electric generation plants), landfill gas (combusted for electric generation), and the biomass portion of municipal solid waste (combusted at waste-to-energy plants). In addition, emissions from land use change include the one-time release of previously sequestered soil carbon due to the soil disturbance involved. In presenting the biogenic CO_2 emissions associated

[19] As documented in Appendices C and D, this methodology builds off MassDEP work associated with GHG reporting by Massachusetts' retail sellers of electricity.

with the combustion of biomass, this inventory uses the convention for biogenic sources adopted by the World Resources Institute, The Climate Registry, and others, which report biogenic CO_2 emissions separately from other GHG emissions. Hence, Table 1 does not indicate quantities of CO_2 released during combustion of biomass.[20] Estimates of CO_2 emissions due to biomass combustion are presented in Table 2 and were determined using EPA's SGIT with the most recent EIA data.[21] CO_2 emissions from Massachusetts' consumption of imported electricity generated from biomass combustion were determined using the methodology discussed above for imported electricity generation and are also included in Table 2.

The Department made the following methodology changes to the 2008-2010 Massachusetts GHG inventory for the biogenic CO_2 emissions from biomass fuel sources.

- Biogenic Emissions from RPS Imported Electricity – subject to same methodology improvement as discussed above in section 3, beginning 2009.
- SGIT does not calculate CO_2 from biogenic sources. Beginning with 2010 emissions, MassDEP obtains biogenic CO_2 emissions from the Massachusetts GHG Reporting Program CRIS for the oxidation of landfill gas and for the combustion of landfill gas through landfill flares and non-grid-connected engines.[22]

In addition, the value of forested lands as a carbon sequestration sink and the carbon released due to forest land lost annually to land use change are documented in the spreadsheet in Appendix B. While other land uses also sequester carbon, the Department focused on forests because those data are most readily available and forests account for the largest portion of naturally sequestered carbon.

While overall forest acreage in Massachusetts expanded greatly from a low point in the mid-1800s (the peak of our agricultural period) to the early 1950s, net forest coverage has begun to decline since then, principally due to the loss of forests to development of land for residential, commercial and industrial uses. At the same time, annual forest carbon sequestration is still increasing as the Commonwealth's relatively young forests mature. The Massachusetts Office of Geographic and Environmental Information (MassGIS) and the University of Massachusetts at Amherst have tracked land use via the interpretation of statewide aerial photography since the 1970s, most recently for photography taken in 2005. To interpolate between available years, and for years since 2005, the Massachusetts Executive Office of Energy and Environmental Affairs has used housing permit data from the US Census Bureau to estimate change in forest cover.

To estimate the net growth of the forest, the Department relied on net growth measured by the United States Department of Agriculture Forest Service at approximately 550 permanent Massachusetts forest plots (known as the Forest Inventory and Analysis (FIA)). The net growth is multiplied by the forest cover acreage to give net growth in tons per county, and converted to tons of CO_2 using a formula derived from chemical analysis of trees (approximately one-half of a

[20] Note, CH_4 and N_2O emissions associated with biomass combustion are included in gross emissions in Table 1, as part of the Stationary Combustion category and Mobile Combustion categories. CO_2 emissions associated with biomass combustion are not included in Table 1.
[21] EIA released the data in June 2013 from which CO_2 emissions from biomass combustion for all sectors were calculated using the EPA SGIT.
[22] In contrast, beginning with 2006 emissions, we have been determining grid-connected landfill gas engine CO_2 emissions based on EIA data.

tree weight is carbon).

In addition to this aboveground forest carbon storage, a significant amount of carbon can be stored below ground in coarse roots and in forest soils. Organic carbon accumulates in forest soils and can reach density levels nearly equal to that of above ground biomass of a mature forest stand. All exposed soils sequester carbon (at a rate determined by soil class, cover type, and disturbance regime), but only forest soil sequestration is included in Table 2. It should be noted that the inclusion of carbon sinks only from forestry represents a substantial but not complete set of carbon sinks in the state.

As land is developed, trees and vegetation (which sequester carbon) are replaced by buildings, roads, etc. These changes in land use lead to the one-time release of significant quantities of carbon previously locked up in natural ecosystem sinks, as the development disrupts the normal course of the long-term carbon cycle. In order to take account of these emissions, this inventory is using land use change data together with estimates of carbon stored in forests and soil to quantify the annual emissions due to land use change.

5. Other Methodological Issues

Several potentially significant sources of GHGs are not included in the Massachusetts inventory due primarily to the difficulty in quantifying emissions in these sectors. These notably include GHG emissions and GHG sequestration from embodied emissions:

- Traditional emissions inventories (including the SGIT) and projections are based on the <u>production</u> of emissions in a geographic area. But emissions generated by the manufacture of products elsewhere and transportation of these products into Massachusetts (and thus "embodied" in these products) are potentially significant, and in the future could be tracked and projected as well. This adjustment becomes more important as manufacturing shifts from Massachusetts to other states and nations (some of which produce significantly more carbon emissions per unit of output than does the production of these goods in Massachusetts). From 1990 to 2005, net imports (imports minus exports) of manufactured products to Massachusetts rose from $9 billion to $25 billion (in constant $1997), becoming equivalent to 41% of our output of manufactured goods. While some academic studies have started to quantify embodied emissions,[23] there is still great uncertainty in such estimates. Further analysis is needed in this area; therefore, embodied emissions were not included in the inventory.
- On the other side of the equation, some embodied emissions are essentially sequestered when they are stored in landfills or used for the manufacture of long lifespan infrastructure. Some examples of sequestered fossil fuels include plastics in landfills, asphalt in roads and a portion of construction materials in permanent buildings. While EPA's SGIT does exclude

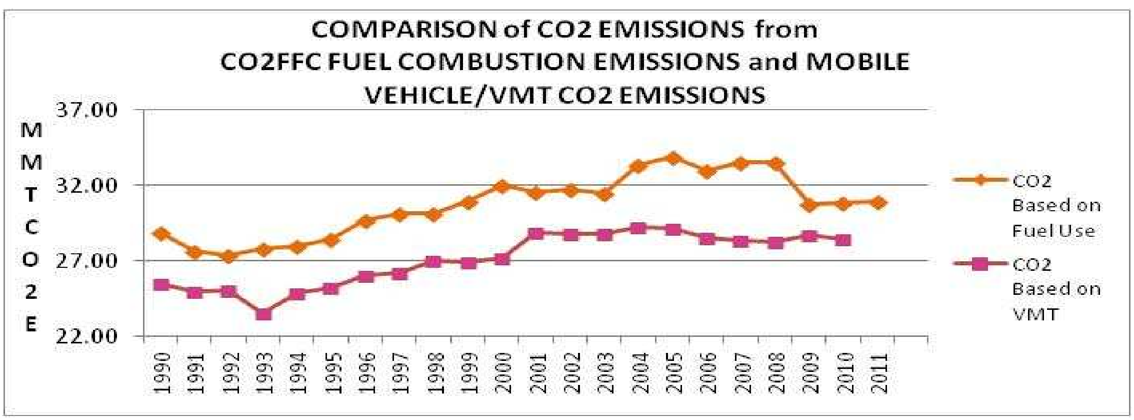
[23] "Embodied Environmental Emissions in U.S. International Trade," 1997-2004," Christopher L. Weber and H. Scott Matthews, Environmental Science & Technology, 2007; "CO_2 Embodied in International Trade with Implications for Global Climate Policy," Glen P. Peters and Edgar G. Hertwich, Environmental Science and Technology, Vol. 42, No. 5, 2008; "Consumption-based accounting of CO_2 emissions," Steven J. Davis and Ken Caldeira, Proceedings of the National Academy of Sciences online, March 8, 2010, at http://www.pnas.org/content/early/2010/02/23/0906974107.full.pdf+html

the non-energy consumption of asphalt and road oil from reported emissions, the fate of most other materials consumed in Massachusetts is not addressed in the inventory.

6. Issues for Future GHG Inventories

Technology changes, methodology changes, and data updates will inevitably affect future GHG emissions inventories. An example of a methodological improvement made for this inventory is calculation of emissions associated with electricity RPS transfers between states to Massachusetts, as detailed in section 3 above. The data for imported electricity in this inventory are developed using methodologies from retail electricity seller GHG reporting; those methodologies are subject to revisions and improvements each year, seeking to use the best data and approaches available.

Beginning with the 2013 release of SGIT, CO_2 emissions from the mobile sector are calculated using two separate approaches: the traditional method based on fuel sales and a new method using vehicle miles traveled (VMT) and vehicle/emission control types as is done for N_2O and CH_4 emissions from mobile sources. While the results of both methods are documented in the Massachusetts GHG inventory in Appendix B, we have chosen to continue to base the official Massachusetts GHG inventory on the traditional calculation of CO_2 from motor fuel sales because this is consistent with how the 1990 baseline emissions were calculated for this sector. The graph below compares the results from the two approaches.



In addition, future inventories may rely on additional data submitted under EPA's Greenhouse Gas Reporting Program or 310 CMR 7.71, Massachusetts' "Reporting of Greenhouse Gas Emissions" rule (beyond landfill emissions and lime manufacturing which are discussed above). Massachusetts' rule requires Massachusetts sources that have an operating permit and/or that emit greater than 5,000 short tons of GHGs annually to report GHG emissions to the Massachusetts GHG registry. Note that reporting was limited to CO_2 for the first reporting year (2009 emissions), and the number of reporting facilities expanded beginning with 2010 emissions when facilities reported six GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6). The reporting rule emissions data will always represent a subset of the full Massachusetts inventory. The full GHG emissions inventory includes emissions from small stationary and mobile sources such as residential and commercial furnaces and personal vehicles, which are not reported individually to MassDEP due to their small size.

GHG emissions for municipal waste combustors (MWCs) are also available from EPA FLIGHT beginning with 2010. The FLIGHT values are derived using different methodologies than the current SGIT methodology used to determine 1990 baseline emissions, and are about one third lower (approximately half a million metric tons of non-biogenic GHG) than the SGIT emissions for 2010. The EPA FLIGHT emissions may be more accurate, as they are largely based on monitors measuring the emissions from most MWC smokestacks. However, for comparability to the 1990 baseline, this 2008-2010 GHG emissions inventory reports MWC GHG emissions using the SGIT approach.

CO_2 emissions from facilities that report pursuant to 310 CMR 7.70, the "Massachusetts CO_2 Budget Trading Program" (which implements Massachusetts' participation in the Regional Greenhouse Gas Initiative (RGGI)), are also reported under the 7.71 reporting rule, as all RGGI facilities are operating permit facilities. RGGI facility reporting under 7.70 and 7.71 began in 2009, and each year's reported emissions represent a subset of total electric sector emissions.

MassDEP posts summaries online of the GHG emissions data reported under 310 CMR 7.71.[24]

[24] see MassDEP GHG Reporting Program Summary Reports for years 2009-2012 at http://www.mass.gov/eea/agencies/massdep/air/climate/ma-greenhouse-gas-emissions-reporting-program.html#3.