VERMONT

Greenhouse Gas Emissions Inventory Update 1990 - 2013

July 2017

VERMONT

Department of Environmental Conservation
Air Quality and Climate Division

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Emissions Summary

The emissions totals shown in this report, both current and historical, are notably higher than those provided in previous Greenhouse Gas Emissions Inventory reports. These differences are due to changes in data availability, methodologies, and updated Global Warming Potential values, which will be described in greater detail later. The total greenhouse gas (GHG) emissions for the state of Vermont showed a slight increase from 8.72 million metric tons CO2 equivalent (MMTCO2e) in 2012 to 8.75 MMTCO2e in 2013. Although total statewide GHG emissions have trended downward since their peak in 2004, in 2013 they were still approximately 4 percent above the established 1990 baseline value of 8.39 MMTCO2e. Annual emissions totals must decrease at a significantly faster and sustained rate to meet the next emissions reduction goals that have been established (Figure 1).

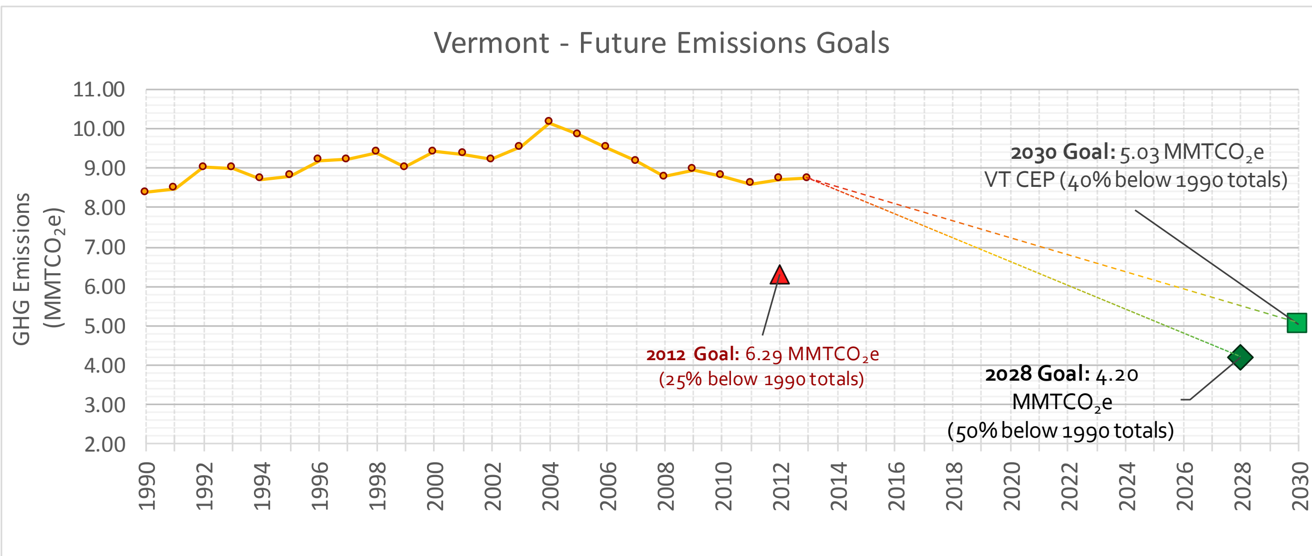

Figure 1. Vermont Historic GHG Emissions Estimates and Future Emissions Reduction Goals

Limited progress in reducing emissions was made in several of the sectors contributing to the GHG emission totals between 2012 and 2013; however, with the variability of several of the larger contributing categories it is difficult to predict whether the overall trends will continue into the future. In the transportation sector, emissions are closely linked to vehicle miles travelled (VMT) which are strongly correlated with fuel prices, the volatility of which makes this sector difficult to predict for the long term. Fuel use in the Residential / Commercial / Industrial sector is also somewhat unpredictable as it is mostly driven by winter temperatures and heating costs, which are also linked to changing fuel prices. Emissions from the electrical sector are estimated using a consumption-based accounting methodology, and so are directly linked to the purchase decisions of Vermont's utilities, as well as to the New England electrical grid generation make-up.

This report attempts to provide comprehensive and accurate greenhouse gas emissions totals for the State of Vermont from 1990 through 2013. The gases included in this inventory are based on those named by the United Nations Framework Convention on Climate Change (UNFCCC) in the Kyoto Protocol[1] and include Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6). Nitrogen trifluoride (NF_3) has been included in the Industrial Processes sector, as it is a greenhouse gas of growing concern. Data for Vermont were available from various sources for all sector categories for 2013.

[1] Source: http://unfccc.int/kyoto_protocol/items/3145.php

Transportation emissions are based on results from a specialized EPA emissions estimation tool (the Motor Vehicle Emissions Simulator, or MOVES Model). Modeled emissions estimates are generated on a triennial basis by the EPA, using a combination of state-provided and EPA input data. These emissions estimations apply to the transportation sector (for 2011 and 2014) and are more accurate and robust than other available data, especially for onroad gasoline and onroad diesel vehicles. Values for 2012 and 2013 were interpolated based on the modeled emissions totals for the available years and categories and are shown in grey text to illustrate that they are projections.

The emissions estimates generated for this report were developed using methodologies consistent with the *Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030*[2] developed by the Center for Climate Strategies (CCS), the most current State Inventory Tool (SIT) modules from the U.S. Environmental Protection Agency, and methodologies developed by the Vermont Agency of Natural Resources and the Vermont Department of Public Service, utilizing data available from a variety of in-state and national sources including the Vermont Agency of Transportation, Vermont Legislative Joint Fiscal Office (JFO), the Vermont Department of Public Service, U.S. Department of Energy, U.S. Department of Agriculture, and others. Historical and updated GHG emissions data have been calculated and are summarized by sector in the tables and graphs that follow.[3]

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[2] Source: http://dec.vermont.gov/air-quality/climate-change

[3] Primary Authors: C. Smythe and J. Merrell, VT DEC – AQCD: collin.smythe@vermont.gov and jeff.merrell@vermont.gov

Overall Changes and General Information

Greenhouse gas emissions in this inventory are reported in million metric tons of CO_2 equivalent ($MMTCO_2e$) which is a convention used to standardize all greenhouse gas emissions in this inventory relative to CO_2. This is important when calculating the emissions of gases other than CO_2, such as methane (CH_4) and Nitrous Oxide (N_2O), as well as HFCs, PFCs, SF_6, and NF_3, since they are all considerably more potent greenhouse gases than CO_2. Carbon dioxide equivalents are calculated based on the potency of the GHG in question, through a multiplier called a Global Warming Potential (GWP). These GWP potency multipliers have been updated by the Intergovernmental Panel on Climate Change (IPCC), and adopted by the U.S. EPA[4] for use in emissions inventories since the previous report. This results in slightly altered emissions totals, including the 1990 baseline, from those shown in the previous inventory. These differences generated by the change in GWP vary by sector, as only sectors or processes that result in GHG emissions other than CO_2 are effected. The two most relevant GWP updates for this inventory are for CH_4 (increasing from 21 to 25) and for N_2O (decreasing from 310 to 298). This means that if the same mass of CO_2 and CH_4 were released into the atmosphere, the CH_4 would be 25 times more potent than CO_2 in terms of warming potential over a 100-year time span, and the same mass of N_2O would be 298 times more potent than the CO_2. Gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3), have GWPs ranging anywhere from 12 to 22,800, and many have extremely long atmospheric lifetimes (Table 1). Because of this, even relatively small amounts of these anthropogenic gases (F-gases) can have disproportionately large effects from a global warming standpoint. By multiplying the total mass of the non-CO_2 gases emitted by their assigned GWP value, a standardized and comparable CO_2 equivalent emission total can be generated.

Table 1. Greenhouse Gas Global Warming Potentials (GWPs) and Atmospheric Lifetimes[5].

GHG Category	Updated GWP	Atmospheric Lifetime (years)
CO_2	1	Variable
CH_4	25	12
N_2O	298	114
HFCs	12 - 14,800	1 - 270
PFCs	7,390 - 12,200	2,600 - 50,000
NF_3	17,200	740
SF_6	22,800	3,200

Data describing the global warming potentials and atmospheric lifetimes for the seven main greenhouse gases considered in this report, and described in the Kyoto Protocol. Ranges of values exist for HFCs and PFCs because there are multiple gases combined into each of those broader categories.

As mentioned previously, changes to GWP values alter the calculated historical emissions totals. The GWP value does not actually result in a data change for the quantity of gases emitted by a certain sector, but instead only describes the warming potency of the gas. As a result, this revision can and should be applied to all previous emissions totals to ensure accurate comparisons. These legitimate updates also result in a change to the 1990 baseline emissions totals, on which all the emission reduction goals for Vermont are based (Figure 1).

[4] Source: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

[5] Source: EPA Overview of Greenhouse Gases: https://www3.epa.gov/climatechange/ghgemissions/gases/n2o.html

Other valid changes to the historical and baseline data occur in this inventory, but those have been driven by updated methodologies, and newly available and more accurate data sources. Great care was taken only to adjust the baseline 1990 emissions values where it was clear that the new data or methodologies would improve the accuracy and reliability of the data. In two of the three cases of non-GWP data adjustment, an anomaly had existed in the previous data (or current EPA data). These two instances were in the semiconductor manufacturing subsection of the Industrial Processes sector, and in the natural gas distribution subsection of the Fossil Fuel Industry sector. The third instance was a data source update detailing wood consumption in the residential subsection of the Residential / Commercial / Industrial Fuel Use sector, from the Vermont Residential Fuel Assessment Survey: 2014-2015[6] conducted on behalf of the Vermont Department of Forests Parks and Recreation.

In several instances, an attempt was made to project updated methodologies back to the baseline; however, due to historical data uncertainties, the results were significantly different than the original baseline values, but were not necessarily more accurate. Where this was the case, previously reported emissions were used for historical totals, after being adjusted with the updated GWP values for applicable gases and processes. The differences in the emissions totals for all contributing sectors in Vermont due to the update in GWP values, the updates in data sources, and the changes in methodologies are illustrated in Figure 2. This GHG emissions (Table 2) presented in this report are those estimates represented by the blue line (Figure 2).

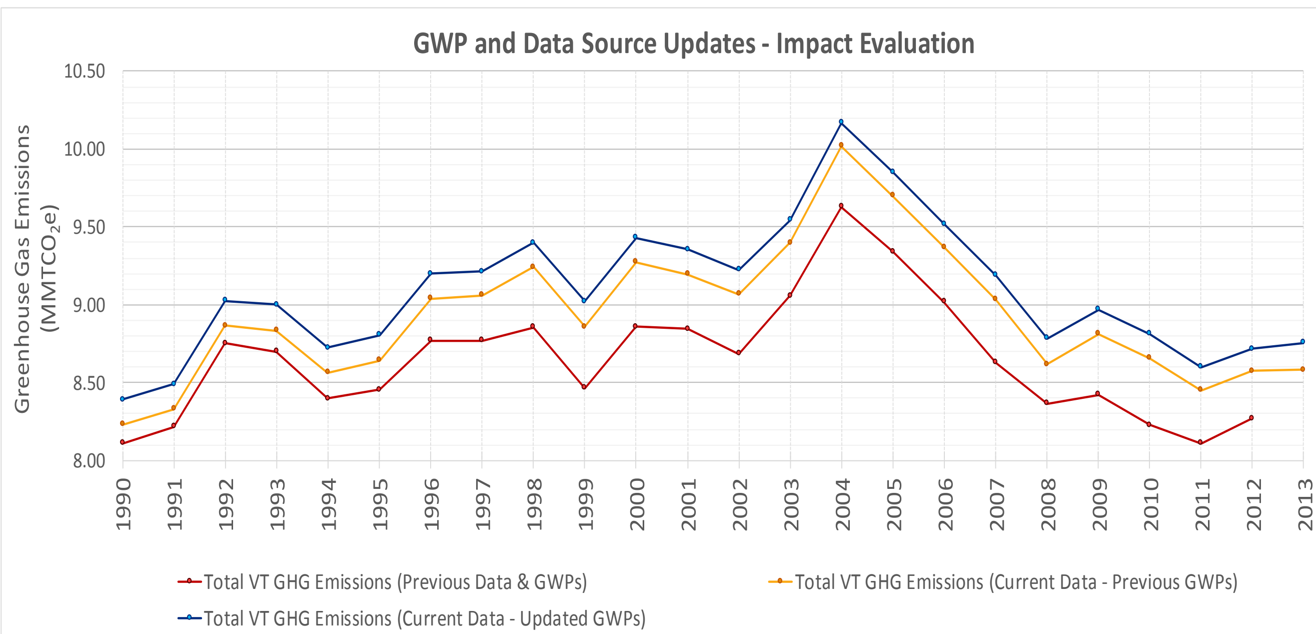

Figure 2. Vermont's GHG Emissions Estimates Resulting from GWP and Data Source Updates.

[6] Source: http://fpr.vermont.gov/forest/wood_biomass_energy/residential_wood_heating

Table 2. Vermont Historic Greenhouse Gas Emissions by Sector
Million Metric Tons CO_2 equivalent ($MMTCO_2e$)[7,8]

Sector	Year 1990	2000	2005	2011	2012	2013
Electricity Supply & Demand (consumption based)	**1.09**	**0.43**	**0.64**	**0.43**	**0.93**	**0.81**
Coal	0	0	0	0	0	0
Natural Gas	0.047	0.018	0.000	0.005	0.001	0.001
Oil	0.014	0.058	0.011	0.042	0.014	0.013
Wood (CH_4 & N_2O)	0.003	0.010	0.014	0.013	0.011	0.015
Residual System Mix	1.03	0.35	0.62	0.37	0.90	0.78
Residential / Commercial / Industrial (RCI) Fuel Use	**2.45**	**2.90**	**3.00**	**2.46**	**2.22**	**2.45**
Coal	0.017	0.003	0.000	0	0	0
Natural Gas	0.314	0.496	0.440	0.438	0.416	0.494
Oil, Propane & Other Petroleum	2.057	2.341	2.494	1.951	1.728	1.875
Wood (CH_4 & N_2O)	0.066	0.063	0.068	0.075	0.075	0.077
Transportation	**3.22**	**3.99**	**4.20**	**3.68**	**3.64**	**3.66**
Onroad Gasoline	2.64	3.20	3.29	2.75	2.70	2.73
Onroad Diesel	0.41	0.66	0.69	0.65	0.63	0.62
Jet Fuel & Aviation Gasoline	0.08	0.07	0.17	0.10	0.10	0.10
Rail / Ship / Boats / Other Nonroad	0.09	0.06	0.05	0.18	0.22	0.22
Fossil Fuel Industry	**0.0077**	**0.0040**	**0.0039**	**0.0044**	**0.0045**	**0.0047**
Natural Gas Distribution[9]	0.0068	0.0030	0.0028	0.0034	0.0034	0.0036
Natural Gas Transmission	0.0009	0.0010	0.0011	0.0011	0.0011	0.0011
Industrial Processes	**0.21**	**0.59**	**0.60**	**0.69**	**0.65**	**0.59**
ODS Substitutes	0.00	0.17	0.21	0.29	0.30	0.31
Electric Utilities (SF_6)	0.04	0.02	0.02	0.01	0.01	0.01
Semiconductor Manufacturing (HFCs, PFCs & SF_6)[10]	0.16	0.37	0.33	0.36	0.32	0.25
Limestone & Dolomite Use	0.00	0.02	0.03	0.02	0.02	0.02
Soda Ash Use	0.006	0.006	0.005	0.004	0.004	0.004
Waste Management	**0.27**	**0.36**	**0.34**	**0.29**	**0.24**	**0.22**
Solid Waste	0.21	0.30	0.28	0.23	0.18	0.15
Wastewater	0.061	0.067	0.068	0.069	0.069	0.069
Agriculture	**1.13**	**1.15**	**1.06**	**1.04**	**1.02**	**1.01**
Enteric Fermentation	0.70	0.69	0.63	0.63	0.61	0.63
Manure Management	0.15	0.19	0.20	0.18	0.17	0.17
Agricultural Soils	0.29	0.26	0.23	0.22	0.24	0.22
TOTAL GROSS EMISSIONS	**8.39**	**9.43**	**9.85**	**8.60**	**8.72**	**8.75**
Change relative to 1990 (baseline)	**—**	**+ 12%**	**+ 17%**	**+ 2%**	**+ 4%**	**+ 4%**

7 Note: Grey text in the transportation sector indicates that the data was interpolated from EPA MOVES Model data produced for the National Emissions Inventory for 2011 and 2014 – produced on a triennial basis.

8 Totals may not sum exactly due to independent rounding.

9 Natural gas distribution data was recalculated using Part 98 emission factors which correlated much better with the emissions reported by Vermont Gas (VGS) to the EPA FLIGHT Tool (https://ghgdata.epa.gov/ghgp/main.do) for 2012.

10 Semiconductor data from 2011 – 2013 is from the EPA FLIGHT Tool, projected back to 1990 based on sector trends from the U.S. Emissions Inventory "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014" and National SIT values. Values are significantly higher than in previous inventories.

Vermont and the United States – Emissions Comparisons

Greenhouse gas emissions produced by human activities in Vermont account for only a very small percentage of total U.S. emissions, approximately 0.1% historically (Figure 3). This is partly due to the small size of the state, the relatively small and rural population, and the comparatively strong environmental ethic of that population (based on per capita GHG emissions – Figure 4). Even though Vermont does produce a small percentage of the total national greenhouse gas emissions, additional steps can be taken to reduce emissions in the state. Several sectors in Vermont have higher contribution percentages than the corresponding national sector (Figure 5), most notably the transportation and Residential/Commercial/Industrial Fuel Use sectors.

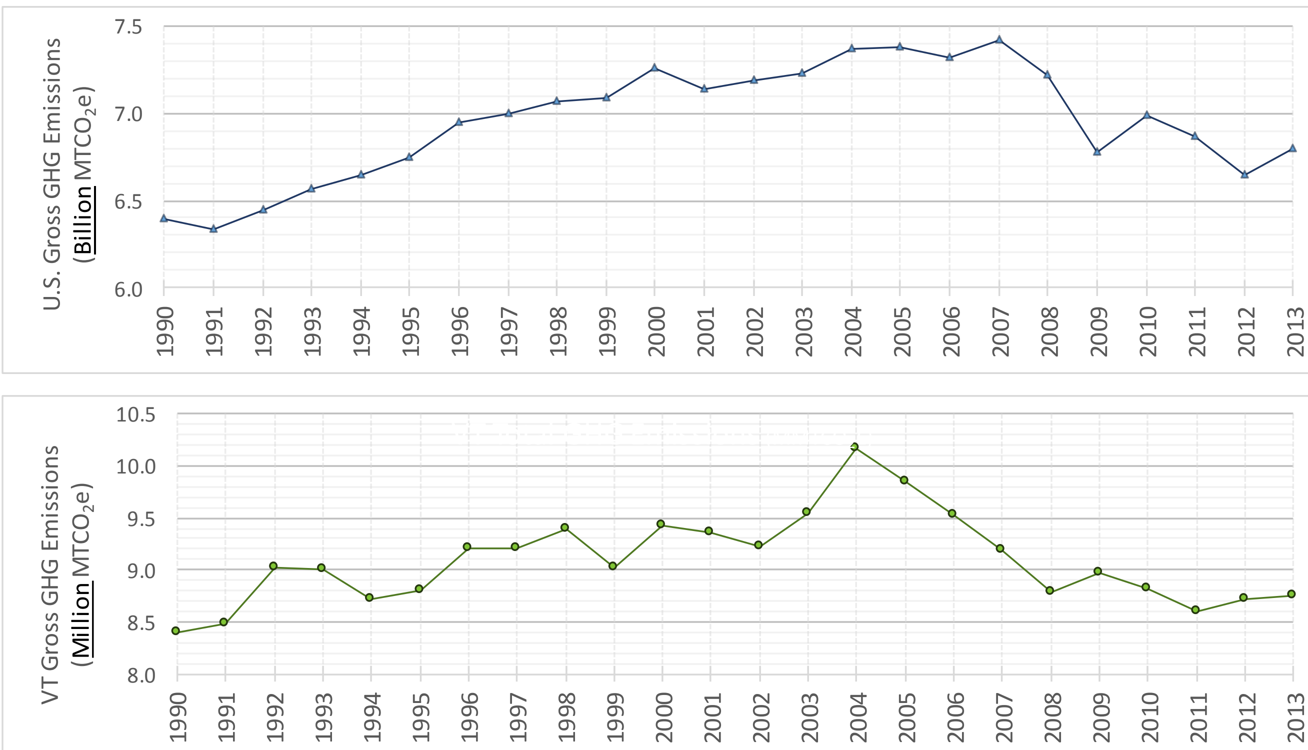

Figure 3. Vermont and the U.S.[11] – Historical Gross GHG Emissions Comparison (1990 – 2013).

A comparison between historical greenhouse gas emissions of Vermont and the U.S. shows similar overall trends in increases and decreases. Vermont contributes only a very small fraction of the total annual U.S. greenhouse gas emissions for any given year, however there is still opportunity to achieve emissions reductions and to lead by example while working towards established future emissions reduction goals.

[11] U.S. data source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014 (April 15, 2016). https://www.epa.gov/sites/production/files/2017-04/documents/us-ghg-inventory-2016-main-text.pdf

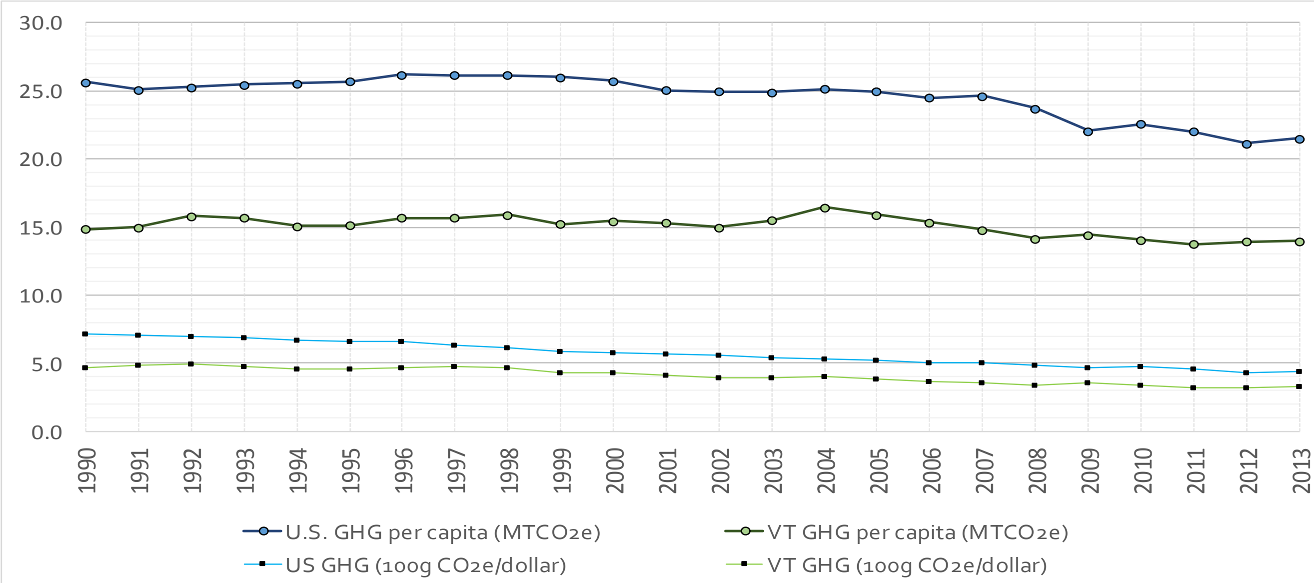

Figure 4. Historical VT & U.S. Gross GHG Emissions per Capita[12] and per Unit Gross Product[13,14] (1990 – 2013).

Comparisons between Vermont and the U.S., in terms of GHG emissions per person and per dollar of economic output, shows Vermont is lower than the national average in both instances; however, the trends have remained relatively constant for Vermont while the national trends have shown more significant decreases over time in both cases.

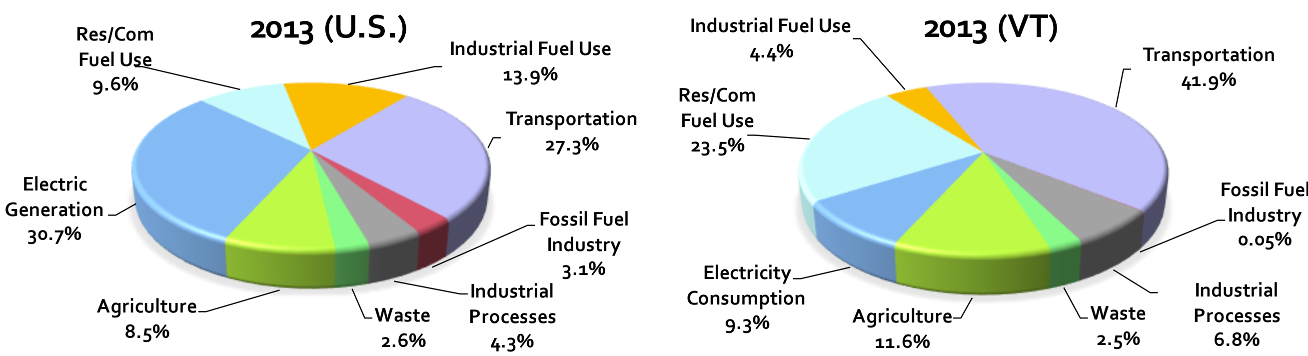

Figure 5. Sector Emissions Contribution Percentages Comparison (2013) – U.S. and Vermont[15]

The percentage of emissions contributed by the transportation sector is considerably higher in Vermont, due in part to relatively high per capita vehicle miles traveled (VMT)[16], and to the rural nature of the state. It should be noted that the Vermont transportation percentage is somewhat inflated relative to the U.S., due to the lack of major point source emissions in Vermont. Residential/Commercial/Industrial Fuel Use is also above average, likely due to winter home heating demands that are well above the U.S. average. Emissions from the electricity sector are significantly lower in Vermont than the U.S., mainly due to large purchases of hydroelectric power from Hydro Québec, and other renewable generation facilities, as well as the use of a consumption-based GHG accounting methodology in VT as compared to a generation-based methodology for the US.

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[12] State and US Population Data: United States Census Bureau (https://www.census.gov/programs-surveys/popest/data/tables.html)

[13] Department of Commerce - U.S. Bureau of Economic Affairs – National GDP data (http://www.bea.gov/national/index.htm)

[14] Department of Commerce - U.S. Bureau of Economic Affairs – State GDP data (http://www.bea.gov/iTable/index_regional.cfm)

[15] Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2014 (redistributed to match VT sector categories). https://www.epa.gov/sites/production/files/2017-04/documents/us-ghg-inventory-2016-main-text.pdf

[16] U.S. DOT – Bureau of Transportation Statistics: Table 5-3: Highway Vehicle-Miles Traveled (VMT): 2008, 2013

Vermont GHG Emissions – Sector Details

Historically, statewide greenhouse gas emissions have remained fairly constant in Vermont, with some sectors exhibiting declines since a peak in 2004 (Figure 6, Figure 7). These declines, due to improvements in products and processes, changes in policies, economic drivers, and behavior change, have unfortunately been somewhat offset by the slight overall increases in state population since 1990.[17]

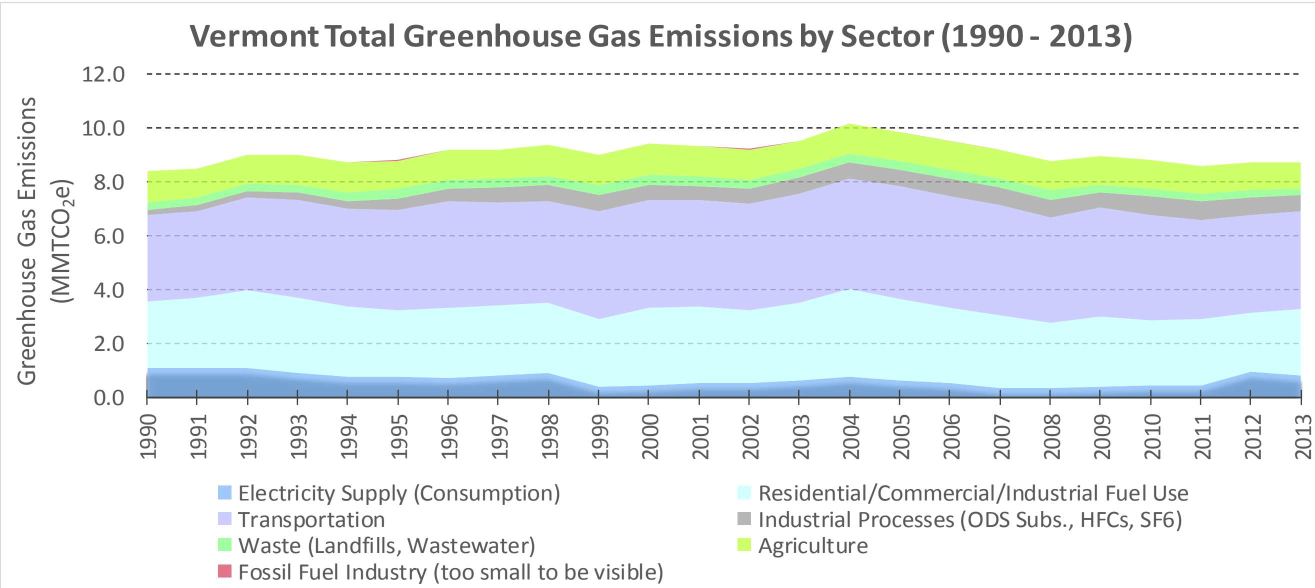

Figure 6. Historic Gross Vermont GHG Emissions.

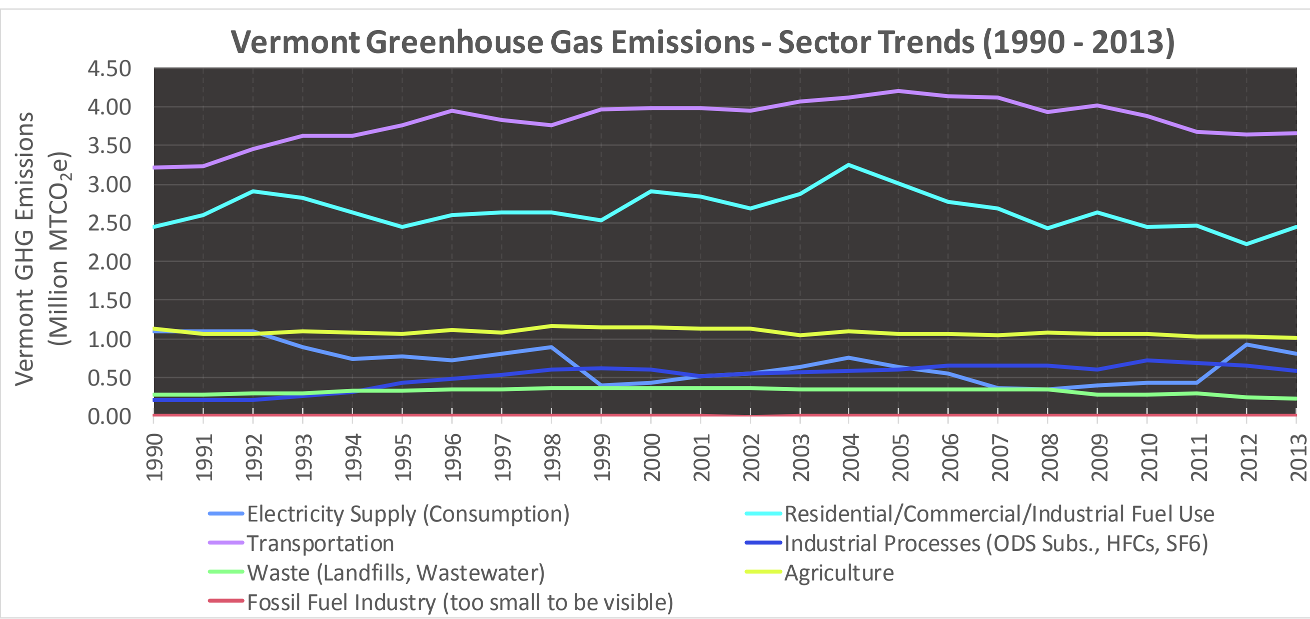

Figure 7. Historic Vermont GHG Emissions by Sector (1990 – 2013).

[17] Source: Vermont Population Data – http://www.healthvermont.gov/health-statistics-vital-records/vital-records-population-data/vermont-population-estimates

Electricity

Greenhouse gas emissions from the electricity sector in Vermont (Figure 8) are calculated based on electricity consumption data and electric utility purchase decisions (supplied by VT DPS[18]). By using this accounting methodology, the emissions from the generation of all the electricity used in Vermont are accounted for, instead of just the electricity that is generated within the state. A major factor in the emissions variability from year to year from this sector is the amount of the New England grid mix, or "Residual Mix" purchased by utilities. The regional grid mix is generally produced by generation sources with higher greenhouse gas emissions rates than the in-state generation and renewable imports, so the amount of the mix purchased is a driving factor of the total electricity sector emissions for Vermont on any given year. Generation sources contributing to the residual mix also change over time, adding to the complexity of the emissions estimation. Fortunately, data is reported and tracked through NEPOOL GIS (New England Power Pool Generation Information System)[19] detailing the makeup of this mix, enabling a more accurate emissions estimate from this portion of the electrical sector.

Much of the electricity used by Vermont customers, that is not from the residual mix pool, is produced through hydroelectric generation, most notably by Hydro Québec. This is increasingly true after the closure of the Entergy Nuclear Vermont Yankee plant. For this report, hydro generation is considered to have zero emissions, however there is ongoing research as to the amount of CH_4 generated as a result of water level fluctuations in reservoirs. Other renewable energy is produced in Vermont; however, in many cases, the Renewable Energy Credits (RECs), which are the environmental attributes created through the production of renewable energy, are currently being sold out of state, and therefore the energy distributed from these generation sources cannot be considered renewable. Recent legislation (H40 – Act 56) has been passed to limit this process, requiring retail electricity providers to have 55% of their portfolio as renewable energy (with RECs attached or retired) by 2017, increasing to 75% by 2032.[20] The regulation also contains provisions for the implementation of distributed energy generation for improved grid reliability and energy transformation projects to reduce fossil fuel consumption.

With movement toward more renewable energy generation in Vermont (requiring the retaining of RECs), less reliance on the regional mix, and general demand side efficiency improvements, electricity sector emissions (Figure 8) are anticipated to become slightly less variable, and to begin a steadier downward trend.

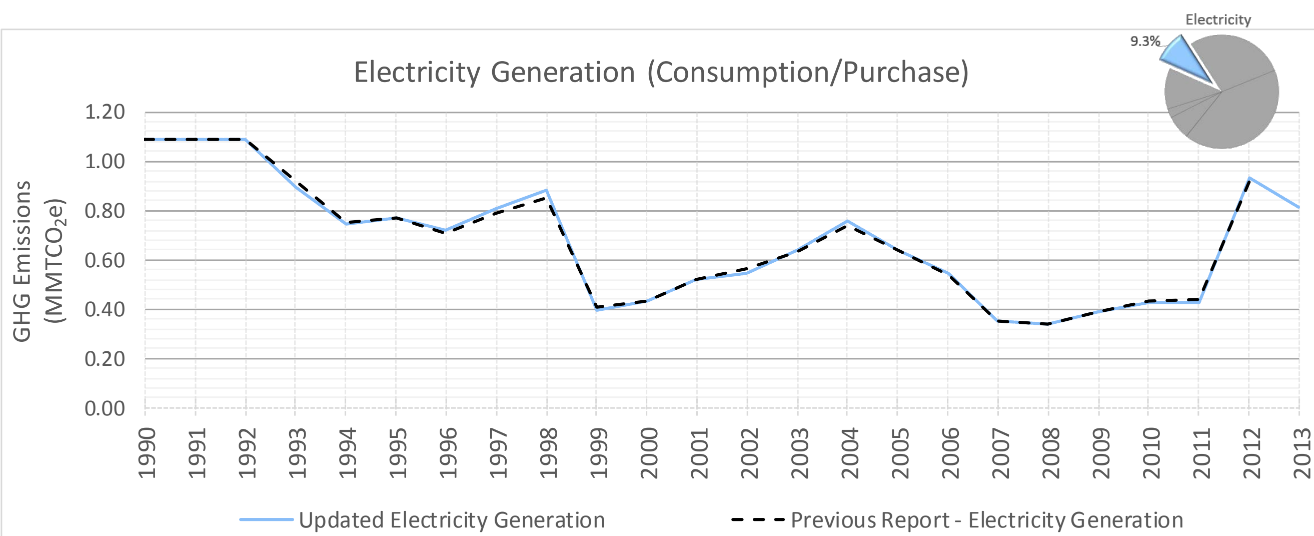

Figure 8. Vermont Electricity Sector GHG Emissions (1990 – 2013).

[18] VT DPS – Vermont Department of Public Service: http://publicservice.vermont.gov/

[19] NEPOOL GIS: http://www.nepoolgis.com/

[20] Vermont Legislature: http://legislature.vermont.gov/assets/Documents/2016/Docs/ACTS/ACT056/ACT056%20As%20Enacted.pdf

Transportation

The transportation sector is the largest emitter of greenhouse gases in Vermont. As a percentage of total emissions, the transportation sector is considerably larger in Vermont than the percentage nationally (Figure 5). This is due to several factors, including the choices of vehicle drivers, the rural nature of the state and longer distances traveled, but also to a somewhat underutilized public transportation system. The percentage contribution from the transportation sector is also somewhat inflated because of significantly lower emissions percentages in other categories for Vermont, notably the electricity and industrial sectors. This is mainly due to the relatively low number of large point source emissions in the state. Transportation emissions are comprised of onroad gasoline, onroad diesel, aviation gasoline/jet fuel, and other non-road sources (Table 2). Of these groupings, the on-road gasoline and on-road diesel are the two major contributors, historically comprising over 90% of the emissions from the sector.

Recent emissions data for the transportation sector has been provided or informed by the EPA MOVES model results. Data from the model is only generated on a triennial basis coinciding with the publishing of the National Emissions Inventory (NEI). Due to the robust and comprehensive nature of the model, the data are considered more accurate than other previously used estimation methods. The most recent MOVES data produced were for 2014 (using MOVES2014a), so values for 2012 and 2013 were interpolated based on the onroad gasoline and onroad diesel results from the 2011 NEI and the 2014 NEI. Straight-line projections were modified with percentage increases and decreases based on regional transportation fuel trends, to more accurately reflect real world emissions curves. Trends from fuel sales data[21] and VMT specific to Vermont[22] did not correlate particularly well with the emissions values generated in MOVES, but regional trends were a better fit, which can be at least partially explained by potential variability in the amount of fuel purchased out-of-state and then combusted in Vermont.

Emissions from the transportation sector have remained fairly constant, with an overall downward trend from 2005 to 2013 (Figure 9). This trend is likely due to improvements to vehicle technologies, stricter emissions regulations, an increased focus on public transportation and low emissions vehicles, etc. Transportation fuel prices also play a role in determining transportation trends and emissions. Based on significant increases in the gasoline and diesel sales indicators and the VMT data for 2015 (Figure 10), emissions totals from the transportation sector are expected to continue to increase in the coming inventories. These increases are due at least in part to a decline in fuel prices during this period.

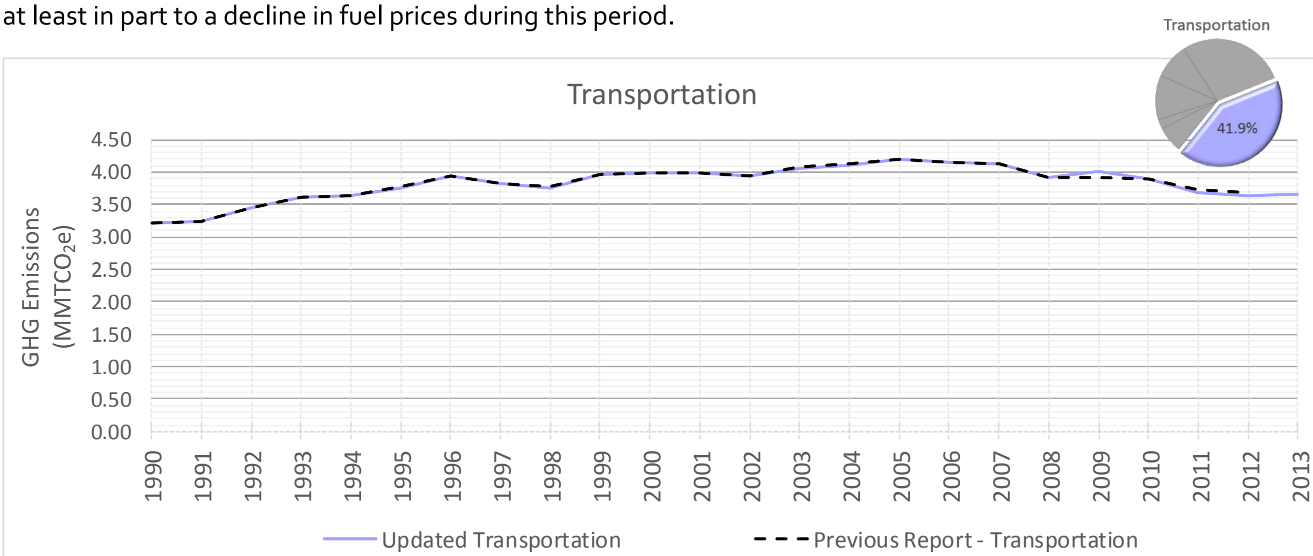

Figure 9. Vermont Transportation Sector GHG Emissions (1990 – 2013).

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21 Vermont Joint Fiscal Office (JFO) – "Gas & Diesel Revenue and Gallons": http://www.leg.state.vt.us/jfo/transportation.aspx

22 VTrans VMT data - http://vtrans.vermont.gov/docs/highway-research

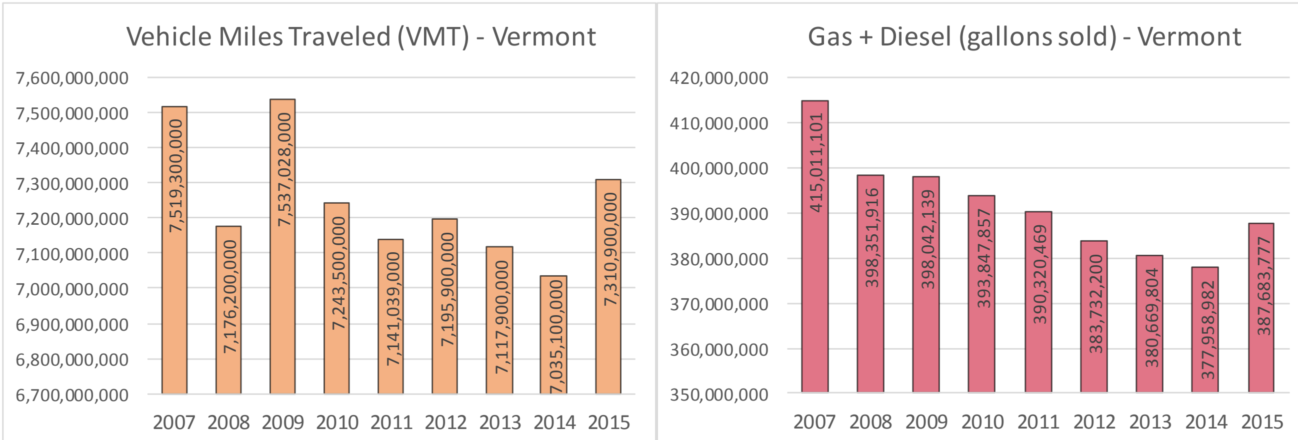

Figure 10. Vermont VMT with Gas and Diesel (gallons sold in Vermont) 2007 – 2015.

Residential/Commercial/Industrial (RCI) Fuel Use

Emissions from the Residential/Commercial/Industrial (RCI) Fuel Use sector in Vermont are second only to the transportation sector (Figure 11). This sector is also proportionally larger for Vermont than for the U.S. mainly due to cold winters and a greater heating demand. Carbon dioxide emissions from the oil, propane, & other petroleum category dominates this sector accounting for approximately 80% of the emissions historically (Table 2).

Wood emissions in this sector would contribute significantly if CO_2 were counted "at the stack," however to maintain consistency with previous reports and IPCC guidelines, only methane (CH_4) and Nitrous oxide (N_2O) are included in the calculated totals for wood combustion emissions. Biogenic CO_2 emissions from wood combustion have been omitted from this and prior statewide GHG emissions inventory update totals because when wood is sustainably harvested it may be carbon neutral, at appropriate timescales with the correct management practices. This means that the amount of carbon sequestered from the atmosphere by the regrowth of sustainably harvested trees (even when combusted) is assumed to counterbalance (and potentially become a sink for) carbon dioxide produced through the combustion of the wood. This is a matter of ongoing debate, due to the timescales of forest regrowth and sequestration potential, as well as differences in land use and forest management practices.

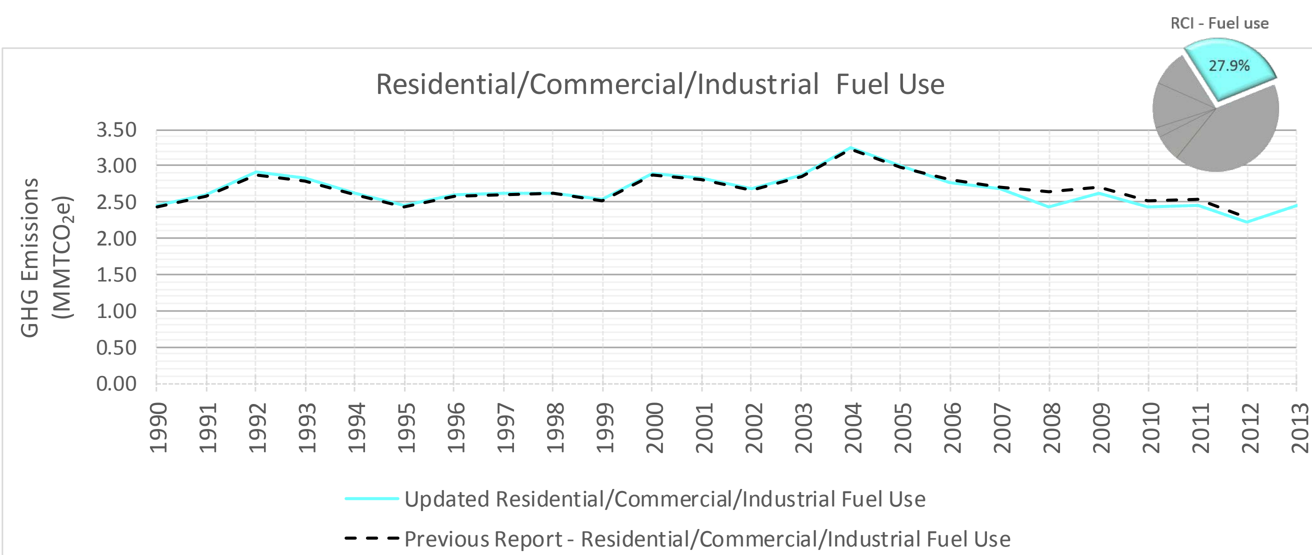

Figure 11. Vermont Residential/Commercial/Industrial Fuel Use Sector GHG Emissions (1990 – 2013).

Fossil Fuel Industry

Fossil Fuel Industry emissions contribute only a small portion of the total emissions for the state. The emissions considered in this sector are produced exclusively through the transmission and distribution of natural gas, since no oil and gas refining occurs, and only a small section of transmission pipeline exists in Vermont. Most of the natural gas infrastructure in Vermont is comprised of individual services, distribution lines, and a small percentage of slightly larger transmission lines accounting for approximately 71 of the 733 total pipeline miles[23]. Natural gas is piped from the TransCanada Pipeline and distributed by Vermont Gas (VGS) to locations in Chittenden and Franklin counties, with a 41-mile expansion project recently completed (2017) now bringing natural gas to Addison county[24].

Previously reported emissions from this category were calculated using average emission leakage rates for pipes and services based on default EPA emissions factors and the associated EPA State Inventory Tool (SIT) module; however, when Part 98 (Mandatory Greenhouse Gas Reporting) emissions factors[25] are applied, the totals correlate much more closely with the emissions total reported by Vermont Gas (VGS) to EPA in 2012 (Figure 12). Since this change in methodology appears to produce more consistent totals, the Part 98 emission factors were applied to pipeline data to update historical emissions estimates. Emissions showed a steady decline as pipe materials were upgraded, however the trend has now leveled off and begun to increase as pipe upgrades have slowed, and additional pipe and services are added. The GWP update has a significant effect on totals in this sector, as natural gas is composed largely of CH_4.

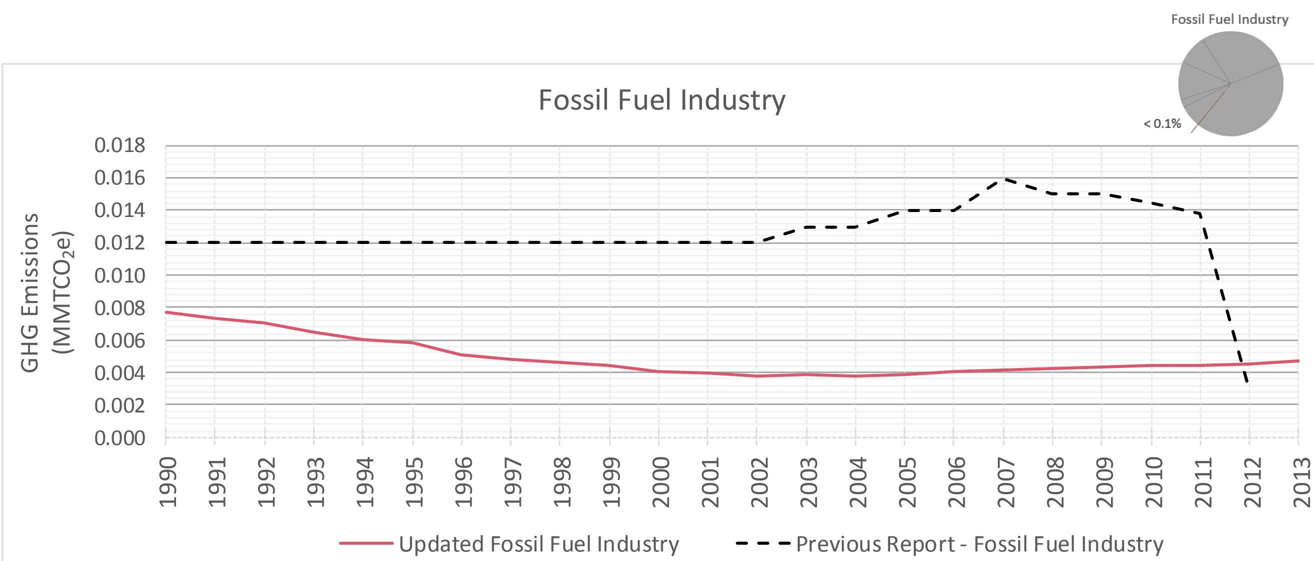

Figure 12. Vermont Fossil Fuel Industry Sector GHG Emissions (1990 – 2013).

[23] PHMSA - http://www.phmsa.dot.gov/pipeline/library/data-stats/distribution-transmission-and-gathering-lng-and-liquid-annual-data

[24] Vermont Gas: http://www.vermontgas.com/vermont-gas-completes-41-mile-expansion-begins-serving-customers-addison-county/

[25] U.S. GPO – Table W-7 to Subpart W of Pert 98: http://www.ecfr.gov/cgi-bin/text-idx?SID=8833205cfe045e8a1154a79834dda5d3&mc=true&node=ap40.21.98_1238.10&rgn=div9

Waste - Municipal Solid Waste & Wastewater

Municipal solid waste (MSW) emissions in the waste sector are generated by the decomposition of material within a landfill. In the first phase of decomposition CO_2 is formed through aerobic decomposition (with oxygen), after which emissions are almost exclusively CH_4, which is produced in anaerobic (without oxygen) conditions by anaerobic and methanogenic bacteria[26]. Carbon dioxide emitted by MSW decomposition is not counted in emissions totals in this inventory as it is considered to produce approximately the same amount of emissions as would be produced if the materials decayed outside of a landfill setting[27].

For the majority of 2013 there was only one major commercial landfill open in Vermont, and another which closed early in 2013. Both facilities are equipped with Landfill Gas to Energy equipment (LFGTE) which convert landfill gas (largely CH_4) to heat or electricity. Two additional smaller closed landfills are also currently outfitted with LFGTE equipment[28]. Converting landfill gas to energy reduces CH_4 emissions to the atmosphere, while producing energy that would otherwise need to come from another generation source. These systems can produce electricity, heat, and pipeline quality gas. Emissions of CH_4 from closed landfills do gradually decline over time, and there are concerns due to the increase in air toxics from combustion of the untreated gas in engines; however, such projects are generally considered beneficial from a GHG perspective.

Overall emissions in Vermont from the waste sector are predicted to decline in the future, driven by a greater focus on recycling and organics diversion through Vermont's Universal Recycling Law[29] (Act 148 of 2012). This law gradually phases in mandates prohibiting the disposal of various materials in landfills, including recyclables, yard waste, and food scraps. The 2013 "Systems Analysis of the Impact of Act 148 on Solid Waste Management in Vermont" estimated that by 2022 the Universal Recycling law would reduce solid waste GHG emissions by 37%. This reduction estimate cannot be directly reconciled with the estimates in this report, as it includes GHG emissions from a lifecycle analysis of the diverted wastes.

Greenhouse gas emissions from wastewater include both CH_4 and N_2O, and have stayed relatively stable over time. There have been slight increases in emissions as populations have grown, but they have been gradual. The Global Warming Potential update for CH_4 also has a relatively large effect on emissions totals for the entire waste section, as almost all the included emissions are methane (Figure 13).

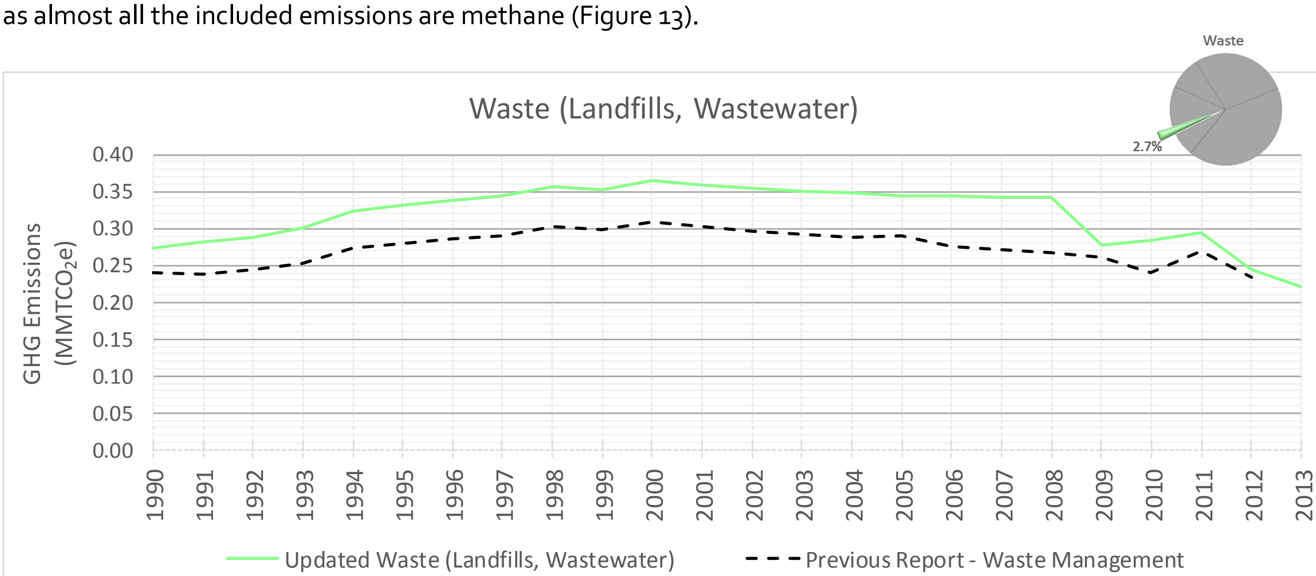

Figure 13. Vermont Waste (Landfills & Wastewater) Sector GHG Emissions (1990 – 2013).

[26] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014 – Waste Section

[27] EPA: https://www3.epa.gov/climatechange/ghgemissions/biogenic-emissions.html

[28] EPA - Landfill Methane Outreach Program: https://www.epa.gov/lmop/landfill-gas-energy-project-data-and-landfill-technical-data#states

[29] Vermont DEC: http://dec.vermont.gov/waste-management/solid/universal-recycling

Agriculture

Emissions estimates from the agricultural sector consist entirely of CH_4 and N_2O from various agricultural sources and processes. As a result, the GWP updates had a significant effect on the emissions from the agricultural sector (Figure 14). The main emissions sources from this sector include enteric fermentation (emissions from digestive processes of ruminant animals), manure management, and agricultural soils (Table 2). Manure management and enteric fermentation emit almost exclusively CH_4, whereas processes associated with agricultural soils emit mainly N_2O. Most of the agricultural soils emissions relate to soil fertilization, including the application of nitrogen based fertilizers.

Anaerobic digesters are one method currently being employed to reduce methane emissions from the manure management process. These "Cow Power" digester systems are engineered to enhance production of CH_4 from manure and use it to generate heat or electricity to be used on the farm, or to be sold back to the grid. In 2013 there were approximately 20 farms with these anaerobic digester systems in Vermont processing the manure from approximately 20,000 animals.[30] The greenhouse gas benefits of anaerobic digesters are somewhat unclear, because the digesters potentially change the decomposition of manure from aerobic (producing CO_2) if the cows were in a pasture, to anaerobic (producing higher-GWP CH_4), but the systems are considered more beneficial than a standard anaerobic lagoon system (where no methane is captured). There are also concerns with air toxics emissions from anaerobic digesters, specifically emissions of formaldehyde from the combustion of the raw biogas in engines. The energy production aspects of these systems can be beneficial, and there is potential for GHG emissions reductions in certain cases and scenarios.

Although livestock populations in Vermont, specifically dairy cows, have been declining in recent years[31], milk production has actually increased. This has been mostly due to better nutrition in livestock diets, and better breeding. Continued improvement of animal diets, coupled with improved manure management practices, more efficient fertilizer application, and more outreach and collaboration with farmers, are expected to drive the downward trend for the agricultural sector into the future (Table 13).

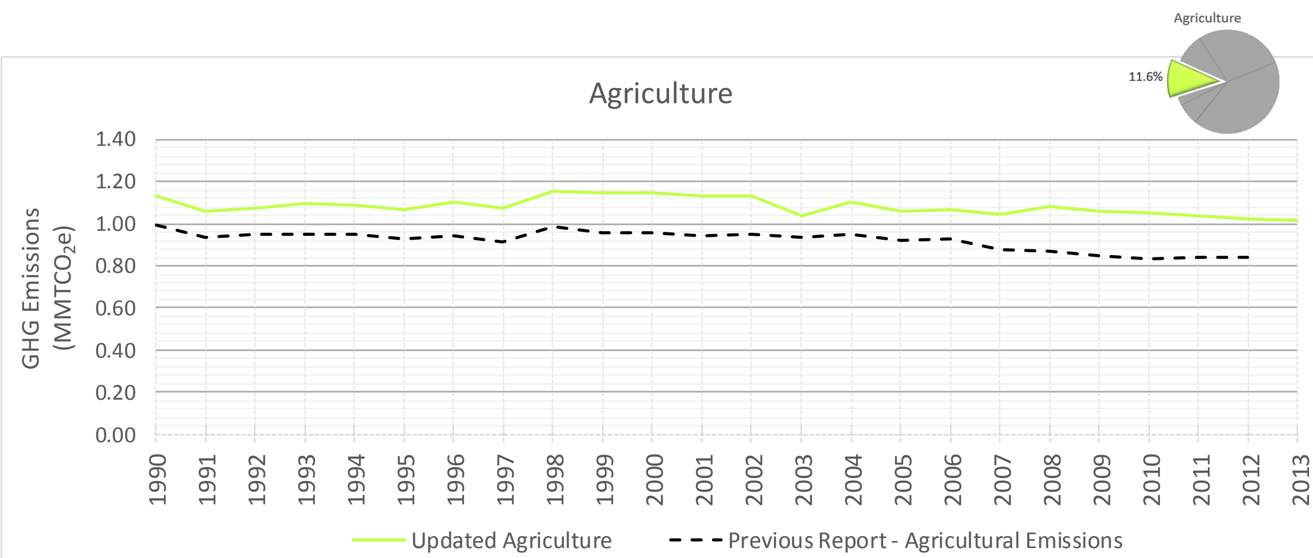

Figure 14. Vermont Agricultural Sector GHG Emissions (1990 – 2013).

[30] VT DEC – AQCD: Annual registration documents

[31] USDA – Quick Stats: https://quickstats.nass.usda.gov/

Industrial Processes

Of the industrial processes included in this statewide inventory, the most prominent from an emissions standpoint are those involving ODS Substitutes and Semiconductor Manufacturing (Table 2). Emissions trended downward from 2010 – 2013 (Figure 15), mostly due to a reduction in emissions from semiconductor manufacturing. Many of the emissions categories included in the Industrial Processes sector of the EPA SIT module are not present in Vermont.

Ozone Depleting Substances (ODS) Substitutes are being used to replace gases that were found to be damaging the stratospheric ozone layer (mainly CFCs and HCFCs). These replacement gases are much less harmful to the ozone layer. Unfortunately, many have very high GWP values, and in some cases extremely long atmospheric lifetimes (Table 1). A similar suite of fluorinated gases (all emitted from anthropogenic sources) are used in several semiconductor manufacturing processes, including HFCs, PFCs, SF_6, and NF_3.

Emissions of ODS Substitutes gradually have been increasing as they have been phased in to replace other gases used in various industrial processes (Table 2), mainly for refrigeration and cooling purposes. Although this trend may flatten out in Vermont as greater restrictions are placed on the use of these potent greenhouse gases, ODS substitutes are an issue of major concern on a global scale. If current practices continue, global HFC levels (a major component of ODS substitutes) will increase dramatically, mainly due to an increase in demand for refrigeration and air conditioning in developing countries[32]. Using an amendment to an existing international agreement to phase out ozone-depleting substances, known as the Montreal Protocol, additional goals have recently been established to drastically reduce the amounts of HFCs generated and used in production. These new agreements and commitments from multiple countries will hopefully slow the projected global increases of these gases significantly in the coming years.

The semiconductor manufacturing subsector has produced the largest change in historical data in this report that is not related to GWP updates. Previously reported semiconductor manufacture emissions were based on an EPA methodology apportioning the total national semiconductor shipment values to states based on census population data. Emitters in Vermont did not disclose their shipment values, and Vermont was assigned an average value based on the remaining total, divided among the nine states having sources that did not disclose data. This method produced a very low emissions total for the semiconductor manufacture process in the state. Since the previous report, the EPA has begun requiring greenhouse gas emissions reporting from all facilities emitting greater than 25,000 metric tons CO_2 equivalents per year to the Greenhouse Gas Reporting Program (GHGRP)[33]. This data is available via the EPA FLIGHT Tool[34] (Facility Level GHG Reporting Tool) for 2011 through 2015, and shows significantly higher emissions than those calculated with the old methodology (Figure 16). Since these reported emissions are considered to be more accurate than the default module values, an attempt has been made to update the historical data (including the 1990 baseline) by projecting the reported (2011 – 2015) data backward through time. This projection was made by applying the national semiconductor manufacturing emissions data curve from the EPA SIT module, as well as semiconductor manufacturing trends described in the Inventory of U.S. GHG Emissions and Sinks: 1990-2014[35], which show an emissions peak in 1999 and a downward trend from 1999 through 2014. Values for specific years were then adjusted slightly to better match the national curve, and to avoid sharp increases or decreases in emissions totals.

[32] EPA - https://www.epa.gov/ozone-layer-protection/recent-international-developments-under-montreal-protocol

[33] EPA Greenhouse Gas Reporting Program: https://www.epa.gov/ghgreporting

[34] EPA FLIGHT Tool: https://ghgdata.epa.gov/ghgp/main.do

[35] EPA - Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014 (April 15, 2016)

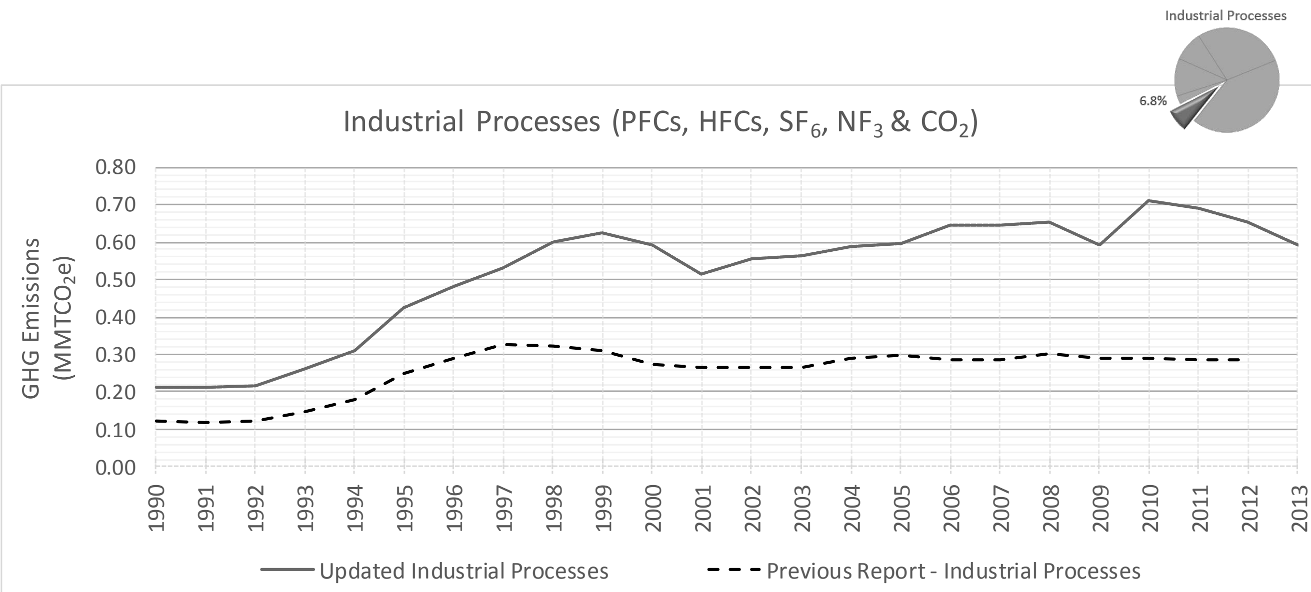

Figure 15. Vermont Industrial Processes Sector GHG Emissions (1990 – 2013).

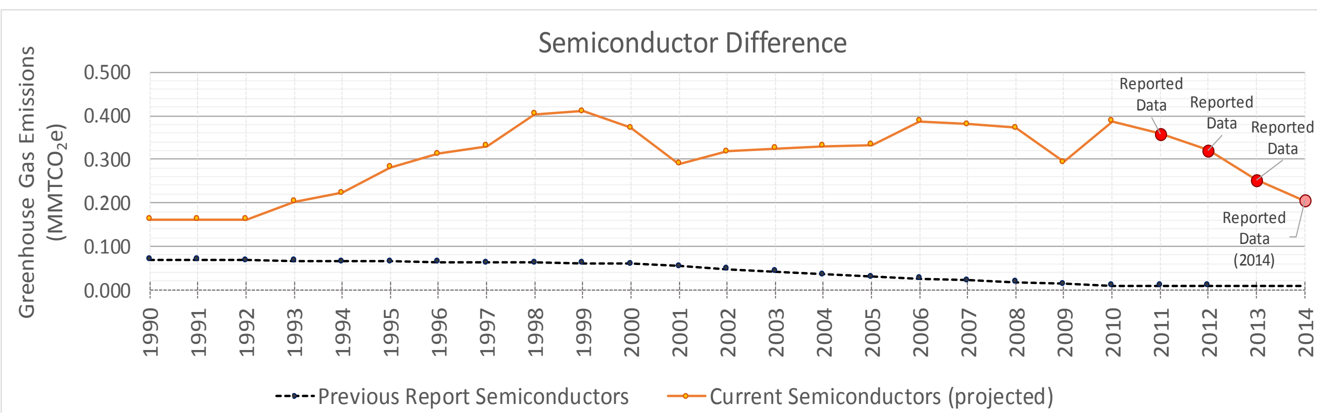

Figure 16. Vermont Semiconductor Manufacturing Emissions – Data Comparison.

Forestry & Land Use[36]

Estimates of carbon dioxide emissions and carbon sequestration attributable to the forest and land use sector in the previous Vermont GHG Emissions Inventory[37] were difficult to quantify due to methodology changes in the base data provided the U.S. Forest Service, Forest Inventory and Analysis (FIA) group, described in the previous inventory. Over the past decades, field measurements and models of each forest carbon pool (e.g. aboveground biomass, litter, down wood) were advancing at different rates, so aboveground forest biomass and acres of forested land were used as indicators of trends in all the forest carbon pools in the previous Vermont inventory report. Fortunately, a new, more consistent forest carbon accounting framework (U.S. Forest Carbon Accounting Framework) is being adopted by FIA that corrects past accounting inconsistencies, making use of improved data collection methods, new remote-sensing information, and models that are universally applied across the U.S.[38]. Even more valuable are improved methods of accounting for soil organic carbon (SOC), which is the largest carbon pool in US forests. The new estimates use field measurements, along with model refinements and expert input from the International Soil Carbon Network. While large stocks of carbon are stored in soils, the rate of change is slow, so these updates did not lead to major changes in annual carbon sequestration totals.

An estimate of forest carbon sequestration in Vermont, based on the carbon pools comprising the "Forest Land Remaining Forest Land" category (aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon) was extracted from the 2017 National Inventory Report (NIR)[39], which has been submitted to EPA for public review. These data were generated using models and methodologies described in the Forest Carbon Accounting Framework and 2017 NIR, and appear to be a much more consistent data set than the values produced by the default forest carbon flux data in the EPA Land Use, Land-Use Change, and Forestry SIT module. The 2017 NIR data were used to modify the default carbon flux data in the EPA SIT module, and sequestration estimates were generated (Figure 17). The Land Use, Land-use Change, and Forestry module consists of multiple input categories (including contributions to forest carbon flux, liming of agricultural soils, urea fertilization, urban trees, landfilled yard trimmings and food scraps, and wildfires); however, historically, the forest carbon flux is responsible for approximately 97 percent of modeled sequestration from this module. Default data were utilized for the remaining sectors in the module run, but emissions estimates were deemed insignificant. Emissions calculated using default values for Landfilled Yard Trimmings and Food Scraps were relatively small and were excluded due to data reliability issues. Other data excluded from this inventory include: wildfire data, total wood products in landfills, and lumber in buildings and wood products. Available data for these sectors are unreliable and these sectors are at least partially captured through the biomass change portion of the FIA annual inventory. Sequestration by urban trees has been added to the modeled forest carbon sequestration value totals. These estimated sequestration totals have not been subtracted from the overall gross greenhouse gas emissions totals generated by the other sectors included in this inventory, but will be used for comparison and estimation purposes in the Biogenic CO_2 Emissions & Forest Carbon Sequestration section at the end of this report.

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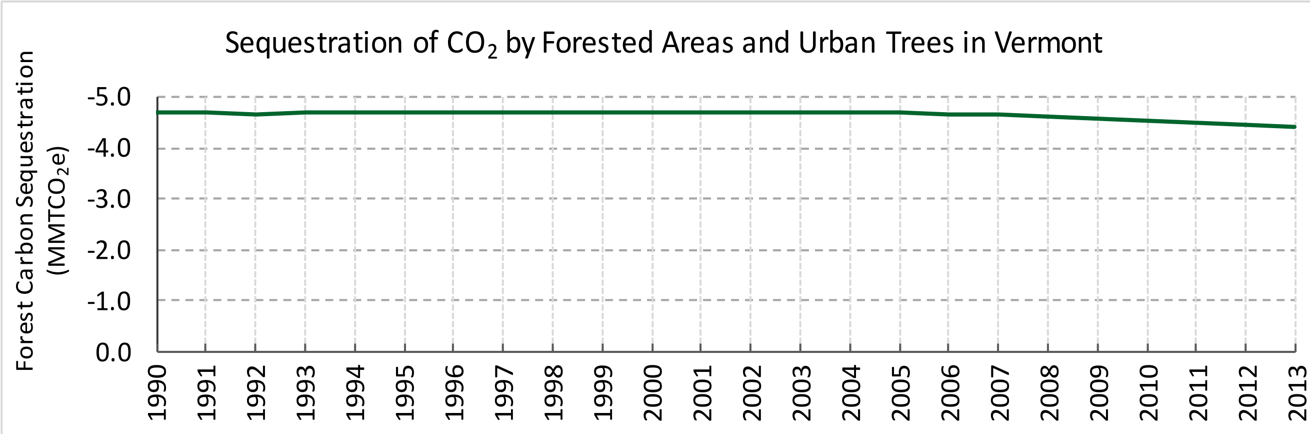
[36] This section developed in collaboration with Sandy Wilmot (VT Dept. of Forests, Parks and Recreation).

[37] Vermont DEC – Vermont GHG Emissions Inventory Update 1990-2012: http://dec.vermont.gov/air-quality/climate-change

[38] U.S. Forest Carbon Accounting Framework: Stocks and Stock Change, 1990-2016 https://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs154.pdf

[39] Domke, G.M., Smith, J.E., Walters, B.F., Nichols, M., Coulston, J.W. In review. Forest land category sections of the Land Use, Land Use Change, and Forestry chapter, and Annex. In: US Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. EPA 430-R-17-XXX.



** Negative values represent carbon sequestration (as opposed to positive emissions).*

Figure 17. Estimates of Carbon Sequestration by Forests and Urban Trees in Vermont.

Forest carbon interactions are complex. Models must account for many factors and rely on many assumptions to predict forest carbon fluxes. The updated data and methodologies from the Forest Carbon Accounting Framework (FCAF) are more consistent than previously generated data; however, the methodology from the previous inventory has been applied to the updated forest carbon data (data source for acres of forest land remained the same) below for analyses and comparison with historical estimates (Figure 18). Forests are generally considered to be carbon sinks (net removers of atmospheric carbon), so an overall increase in forest land and in sustainably managed forests, is beneficial in moderating climate warming caused by atmospheric CO_2. Being net carbon sinks, forests are incredibly important in the carbon cycle, and adding additional forest area can help to mitigate some of the CO_2 being emitted by anthropogenic sources.

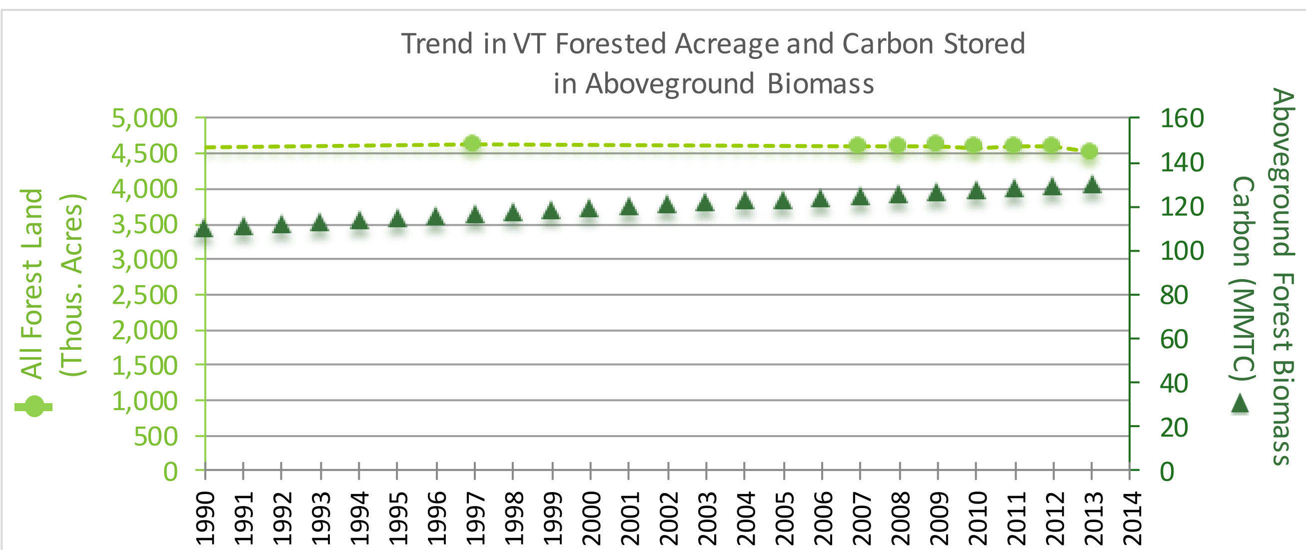


Figure 18. Forest Land and Aboveground Forest Biomass Estimates Using Previous Methodologies.

Conclusions and Recommendations

Over the past decade, Vermont's annual greenhouse gas (GHG) emissions have declined, and have remained below the peak levels that occurred in 2004. However, our most recent estimates reveal that this steady decline has ceased, and GHG emissions actually increased slightly from 2011 through 2013 to levels that are still above the 1990 baseline. Vermont also fell short of reaching the established 2012 goal to reduce GHG emissions to 25 percent below 1990 levels. Unless significant actions are identified and implemented to curtail emissions from multiple sectors, the next goal established by the Vermont Comprehensive Energy Plan (2016)[40], to reduce GHG emissions by at least 40 percent below 1990 baseline levels by 2030, will also be unattainable.

There is far-reaching scientific consensus that the Earth is warming primarily due to anthropogenic emissions of greenhouse gases. Continued warming will most likely impact Vermont with events such as higher peak summer temperatures, warmer and wetter winters, increased periods of drought, increased frequency of severe precipitation events, etc. that will negatively impact both natural ecosystems and built infrastructure.[41] These effects can be moderated through actions that successfully begin to reduce the excessive release of GHGs to our atmosphere.

Although Vermont is responsible for only a small fraction of global GHG emissions, it has the opportunity to continue as a national and international leader to reduce greenhouse gas emissions from all sectors of the economy, and to adapt to the impacts of a changing climate. The participation of Vermont and eight other states in the Regional Greenhouse Gas Initiative (RGGI) provides one model to demonstrate that it is possible to simultaneously reduce GHG emissions from the electricity sector and make Vermont more affordable. Vermont's path forward must look to develop effective GHG reduction actions for all sectors to meet the stated goals, without unduly burdening the most vulnerable Vermonters. The Vermont Climate Action Commission announced in July 2017 by Governor Scott through Executive Order No. 12-17, represents a significant opportunity to take these next planning and implementation steps to simultaneously reduce GHG emissions & meet our energy needs in accordance with established goals, and promote the economic well-being of Vermont.

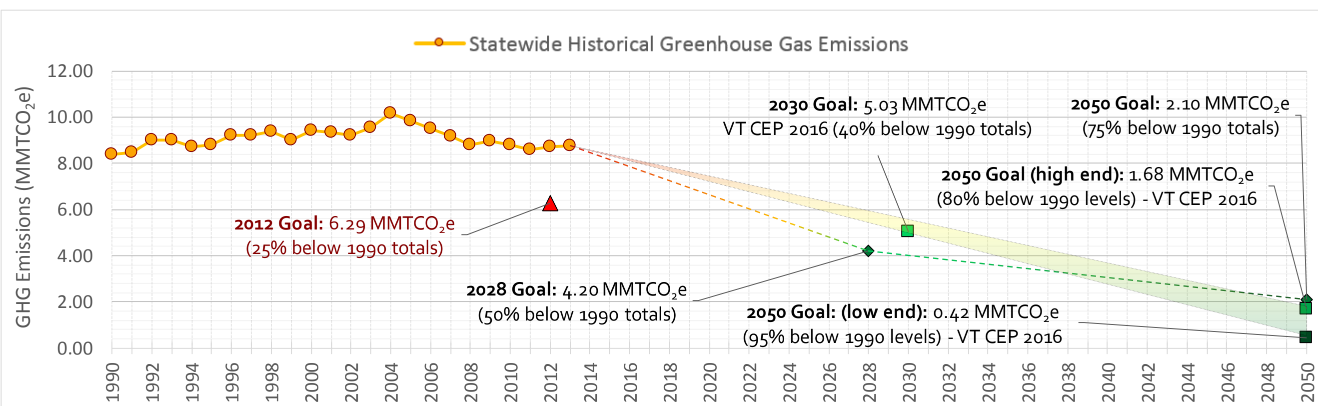


Figure 19. GHG Emissions Trends and Goals for Vermont.

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[40] VT Dept. of Public Service – Comprehensive Energy Plan 2016: https://outside.vermont.gov/sov/webservices/Shared%20Documents/2016CEP_Final.pdf

[41] State of Vermont – Climate Change in Vermont: http://climatechange.vermont.gov/

Biogenic CO_2 Emissions & Forest Carbon Sequestration – Additional Information

Emissions of biogenic CO_2 (emissions related to the combustion or decomposition of biologically based materials) have not been included in the totals presented in this, or in previous, Vermont greenhouse gas emissions inventory reports. This is because, as is described in prior sections, the CO_2 produced in these processes is either considered to be at least partially offset by carbon sequestration through forest growth, or thought to equal the emissions of CO_2 that would be produced if materials decomposed outside of human influence. The emissions from these sources were meant to be accounted for in the land use section, which was formerly impossible to reliably quantify with the available data and methodologies.

These sources of CO_2 were not included directly in greenhouse gas emissions inventories in part to illustrate the difference between "renewable" or biologically-based (biogenic) sources of carbon, that can be reconstituted within the carbon cycle on human timescales, versus the combustion of fossil fuels which adds back to atmosphere a tremendous amount of carbon that had been "permanently" sequestered, and is only reformed on geologic timescales. Although these are important distinctions, the fact remains that CO_2 released from any source is contributing to the overall cumulative concentration of CO_2 currently in the atmosphere and exacerbating the warming of the planet.

Per Intergovernmental Panel on Climate Change (IPCC) emissions inventory preparation guidelines, carbon emissions from biogenic sources and subsequent sequestration should be accounted for by utilizing the land use, land-use change section methodologies, providing estimations of carbon emissions and sequestration (mainly by forests). Until recently, historical data comparisons of forest carbon flux and sequestration were not possible, due to changing modeling and FIA plot sampling methodologies. However, with the recent adoption of the Forest Carbon Accounting Framework (FCAF) methods and techniques, these estimates have become more consistent and reliable (see Forestry & Land Use section).

For this section of the report, Biogenic CO_2 emissions totals from at-the-stack wood combustion have been calculated for the residential, commercial, and industrial subsectors (RCI), as well as for the electrical generation sector. Estimates were generated from annual wood use data reported to the State of Vermont, and from the Vermont Residential Fuel Assessment 2014-2015[42] survey report. If all biogenic CO_2 stack emissions from these sectors were included in this inventory, without the offsetting effect of sequestration, the overall emissions totals would be significantly higher (Figure 20). Estimates of biogenic CO_2 from landfills and agricultural processes were not included, as reliable data were not available, and portions of the emissions were accounted for elsewhere in this inventory.

Sequestration values and biogenic CO_2 emissions totals could potentially be used to adjust for the net greenhouse gas emissions of the state. This has not been done for this report, in part due to the temporal and spatial complexity of modeling sequestration by the forest system. There is also ongoing debate about the degree of carbon neutrality attributable to all biogenic CO_2. By providing an estimate the biogenic CO_2 and sequestration totals, but omitting them from the overall statewide emissions totals, consistency is maintained with gross emissions values reported in previous inventories, and additional information is supplied to illustrate the potential range of annual greenhouse gas emissions in Vermont. The annual net greenhouse gas emissions total, including biogenic CO_2 from point-of-use emissions as well as the removal of CO_2 by sequestration, is likely somewhere in the range shown on Figure 20. These scenarios range from the addition of biogenic CO_2 with no sequestration accounted for (red line), to the exclusion of biogenic CO_2 with all modeled sequestration accounted for (green line), with the blue line depicting the most

[42] State of Vermont – Department of Forest, Parks & Recreation
http://fpr.vermont.gov/sites/fpr/files/About_the_Department/Library/Library/FINAL_2015%20Residential%20Fuel%20Assessment%20Report.pdf

plausible estimation of "net GHG emissions", including both the biogenic CO_2 from wood combustion and the modeled sequestration.

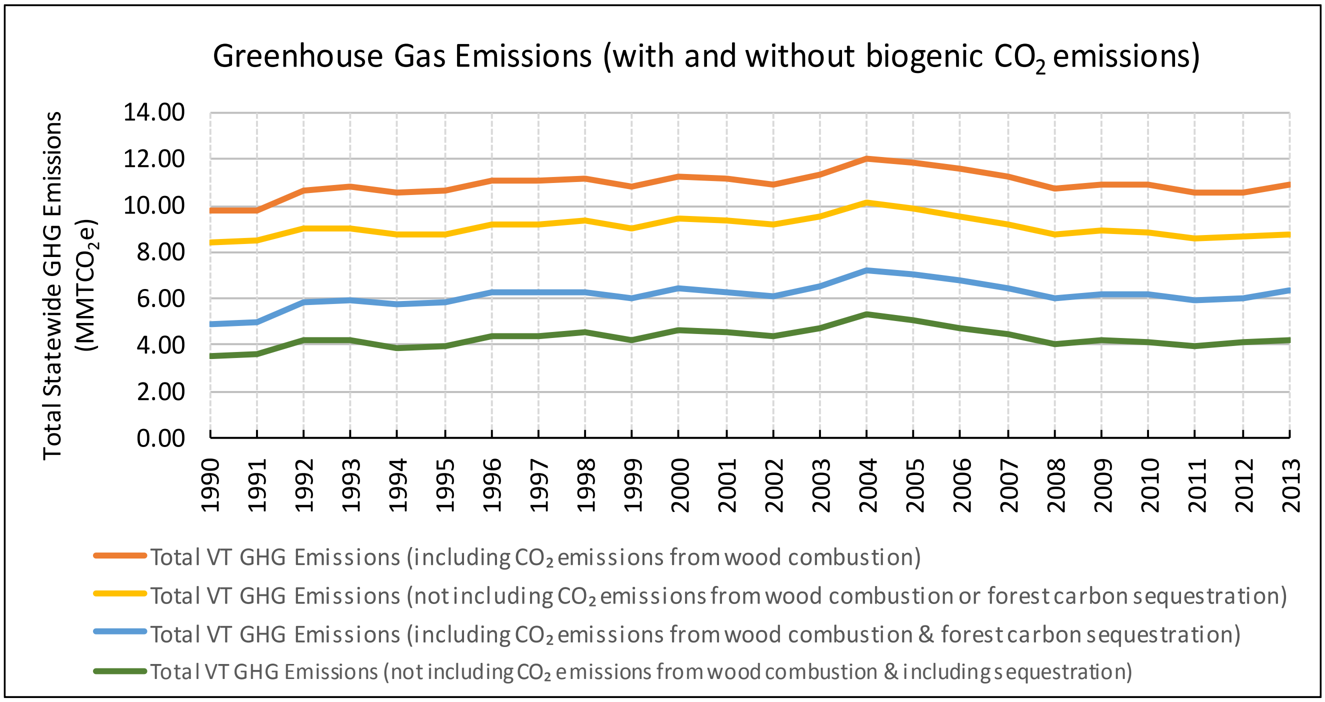
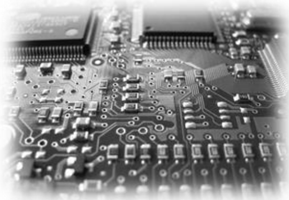


Figure 20. Vermont GHG Emissions Trends with and without Biogenic CO_2 from Wood Combustion and Forest Carbon Sequestration.



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