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Greenhouse Gas Emissions Inventory Update: Comprehensive 1990 - 2014

June 2018

VERMONT

Department of Environmental Conservation
Air Quality and Climate Division

Going forward Greenhouse Gas Emissions Inventory Update reports will be designated as either “Comprehensive” or as “Brief.” Comprehensive reports will provide a greater level of detail on certain sectors and graphics than the reports designated as “Brief,” and will coincide with the calendar year releases of the triennial National Emissions Inventory (NEI) compiled by the U.S. Environmental Protection Agency (EPA). This is due mainly to the fact that several sectors in the inventory report are based on calculations and data from the NEI, as well as various other tools and datasets from the EPA and other agencies. In many cases EPA’s release of this national level inventory enables more robust analyses for the given year and provides additional emissions estimate checks for individual sectors.

Introduction - Emissions Summary

Greenhouse gas (GHG) emissions estimates for Vermont continued to rise for calendar year 2014, increasing from 9.10 million metric tons CO_2 equivalent ($MMTCO_2e$) in 2013 to 9.45 $MMTCO_2e$ in 2014. This increase puts Vermont approximately 10% above the 1990 baseline value of 8.59 $MMTCO_2e$ and adds to the difficulty of reaching the established statewide goals [1,2] (Figure 1). In the previous report (1990-2013) global warming potential (GWP) values were updated, which led to increases in the historical emissions estimates. The GWP values used in this report are consistent with those from the previous report. There were data and methodology updates for multiple sectors, specifically the agriculture, transportation, and industrial processes sectors, resulting in higher emissions values for 2013 from the previous report and adjusted 1990 baseline and goal values. Emissions estimates in this inventory supersede all previous Vermont Greenhouse Gas Emissions Inventory Update report values because they reflect continuous data and methodology improvements.

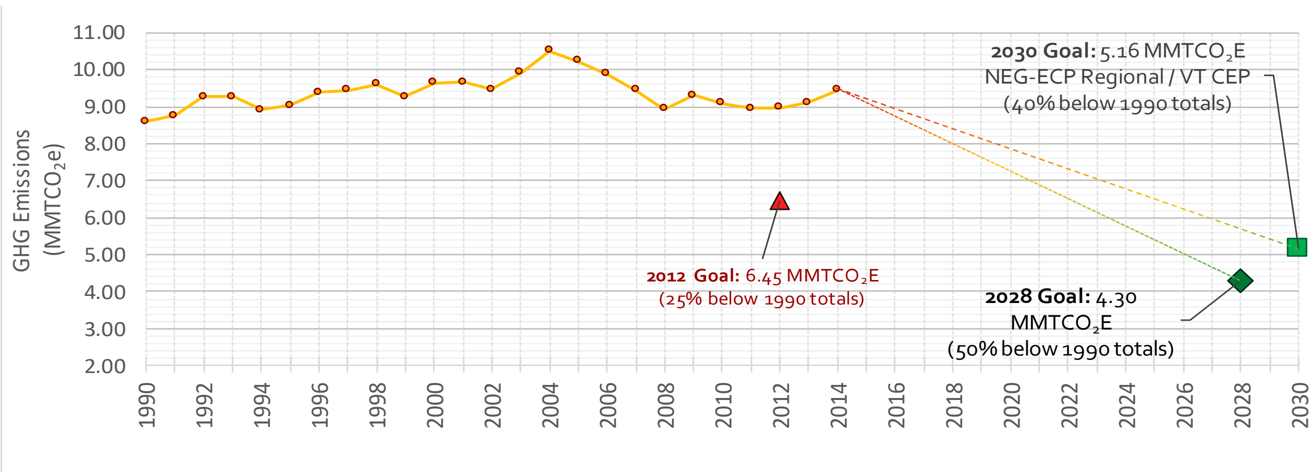

Figure 1. Vermont Historic GHG Emissions Estimates and Future Emissions Reduction Goals

Progress in sector specific emissions reductions between 2013 and 2014 was limited. Emissions decreases were limited to the industrial processes and municipal solid waste sectors; however, these reductions were more than offset by additional emissions from the electricity generation, residential, commercial, and industrial (RCI) fuel use, and transportation sectors. Emissions from the electricity generation and RCI sectors are somewhat unpredictable and vary based on the purchase decisions of utilities and the length and severity of the winter, however it is still concerning that emissions totals increased in these sectors. Transportation emissions have also shown an increase, driven by the onroad gasoline emissions, and based on several key indicators (vehicle miles traveled, and gallons of fuel sold), it appears likely that emissions from this sector will continue to increase in the next several inventory years.

Transportation emissions are based on results from a sophisticated 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 or methodologies, especially for onroad gasoline and onroad diesel vehicles. Values for 2012 and 2013 were interpolated in the previous report based on the modeled emissions totals for the available years and categories and are shown in grey text to illustrate that they are projections.

[1] Vermont Statute 10 V.S.A. § 578: http://legislature.vermont.gov/statutes/section/10/023/00578
[2] Source: Vermont Comprehensive Energy Plan (CEP 2016)

This report attempts to provide comprehensive and accurate greenhouse gas emissions totals for the State of Vermont from 1990 through 2014. 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[3] 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 also been included as it was added to the original list of six greenhouse gases previously specified in the Kyoto Protocol.

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* developed by the Center for Climate Strategies (CCS)[4], 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. Greenhouse gas emissions data have been calculated for the years 1990-2014 and are summarized by sector in Table 1 and in the sector specific tables and graphs that follow.[5]

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

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

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

Table 1. Vermont Historic Greenhouse Gas Emissions by Sector[6,7]

Sector	Million Metric Tons CO_2 Equivalent: $MMTCO_2e$					
	1990	**2000**	**2005**	**2012**	**2013**	**2014**
Electricity Supply & Demand (consumption based)	**1.09**	**0.43**	**0.64**	**0.93**	**0.81**	**0.84**
Coal	0	0	0	0	0	0
Natural Gas	0.047	0.018	0.000	0.001	0.001	0.000
Oil	0.014	0.058	0.011	0.014	0.013	0.021
Wood (CH_4 & N_2O)	0.003	0.010	0.014	0.011	0.015	0.014
Residual System Mix	1.03	0.35	0.62	0.90	0.78	0.81
Residential / Commercial / Industrial (RCI) Fuel Use	**2.41**	**2.86**	**2.98**	**2.21**	**2.46**	**2.60**
Coal	0.017	0.003	0.000	0	0	0
Natural Gas	0.314	0.496	0.440	0.416	0.494	0.550
Oil, Propane & Other Petroleum	2.057	2.341	2.494	1.729	1.875	1.957
Wood (CH_4 & N_2O)	0.022	0.021	0.041	0.069	0.093	0.095
Transportation	**3.38**	**4.15**	**4.49**	**3.83**	**3.88**	**4.10**
Onroad Gasoline	2.64	3.20	3.29	2.70	2.73	3.03
Onroad Diesel	0.41	0.66	0.69	0.63	0.62	0.54
Jet Fuel & Aviation Gasoline	0.08	0.07	0.17	0.10	0.10	0.09
Rail / Ship / Boats / Other Nonroad	0.25	0.23	0.34	0.40	0.43	0.44
Fossil Fuel Industry	**0.0077**	**0.0040**	**0.0039**	**0.0045**	**0.0047**	**0.0048**
Natural Gas Distribution[8]	0.0068	0.0030	0.0028	0.0034	0.0036	0.0037
Natural Gas Transmission	0.0009	0.0010	0.0011	0.0011	0.0011	0.0011
Industrial Processes	**0.21**	**0.59**	**0.59**	**0.65**	**0.60**	**0.57**
ODS Substitutes	0.00	0.17	0.21	0.30	0.31	0.32
Electric Utilities (SF_6)	0.04	0.02	0.01	0.01	0.01	0.01
Semiconductor Manufacturing (HFCs, PFCs & SF_6)[9]	0.16	0.37	0.33	0.32	0.25	0.21
Limestone & Dolomite Use	0.00	0.02	0.03	0.02	0.03	0.04
Soda Ash Use	0.006	0.006	0.005	0.004	0.004	0.004
Waste Management	**0.27**	**0.36**	**0.34**	**0.24**	**0.22**	**0.21**
Solid Waste	0.21	0.30	0.28	0.18	0.15	0.14
Wastewater	0.061	0.067	0.068	0.069	0.069	0.069
Agriculture	**1.22**	**1.23**	**1.17**	**1.10**	**1.12**	**1.12**
Enteric Fermentation	0.70	0.69	0.63	0.62	0.64	0.64
Manure Management	0.18	0.22	0.23	0.20	0.20	0.20
Agricultural Soils	0.35	0.33	0.31	0.28	0.29	0.29
TOTAL GROSS EMISSIONS	**8.59**	**9.64**	**10.22**	**8.97**	**9.10**	**9.45**
Change relative to 1990 (baseline)	**–**	**+ 12%**	**+ 19%**	**+ 4%**	**+ 6%**	**+ 10%**

[6] 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 in the previous report – produced on a triennial basis.

[7] Totals may not sum exactly due to independent rounding.

[8] 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.

[9] Semiconductor data from 2011 – 2014 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.

Global Warming Potentials

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 (CO_2e) are calculated based on the averaged radiative forcing impact of the specific GHG through a multiplier called a Global Warming Potential (GWP). These GWP potency multipliers are reviewed and updated by the Intergovernmental Panel on Climate Change (IPCC), and subsequently adopted by the U.S. EPA for use in emissions inventories. GWP values shown below (Table 2) are from the IPCC AR4 report[10], and are based on a 100-year time horizon.

Table 2. Greenhouse Gas Global Warming Potentials (GWPs) and Atmospheric Lifetimes.[11]

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 (based on 100-yr time horizon).

[10] IPCC Fourth Assessment Report (2.10.2): https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

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

Vermont and the United States – Emissions Comparison

Although greenhouse gas emissions generated in Vermont make up a small percentage of the U.S. total, approximately 0.1% historically, Vermont's emissions have increased from 2011 through 2014 (Figure 2).

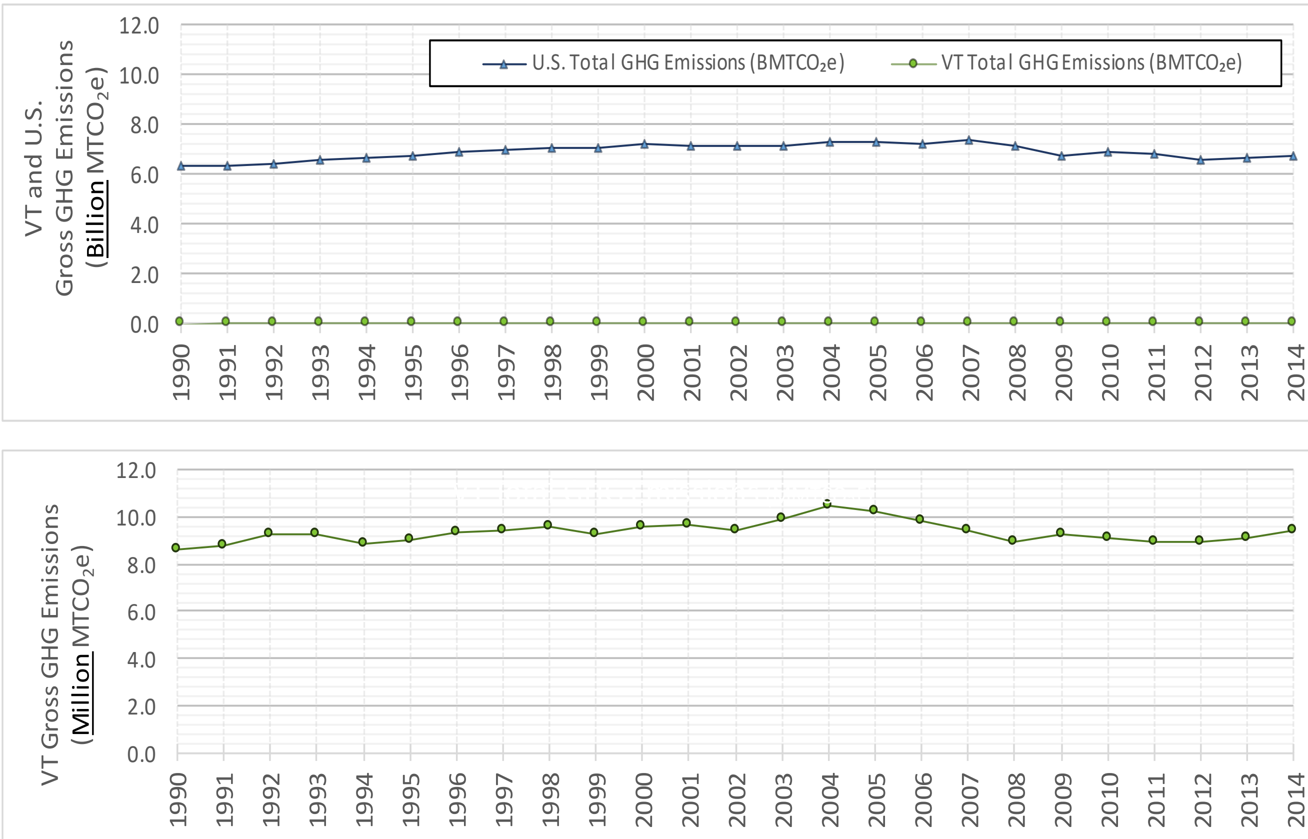

Figure 2. Vermont and the U.S.[12] – Historical Gross GHG Emissions Comparison (1990 – 2014).

[12] U.S. data source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2015 (April 2017). https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf

Vermont has a considerably lower per capita CO_2e emissions than the national average, however, the difference between the two has been decreasing over time (Figure 3).

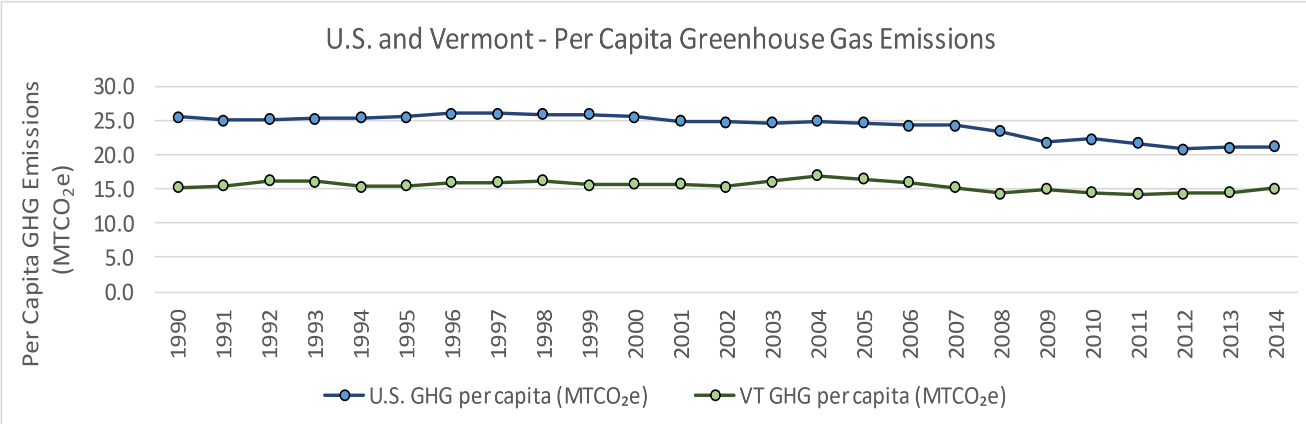

Figure 3. VT & U.S. Gross GHG Emissions per Capita[13,14,15] (1990 – 2014).

Economic growth in Vermont and the U.S. has increased from the 1990 baseline levels at a much faster rate than GHG emissions (Figure 4), indicating that over time each unit of goods and services produced has resulted in a smaller release of GHG emissions.

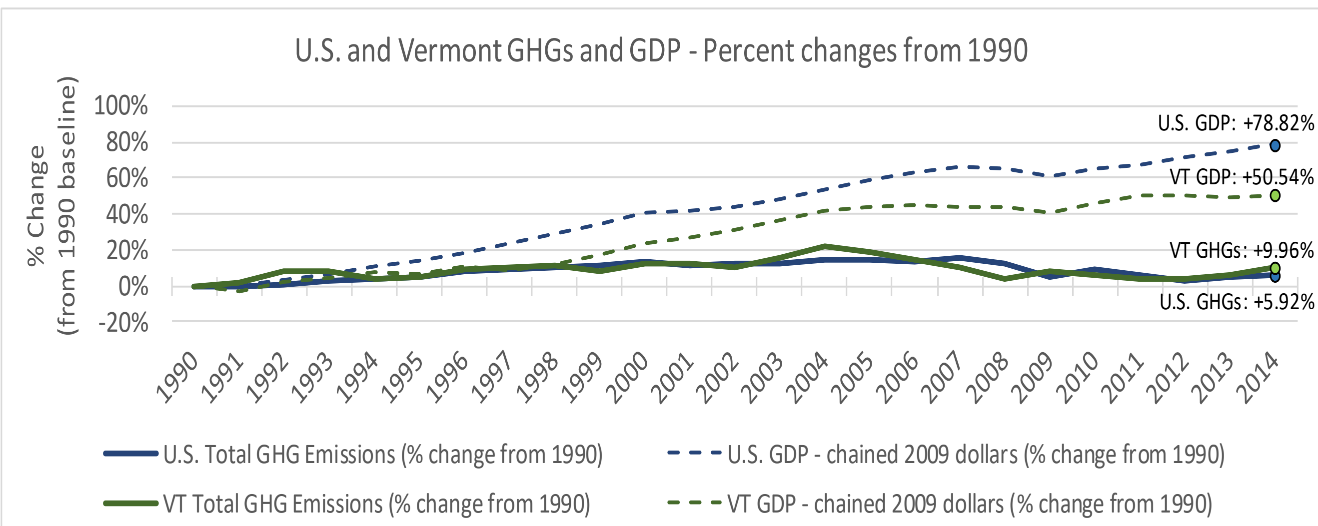

Figure 4. VT & U.S. Percent Change GDP vs. Percent Change GHG Emissions [13,14,15] (1990 – 2014).

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[13] State and US Population Data: United States Census Bureau (https://www.census.gov/programs-surveys/popest/data/tables.html)
[14] Department of Commerce - U.S. Bureau of Economic Affairs – National GDP data (http://www.bea.gov/national/index.htm)
[15] Department of Commerce - U.S. Bureau of Economic Affairs – State GDP data (http://www.bea.gov/iTable/index_regional.cfm)

There are several sectors in VT which contribute significantly higher percentages and should be areas of focus for state mitigation efforts. These sectors include Transportation, Residential / Commercial fuel use, and Agriculture (Figure 5). It should be noted that the percentage contribution for transportation is somewhat inflated in Vermont due to the comparative lack of large GHG emissions point sources, including industrial manufacturing and electricity generation facilities.

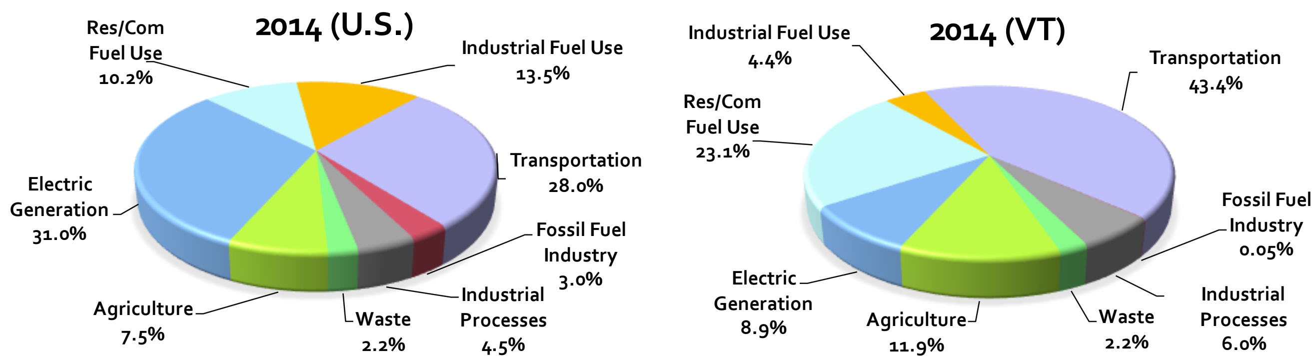


Figure 5. Sector Emissions Contribution Percentages Comparison (2014) – U.S. and Vermont[16]

[16] U.S. data source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2015 (redistributed to match VT sector categories). https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf

Vermont GHG Emissions – Sector Details

Statewide greenhouse gas emissions have remained relatively constant in Vermont historically, with some variation and fluctuation within sectors (Figure 6 and Figure 7). Overall emissions are still below the peak levels in 2004, but annual emissions levels have generally been increasing since 2011.

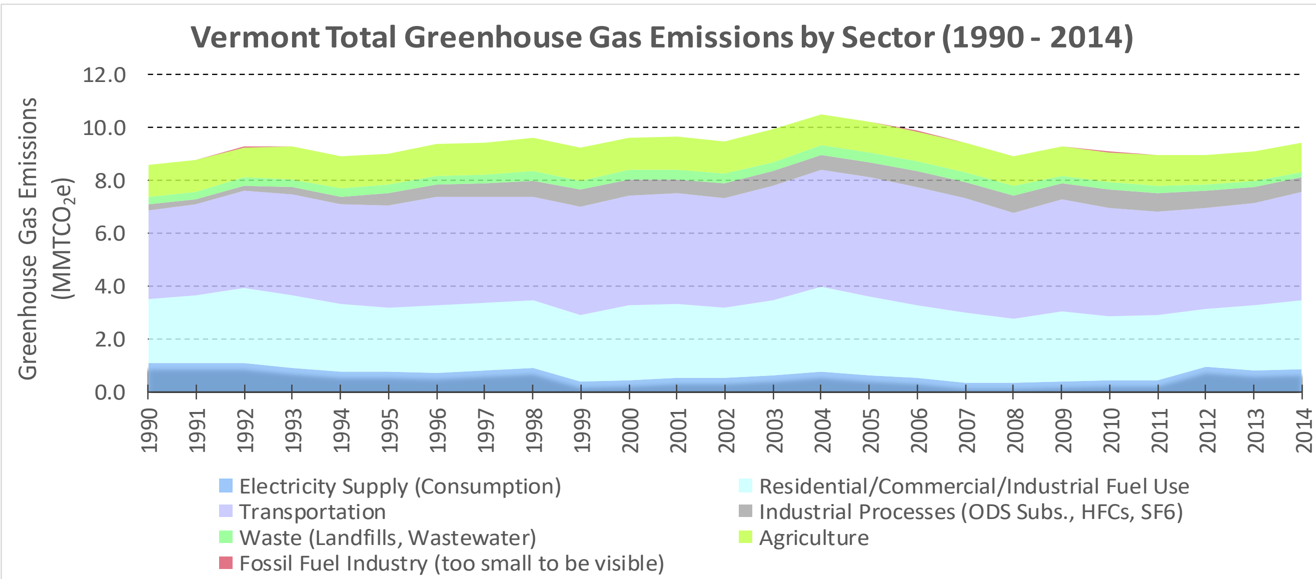


Figure 6. Historic Gross Vermont GHG Emissions.

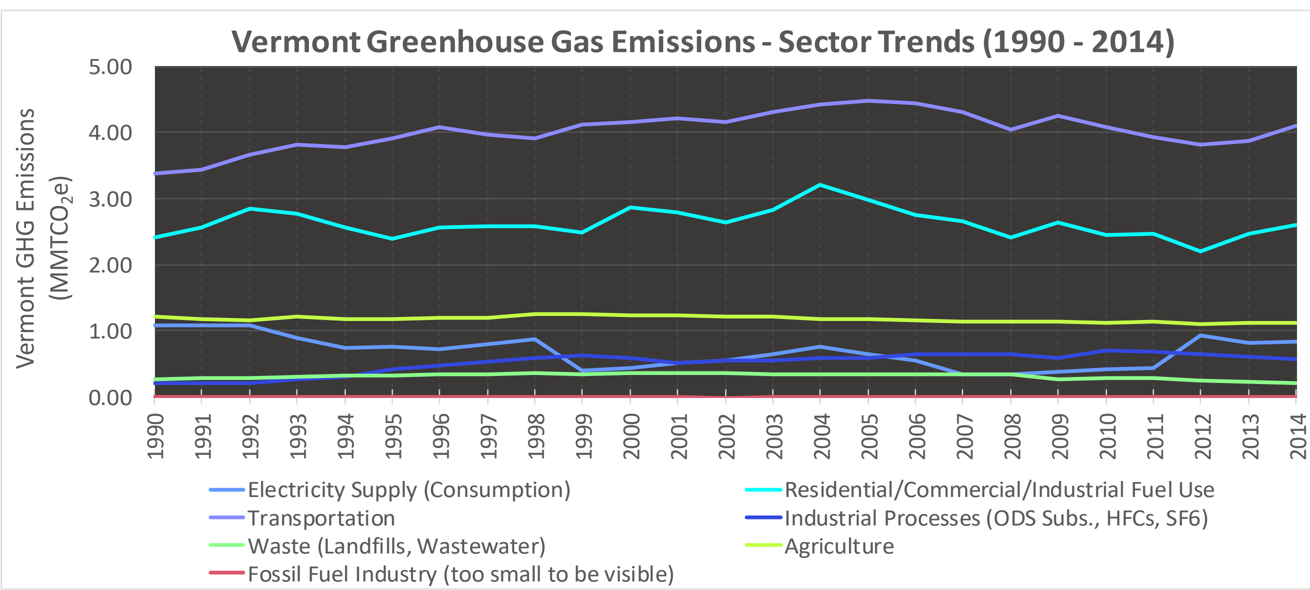


Figure 7. Historic Vermont GHG Emissions by Sector (1990 – 2014).

Transportation

The transportation sector is the largest contributing sector to greenhouse gas emissions in Vermont. Emissions in this sector come from onroad gasoline vehicles, onroad diesel vehicles, aviation gasoline/jet fuel, and other non-road sources. Of these categories, on-road gasoline and on-road diesel vehicles are the two major contributors, historically comprising approximately 85% to 90% of the emissions from the sector.

Recent onroad emissions data has been taken from, or informed by, data from the National Emissions Inventory (NEI).[17] The NEI is produced triennially and the onroad estimates are generated using the MOtor Vehicle Emissions Simulator model (MOVES).[18] Estimates produced by the MOVES model are considered to be more accurate and robust than other estimation methods that could be employed at the State level with available data. Data for years between the available triennial NEI years (i.e., 2011 & 2014) were interpolated from the NEI estimates based on indicators such as vehicle miles travelled (VMT)[19] (Figure 8) and fuel sales data[20] (Figure 9).

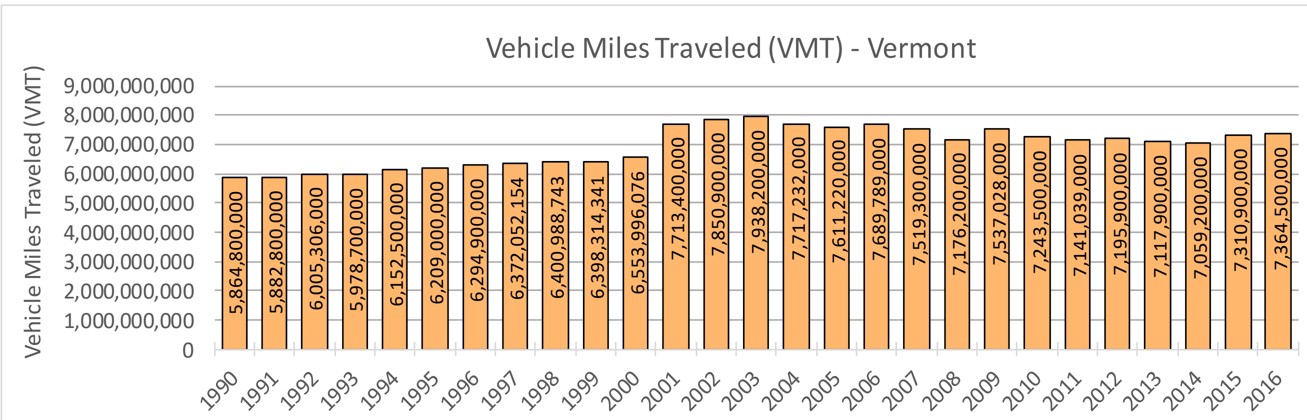


Figure 8. Annual Vehicle Miles Traveled (VMT) in Vermont.

[17] EPA – NEI2014: https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data
[18] EPA MOVES model: https://www.epa.gov/moves/moves2014a-latest-version-motor-vehicle-emission-simulator-moves
[19] VTrans VMT data - http://vtrans.vermont.gov/docs/highway-research
[20] Vermont Joint Fiscal Office (JFO) – "Gas & Diesel Revenue and Gallons": http://www.leg.state.vt.us/jfo/transportation.aspx

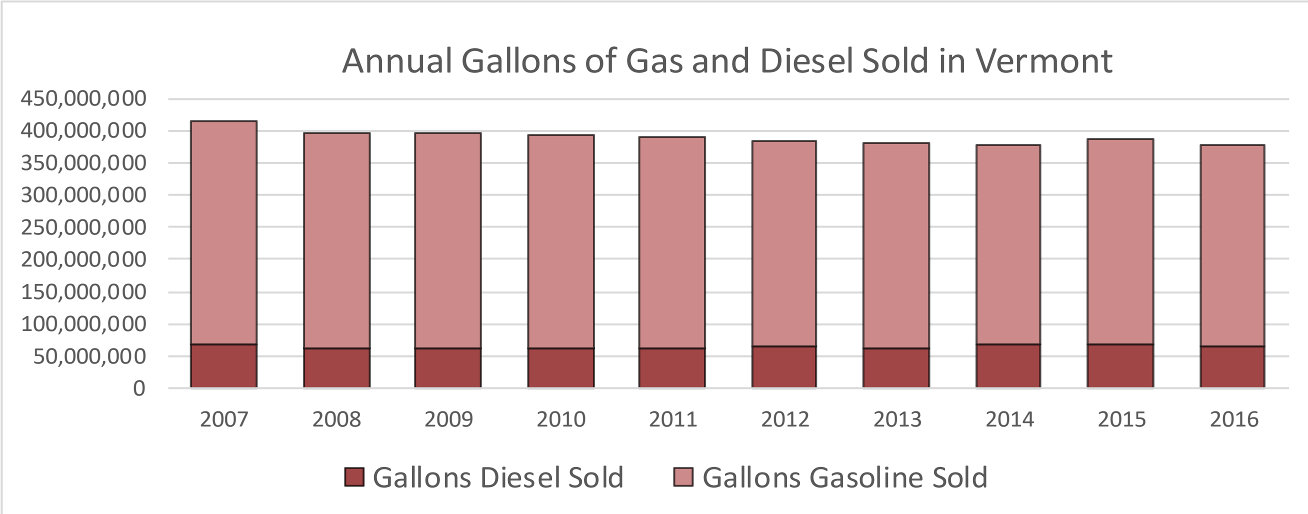


Figure 9. Annual Gallons of Gas and Diesel Sold in Vermont.

NEI emissions estimates for the non-road sectors are not nearly as accurate or reliable as the onroad sectors due to outdated emission factors, and unreliable state level vehicle and equipment population, age, and usage estimates. In the previous inventory the non-road emission totals were taken from earlier report values and adjusted for GWP changes. This report shows relatively large differences in the non-road sector emissions from the previous report because of recent Federal Highway Administration (FHWA) data collection and methodology changes. The largest contribution to this change is the inclusion of the lawn & garden, and recreational equipment subsectors, which were previously not included in the FHWA data. Rather than showing a drastic increase in sector emissions going forward, the historical data has been adjusted using ratios of these subsectors to the current totals, and projecting backward using the previous totals which did not include these two subsectors. The difference caused by this historical data change for the nonroad sector effects the 1990 baseline (Figure 10) as well as the established reduction goal values. FHWA has also updated data and methodologies for the aviation gasoline and jet fuel, but the emissions totals do not appear to have changed substantially.

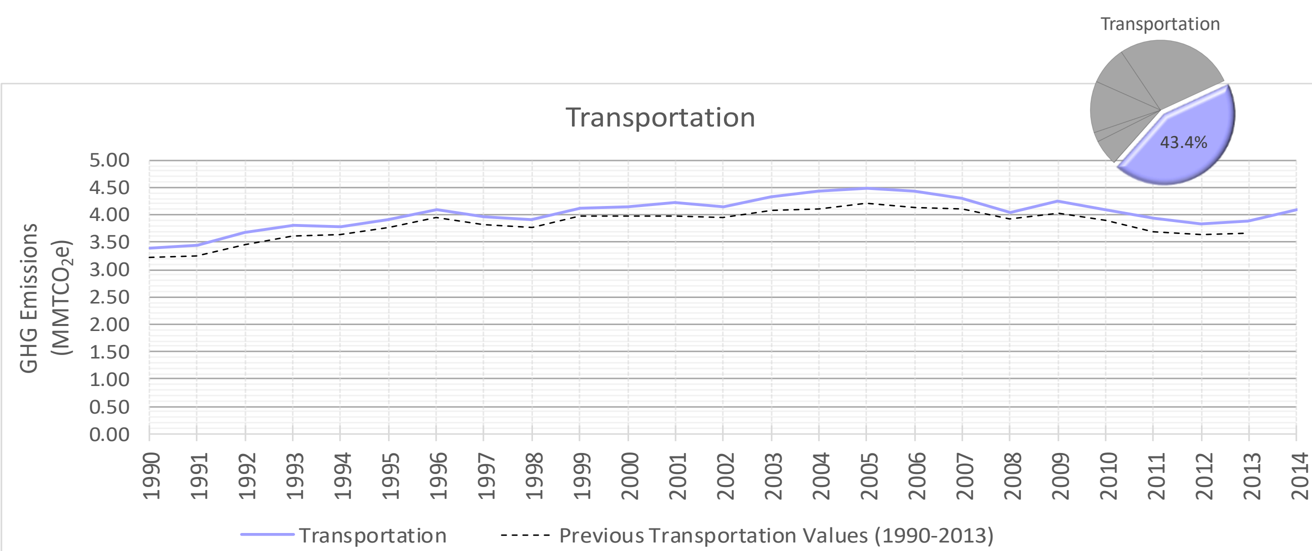


Figure 10. Vermont Transportation Sector GHG Emissions (1990 – 2014).

Residential/Commercial/Industrial (RCI) Fuel Use

The Residential/Commercial/Industrial (RCI) Fuel Use sector is the second largest contributing sector to statewide greenhouse gas emissions (Figure 11). This sector is also proportionally larger for Vermont than for the U.S. mainly due to relatively colder winters and greater overall heating demand. Carbon dioxide emissions from the oil, propane, & other petroleum category dominates this sector accounting for approximately 80% of the emissions historically.

Emissions from wood combustion 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 GHG emissions.

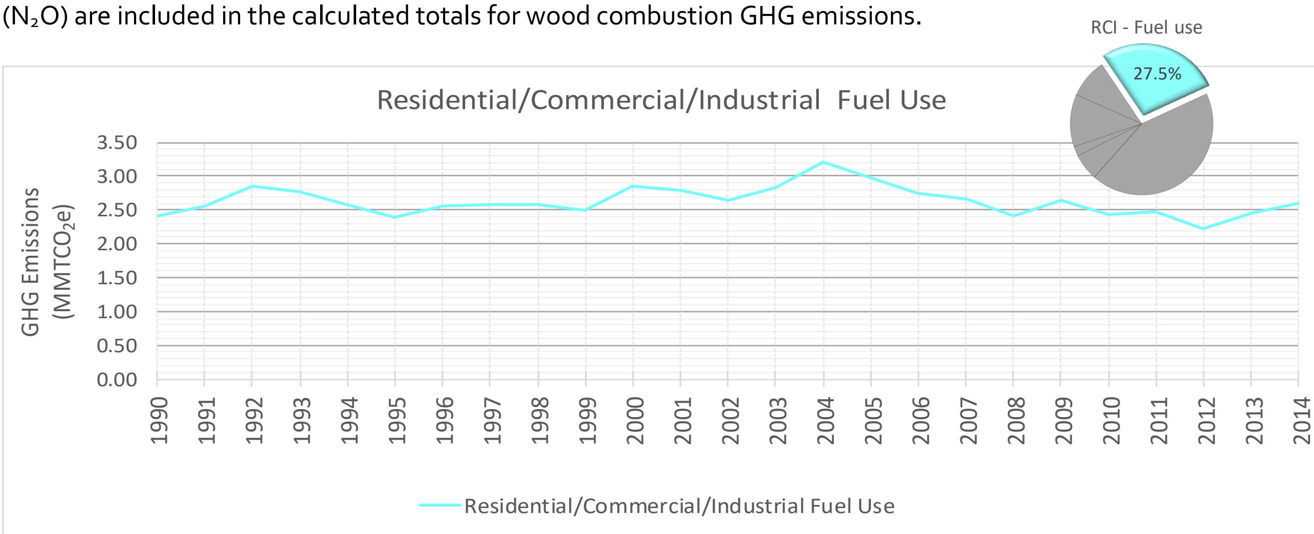


Figure 11. Vermont Residential/Commercial/Industrial Fuel Use Sector GHG Emissions (1990 – 2014).

Agriculture

Greenhouse gas emissions from the agricultural sector consist entirely of CH_4 and N_2O from various sources and processes, as the CO_2 is considered carbon neutral for inventory reporting purposes. The main emissions sources from this sector include enteric fermentation (emissions from digestive processes of ruminant animals), manure management, and agricultural soils. Emissions in this sector have been trending downward since 1999 but have been increasing slightly since 2012 (Figure 12). Changes to default data in the EPA State Inventory Tool (SIT) module have caused slight increases in emissions from this sector from the totals shown in the previous inventory.

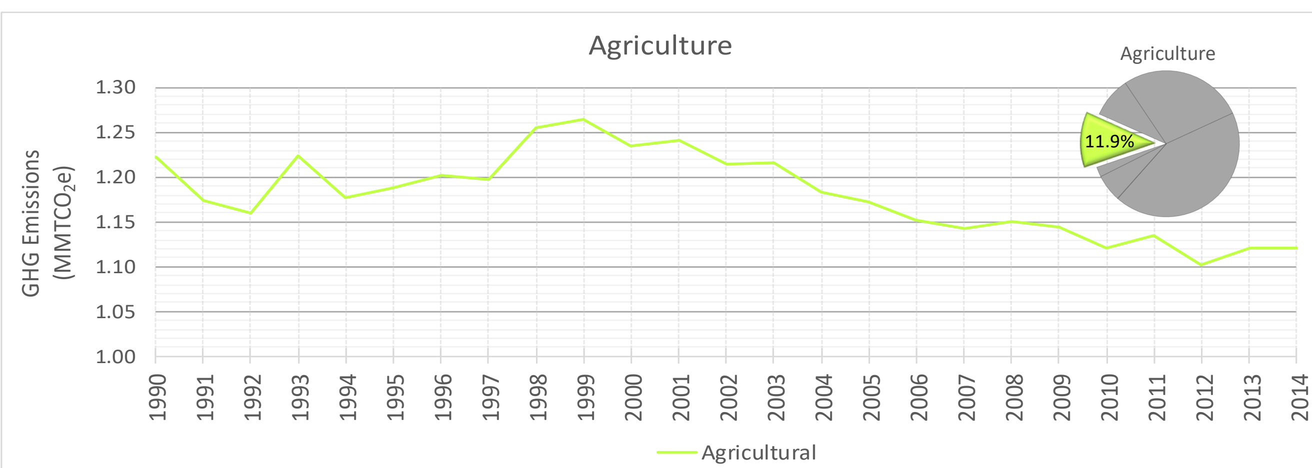


Figure 12. Vermont Agricultural Sector GHG Emissions (1990 – 2014).

Electricity

Greenhouse gas emissions from the electricity sector in Vermont (Figure 13) are calculated based on electricity consumption data and electric utility purchase decisions.[21] This methodology is consistent with that used in the Center for Climate Strategies 2007 report.[22] By using this accounting methodology, the emissions from the generation of all the electricity consumed in Vermont are accounted for, instead of only the electricity that is generated within the state. Because this sector is based on the purchase decisions of utilities, it is variable in terms of greenhouse gas emissions for any given year.

Much of the in-state electricity generation in Vermont is from renewable sources (e.g. hydro), however currently only approximately 18 percent of the electricity used in Vermont is generated in the state. Most of the electricity used by Vermonters is purchased from Hydro Québec or from the New England ISO grid mix. Electricity generation from hydro sources is considered carbon neutral for the purposes of this inventory, however there is some evidence to support the investigation and inclusion of CH_4 emissions associated with the necessary reservoir drawdowns for hydro power generation in inventory totals.

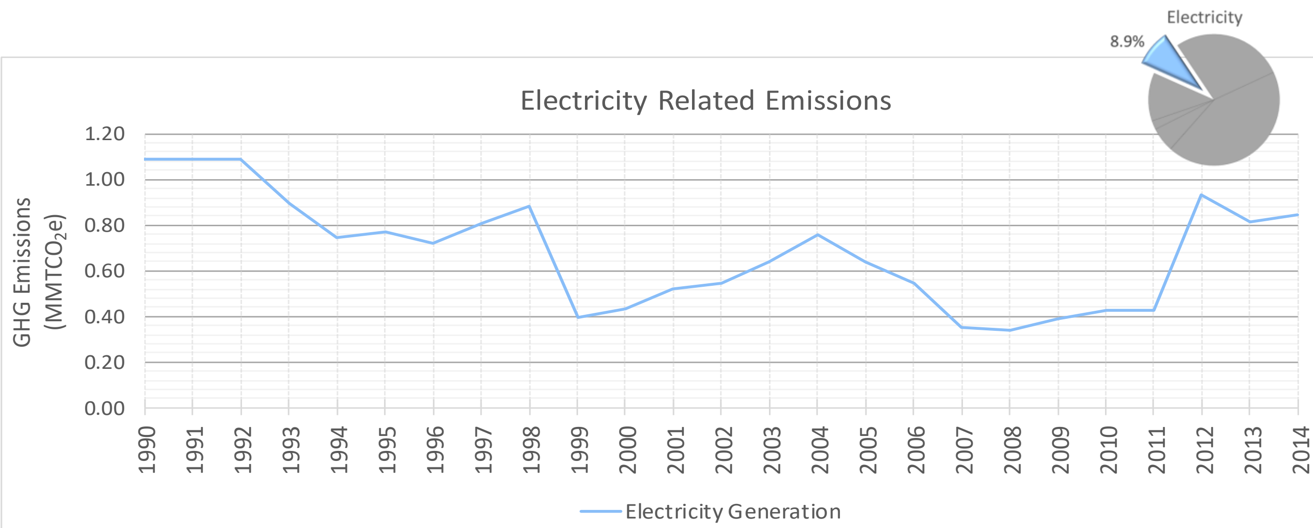


Figure 13. Vermont Electricity Sector GHG Emissions (1990 – 2014).

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

[22] Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030: http://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/Vermont_GHG_Emissions_Inventory_and_Projection_Sept-2.pdf

Industrial Processes

Many of the industrial emissions processes and categories generally included in greenhouse gas emissions inventories are not present in Vermont. Of the applicable industrial processes that are occurring in the state, the two most significant contributions to GHG emissions totals are from ozone depleting substances (ODS) substitutes and semiconductor manufacturing.

Processes involving ODS substitutes and semiconductor manufacturing both emit greenhouse gases that have extremely high GWP values, and in some cases incredibly long atmospheric lifetimes. Anthropogenic gases used in these processes include HFCs, PFCs, SF_6, and NF_3. Although the total emissions of these gases are relatively small (Figure 14), their high warming potencies and generally long lifetimes makes them a concern in terms of their accumulation in the atmosphere and their long-lasting impact on the warming of the planet.

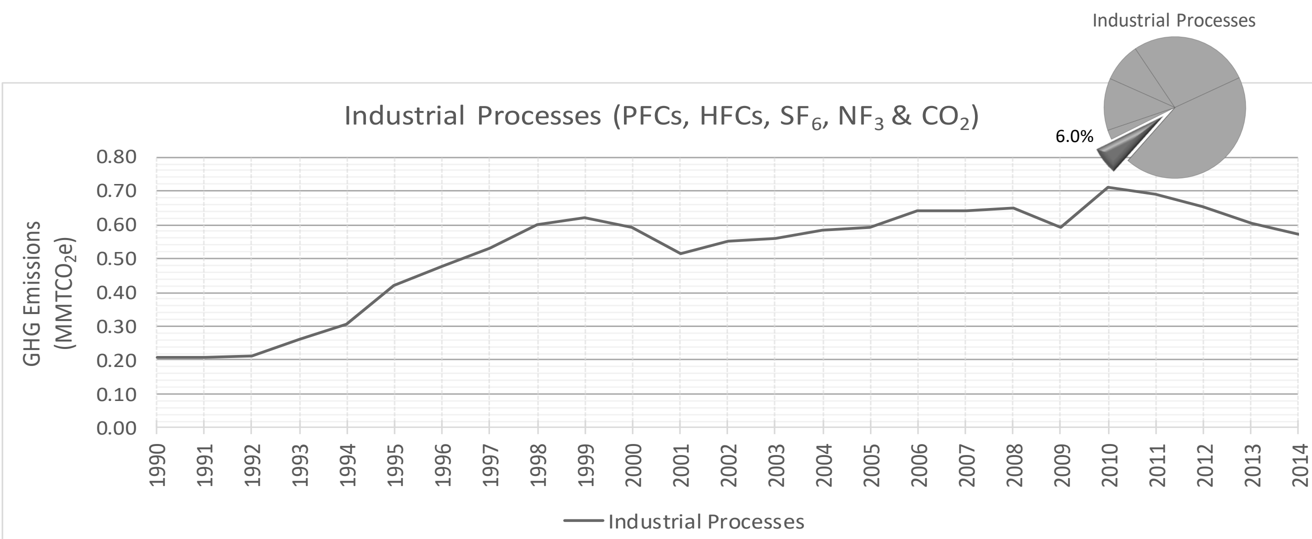


Figure 14. Vermont Industrial Processes Sector GHG Emissions (1990 – 2014).

Waste - Municipal Solid Waste & Wastewater

Greenhouse gas emissions from the waste sector (Figure 15) consist of municipal solid waste (MSW) and wastewater emissions. Only CH_4 and N_2O emissions from the decomposition of the waste materials are accounted for in this sector, as the emitted CO_2 is defined as biogenic and considered to be carbon neutral for inventory reporting purposes.

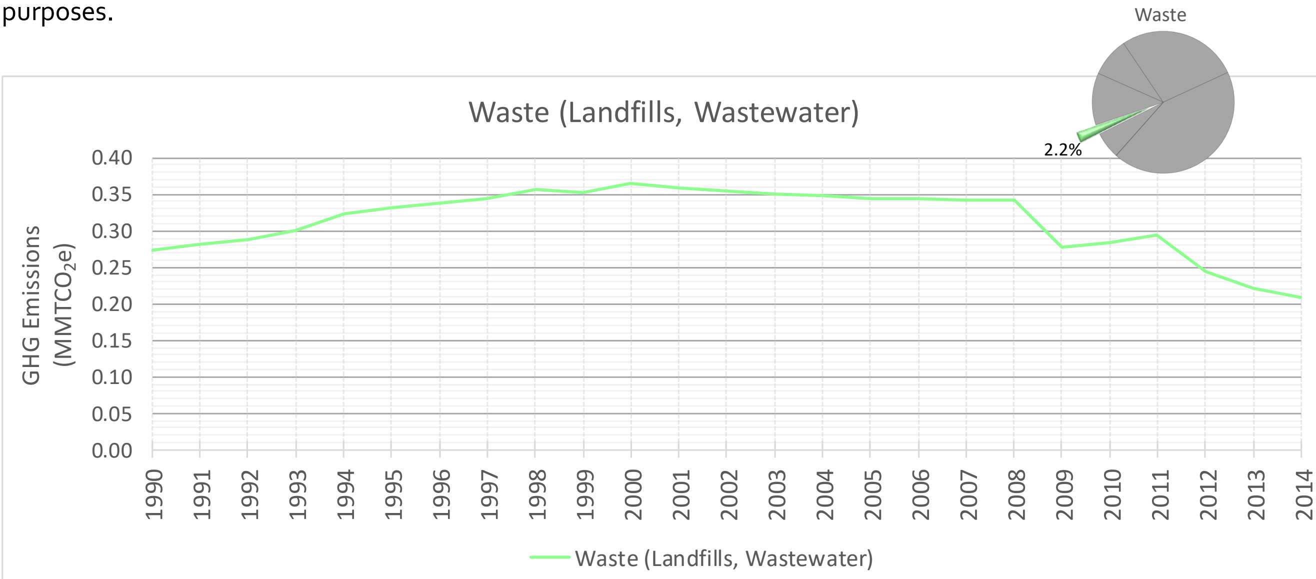


Figure 15. Vermont Waste (Landfills & Wastewater) Sector GHG Emissions (1990 – 2014).

Fossil Fuel Industry

Fossil fuel industry emissions contribute only a small portion of the total emissions for the state (Figure 16). The emissions considered in this sector are produced exclusively through the transmission and distribution of natural gas, since oil and gas refining does not occur in the state. Most of the natural gas infrastructure in Vermont consists of individual services, distribution lines, and a small percentage of slightly larger transmission lines accounting for approximately 74 of the 749 total pipeline miles.[23]

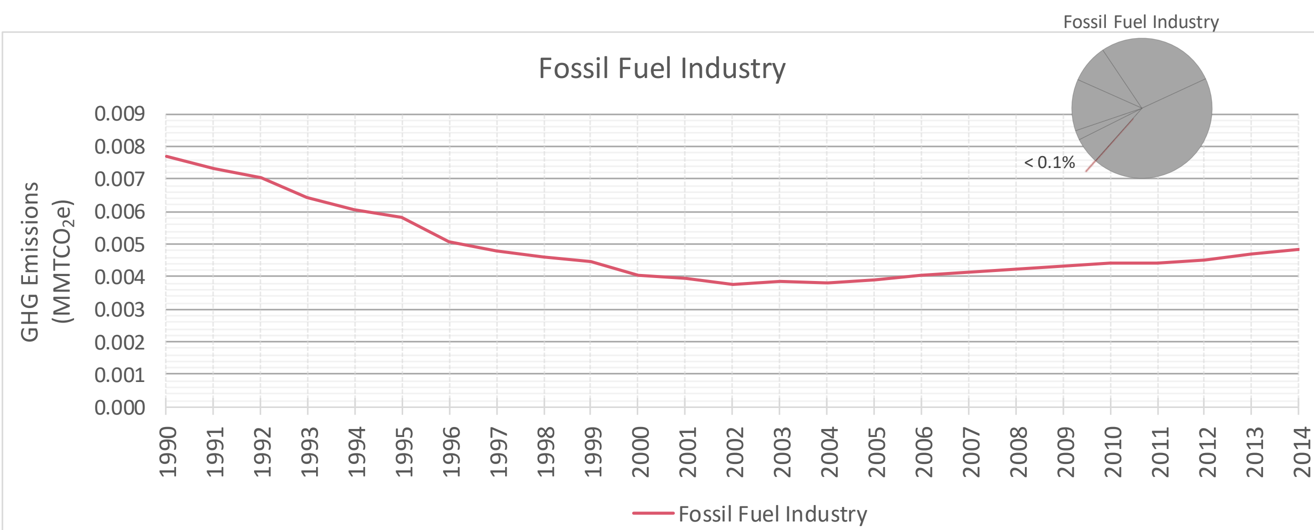
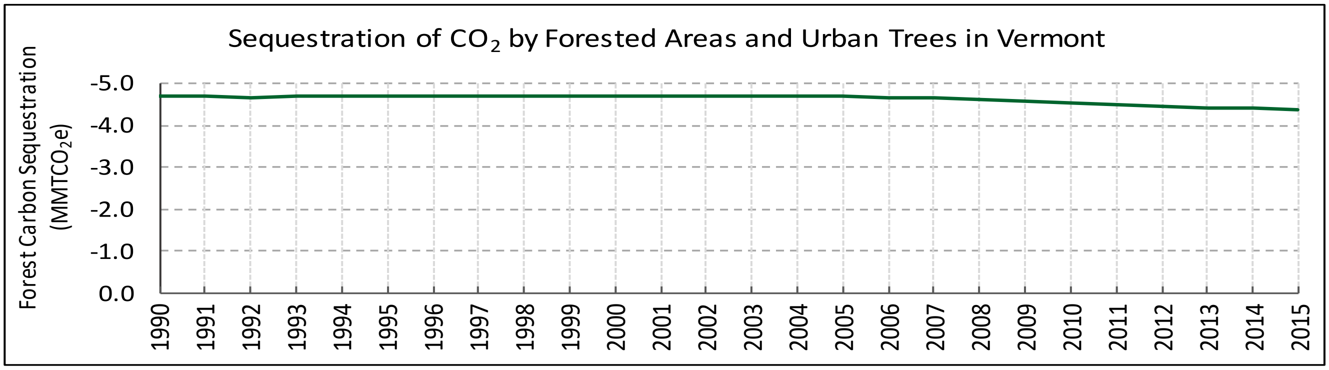


Figure 16. Vermont Fossil Fuel Industry Sector GHG Emissions (1990 – 2014).

[23] PHMSA - https://cms.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-annual-data

Forestry & Land Use[24]

Historically, estimates of CO_2 emissions and carbon sequestration attributable to the forest and land use sector were difficult to quantify for comparison purposes, as the methodologies used by the U.S. Forest Service to collect the base data were not consistent through time. A recent update in the methodology of the Forest Service[25] (Forest Inventory and Analysis group), described in the previous inventory report (1990-2013)[26], has implemented new approaches and attempted to correct past inconsistencies in the data to make the historical data estimates more comparable to the current values. The forest carbon sequestration estimates (Figure 17) have been extracted from the 2017 National Emissions Report (NIR). [27]



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

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

Due to the complexity of modeling forest carbon within the system, and the many assumptions and factors for emissions and sequestration calculations, forested land and aboveground forest biomass are shown below (Figure 18) as indicators for carbon sequestration trends (as in prior inventories). Estimates of carbon sequestration by forests in Vermont are shown, however these totals are not reflected in the reported gross GHG values in Table 1.

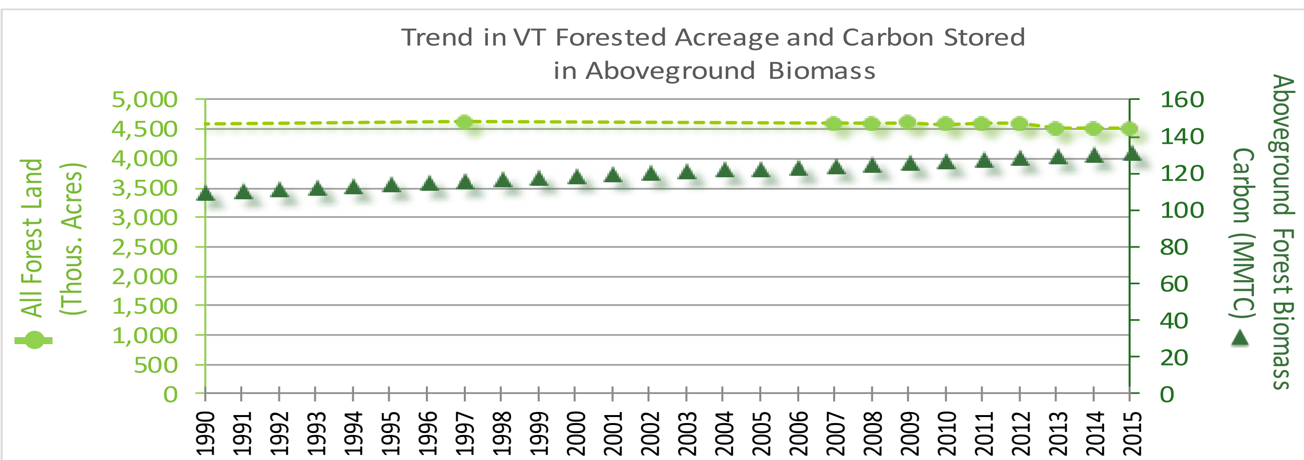


Figure 18. Forest Land and Aboveground Forest Biomass Estimates Using Previous Methodologies.

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

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

[26] Vermont DEC – Vermont GHG Emissions Inventory Update 1990-2013: http://dec.vermont.gov/air-quality/climate-change

[27] 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.

Black Carbon (BC)

Black carbon (BC) is a component of particulate matter produced from the incomplete combustion of fossil fuels, biofuels, or biomass, and has both significant health implications as well as climate forcing properties.[28] Climate impacts of black carbon are both direct and indirect. The direct impact of BC stems from the actual absorption of incoming and outgoing radiation by the dark particles, which causes atmospheric warming. The indirect impacts include a lowering of albedo in snow-covered areas (a darkening of the surface which decreases reflectivity) which accelerates melting in those areas, as well as an influence on the formation and properties of clouds, including precipitation patterns and reflectivity. There is some uncertainty surrounding the climate impacts of certain black carbon sources because of the fact that BC is co-emitted with organic carbon (OC) and other gasses which have a cooling effect on the atmosphere. This uncertainty is, however, less applicable for the two main sources in Vermont (Figure 19), those being residential wood combustion (RCI sector) and diesel engines (Transportation sector). The positive radiative forcing from diesel engines is well established, and although the net forcing for residential wood combustion is less certain, the snow-covered nature of Vermont makes the indirect impact on albedo much more relevant and so increases the certainty that BC from this source is contributing to regional warming.[29]

Inventory estimates of black carbon are generally based on established ratios of BC to OC in particulate matter (PM) for different emission sources, and elemental carbon (EC) is generally used as a proxy for BC.[30] Although the total tons of BC emitted from anthropogenic sources in Vermont are low, the high global warming potential (100-yr GWP: 900)[31] makes the totals significant when converted to carbon dioxide equivalent (CO_2e). Mitigating BC emissions has the potential to impact regional warming relatively quickly, because BC has an atmospheric lifetime of several days to two weeks. Reducing black carbon emissions should be included as part of a comprehensive mitigation strategy that also reduces emissions of longer lived greenhouse gases.

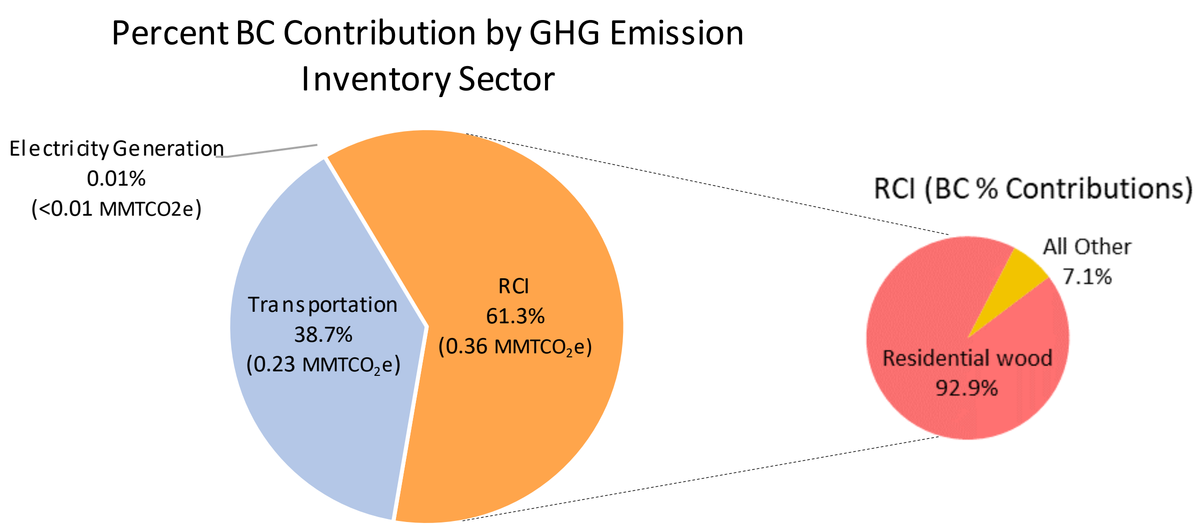

Figure 19. Black carbon contributions and emissions totals from anthropogenic sources in Vermont.

[28] EPA Report to Congress on Black Carbon: http://www.epaarchive.cc/airquality/blackcarbon/index.html

[29] Bond et al, 2013 - Bounding the role of black carbon in the climate system: a scientific assessment: http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50171/epdf

[30] CARB 2015 BC Emission Inventory – TSD: https://www.arb.ca.gov/cc/inventory/slcp/doc/bc_inventory_tsd_20160411.pdf

[31] IPCC WG1AR5 Report: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

Conclusions and Recommendations

Vermont greenhouse gas emissions estimates for 2014 show an increase from 2013 levels as well as a continued increase as compared to the 1990 baseline. Although the state totals are still below the 2004 peak levels, a concerning trend is developing with annual emissions increases from 2011 through 2014 (Figure 20). Each successive year of increasing emissions levels makes achieving the state's emission reduction goals significantly more difficult. The established greenhouse gas reduction goals are shown in Figure 20 below and are listed in state statute (10 V.S.A. § 578) and in the Comprehensive Energy Plan.[32]

The overwhelming majority of climate scientists agree that the earth is warming, and that the warming is driven by anthropogenic activities.[33] The degree to which the planet will warm is uncertain and depends in part on the degree to which humans can slow the emissions of greenhouse gases to the atmosphere; however, effects of a warming planet are already being realized and will continue to intensify in the years to come. Global temperatures will continue to rise, the intensity of storms will likely increase, droughts and heat waves will become more common, and winters will become shorter and warmer.[34] Impacts from these global changes will adversely affect both the ecosystems and infrastructure of Vermont, which will have social and economic consequences.

Even though Vermont contributes only a small fraction to the overall U.S. greenhouse gas emissions total, it has an opportunity to be a leader in the implementation of strategies to mitigate the effects of greenhouse gases, and in taking actions to adapt to a warming climate. Both mitigation and adaptation are critical components in planning and working toward a more climate resilient Vermont.

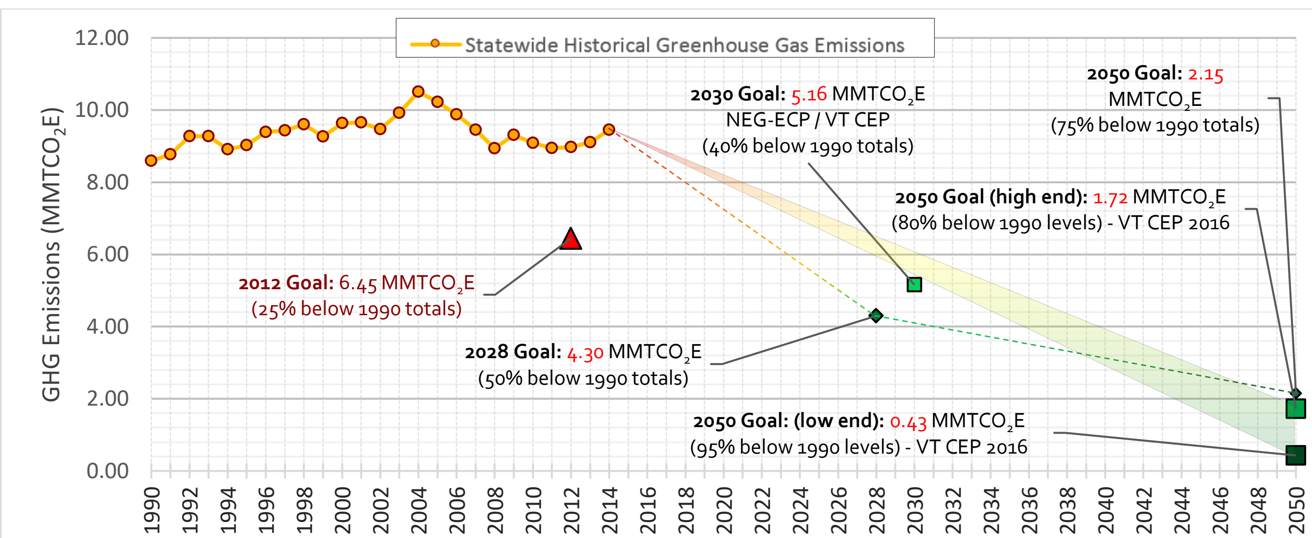

Figure 20. GHG Emissions Trends and Goals for Vermont.

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

[33] NASA: https://climate.nasa.gov/scientific-consensus/

[34] NASA – The Consequences of Climate Change: https://climate.nasa.gov/effects/

Biogenic CO_2 Emissions & Forest Carbon Sequestration – Additional Information

Carbon dioxide emissions from the combustion or decomposition of biologically based materials (biogenic CO_2) have not been included in the totals reported in this, or previous inventory reports (per IPCC guidelines). Biogenic CO_2 emissions are generally accounted for in the "land use, land-use change" section of an emissions inventory, however until recently the inconsistencies in the forest carbon base data made using this methodology impractical. Even with the new Forest Service methodologies (see Forestry & Land Use section), other data necessary for the EPA State Inventory Tool module calculations are not readily available for Vermont.

Calculations have been completed to estimate the at-the-stack biogenic CO_2 emissions from the residential / commercial and industrial fuel use sector (RCI), as well as for the electricity generation sector. Estimates of biogenic CO_2 from the waste and agricultural sectors have not been included in these estimates. Work is underway to better understand and quantify the applicable biogenic CO_2 emissions from these sectors for possible inclusion in future inventories.

Statewide net greenhouse gas emissions could be calculated by adjusting the current estimates with the estimated carbon sequestration and biogenic CO_2 emission values, however this has not been done for the overall totals in this report. There are several factors influencing this decision, including uncertainty about the carbon neutrality of various forms of biogenic CO_2, as well as the complexity of estimating and quantifying carbon sequestration. Instead of including the sequestration and biogenic CO_2 in the reported emissions totals, Figure 21 illustrates several scenarios ranging from the inclusion of the calculated biogenic CO_2 emissions with no carbon sequestration, to the inclusion of carbon sequestration without accounting for biogenic CO_2. The actual net emissions are likely in the range of the black dashed line, which includes biogenic CO_2 emissions and carbon sequestration by forests. These data emphasize both the importance of forests in sequestering carbon, as well as the fact that anthropogenic activities in Vermont currently are releasing more GHG emissions each year than can be sequestered.

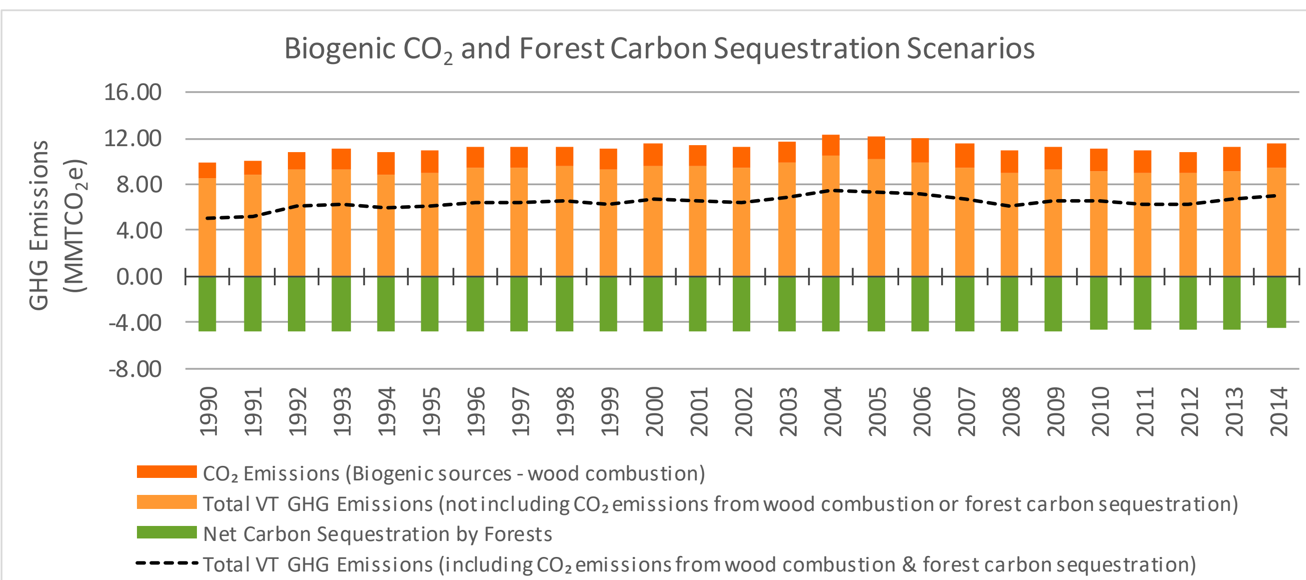

Figure 21. Vermont GHG Emissions Estimates with and without Biogenic CO_2 from Wood Combustion and Forest Carbon Sequestration.