VERMONT

DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Agency of Natural Resources

Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990 – 2017

Prepared by the Air Quality and Climate Division

in accordance with 10 V.S.A. § 582

May 2021

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Note to Readers

Vermont Greenhouse Gas Emissions Inventory and Forecast reports are designated as either "Comprehensive" or as "Brief." Comprehensive reports will coincide with the calendar year releases of the triennial National Emissions Inventory (NEI) produced by the U.S. Environmental Protection Agency (EPA) and will provide a greater level of detail on sectors and graphics than the reports designated as "Brief." This is due mainly to the fact that the NEI helps to inform details and more granular information for several sectors.

The following report for the 1990 – 2017 inventory and forecast is designated as Comprehensive.

This and previous reports may be found at the following link:
https://dec.vermont.gov/air-quality/climate-change

List of Previous Reports:

- *Greenhouse Gas Emissions Inventory Update and Forecast: Brief (1990 – 2016)*
- *Greenhouse Gas Emissions Inventory Update: Brief (1990 – 2015)*
- *Greenhouse Gas Emissions Inventory Update: Comprehensive (1990 – 2014)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2013)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2012)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2011)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2009)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2008)*
- *Greenhouse Gas Inventory and Reference Case Projections - Governor's Commission on Climate Change (1990 - 2030)*

Acronyms & Abbreviations

AADT: annual average daily traffic

AAFM: Agency of Agriculture, Food and Markets

AR4: Intergovernmental Panel on Climate Change Fourth Assessment Report

ANR: Agency of Natural Resources

BAU: business-as-usual

Btu: British thermal unit

CCS: Center for Climate Strategies

CEP: Comprehensive Energy Plan

CFCs: chlorofluorocarbons

CH_4: methane

CO_2: carbon dioxide

DMV: Department of Motor Vehicles

e-CFR: Electronic Code of Federal Regulations

EC: elemental carbon

EIA: Energy Information Administration

EPA: Environmental Protection Agency

FLIGHT: Facility Level Information on GreenHouse gases Tool

$MMTCO_2e$: million metric tons carbon dioxide equivalent

GHG: greenhouse gas

GHGRP: GreenHouse Gas Reporting Program

GWP: global warming potential

HFC: hydrofluorocarbon

HCFCs: hydrochlorofluorocarbons

HPMS: Highway Performance Monitoring System

HQ: Hydro-Québec

IP: industrial processes

IPCC: Intergovernmental Panel on Climate Change

ISO-NE: independent systems operator – New England

JFO: Joint Fiscal Office

LCA: life cycle assessment

LEAP: Low Emissions Analysis Platform model

LFG: landfill gas

LFGTE: landfill gas-to-energy

LULUCF: land-use, land use change, and forestry

MOVES: MOtor Vehicle Emissions Simulator model

N_2O: nitrous oxide

NEI: National Emissions Inventory

NEPOOL-GIS: New England Power Pool - Generation Information System

NF_3: nitrogen trifluoride

NG: natural gas

ODS: ozone depleting substances

PHMSA: Pipeline and Hazardous Materials Safety Administration

PFC: perfluorocarbon

PSD: Public Service Department

RCI: residential/commercial/industrial

REC: renewable energy certificate

RES: Renewable Energy Standard

SEDS: State Energy Data System

SF_6: sulfur hexafluoride

SIT: State Inventory Tool

SNAP: Significant New Alternatives Program

UNFCCC: United Nations Framework Convention on Climate Change

USDA: United States Department of Agriculture

VMT: vehicle miles traveled

VTrans: Vermont Agency of Transportation

Executive Summary

The concentration of greenhouse gases (GHG) in the earth's atmosphere are increasing due to human caused emissions. Greenhouse gases absorb solar radiation and trap heat energy in the atmosphere, which warms the planet and is already having impacts here in the Northeastern U.S. and around the globe.[1] Understanding Vermont's contribution to this global problem and the sources and sectors which are responsible for these emissions is a critical first step in mitigating climate change. The goal of this inventory is to provide that understanding of emissions for Vermont in a way that is consistent with other jurisdictions to enable the tracking of emissions levels through time and to help inform decisions on future mitigation pathways.

The Vermont Greenhouse Gas Emissions Inventory and Forecast reports are required in Vermont statute 10 V.S.A. § 582 in order to establish historic 1990 and 2005 baseline GHG levels and to track changes in emissions through time to determine progress toward the state's GHG reduction targets as established in 10 V.S.A. § 578.[2] Greenhouse gas reduction targets previously listed in 10 V.S.A. § 578 have been modified by the passage of the Global Warming Solutions Act (Act 153) in 2020.[3] The updated targets are now mandatory reductions of 26% below 2005 levels by 2025, 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050.

Calculation methodologies used in this report are primarily based on EPA State Inventory Tool (SIT) methodologies, which the EPA creates for state use to assist states with comprehensive and often complex estimation methods, as well as to help maintain consistency in inventory reporting across jurisdictions. The methods used in this inventory are generally informed by the Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030 report and are consistent with Intergovernmental Panel on Climate Change (IPCC) guidelines. Many of the calculations in this inventory rely on large federal datasets, especially the Energy Information Administration (EIA) State Energy Data System (SEDS) dataset, which contributes to the lag time between the inventory year and the year of release that averages roughly three years.

Most of the methodologies in this inventory were the same as those used in the previous inventory with one notable exception. A change was made to the transportation sector calculation methodology transitioning away from the triennial National Emissions Inventory (NEI) vehicle miles traveled (VMT) based values to a method based on fuel sales data, which is the method suggested by the IPCC. This change was made in large part because of unresolvable issues with the 2017 NEI values and because accurately projecting data for years between NEI values is problematic. The change in methodology for the transportation sector does have significant impacts on overall emissions levels, lowering levels in the 2005 baseline year by 0.4 $MMTCO_2e$ and causing even greater decreases in the more recent years as compared to what was presented in the previous inventory report.

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[1] U.S. Global Change Research Program – Fourth National Climate Assessment: Chapter 18: Northeast https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf

[2] Vermont Statute 10 V.S.A. § 582: https://legislature.vermont.gov/statutes/section/10/023/00582
_Vermont Statute 10 V.S.A. § 578: https://legislature.vermont.gov/statutes/section/10/023/00578

[3] Vermont Legislature - Global Warming Solutions Act (Act 153): https://legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT153/ACT153%20As%20Enacted.pdf

In this inventory report GHG emissions totals in Vermont are 8.66 $MMTCO_2e$, 0.3% above the 1990 baseline levels in 2017 and 13.1% below 2005 levels. Emissions declined 0.44 $MMTCO_2e$ from 2016 to 2017 with the majority of that decrease (0.32 $MMTCO_2e$) coming from the electricity sector and 0.1 $MMTCO_2e$ coming from the transportation sector. The remainder of sectors in the inventory remained relatively flat.

The official emissions totals in this inventory report are gross annual emissions totals; however, it is also important to acknowledge the sequestration part of the picture and to have an understanding of net GHG emissions for the state. Similar to the previous inventory report, sequestration totals related to forest land have been included for informational purposes and to help account for emissions of biogenic CO_2, which are not included in the gross inventory totals.

This report provides both short term (2018 and 2019) and slightly longer term (5 and 10 year) emissions projections. Short term projections are based on the standard inventory methodologies wherever possible and other values are carried forward from previous years where necessary. Emissions totals in 2018 and 2019 are projected to decline by 0.03 and 0.05 $MMTCO_2e$ respectively. Longer term emissions forecasts are incredibly difficult to predict accurately. This has been made even more difficult with the impact on emissions from the COVID pandemic. Modeled emissions trajectories by sector have been taken from more robust projections completed by the Rhodium Group for their ClimateDeck and Taking Stock report to at least provide directionality of the emissions trajectories by sector.[4] Emissions projections for 2022 and 2027 are fraught with uncertainties, such as policies stemming from the implementation of the Global Warming Solutions Act, federal actions, and changes in VMT, but are roughly projected to be 8.02 and 8.04 $MMTCO_2e$ respectively.

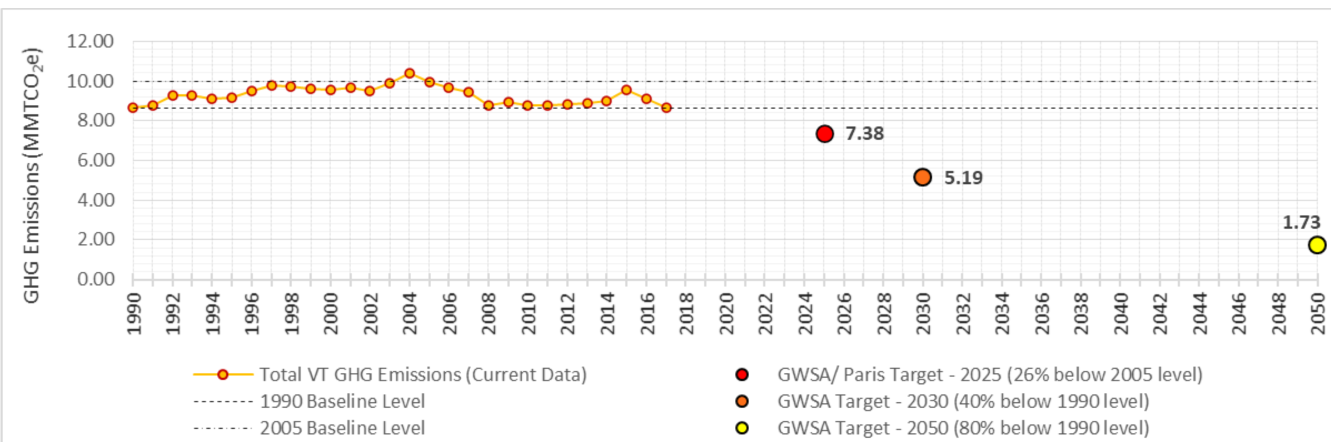

Figure 1: Vermont statewide greenhouse gas emissions levels and mandated reduction targets as defined in 10 V.S.A. § 578.

[4] Rhodium Group – Climate Deck information: https://rhg.com/data_story/climate-deck/
Rhodium Group – Taking Stock report: https://rhg.com/wp-content/uploads/2020/07/Taking-Stock-2020-The-COVID-19-Edition.pdf

1. Introduction

Vermont Greenhouse Gas Emissions Inventory and Forecast reports are prepared annually in accordance with 10 V.S.A. § 582. This report provides estimates of anthropogenic greenhouse gas emissions for the state of Vermont for the years 1990 – 2017, with additional preliminary estimates for 2018 and 2019. Emissions in the report are estimated by sector and include the same greenhouse gases as the U.S. Greenhouse Gas Emissions and Sinks reports, with totals shown in million metric tons of CO_2 equivalent ($MMTCO_2e$).

The annual inventory reports quantify and track greenhouse gas emissions for the state of Vermont as accurately and consistently as possible over time and establish the 1990 and 2005 baseline levels as codified in 10 V.S.A. § 578. In 2020, 10 V.S.A. § 578 was amended by the Global Warming Solutions Act (Act 153) which changed the GHG emissions reduction targets to requirements. These new mandated levels are 26% below 2005 levels by 2025, 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050.

This emissions inventory report quantifies emissions estimates by sector to be able to identify relative contributions from different sources. The sectors in this report are defined based on the sectors in the *Greenhouse Gas Inventory and Reference Case Projections, 1990-2030* report. It is also important, to the extent possible, to maintain consistency and comparability with greenhouse gas inventories of other states in the region, with the National Emissions Inventory, and with past emissions methodologies. Consistency in methods among states helps to minimize the risk of emissions being unaccounted for, or double counted, and achieves a more accurate representation of regional emissions.

1.1 Background Information

Greenhouse gases (GHGs) are gases that warm the planet by trapping heat in the atmosphere. These gases allow shortwave solar radiation to reach the earth's surface but absorb the longer wave radiation that is reradiated from the surface and keep that heat energy trapped within the atmosphere rather than allowing it to escape back into space. The higher the concentrations of greenhouse gases in the atmosphere, the more heat energy is trapped and the warmer the planet becomes.

There are many gases that trap heat in the atmosphere. The most significant of these gases, and the ones included in the National Inventory Report, are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Some of these greenhouse gases do occur naturally in the atmosphere, such as CO_2, CH_4, and N_2O, but since the industrial revolution human activities have rapidly increased their concentrations leading to warming of the planet.[5]

[5] IPCC 2013: IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth* 1 *Assessment Report of the Intergovernmental Panel on Climate Change*. [Stocker, T.F., D. Qin, G.-K., Plattner, M. 2 Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, 3 Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Some greenhouse gases are more effective at trapping heat in the atmosphere than others and remain in the atmosphere for different amounts of time. In order to make the gases comparable the Intergovernmental Panel on Climate Change (IPCC) developed a method using global warming potentials (GWPs), which account for the heat trapping potency and the atmospheric lifetime of the gas and set them relative to CO_2 on a per unit of mass basis. Emissions totals in this report incorporate those GWP adjustments and are reported in million metric tons of CO_2 equivalent ($MMTCO_2e$). The GWP values used in this report are listed in Table 1 and are those specified by the United Nations Framework Convention on Climate Change (UNFCCC) in the IPCC guidelines for use in national inventories and are the 100-year weighted GWP values from the IPCC Fourth Assessment Report (AR4).[6]

Table 1: Global warming potential values.[7]

GHG Category	AR4 GWP Value	Atmospheric Lifetime (years)
CO_2	1	Variable
CH_4	25	12
N_2O	298	114
HFCs	124 - 14,800	1 - 270
PFCs	7,390 - 12,200	2,600 - 50,000
NF_3	17,200	740
SF_6	22,800	3,200

1.2 Inventory Development and Methodologies

Estimates of greenhouse gas emissions in this report have been calculated using methodologies largely based on methods used in, or developed for, the *Greenhouse Gas Inventory and Reference Case Projections, 1990-2030* report and are compatible with IPCC GHG inventory guidelines.[8] Data availability is a key factor influencing methodology decisions with the intention of providing the most accurate emissions estimates possible while maintaining comparability to historical data estimates to allow for the tracking of emissions levels over time. Because of the lack of Vermont specific datasets that both encompass the entire state as well as extend back far enough in time to inform the 1990 baseline year, a number of default federal datasets are used to inform the emissions calculations. Where more detailed Vermont specific data exists, the potential additional accuracy of the dataset is balanced with the need to keep the methodologies consistent through time, with the goal of producing the most accurate and historically comparable inventory possible.

Different sectors in the inventory employ a number of methodologies using different Vermont specific datasets to estimate the associated GHG emissions. These sources include, but are not limited to, data submitted to the Agency of Natural Resources (ANR) Air Contaminant Registration Program, data provided by the Vermont Public Service Department (PSD), data

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[6] IPCC 2007: http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

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

[8] IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The National Greenhouse Gas 9 Inventories Programme, The Intergovernmental Panel on Climate Change

from the Vermont Agency of Transportation (VTrans), and data submitted to EPA through the Greenhouse Gas Reporting Program (GHGRP). For many sectors, state inventory tool (SIT) modules are used that have been developed by EPA to assist states with GHG emissions estimates and to help maintain consistency in methodologies across states. These SIT methodologies generally incorporate larger federal datasets, including data from the US Department of Agriculture (USDA), Energy Information Administration (EIA), and others, which can be updated if more accurate local data are available.

One change in methodology in this inventory as compared to the 1990 – 2016 Greenhouse Gas Emissions Inventory Update and Forecast is in the transportation sector and is related to a switch from a VMT based emissions estimation methodology to a fuel consumption-based approach. In addition, there were updates to several of the EPA SIT modules which led to differences between the two inventories. Due to continual updates to the EPA tools, as well as updates to the incorporated historical federal dataset values, emission factors, and methodologies, historical emissions estimates in this report may be different from those in previous reports. Values in this inventory supersede all values in previous reports.

The largest source sectors of GHG emissions in Vermont in 2017 were the transportation, residential commercial and industrial (RCI) fuel use, agriculture, and industrial processes sectors. Overall percent contributions by sector have changed somewhat compared to the previous inventory because of the methodology update in the transportation sector, but transportation remains the largest contributor as seen in Table 2.

Table 2: GHG Emissions for 2017 and Sector Contributions.

Inventory Sector	$MMTCO_2e$ (2017)	Percent of Total
Transportation/ Mobile Combustion	3.39	39.1%
Res/Com Fuel Use	2.69	31.0%
Agriculture	1.37	15.8%
Industrial Processes	0.57	6.5%
Electric Generation	0.49	5.7%
Waste	0.13	1.5%
Fossil Fuel Industry	0.03	0.3%
TOTAL	**8.67**	**100%**

2. Vermont Greenhouse Gas Emissions Overview

2.1 Vermont GHG Comparisons

Total greenhouse gas emissions from the state of Vermont are a small fraction of the U.S. as a whole (Figure 2 and Figure 3) and are small even when compared to other states.[9] However, based on data from 2016 Vermont had the highest per capita greenhouse gas emissions in New England, although still below the national average.[10] The small population of Vermont drives the low overall greenhouse gas emission contribution from the state, but the relatively high per capita value illustrates that there is progress to be made in terms of emissions reductions.[11]

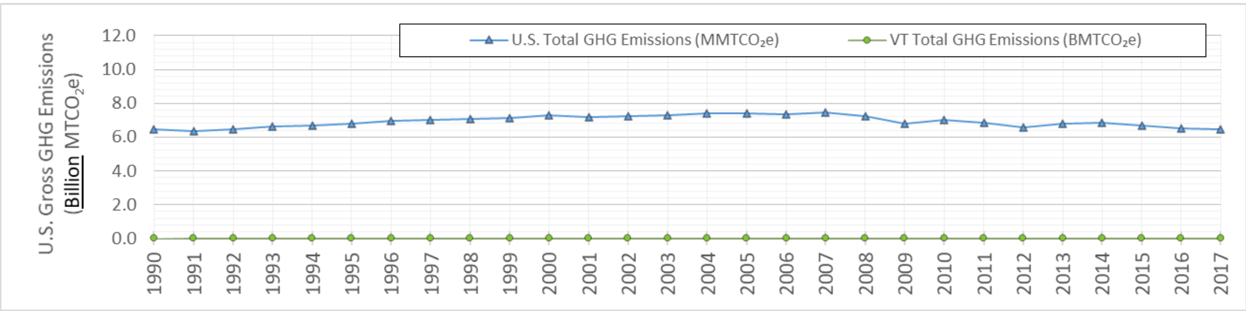

Figure 2: U.S. and Vermont gross GHG emissions in billion $MTCO_2e$ (note that the Vermont series appears adjacent to the horizontal axis).

Figure 3: Vermont gross GHG emissions in million $MTCO_2e$.

When comparing U.S. greenhouse gas emissions to Vermont by sector there are several major differences to note. One major difference is that emissions from the transportation sector contribute a larger percentage in Vermont than for the U.S. as a whole, as illustrated in Figure 4 and Figure 5. The high per capita vehicle miles traveled in Vermont, influenced by the rural

[9] EIA – Energy-Related CO2 Emission Data Tables: https://www.eia.gov/environment/emissions/state/
[10] EAN 2019 Annual Progress Report: https://www.eanvt.org/wp-content/uploads/2020/03/EAN-report-2020-final.pdf
[11] U.S. Census Bureau: Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019 (NST-EST2019-01) : https://www.census.gov/data/tables/time-series/demo/popest/2010s-state-total.html

nature of the state, is one reason for this discrepancy.[12] The residential/commercial/industrial (RCI) fuel use and agriculture sectors also have greater percent shares in Vermont than the national average due to the climate of Vermont and the economic focus on agriculture in the state.

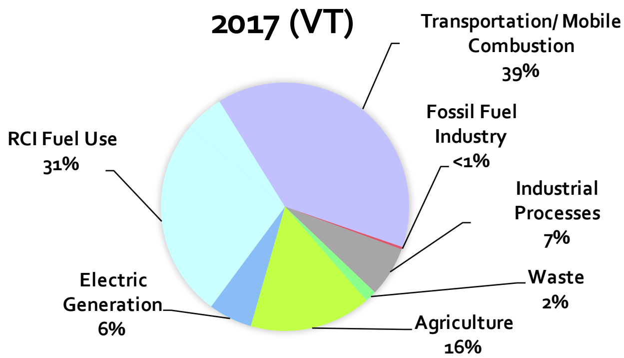

Figure 4: Vermont GHG percent contributions by sector.

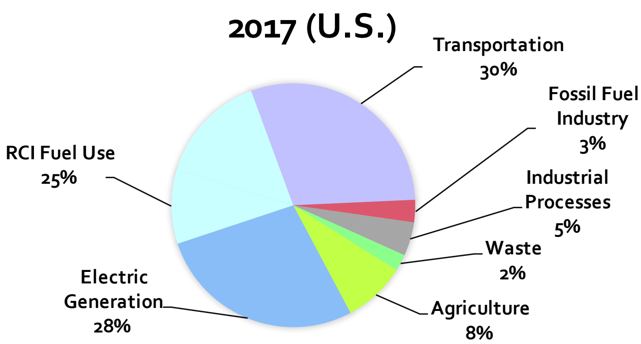

Figure 5: U.S. GHG percent contributions by sector. Data for the U.S. contributions by sector has been reallocated to match the Vermont sector categories in this report.

2.2 Vermont GHG Emissions by Sector

2.2.1 Overview

Tracking greenhouse gas emissions by sector helps to understand the contributions from different sources and sectors. There are different ways to organize greenhouse gas emissions estimates within an inventory, and many inventories are broken out by greenhouse gas or by different groupings of source categories. This inventory uses the sectors listed in Vermont statute and used in the Greenhouse Gas Inventory and Reference Case Projections, 1990-2030 report.[13]

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[12] VTrans – Vermont Transportation Energy Profile (2019): https://vtrans.vermont.gov/sites/aot/files/planning/documents/planning/The%20Vermont%20Transportation%20Energy%20Profile_2019_Final.pdf

[13] Vermont Statute: 10 V.S.A. § 582

Those sectors include transportation/mobile sources, residential/commercial/industrial fuel use, agriculture, industrial processes, electricity consumption, waste, and the fossil fuel industry. Figure 6 below shows an illustration of the historical percent contributions by sector back to the 1990 baseline. Greenhouse gas emissions by sector with descriptions of basic methodologies are provided in more detail in the following subsections.

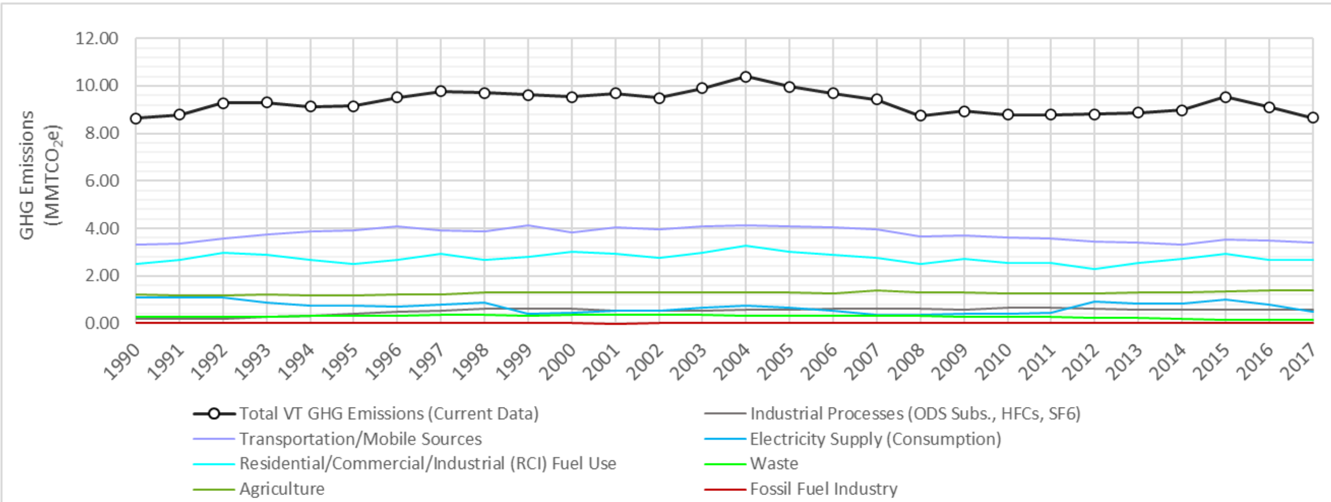

Figure 6: Total and sector-specific GHG emissions in Vermont, 1990-2017.

2.2.2 Transportation/Mobile Sources

The transportation and mobile sources sector remains the largest contributor to greenhouse gas emissions in Vermont and was responsible for 3.39 $MMTCO_2e$, or 39.1 percent of the total emissions for the state in 2017 (Figure 7). Emissions from onroad gasoline and diesel vehicles, aviation gasoline and jet fuel, and other non-road sources are the main contributors to emissions in this sector. The emissions totals shown in this inventory are lower than those shown in the previous inventory report due to an update in the calculation methodology, which is described in detail below.

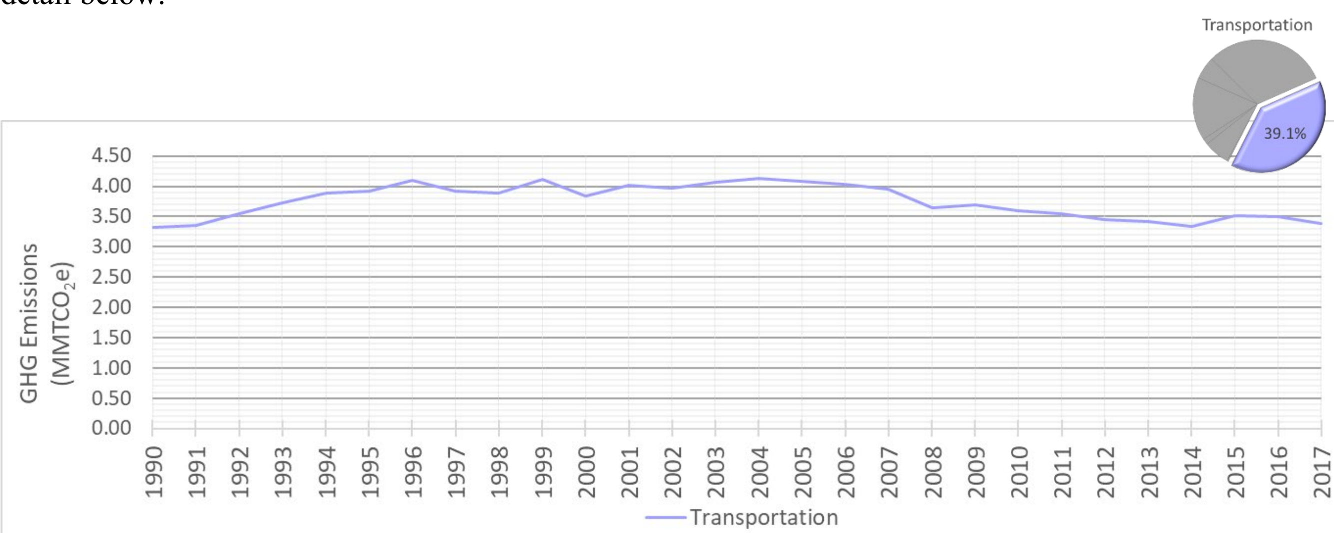

Figure 7: Vermont GHG emissions from transportation/mobile sources sector.

Greenhouse gas emissions for the onroad portion of the transportation sector were previously taken directly from the National Emissions Inventory (NEI) for years when they were available (2011, 2014, 2017).[14] The NEI is a multi-pollutant emissions inventory developed by the U.S. EPA on a triennial basis and the onroad portions rely on emissions estimates generated using the MOtor Vehicle Emission Simulator (MOVES) model.[15] The Agency of Natural Resources (ANR) compiles inputs for the onroad sector for each NEI by county which EPA supplements and uses to estimate the emissions of many different pollutants. The inputs are generated using detailed vehicle fleet data from the Department of Motor Vehicles (DMV) registration database and vehicle miles travelled (VMT) data from the Vermont Agency of Transportation (VTrans). The MOVES model is a complex model that contains detailed and very granular emissions rates and applies them to corresponding VMT to calculate emissions. MOVES incorporates and accounts for factors like temperature profiles, speed profiles, fuel formulations, etc., which effect emissions totals, and so produces an estimate that incorporates a lot of detail from the vehicle fleet and driving patterns. For years after 2011 not coinciding with NEI inventory reports, transportation sector emissions were interpolated or extrapolated by adjusting the most recent NEI values by the percent change in in-state fuel sales and annual VMT.

In reviewing the 2017 NEI GHG emissions values for gasoline and diesel from onroad transportation in preparation for this inventory, the values were considerably lower than what had been projected in the 1990 – 2016 Vermont GHG inventory report for that year based on adjusting the 2014 NEI values using percent changes in VMT and fuel sales. In spite of an approximate 5% (365 million mile) increase in VMT between 2014 and 2017, the NEI estimated GHG emissions decreased by roughly 7% as shown in Figure 8 below. Although a decrease in GHG emissions is possible with an increase in VMT due to improving vehicle fuel economies and changing fleet characteristics due to fleet turnover, a reduction of this magnitude in a three-year time period with a corresponding VMT increase on this scale seems unlikely. Efforts to determine the reasons for this unexpected result, including discussions with EPA staff responsible for the NEI and multiple additional in-house MOVES runs, were ultimately inconclusive. Given the inability to determine the cause of, or to rationalize, this discrepancy, the decision was made to adopt an emissions calculation methodology based on fuel consumption data rather than the VMT based MOVES estimates going forward, which is less detailed but more consistent with the historical emissions estimation methodology for years before 2011. Because the historical data in the report had been taken from the *Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030* report, which utilized an older version of the EPA SIT module, this methodology update is only strictly applicable to years 2011 through 2016, although updates to the SIT module have led to some additional differences between the previous historical values and those calculated in this report.

In contemplating different methodological approaches to calculating GHG emissions from the transportation sector several factors were considered. The previously used EPA MOVES estimates for Vermont from 2011 through 2016 contain a significant amount of detail on

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[14] EPA National Emissions Inventory: https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

[15] EPA MOVES model: https://www.epa.gov/moves

Vermont's vehicle fleet and emissions rates from an extremely large amount of vehicle, road type, and speed combinations, but rely heavily on estimated vehicle miles traveled in the state. Estimates of VMT are an important indicator of vehicle use and associated emissions in the state and are designed to capture all of the vehicle miles being traveled on Vermont roads, but are based on separate calculations involving road segment lengths and annual average daily traffic (AADT) values which are informed by highway performance monitoring system (HPMS) data, or other statistical methodologies. Incorporating these additional datasets into GHG emissions estimates adds a level of complexity and increases the uncertainty of this method. An alternative method for the transportation/mobile sources sector is to use estimates of fuel consumption. To calculate emissions of many different pollutants detail on vehicle type, engine controls, and age are critical for generating accurate emissions estimates, including CH_4 and N_2O as described below. For CO_2, however, an accurate emissions estimate can be calculated based almost entirely on the gallons of the various fuels combusted coupled with their corresponding fuel specific emission factors. Fuel sales data provides less granularity in terms of where and how the GHG emissions are occurring, and would not account for emissions from vehicles that enter and then leave Vermont without refueling, or border leakage, but the fuel totals themselves at least do not rely on additional modeling to inform them.

Using fuel combustion totals, with fuel sales as a proxy, is the method recommended by the IPCC when appropriate and reliable data is available. As mentioned previously, this method for estimating emissions from the transportation sector is less granular and so does not provide detail to separate onroad emissions from nonroad emissions of CO_2 from the sector, which is one of the reasons the NEI values had been used previously. The fuel-based method does have the advantage of relying on data and methodology that is straightforward and that can be calculated annually without the need for interpolation or extrapolation of totals based on indicators. Using the fuel-based method sacrifices detail in source contributions, but better aligns with IPCC guidelines as well as the historical estimates completed for the Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990 – 2030 report.

The updated methodology used for calculating CO_2 emissions based on fuel combustion totals for onroad and nonroad transportation and mobile sources relies on the EPA CO_2 from Fossil Fuel Combustion (CO_2FFC) SIT module, which is also used for estimating emissions in the residential/commercial/industrial (RCI) fuel use sector. This tool uses estimates of energy consumption in the transportation/mobile sector by fuel and multiplies them by the carbon content for each fuel. The main fuels which contribute to the emission totals include motor gasoline, distillate fuel (diesel), and aviation gasoline and jet fuel. The default data in the tool is from the EIA SEDS 2018 dataset and contains estimated energy consumption by fuel type in billions of Btu from 1990 through 2018. The amount of gasoline and onroad (non-dyed) diesel fuel sold in Vermont is available and reported through the Joint Fiscal Office (JFO).[16] Gasoline fuel sales data from JFO has been incorporated into the SIT module in place of the default SEDS data, after first adjusting the values to remove the approximate contribution from aviation gasoline and ethanol. Diesel sales data has not been incorporated into this inventory because it is unclear if the nonroad end uses covered by the JFO data would match those covered in the SEDS

[16] Vermont Joint Fiscal Office – Gasoline and Diesel Gallons Sold: https://ljfo.vermont.gov/search/filter/keywords/gas/author/neil-schickner/subject/transportation

dataset, which could lead to under or over counting of emissions. Default SEDS data has been used for this portion of the calculation after first removing the biodiesel component.

Emissions of CH_4 and N_2O from the onroad and nonroad sector are calculated differently from the CO_2 component. As mentioned previously, pollutants such as CH_4 and N_2O are technology dependent and so have differing emissions factors depending on the type and age of the vehicle producing them. Estimates of these GHGs were calculated using the EPA SIT CH_4 and N_2O Emissions from Mobile Combustion module, which estimates emissions in a similar way but is much less sophisticated than the MOVES model. This module calculates emissions from onroad transportation using VMT by vehicle type and applying emission factors to those VMT values after they are further separated and refined by vehicle age class and applicable emissions control systems. Default data is used for the vehicle age distributions and engine emissions control technologies but the default VMT data is adjusted using vehicle class percent compositions from FHWA and applying them to Vermont specific VMT data from VTrans back to 1990. An updated version of the mobile combustion SIT module does allow for the estimation of CO_2 using this VMT based methodology, however, the guidance document for the tool states that it is not as accurate as the estimates from the fuel based CO_2FFC module.[17]

Motor gasoline (including onroad and nonroad use of gasoline) accounts for approximately 75% of CO_2 emissions from the sector and distillate fuel (diesel) accounts for just over 21% as shown in Table 3. It is not possible to break out the onroad versus nonroad emissions totals in the EPA SIT CO_2FFC module, however, a general breakdown of contributions has been provided for informational purposes in Table 4 and Table 5 to illustrate the approximate percent contributions based on values taken from the 2017 NEI and the previous nonroad methodology.

Table 3: Mobile source contributions by fuel type.

Onroad and Nonroad Transportation (CO_2)	MMTCO_2e (2017)	Percent Contribution (2017)
Motor Gasoline	2.52	75.1%
Distillate Fuel (Diesel)	0.71	21.3%
Aviation Gasoline and Jet Fuel	0.10	2.9%
All Other Mobile Fuel Use	0.02	0.7%

Table 4: Percent contribution to transportation emissions from onroad and nonroad sources (2017 NEI).

Transportation Subsector *(NEI and Previous Nonroad methodology)*	Percent Contribution (2017)
Onroad Gasoline and Diesel	85%
Farm/Rail/Boats/Other Diesel and Gas (nonroad)	15%

[17] EPA SIT Mobile Combustion User's Guide: https://www.epa.gov/sites/production/files/2020-10/documents/mobile_combustion_users_guide.pdf

Table 5: Percent contribution to transportation emissions by vehicle type (2017 NEI).

Onroad Transportation Subsector *(2017 NEI)*	Percent Contribution (2017)
Light-duty Gasoline Vehicles	84%
Heavy-duty Diesel Vehicles	13%
Light-duty Diesel Vehicles	2%
Heavy-duty Gasoline Vehicles	1%

As noted above the change in methodology from a VMT based estimate to a fuel consumption-based estimate has significant implications for emissions from the sector, and for the state as a whole (Figure 8). Rationale for the methodology change has been provided above, however, it is important to understand that both of these estimation methods are valid and the reason the estimates produced by the two differing methodologies don't correlate well is not completely understood. Trends in VMT (Figure 9) and fuel sales (Figure 10) also do not track particularly well with each other for reasons including the differences and uncertainties incorporated into the estimates, as well as fleet turnover and fuel economy improvements.

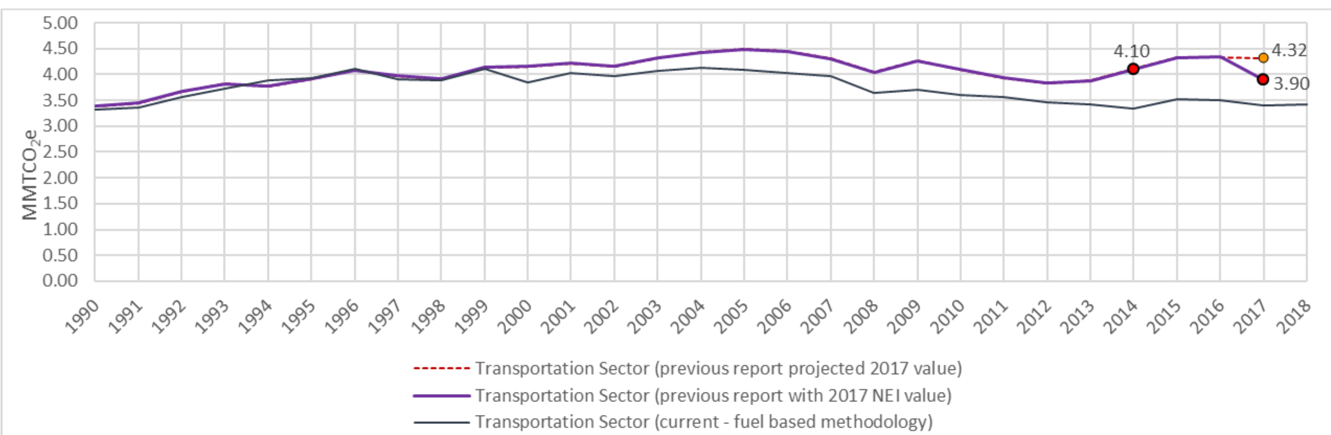

Figure 8: Comparison of GHG emissions based on NEI methodology to the updated fuel combustion methodology.

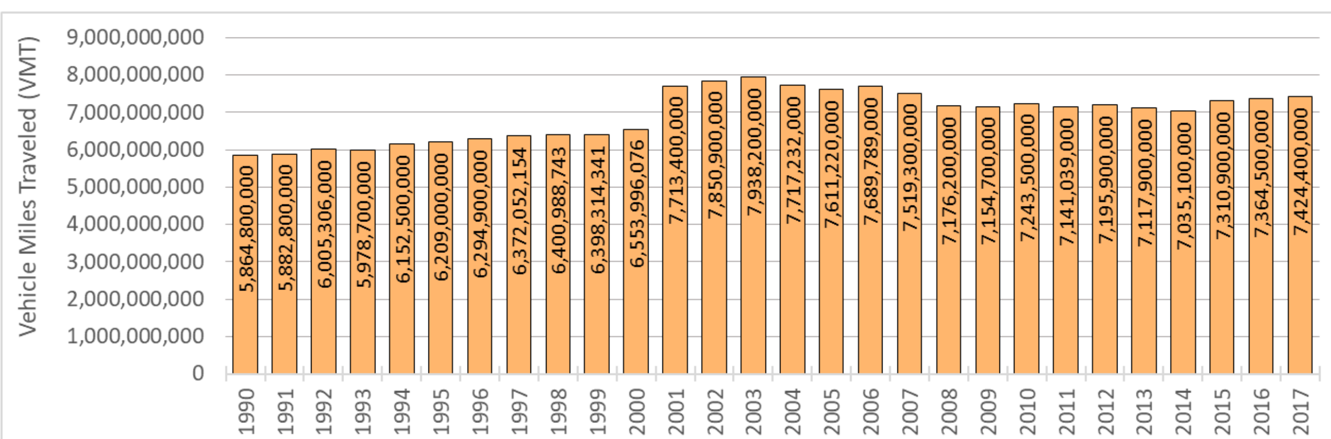

Figure 9: Vehicle miles traveled in Vermont by year (Source: VTrans).

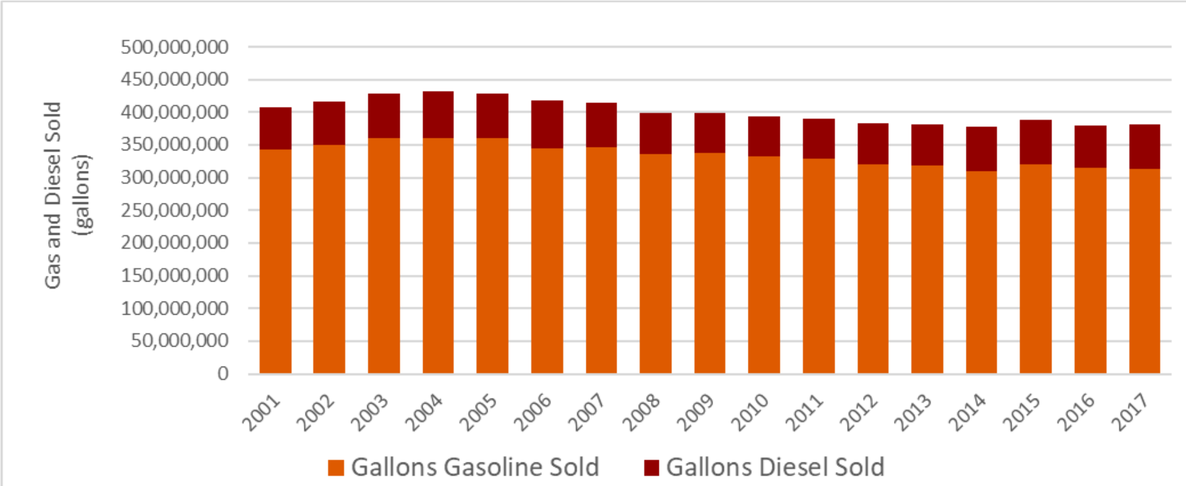

Figure 10: Gallons of gasoline and diesel sold in Vermont by year (Source: Joint Fiscal Office).

2.2.3 Residential/Commercial/Industrial (RCI) Fuel Use

The Residential/Commercial and Industrial Fuel Use sector includes greenhouse gas emissions mainly from building energy use. Emissions in this sector are mostly from fuel oil, propane, and natural gas used for heating buildings, heating water, and cooking. The RCI sector contributed 2.69 $MMTCO_2e$ in 2017, which was unchanged from the previous year (Figure 11), and which made up 31% of total statewide GHG emissions. Greenhouse gases accounted for in this sector include CO_2, CH_4, and N_2O. Carbon dioxide from wood combustion is considered to be of biogenic origin and is not included in the totals shown in this sector.

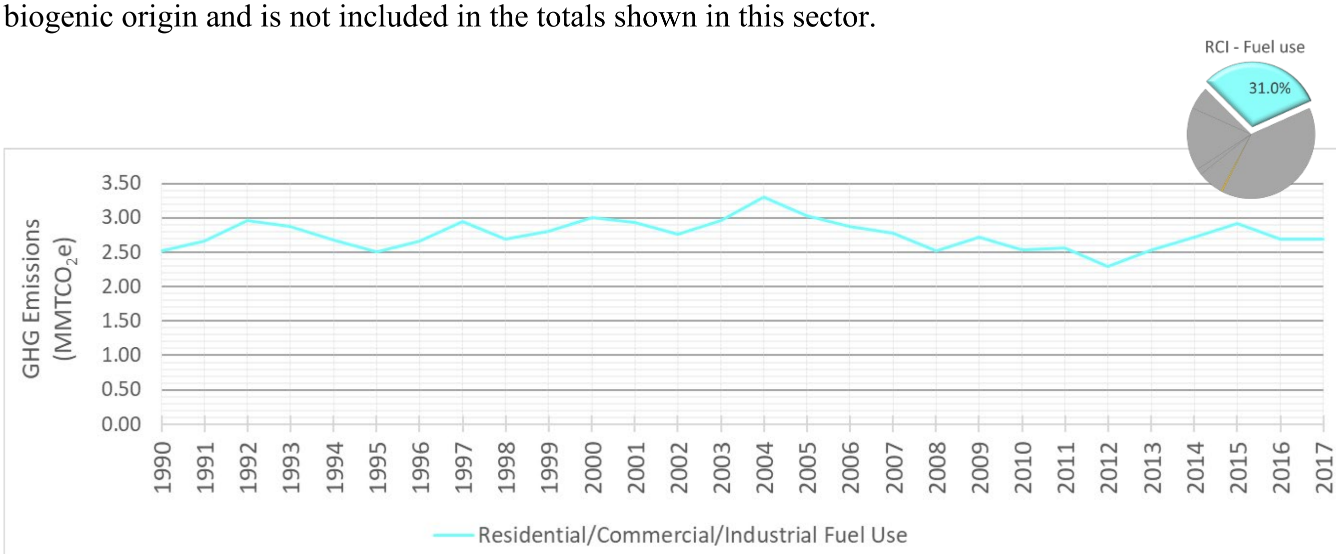

Figure 11: Vermont GHG emissions from the RCI sector, 1990-2017.

The residential piece of the RCI sector is the largest contributor at roughly 55% of the sector total (Table 6). Distillate fuel oil and propane use in the residential sector account for approximately 44% of GHG emissions from the entire RCI sector (Table 7), and about 80% of the residential total. Methane and nitrous oxide from wood combustion are included in the totals for each subsector and emissions estimates are informed by data from Vermont Residential Fuel Assessment reports and by point source registration data submitted annually to the ANR Air Quality and Climate Division.[18]

Table 6: GHG emissions contribution of residential, commercial, and industrial subsectors.

RCI Sector (2017)	$MMTCO_2e$	% of Total
Residential	1.47	54.8%
Commercial	0.77	28.7%
Industrial	0.44	16.5%
Total	**2.69**	**100.0%**

Table 7: GHG emissions contributions by fuel type within the RCI sector.

RCI Residential Sector (2017)	$MMTCO_2e$	% of Total
Fuel Oil	0.76	51.8%
Propane	0.40	27.1%
Natural Gas	0.19	13.1%
Kerosene	0.03	1.7%
Wood (CH_4 and N_2O only)	0.09	6.3%
Total	**1.47**	**100.0%**

Emissions estimates in the RCI sector are calculated using two EPA SIT modules. The first is the CO_2 from Fossil Fuel Combustion tool (CO_2FFC) and the second is the Methane and Nitrous Oxide Emissions from Stationary Combustion tool. All of the fossil fuel values used in these tools are default values from the EIA SEDS dataset. The general methodology for the calculations in this sector, completed using the EPA SIT modules listed above, multiplies the total energy consumption in billion British Thermal Units (Btu) for each applicable subsector from the SEDS dataset by a fuel specific emission factor and then by a fuel specific combustion efficiency value. Datasets used to inform the fuel and Btu consumption estimates in the SEDS dataset related to this sector differ by fuel and by year but are generally based on national level reporting of sales data by state.[19]

2.2.4 Agriculture

The agriculture sector accounts for emissions of CH_4 and N_2O from agricultural practices in the state, including animals and crop production. Carbon dioxide in this sector is almost exclusively biogenic, and so not included in the sector totals, with the exception of CO_2 associated with liming and urea fertilization. Greenhouse gas emissions for the sector were 1.37 $MMTCO_2e$ in 2017, which was down from 2016 (Figure 12) and was 15.8% of the total statewide emissions.

[18] Vermont Forest Parks and Recreation – Residential Fuel Assessment for the 2018 – 2019 Heating Season: https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Wood_Biomass_Energy/Library/2019%20VT%20Residential%20Fuel%20Assessment%20Report%20FINAL.pdf
[19] EIA SEDS – "Technical notes & documentation - complete 2018" – Section 4: Petroleum: https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf

The subsectors of the agriculture sector include enteric fermentation, manure management, agricultural soils, rice cultivation, liming of soils, urea fertilization, and agricultural residue burning, although not all have associated values or emissions within Vermont.

Figure 12: Vermont GHG emissions from the agriculture sector, 1990-2017.

The majority of the greenhouse gas emissions from the agriculture sector are from three of the subsectors listed above, with enteric fermentation (CH_4 produced as a part of the digestive process of ruminant animals) making up the largest portion at 0.64 $MMTCO_2e$, or 47% of the sector total (Table 8). Manure Management and Agricultural Soils make up the majority of the remainder at 0.35 and 0.33 $MMTCO_2e$, respectively. Greenhouse gas emissions estimates from manure management consist of both CH_4 and N_2O from the storage of animal waste in different management systems. Emissions of N_2O from agricultural soils occur naturally, but several agricultural activities increase the amount of available nitrogen in the soils leading to increases in emissions of N_2O. These activities include the application of fertilizers, animal production, the incorporation of crop residues, and the cultivation of nitrogen-fixing crops and highly organic soils (histosols).[20]

Table 8: GHG emissions contributions of subsectors within the agriculture sector.

Agriculture Sector Breakdown (2017)	**$MMTCO_2e$ (2017)**	**Percent Contribution**
Enteric Fermentation	0.64	47%
Manure Management	0.35	25%
Agricultural Soils	0.33	24%
Liming and Urea Fertilization	0.05	3%
Total	**1.37**	**100%**

[20] EPA State Inventory Tool: User's Guide for Estimating carbon dioxide, methane, and nitrous oxide emissions from agriculture using the state inventory tool: https://www.epa.gov/sites/production/files/2020-10/documents/ag_module_users_guide.pdf

Greenhouse gas emissions estimates in the agriculture sector are calculated using an EPA SIT module (Carbon Dioxide, Methane, and Nitrous Oxide from Agriculture module). Most of the emissions are associated with animal populations. Emissions from enteric fermentation are calculated using the total animal populations by animal type multiplied by region-specific emission factors. Methane and nitrous oxide emissions related to manure management involve estimating the waste produced for the animal populations and multiplying by emission factors which are adjusted with a conversion factor, depending on the applied manure management system. The majority of GHG emissions associated with agricultural soils are based on the residues or cultivation of certain crop types or soil types and various emission factors, or on the use of fertilizers with applied emission and conversion factors. Data used in the tool are almost exclusively default data which are taken from various US Department of Agriculture (USDA) datasets. One adjustment made is to modify the population of dairy cows in the manure management portion of the tool as a method to remove the waste that is estimated to enter anaerobic digester facilities as informed by ANR point source registration data and the EPA AgSTAR database.[21]

The agriculture sector datasets and methodologies are currently being reviewed by the Vermont Agency of Agriculture, Food & Markets (AAFM) to determine if there are areas where improvements can be made. Methods for estimating sequestration in the agriculture sector and the impact of agricultural practices that help to reduce GHG emissions are also being actively investigated as part of the ongoing work related to the Global Warming Solutions Act and the Vermont Climate Council.

2.2.5 Industrial Processes

The Industrial Processes (IP) sector for the Vermont inventory includes GHG emissions from ozone depleting substances (ODS) substitutes, semiconductor manufacturing, limestone and dolomite use, electric power transmission and distribution systems, soda ash, and urea consumption. There are additional processes generally covered by this sector, but they are not currently occurring in Vermont. Greenhouse gases emitted by the processes in this sector include CO_2, HFCs, PFCs, NF_3, and SF_6 with nearly 95% of all the GHG emissions in the sector being anthropogenic fluorinated gases (F-gas). Total GHG emissions from the sector were 0.57 $MMTCO_2e$ in 2017, which is similar to the 2016 totals (Figure 13) and was 6.5% of total statewide emissions for 2017.

[21] EPA AgSTAR – Livestock Anaerobic Digester Database: https://www.epa.gov/agstar/livestock-anaerobic-digester-database

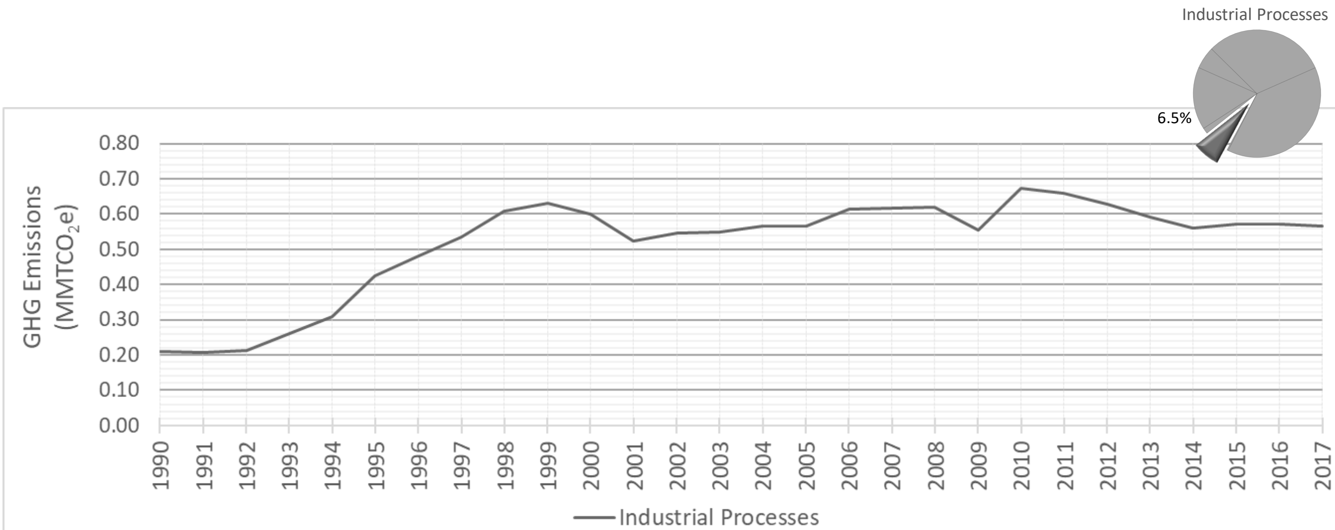

Figure 13: Vermont GHG emissions from the industrial processes sector, 1990-2017.

ODS substitutes and semiconductor manufacturing combined make up nearly 94% of the total GHG emissions from the sector (Table 9), with limestone and dolomite use contributing an additional 4.2% and SF_6 from electric utilities, soda ash use, and urea consumption making up the remaining 2.2%.

Table 9: GHG emissions contributions of subsectors with the industrial process sector.

Industrial Processes	$MMTCO_2e$	% of Total
ODS Substitutes	0.337	59.6%
Semiconductor Manufacturing (HFC, PFC & SF_6)	0.193	34.1%
Limestone & Dolomite Use	0.024	4.2%
Electric Utilities (SF_6)	0.006	1.1%
Soda Ash Use	0.004	0.7%
Urea Consumption	0.002	0.4%
Total	**0.566**	**100.0%**

Ozone depleting substances substitutes contribute over half of the GHG emissions in the IP sector. These emissions are associated with hydrofluorocarbons (HFCs) present in end uses like refrigeration equipment, air conditioning equipment, aerosol propellants, and foams. High GWP hydrofluorocarbons were being incorporated into these end uses and products to phase out the use of ozone depleting substances (CFCs and HCFCs) following ratification of the Montreal Protocol. This initiative was successful in reducing emissions that deplete the stratospheric ozone layer, but the replacement HFCs are often very high GWP alternatives, many of them thousands of times more potent than CO_2 in their ability to warm the planet. Global emissions of HFCs from these end uses are growing rapidly and are expected to increase by roughly twenty times in the next several decades, driven by increases in demand for refrigeration and air conditioning, especially in developing countries.[22]

In collaboration and coordination with other U.S. Climate Alliance states, with leadership from California, the Vermont legislature passed Act 65 (2019) which requires, with subsequent rulemaking, the phase down of high GWP HFCs that had been previously required under the partially vacated EPA Significant New Alternatives Program (SNAP) rules.[23] Act 65 phases out the use of high GWP HFCs in certain end uses by certain dates based on evaluations and determinations of available substitutes completed through the SNAP program based on the impacts to human health and the environment.

Estimates of GHG emissions from the ODS Substitutes sector are derived from a tool developed by California for use by U.S. Climate Alliance states. The tool is based on an F-gas model which estimates annual HFC emissions from equipment by production year and includes leakage rates from charging new and used equipment, leakage rates from existing equipment, and end of life equipment loses. These HFC emissions estimates for California are then apportioned to a per capita value (or per vehicle) and adjusted based on state-specific factors such as the percentage of households with AC units or using heat pumps. Per capita values were then applied to the population of Vermont to produce an estimated business as usual baseline value. The tool also contains adjusted estimates based on emissions reductions associated with various HFC mitigation strategies, including adopting the EPA SNAP prohibitions. Following adoption of Act 65 in Vermont values incorporating the SNAP reductions will be used, however, the earliest prohibition dates pursuant to Act 65 did not come into effect until January 1, 2021 and so the associated reductions are not reflected in the data prior to that date, including the values presented in this inventory.

Greenhouse gas emissions related to semiconductor manufacturing include HFCs, PFCs, SF_6, and NF_3 and account for roughly 34% of the total for the sector. Emissions of the F-gases in semiconductor manufacturing occur in the plasma etching and chemical vapor deposition processes.[24] Greenhouse gas emissions data for the semiconductor manufacturing sector is pulled directly from the EPA Facility Level Information on GreenHouse gases Tool (FLIGHT) for all available years (2011 through 2019).[25] Data in the FLIGHT tool is reported directly by facilities through the EPA Greenhouse Gas Reporting Program (GHGRP) which requires annual reporting of GHG emissions by applicable sources and facilities.[26] Currently historical

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

[23] EPA Significant New Alternatives (SNAP) program: https://www.epa.gov/snap/overview-snap
10 V.S.A. § 586:
https://legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT065/ACT065%20As%20Enacted.pdf
Vermont HFC Rulemaking – Chapter 38: Rules regarding the phase-down of the use of Hydrofluorocarbons:
https://dec.vermont.gov/sites/dec/files/aqc/laws-regs/documents/Vermont_HFC_Rule_Adopted_CLEAN.pdf

[24] EPA State Inventory Tools – User's Guide for Estimating carbon dioxide, nitrous oxide, HFC, PFC, NF_3, and SF_6 emissions from Industrial Processes using the State Inventory Tool: https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool

[25] EPA FLIGHT Tool: https://ghgdata.epa.gov/ghgp/main.do?site_preference=normal

[26] EPA – Greenhouse Gas Reporting Program (GHGRP): https://www.epa.gov/ghgreporting

emissions estimates in this sector are based on projecting reported 2011 emissions totals backwards through time to 1990 based on historical national trends in the sector; however, work is ongoing to obtain more specific and accurate data for this sector.

The remaining 6% of emissions from the sector are from limestone and dolomite use, soda ash, urea consumption, and electric power transmission and distribution systems. Emissions from these subsectors are based on default values in the EPA Industrial Processes SIT module. Limestone and dolomite use, soda ash, and urea consumption emissions are all based on production or consumption data multiplied by applicable emissions factors. Emissions of SF_6 from electric power transmission and distribution are based on an estimate of the quantity of SF_6 consumed annually multiplied by an emission factor. SF_6 is often used as an insulator in electrical transmission and distribution equipment.

2.2.6 Electricity Consumption

Greenhouse gas emissions associated with the electricity sector made up 5.7% of emissions for the state in 2017, with emissions of 0.49 $MMTCO_2e$. Emissions from the sector declined 0.32 $MMTCO_2e$ between 2016 and 2017 as shown in Figure 14. Estimates of emissions from electricity are based on electricity consumption rather than exclusively on in-state generation. This consumption-based approach was chosen because it is consistent with the majority of states in the region and accounts for emissions associated with all of the electricity used by Vermonters rather than only for what is generated within the boundaries of the state. This is especially relevant in Vermont, because Vermont consumes more than 3 times as much energy as it generates.[27]

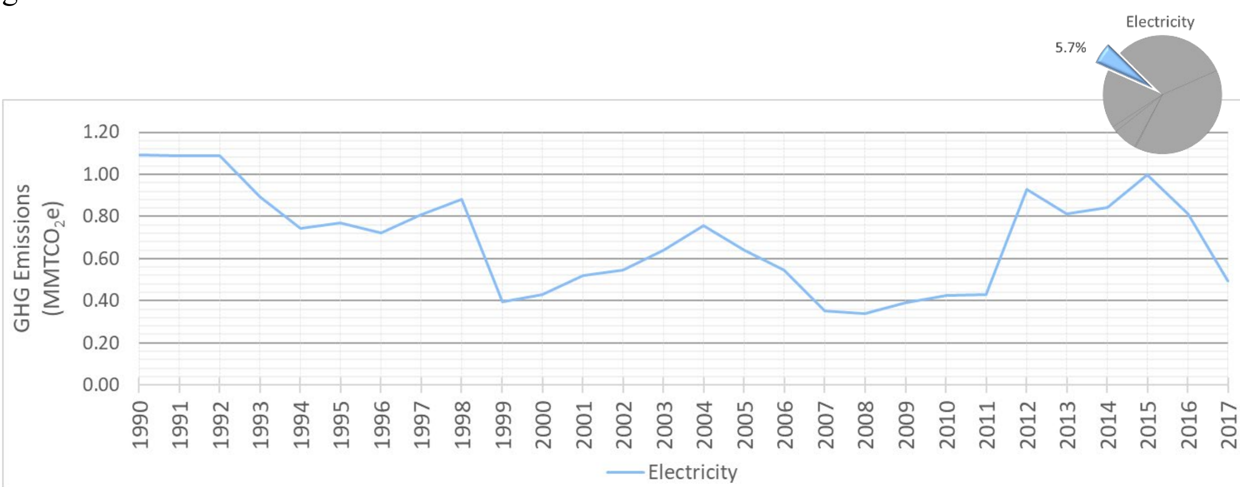

Figure 14: Vermont GHG emissions from the electricity sector, 1990-2017.

Calculations of the GHG emissions from the electricity sector are performed using a methodology previously developed in collaboration with the Vermont Public Service Department (PSD). Emissions are estimated by using generation specific emission factors from the New England Independent Systems Operator - New England (ISO-NE) Power Pool Generation

[27] EIA – State Profile and Energy Estimates: https://www.eia.gov/state/?sid=VT

Information System (NEPOOL GIS) coupled with data from PSD on the purchase decisions of utilities including adjustments for renewable energy certificate (REC) retirements.[28] Wind, solar PV, hydropower and nuclear generation are considered zero GHG emitting for the purposes of this inventory. Electricity generated through biomass combustion is considered to emit zero CO_2 emissions because the CO_2 is of biogenic origin, but CH_4 and N_2O emissions are included.

Hydropower is a source of electricity with associated biogenic emissions that are not counted in this inventory. Emissions from the decomposition of organic material in hydro reservoirs occurs due to the initial flooding of the land and later water level fluctuations. Emissions from Hydro-Québec (HQ) reservoirs are of interest because of the large contribution to the Vermont electricity portfolio from HQ. This inventory does not account for the emissions from the flooding of land for two reasons. The first reason is that those emissions occur gradually over time and do not fit well within the framework of gross annual emissions used in this inventory. The second reason is that those emissions would be accounted for in the land-use, land use change, and forestry sector of the inventory, and emissions from the flooding of land for the HQ reservoirs have been captured in the Canadian National Inventory Report using the methodology specified in the IPCC inventory guidance.[29] Understanding the full emissions picture associated with different types of electricity generation is important because of the focus on mitigation strategies based on electrification, but that comparison cannot be made using the annual gross emissions framework and would be more appropriate for a life cycle analysis.

The current inventory methodology accounts for the sale and retirement of renewable energy certificates (RECs). The Vermont legislature established a Renewable Energy Standard (RES) through 30 V.S.A. § 8002-8005 which, starting in January 2017, required electric distribution utilities to acquire and retire enough environmental attributes from qualified renewable generation to cover the required percentages of their annual retail electricity sales.[30] Required renewability portfolio percentages increase from 55% in 2017 to 75% in 2032.[31] Renewability does not necessarily equate to zero emission electricity, but generally resources considered renewable under the RES are also considered zero GHG emitting in the inventory as they tend to have no emissions at the point of generation or the emissions produced are of biogenic origin.

Greenhouse gas emissions from the electricity sector continue to decline through 2019, based on the purchase decisions of utilities and REC retirements driven by the RES requirements and individual utility goals and commitments. The declining emissions totals for 2018 and 2019, 0.18 and 0.13 $MMTCO_2e$ respectively, are due largely to the purchase of nuclear generation and Hydro-Québec RECs.

[28] NEPOOL GIS – Public Reports – NEPOOL Residual Mix: https://www.nepoolgis.com/public-reports/
[29] National Inventory Report: Greenhouse Gas Sources and Sinks in Canada – Part 2 – A3.5.6.2. Flooded Lands: http://publications.gc.ca/collections/collection_2020/eccc/En81-4-2018-2-eng.pdf
[30] Vermont Renewable Energy Standard: https://legislature.vermont.gov/statutes/chapter/30/089
Public Service Department website: https://publicservice.vermont.gov/renewable_energy/state_goals
[31] Vermont Public Utility Commission: https://puc.vermont.gov/electric/renewable-energy-standard

2.2.7 Waste

Emissions of greenhouse gases associated with the waste sector include CH_4 and N_2O from solid waste and wastewater. Carbon dioxide associated with the waste sector is considered biogenic and is not included in the totals for the sector. Total emissions from the waste sector stayed relatively flat from 2016 to 2017 with a decrease of only 0.01 MMTCO2e (Figure 15). Emissions contributions from solid waste and wastewater are fairly even with wastewater contributing 0.06 $MMTCO_2e$ in 2017 and solid waste contributing 0.07 $MMTCO_2e$. With a total contribution of 0.13 $MMTCO_2e$ for the sector in 2017 the waste sector makes up 1.5% of GHG emissions for Vermont.

Figure 15: Vermont GHG emissions from the waste sector, 1990-2017.

Calculations of the CH_4 and N_2O emissions from the wastewater sector are completed using the EPA SIT Wastewater module. Currently the tool is being used with default values provided by EPA with the exception of modifications to the fraction of the population not on septic and to the percentage of biosolids used as fertilizer. These non-default values are from a report on Wastewater Treatment Sludge and Septage Management in Vermont from the Waste Management and Prevention Division (WMPD).[32] There are no default data available for industrial wastewater calculations and so they are not included in the current (or previous) inventory totals, however overall emissions from these sources are thought to be relatively small. Inputs and additional data sources continue to be investigated to improve the estimates for this sector.

The calculation methodology for the wastewater sector in the EPA SIT module is consistent with the *IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006)* and include CH_4 from municipal wastewater, direct N_2O from municipal wastewater, and N_2O from biosolids. Emissions are calculated for the three subsectors using a number of emission factors and population and activity data. Methods are population-based and depend on calculated per capita

[32] WMPD report: https://dec.vermont.gov/sites/dec/files/wmp/residual/RMSWhitePaper20180507.pdf

values and emission factors for variables such as percentage of organic content in wastewater, protein consumption and nitrogen content, and CH_4 and N_2O emission factors. Specific methodologies and calculations can be found in the User's Guide for the Wastewater module SIT module.[33]

The GHG emissions from solid waste portion of the inventory employs a methodology that is based on reported landfill gas (LFG) totals since the necessary data became available in 2009. Historical data from before 2009 are from calculations completed for the 2007 *Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030 report* and have been adjusted for changes in GWP in previous inventories. The majority of the emissions from the solid waste sector are associated with the two largest landfills in Vermont, in Coventry and Moretown, of which only the Coventry landfill remains open. Both landfills have landfill gas to energy (LFGTE) systems which capture LFG generated by the decomposition of material in the landfill which is then either combusted in engines or flared. This method of calculating emissions from the solid waste sector was adopted previously because it is based mostly on measured LFG values which were considered to be more accurate than estimates of total LFG generated based on waste disposal data.

Landfill gas is made up of approximately 50% methane; however, when the LFG is combusted the CH_4 is converted to CO_2. Since the generated CO_2 emissions are related to the decomposition of biogenic material within the landfill, they are not included in the gross emissions totals for the sector as per EPA and IPCC guidelines. Fugitive emissions of LFG are accounted for where the CH_4 escapes into the atmosphere and is not combusted, but reported estimates of fugitive LFG are generally only in the range of 10% - 25% of the total LFG generated annually. Even though the fugitive emissions are a relatively small percentage of the total LFG generated, they still account for approximately 85% - 90% of the total GHG emissions from the two largest landfills. Because there are additional smaller closed landfills in the state that are still emitting LFG as they age, albeit at declining rates, an additional 15% of the total estimated $MMTCO_2e$ is added onto the total to account for those smaller closed landfills.

2.2.8 Fossil Fuel Industry

Emissions of greenhouse gases from the fossil fuel industry accounted for 0.03 $MMTCO_2e$ in 2017 and made up 0.3% of the total emissions for the state. These values increased from 2016 to 2017 (Figure 16). Contributions from this sector are relatively low because there is no production or refining of petroleum occurring in Vermont and the only emissions included in this sector are fugitive emissions related to the transmission and distribution of natural gas (NG). All of the GHG emissions associated with the combustion of the various fossil fuels in the state are captured within the other sectors of the inventory.

[33] EPA State Inventory Tool – Wastewater User's Guide: https://www.epa.gov/sites/production/files/2020-10/documents/wastewater_users_guid.pdf

Figure 16: Vermont GHG emissions from the fossil fuel industry sector, 1990-2017.

The transmission of natural gas in Vermont is limited, with only 118 miles of total transmission pipeline in the state in 2017. Emissions of CH_4 are related to leakage of NG from transmission lines and are calculated using an EPA SIT module. The total miles of lines are multiplied by an emission factor as a leakage rate per mile and type of pipeline. Leakage rates used for the calculation are default values provided in the tool by EPA, and the total transmission line mileage is from the Pipeline and Hazardous Materials Safety Administration (PHMSA).[34]

Greenhouse gas emissions associated with natural gas distribution in Vermont are calculated in a similar fashion as emissions from NG transmission, except instead of transmission lines it accounts for the smaller distribution lines and service lines. Emission factors per service and per mile of distribution pipeline from the Electronic Code of Federal Regulations (e-CFR) are multiplied by the number of services and miles of distribution line from PHMSA to come up with annual emissions of CH_4 from the NG distribution system.[35]

3. Additional Emissions Inventory Considerations

3.1 Land Use, Land-Use Change, and Forestry

One critical component to understanding the entirety of the greenhouse gas picture for the state of Vermont is land use. A large amount of carbon can be either emitted or sequestered (forests and other vegetation remove or "sequester" CO_2 from the atmosphere and convert it into stored biological material through photosynthesis) from changes in land use or ecosystems, from leaving forests as forest or increasing forested acreage, to draining wetlands, to converting

[34] PHMSA – 2010+ Pipeline Miles and Facilities: https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-mileage-and-facilities
[35] E-CFR: Table W-7 to Subpart W of Part 98—Default Methane Emission Factors for Natural Gas Distribution: https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=328f7871a490eca0ae8ad578562d373b&mc=true&n=sp40.23.98.w&r=SUBPART&ty=HTML#ap40.23.98_1238.15

agricultural land, to clearing forests for development. Because land use and land-use change are large and complex components and systems, reliable, accurate, and repeatable quantification of the carbon fluxes (net carbon emitted or sequestered) from these systems is difficult. Work is underway through the U.S. Climate Alliance and the Global Warming Solutions Act process to establish a more complete picture of net carbon fluxes from land use and land-use change in the state; however, as in previous inventories, this inventory focuses exclusively on data for carbon fluxes related to forests.

Based on IPCC guidelines, the land-use, land use change, and forestry (LULUCF) sector is intended to include all changes in carbon stocks within forest land, cropland, grassland, wetlands, settlements, and other land. Changes in carbon stocks refer to the gains or losses of the total carbon that is contained within a system. The six categories are then subdivided into either land that has remained in the category or has been converted to a different category with the focus of the sector being on managed land. Managed land is broadly defined but is used because it is a representation of anthropogenically related emissions and removals, even though the carbon removals are often related to, or associated with, natural processes on those lands. Because of the complexity of estimating the fluxes from the LULUCF sector, the other New England states also do not currently include comprehensive land use related estimates in their GHG inventories. There is an EPA SIT module for calculating these fluxes for certain components, but the available data that have been incorporated into the tool are considered by some to be inadequate or unreliable, although much work is currently underway to improve these estimates. There are data available from the U.S. Forest Service quantifying carbon stocks and fluxes associated with forests in Vermont, which have been used in this, and in previous, inventories. These data are produced for the National Emissions Inventory but have been used to report state-specific estimates.[36] The dataset includes estimates of carbon fluxes for Forest Land Remaining Forest Land, Land Converted to Forest Land, Forest Land Converted to Land, and Urban Trees in Vermont. Data on carbon flux from forested systems are not included in the gross totals, but are reported as a separate component in Figure 17, consistent with previous inventory reports.

The carbon cycle within a forest system is complex and the total flux includes estimates of aboveground forest biomass, belowground forest biomass, dead wood, litter, mineral soils, organic soils, and drained organic soils. Forests of Vermont are a net carbon sink and are estimated to have sequestered 4.63 $MMTCO_2e$ in 2017. While this total is significant, because the focus of this inventory is on *gross* annual *emissions* of greenhouse gases rather than net carbon emissions, the sequestration values are not subtracted from the gross annual emissions totals. It should also be noted that based on the data from the U.S. Forest Service the rate of sequestration has been gradually declining since the 1990 baseline (Figure 17). Total forested acres are also a good indicator of sequestration potential for forests in Vermont and the estimates for 1990-2017 are included here for reference (Figure 18).[37]

[36] USDA – Forest Service - Domke, Grant M.; Walters, Brian F.; Nowak, David J.; Smith, James, E.; Ogle, Stephen M.; Coulston, J.W.; Wirth, T.C. 2020. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 p. https://doi.org/10.2737/FS-RU-227.
[37] USDA – Forests of Vermont reports (multiple years): https://www.fs.fed.us/nrs/pubs/ru/ru_fs164.pdf

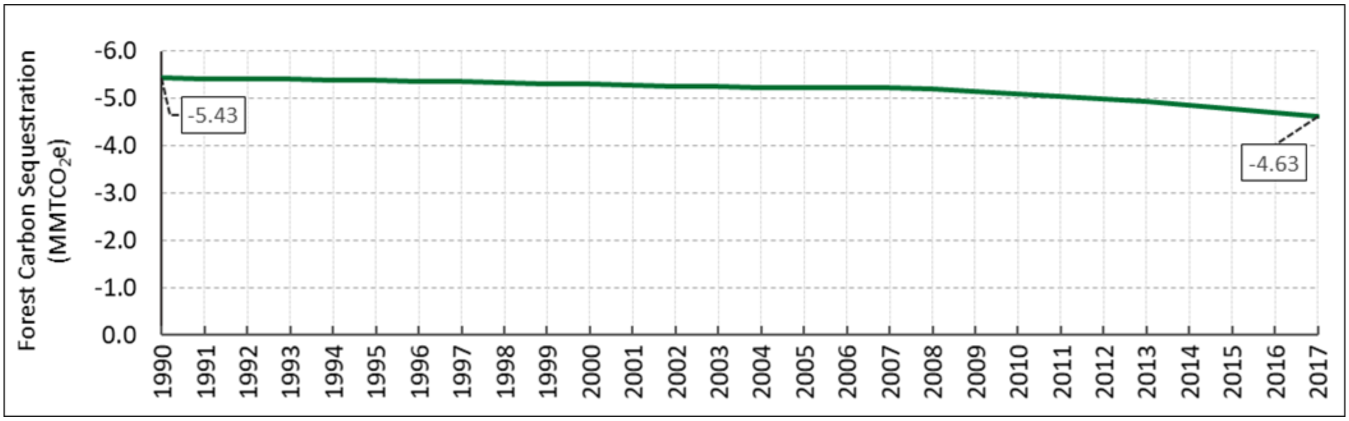

Figure 17: Sequestration of CO_2 by forested areas and urban trees in Vermont, 1990-2017.

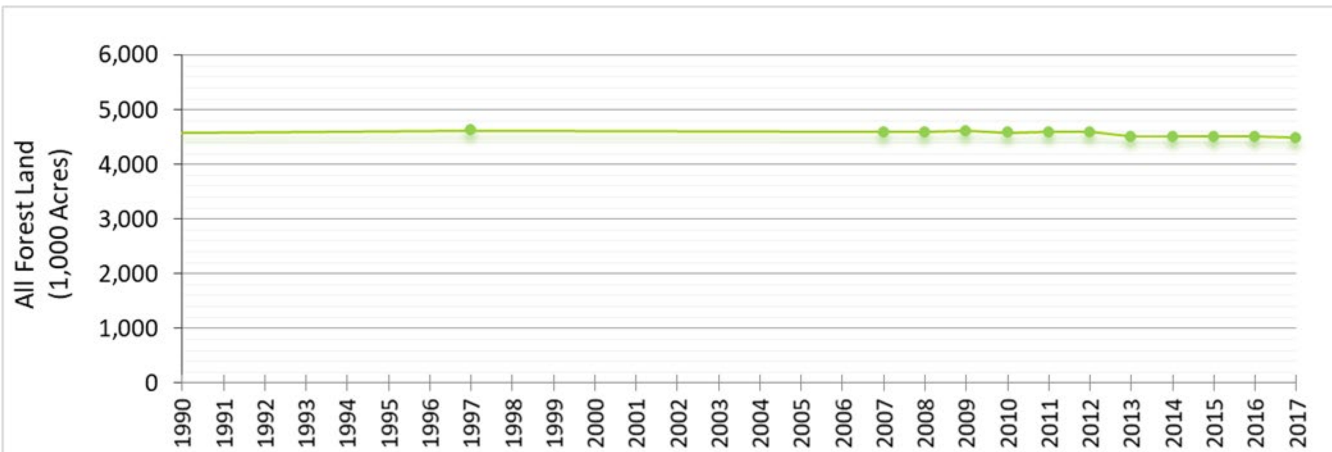

Figure 18: Forested land area in Vermont, 1990-2017.

3.2 Biogenic CO_2

Biogenic CO_2 is directly tied to the LULUCF sector. Biogenic CO_2 is carbon dioxide that is emitted as a part of the natural carbon cycle, or related to the combustion or decomposition of biologically based materials (excluding fossil fuels).[38] Carbon dioxide emissions from the combustion of fossil fuels are coming from a geologic source, which is on a significantly longer time scale than carbon in the much faster carbon cycle which moves between pools on the order of months to centuries, which means that combusting fossil fuels adds more carbon that was in long term storage into the atmosphere.[39] Carbon dioxide emitted from the combustion or decomposition of biogenic materials which are a part of the faster carbon cycle are assumed to be either sequestered by the regrowth of the biogenic material that produced them, or captured in the flux from the land use change. The distinction between short-term and long-term carbon

[38] EPA Science Advisory Board – Carbon Dioxide Accounting for Emissions from Biogenic Sources: https://yosemite.epa.gov/sab/sabproduct.nsf/0/2F9B572C712AC52E8525783100704886

[39] California Greenhouse Gas 2000-2018 Emissions Trends and Indicators Report: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2018/ghg_inventory_trends_00-18.pdf

storage is important; however, depending on the actual timescale of carbon movement within the faster carbon cycle, the sequestration of CO_2 emitted by the combustion or decomposition of biogenic materials may still be on a longer timescale than would be required to meet mandated GHG emissions reductions.

IPCC guidelines recommend excluding biogenic CO_2 from inventory totals within each sector, the theory being that those emissions are captured in the net fluxes within the LULUCF sector. This is problematic because of the lack of complete and reliable data to compile and quantify a robust and accurate LULUCF sector. The annual flux of carbon in forests is currently being captured in the inventory and so a portion of the biogenic CO_2 issue is being mitigated in terms of wood combustion, but only in terms of net GHG emissions.

Because of the question around timelines of carbon neutrality (timeline for the full re-sequestration of various forms of biogenic CO_2 emitted) and the fact that the LULUCF sector is not considered in the gross emissions totals for the state, it is important to understand the potential implications for including CO_2 emitted from biogenic sources in our inventory totals. Calculations have been completed to estimate at the stack CO_2 emissions from wood combustion for the RCI and electricity sectors, to help inform this topic. Scenarios including carbon sequestration from forests as well as the emissions of biogenic CO_2 from wood combustion from the RCI and electricity sectors are shown in Figure 19. Sequestration is shown in green as negative emissions (below the axis), while the light orange represents the gross annual emissions (excluding biogenic CO_2), and the dark orange represents the emissions of biogenic CO_2 from the RCI and electricity sectors.

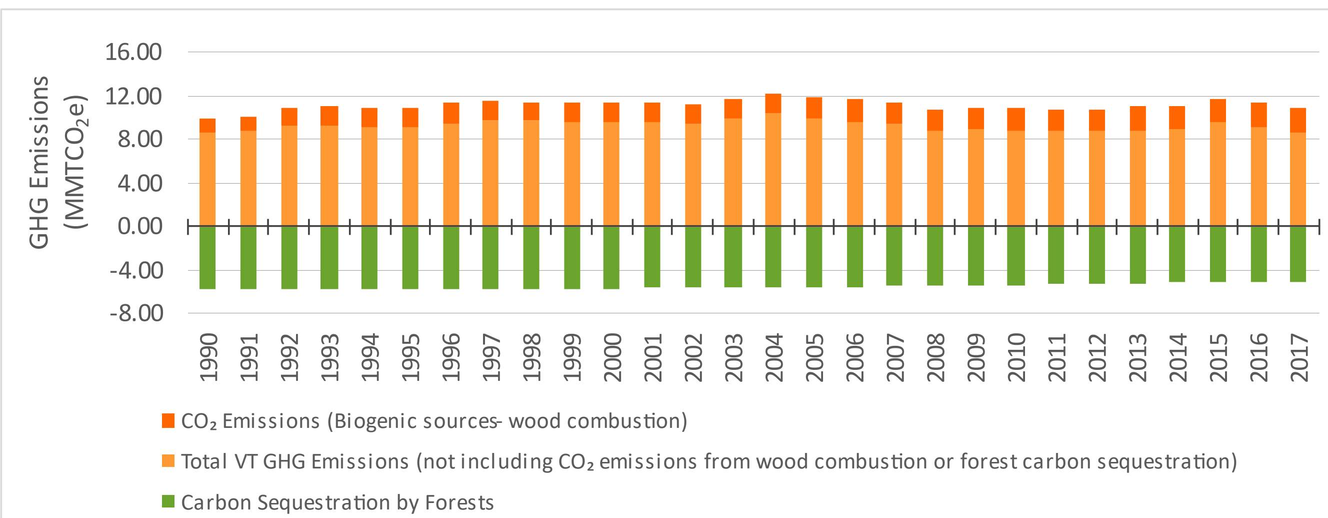

Figure 19: Vermont biogenic CO_2 emissions and sequestration scenarios, 1990-2017.

3.3 Lifecycle Assessments and Consumption Based Inventories

There are multiple ways to look at GHG emissions associated with an area or attributable to a population. This GHG emissions inventory is a snapshot of anthropogenic emissions generated annually within the boundaries of the state of Vermont, with the exception of the electricity sector. It is used to track emissions generated annually that are associated with each sector in the inventory. The inventory does not include emissions associated with the entire lifecycle of a product or process, nor does it include lifecycle emissions associated with the consumption of goods or services. Because this inventory is an annual snapshot of emissions from each sector in the state, incorporating lifecycle emissions into this inventory framework is problematic as full lifecycle emissions often stretch over multiple years and could also lead to double counting of emissions if included upstream emissions were already accounted for by another jurisdiction in their inventory.[40] Through the Global Warming Solutions Act Process the Vermont Department of Environmental Conservation and its partner state agencies are evaluating the role that lifecycle or consumption-based inventories could play in understanding Vermont's GHG emissions profile and informing future policy discussions.

Greenhouse gas emissions estimates using lifecycle assessments endeavor to evaluate all of the associated emissions of the process or production (most often a consumer product), including the emissions related to the inputs, manufacturing, transport, use, and disposal.[41] Lifecycle analyses are an important way to view and understand emissions associated with products or activities. They provide a different, but more holistic and complex, representation of the GHG emissions associated with a product or service. As an example, a lifecycle analysis might estimate emissions from the extraction, refining, transport, and combustion of natural gas, the emissions associated with the materials and construction of hydroelectric dams and flooding of land area, or the mining, transport, production, use, and disposal of electric vehicle batteries and the associated materials. A lifecycle analysis is highly complex exercise but one that can provide important information for informing decisions on policies or mitigation strategies.

Consumption based inventories incorporate lifecycle emissions but focus instead on the entirety of emissions associated with a consumed good or service and assign those to the final consumer, which in this case would be consumers within the state of Vermont. Because consumption-based inventories focus on the consumption of goods rather than production, they provide an alternative understanding of the climate impacts of consumer choices and behaviors.[42] A consumption-based inventory does not include emissions associated with the goods or services that are produced because they are accounted for instead by the consumer of those goods.

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[40] EPA – Life-Cycle GHG Accounting Versus GHG Emission Inventories: https://www.epa.gov/sites/production/files/2016-03/documents/life-cycle-ghg-accounting-versus-ghg-emission-inventories10-28-10.pdf

[41] Association of Environmental Professionals, California Chapter, Climate Change Committee (August 2017) – Production, Consumption and Lifecycle Greenhouse Gas Inventories: Implications for CEQA and Climate Action Plans: https://califaep.org/docs/Draft_AEP_White_Paper_Lifecycle_CEQA_CAPs_082017.pdf

[42] Oregon DEQ – Oregon's Greenhouse Gas Emissions through 2015: https://www.oregon.gov/deq/FilterDocs/OregonGHGreport.pdf

3.4 Black carbon

Black carbon (BC) is a short-lived airborne particle that both warms the planet and is linked to adverse health impacts. It is a component of particulate matter (PM) that is related to the incomplete combustion of fossil fuels, biofuels, or biomass that stays in the atmosphere on the timescale of days to weeks.[43] Despite the short atmospheric lifetime, BC is considered an important climate forcer because it has a 100-year GWP value of 910 and a 20-year GWP value of 3,200.[44] Because of the short atmospheric residence time of BC emissions, mitigation strategies can have impacts on regional warming relatively quickly as noted in the EPA Report to Congress on Black Carbon.

Black carbon influences global temperatures both directly and indirectly. Direct impacts of BC emissions are from the absorption of incoming and outgoing solar radiation by the dark particles, which causes warming. The indirect impacts of BC, which are more pronounced in areas with snow cover, are related to the dark particles settling on snow or ice and lowering the albedo (reflectivity) of the surface. The albedo of surfaces varies, but fresh snow has a high reflectivity value of 80-90%, which means it reflects the majority of incoming solar radiation back out through the atmosphere.[45] Particles of BC on the white snow decrease the albedo and accelerate the melting of the snow which exposes darker material underneath further decreasing the albedo. Another indirect effect of BC is its influence on the formation and properties of clouds which alter precipitation patterns and reflectivity, but the influence on climate is not yet well understood.

There is uncertainty surrounding the climate impacts of some sources of BC emissions because BC is always emitted with organic carbon (OC) and gases that have a net cooling effect on the atmosphere. The two main sources of BC emissions in Vermont are residential wood combustion in the RCI sector and diesel engines in the Transportation sector (Figure 20). It has been well established that BC emitted from diesel engines is net warming [46]. Whether emissions of BC from residential wood combustion are net warming is less certain. Because Vermont has snow cover for several months of the year, coinciding with the heating season, the indirect impact of BC on albedo is likely greater here than in many other areas with less snow and increases the likelihood that BC from this source is contributing to regional warming.

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[43] EPA Report to Congress on Black Carbon (2012): https://www3.epa.gov/airquality/blackcarbon/2012report/fullreport.pdf
[44] California – USCA Inventory and Methodology of HFC Black Carbon Methane 31 October 2018.docx
[45] NASA – NASA Satellites See Arctic Surface Darkening Faster: https://www.nasa.gov/content/goddard/nasa-satellites-see-arctic-surface-darkening-faster/
[46] Bond et al, 2013 - Bounding the role of black carbon in the climate system: a scientific assessment: 1.2.8. Net Climate Forcing by Black-Carbon-Rich Source Categories: https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/jgrd.50171

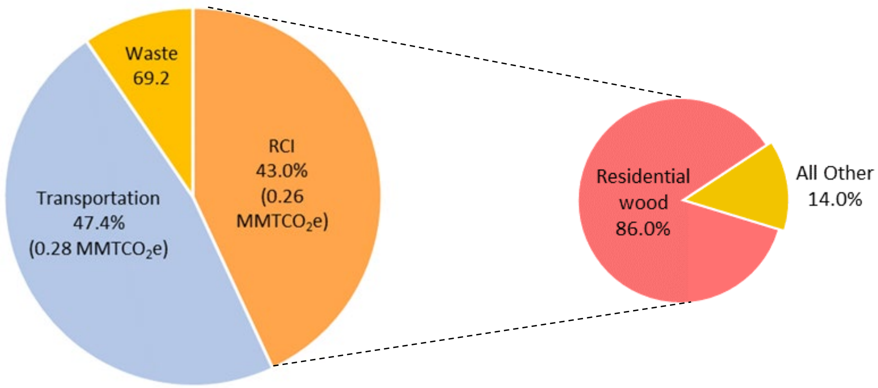

Figure 20: Black carbon emissions contributions in Vermont.

Emissions estimates of elemental carbon (EC) are generally used as a proxy for BC emissions. Speciation profiles (percentage of chemical composition) for EC are applied to the appropriate mass of $PM_{2.5}$ (particulate matter less than 2.5 microns in width) to estimate the emissions of BC. Black carbon emissions estimates have been extracted as the elemental carbon component of $PM_{2.5}$ totals for combustion related activities from the 2017 NEI, which have been adjusted using the GWP value of 910 as referenced above. Black carbon emissions in Vermont totaled 0.6 $MMTCO_2e$ in 2017, which was similar to values reported for 2014. The percent contributions of BC by sector in 2017 are different than those from the 2014 NEI, which was the last time they were reported. The 2014 NEI data showed the RCI sector contributing 61.3% of the total BC emissions with 92.9% of those being from residential wood combustion; however, data in the 2017 NEI show emissions from the RCI sector only making up 43% of the combustion related BC totals for the state (Figure 20). This difference is potentially due to updates to the Nonroad model used to estimate emissions from the mobile nonroad sector in the 2017 NEI since emissions from nonroad diesel equipment made up 70% of the transportation sector BC emissions in 2017.

4. Emissions Forecasts

4.1 Preliminary Greenhouse Gas Emissions Estimates for 2018 and 2019

The *Vermont Greenhouse Gas Emissions Inventory and Forecast* reports are based on the availability of EPA tools and data from a number of federal agencies. Accurate estimates of GHG emissions require accurate and complete data. This is coupled with the desire to keep the emissions estimates comparable through time for the purpose of tracking emissions levels compared to mandated target levels. Accuracy of emissions estimates and the underlying data is important; however, it is also important to have as up-to-date estimates and data as soon as possible in order to inform decision making processes. To that end, an attempt has been made to provide preliminary estimates for calendar years 2018 and 2019 in this inventory report as shown in Table 10. Some of the estimates are essentially complete as the data was available to run the tools out through 2019. In instances where this was not the case the values have been carried forward from the previous year. Values shown in black have been estimated with the current standard methodologies and values shown in grey have been carried forward.

Table 10: Preliminary GHG emissions estimates for 2018 and 2019.

Sector	1990	2005	2012	2013	2014	2015	2016	2017	2018	2019
Electricity Supply & Demand (Consumption - based)	**1.09**	**0.64**	**0.93**	**0.81**	**0.84**	**1.00**	**0.81**	**0.49**	***0.18***	***0.13***
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*	*0.00*
Natural Gas	0.05	0.00	0.00	0.00	0.00	0.02	0.00	0.01	*0.00*	*0.00*
Oil	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.00	*0.00*	*0.00*
Wood (CH_4, N_2O)	0.00	0.01	0.01	0.02	0.01	0.01	0.01	0.01	*0.01*	*0.01*
Residual System Mix	1.03	0.62	0.90	0.78	0.81	0.96	0.79	0.47	*0.17*	*0.11*
Residential/ Commercial/ Industrial (RCI) Fuel Use	**2.52**	**3.04**	**2.30**	**2.53**	**2.72**	**2.92**	**2.69**	**2.69**	***2.93***	***2.93***
Coal	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*	*0.00*
Natural Gas	0.32	0.44	0.43	0.51	0.57	0.64	0.65	0.65	*0.75*	*0.75*
Oil, Propane, & Other Petroleum	2.12	2.52	1.78	1.93	2.06	2.19	1.95	1.94	*2.08*	*2.08*
Wood (CH_4, N_2O)	0.07	0.07	0.09	0.09	0.09	0.09	0.10	0.10	*0.10*	*0.10*
Transportation	**3.32**	**4.09**	**3.46**	**3.42**	**3.33**	**3.52**	**3.49**	**3.39**	***3.43***	***3.40***
Motor Gasoline (Onroad and Nonroad) (CO_2)	2.57	3.14	2.58	2.56	2.49	2.58	2.54	2.52	*2.55*	*2.53*
Diesel (Onroad and Nonroad) (CO_2)	0.45	0.65	0.70	0.70	0.69	0.76	0.76	0.71	*0.72*	*0.72*
Hydrocarbon Gas Liquids, Residual Fuel, Natural Gas (CO_2)	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	*0.00*	*0.00*
Jet Fuel & Aviation Gasoline (CO_2)	0.08	0.13	0.10	0.10	0.09	0.11	0.12	0.10	*0.11*	*0.11*
Non-Energy Consumption - Lubricants (CO_2)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	*0.02*	*0.02*
All Mobile (CH_4, N_2O)	0.19	0.14	0.05	0.05	0.04	0.04	0.04	0.04	*0.03*	*0.02*
Fossil Fuel Industry	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	***0.03***	***0.03***
Natural Gas Distribution	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*	*0.00*
Natural Gas Transmission	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	*0.02*	*0.02*
Industrial Processes	**0.21**	**0.56**	**0.63**	**0.59**	**0.56**	**0.57**	**0.57**	**0.57**	***0.56***	***0.59***
ODS Substitutes	0.00	0.18	0.28	0.29	0.31	0.32	0.33	0.34	*0.34*	*0.36*
Electric Utilities (SF_6)	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	*0.01*	*0.01*
Semiconductor Manufacturing (HFC, PFC & SF_6)	0.16	0.33	0.32	0.25	0.21	0.21	0.21	0.19	*0.18*	*0.20*
Limestone & Dolomite Use	0.00	0.03	0.02	0.03	0.04	0.03	0.03	0.02	*0.02*	*0.02*
Soda Ash Use	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*	*0.00*
Urea Consumption	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*	*0.00*
Waste Management	**0.26**	**0.34**	**0.24**	**0.22**	**0.20**	**0.15**	**0.14**	**0.13**	***0.14***	***0.14***
Solid Waste(CH_4, N_2O)	0.21	0.28	0.18	0.15	0.14	0.10	0.08	0.07	*0.08*	*0.08*
Wastewater	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	*0.06*	*0.06*
Agriculture	**1.23**	**1.29**	**1.25**	**1.29**	**1.31**	**1.35**	**1.38**	**1.37**	***1.37***	***1.37***
Enteric Fermentation	0.70	0.63	0.62	0.64	0.64	0.63	0.64	0.64	*0.64*	*0.64*
Manure Management	0.18	0.33	0.32	0.32	0.32	0.34	0.36	0.35	*0.35*	*0.35*
Agricultural Soils	0.35	0.32	0.30	0.32	0.33	0.33	0.33	0.33	*0.33*	*0.33*
Liming and Urea Fertilization	0.00	0.00	0.00	0.01	0.03	0.05	0.05	0.05	*0.05*	*0.05*
Gross Emissions Total	**8.64**	**9.97**	**8.81**	**8.88**	**8.98**	**9.54**	**9.10**	**8.67**	***8.64***	***8.59***

** Value Carried Forward from Previous Year*

4.2 Five- and Ten-Year Projections

Emissions in future years are very difficult to predict, and even forecasting the directionality of emissions levels by sector is problematic. Estimating GHG emissions in future years has many layers of complexity. These include factors and assumptions related to policies, changing technologies, the economy, and behavioral changes, which are all difficult, if not impossible, to accurately predict. All of these complicating factors have now been exacerbated by the ongoing pandemic and the associated economic and social implications.

Because these longer-range projections are complex and are not the main focus of this inventory, modeled projection curves for Vermont generated by the Rhodium Group through their ClimateDeck and Taking Stock reports have been used to estimate emissions totals for 2022 and 2027 (as required in 10 V.S.A. § 582) and are shown in Table 11 for all sectors except the fossil fuel industry sector.[47] The Rhodium projections are based on a "V" shaped COVID economic recovery scenario and incorporate both open source and proprietary models that are consistent with the National GHG inventory produced by EPA. Projected emissions estimates for the five- and ten-year time horizons in this inventory do not completely align with the projections made in the previous inventory report. The discrepancies between the projected emissions estimates in the two reports are due to the uncertainty inherent in the projections themselves, which in this case included assumptions around federal policies and standards as well as a major economic recession, from which the timeline and extent of recovery is still unclear. For the transportation sector estimates specifically the values in Table 11 have been impacted by the update to the methodology for the sector and the lower emissions levels observed in the calculated estimates. Projections for the fossil fuel industry sector were estimated by applying the average percent increase from 2005 because the sector categories did not match well with the Rhodium Group analysis.

Additional modeling is currently underway to project GHG emissions in Vermont for future years to inform the development of the Comprehensive Energy Plan (CEP). A contractor is running the Low Emissions Analysis Platform (LEAP) model to determine business-as-usual (BAU) emissions estimates for Vermont by sector[48]. The projected emissions values produced with the LEAP model will likely be different than those estimated using the Rhodium Group modeling projection curves due to differences in model calculation methodologies, incorporated datasets, and assumptions between the two modeling platforms.

[47] Rhodium Group – Climate Deck information: https://rhg.com/data_story/climate-deck/
Rhodium Group – Taking Stock report: https://rhg.com/wp-content/uploads/2020/07/Taking-Stock-2020-The-COVID-19-Edition.pdf

[48] SEI LEAP model: https://www.sei.org/projects-and-tools/tools/leap-long-range-energy-alternatives-planning-system/

Table 11: Five- and Ten-Year GHG emissions projections.

Inventory Sector	(MMTCO2e) 2022	(MMTCO2e) 2027
Transportation/Mobile	3.25	3.36
Residential/Commercial/Industrail (RCI) Fuel Use	2.62	2.51
Agriculture	1.30	1.30
Industrial Processes	0.61	0.64
Electricity	0.08	0.07
Waste	0.13	0.13
Fossil Fuel Industry	0.03	0.04
Total	**8.02**	**8.04**

5. Conclusion

Emissions of greenhouse gases in Vermont declined from 9.10 MMTCO_2e in 2016 to 8.67 MMTCO_2e in 2017. This 0.44 MMTCO_2e reduction was largely attributable to declining emissions in the transportation sector (0.1 MMTCO_2e) and the electricity sector (0.32 MMTCO_2e). Emissions have declined 0.87 MMTCO_2e from 2015 to 2017. Approximately 57% of the observed reductions are due to declines seen in emissions from the electricity sector which, as of 2018, accounts for only a small fraction of emissions in the inventory. It should also be noted that the reductions from the electricity sector are linked to the RES and the purchases of additional RECs to meet RES targets. The other main factor contributing to the steep decrease in emissions from 2015 to 2017 is the RCI sector, which is potentially related to the annual variability due to heating demand fluctuations with ambient temperature changes rather than sustained reductions from mitigation measures.

The update in methodology for the transportation sector has implications on historical emissions estimates and meeting mandatory reduction targets specified in 10 V.S.A. § 578. Historic emissions totals were modified using the updated methodology and fuel sales data back to 1990, which has made the sector more consistent and comparable through time as compared to the previous NEI VMT based methodology, which was only available on a triennial period and did not reach back to the 1990 baseline. This update to the transportation sector methodology lowers GHG levels for the sector, putting the totals for 2017 only 0.3% above the 1990 baseline, as well as lowering the 2005 baseline level by 0.4 MMTCO_2e. This instantaneous "progress" toward the mandated levels from this methodology change should not be mistaken for steady progress reducing emissions over time from mitigation efforts. Although the updated data for the transportation sector does show some emissions reductions from that sector in the last few years, more rapid and sustained reductions will be required to reach any sector specific or overall required reductions.

Based on the updated historical values and 2017 estimates, Vermont would need average annual reductions of 0.16 MMTCO_2e to reach the 10 V.S.A. § 578 target of being 26% below 2005 levels by 2025 and would need reductions of 0.27 MMTCO_2e per year to hit the 2030 mandatory level of 40% below the 1990 baseline. Reaching the 2050 reduction of 80% below 1990 levels would require average annual reductions of 0.21 $MMTCO_2e$.

The annual snapshot of gross GHG emissions totals provided by this inventory are an important metric for tracking emissions levels through time. It is a tool to help inform where to focus mitigation strategies and to understand how those strategies are impacting emissions of GHGs in the state. Emissions totals in this inventory are not, however, the only way to present or estimate GHG emissions associated with the state. The inventory methodologies follow accepted guidelines and protocols that make it comparable with other jurisdictions which is important for consistency in a regional and global context, but it does not include emissions that are occurring outside of the state boundaries (with the exception of the electricity sector) that are associated with activities or choices made by Vermonters, which are also important to understand and consider for decisions regarding mitigation actions and policy decisions.

Appendix A – Vermont Historic Greenhouse Gas Emissions by Sector[49,50]

Sector	Million Metric Tons CO_2 Equivalent: $MMTCO_2e$																			
	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Electricity Supply & Demand (consumption based)	**1.09**	**0.77**	**0.43**	**0.52**	**0.55**	**0.64**	**0.76**	**0.64**	**0.54**	**0.35**	**0.34**	**0.39**	**0.43**	**0.43**	**0.93**	**0.81**	**0.84**	**1.00**	**0.81**	**0.49**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.05	0.00	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.02	0.00	0.01
Oil	0.01	0.01	0.06	0.03	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.01	0.01	0.02	0.01	0.00	0.00
Wood (CH_4 & N_2O)	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
Residual System Mix	1.03	0.75	0.35	0.47	0.51	0.59	0.71	0.62	0.51	0.31	0.29	0.34	0.36	0.37	0.90	0.78	0.81	0.96	0.79	0.47
Residential / Commercial / Industrial (RCI) Fuel Use	**2.52**	**2.50**	**3.01**	**2.93**	**2.76**	**2.96**	**3.29**	**3.04**	**2.87**	**2.77**	**2.52**	**2.72**	**2.53**	**2.56**	**2.30**	**2.53**	**2.72**	**2.92**	**2.69**	**2.69**
Coal	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.32	0.38	0.50	0.42	0.44	0.44	0.46	0.44	0.42	0.47	0.46	0.45	0.44	0.45	0.43	0.51	0.57	0.64	0.65	0.65
Oil, Propane & Other Petroleum	2.12	2.05	2.44	2.45	2.25	2.44	2.77	2.52	2.37	2.23	1.98	2.18	2.01	2.03	1.78	1.93	2.06	2.19	1.95	1.94
Wood (CH_4 & N_2O)	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10
Transportation	**3.32**	**3.93**	**3.84**	**4.02**	**3.98**	**4.07**	**4.13**	**4.09**	**4.03**	**3.96**	**3.64**	**3.70**	**3.60**	**3.55**	**3.46**	**3.42**	**3.33**	**3.52**	**3.49**	**3.39**
Motor Gasoline (Onroad and Nonroad) (CO_2)	2.57	2.77	3.01	3.00	3.07	3.17	3.17	3.14	3.02	3.02	2.79	2.73	2.69	2.65	2.58	2.56	2.49	2.58	2.54	2.52
Diesel (Onroad and Nonroad) (CO_2)	0.45	0.85	0.54	0.73	0.65	0.67	0.64	0.65	0.70	0.68	0.62	0.66	0.73	0.72	0.70	0.70	0.69	0.76	0.76	0.71
Hydrocarbon Gas Liquids, Residual Fuel, Natural Gas (CO_2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Jet Fuel & Aviation Gasoline (CO_2)	0.08	0.06	0.07	0.06	0.03	0.03	0.13	0.13	0.16	0.14	0.11	0.21	0.09	0.10	0.10	0.10	0.09	0.11	0.12	0.10
Non-Energy Consumption - Lubricants (CO_2)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
All Mobile (CH_4, N_2O)	0.19	0.22	0.20	0.22	0.20	0.18	0.16	0.14	0.13	0.11	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.04	0.04
Fossil Fuel Industry	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**
Natural Gas Distribution	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas Transmission	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Industrial Processes	**0.21**	**0.42**	**0.60**	**0.52**	**0.55**	**0.55**	**0.57**	**0.56**	**0.61**	**0.61**	**0.62**	**0.55**	**0.67**	**0.66**	**0.63**	**0.59**	**0.56**	**0.57**	**0.57**	**0.56**
ODS Substitutes	0.00	0.07	0.18	0.19	0.18	0.18	0.18	0.18	0.20	0.21	0.22	0.23	0.25	0.26	0.28	0.29	0.31	0.32	0.33	0.34
Electric Utilities (SF_6)	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Semiconductor Manufacturing (HFCs, PFCs & SF_6)[15]	0.16	0.28	0.37	0.29	0.32	0.33	0.33	0.33	0.39	0.38	0.37	0.29	0.39	0.36	0.32	0.25	0.21	0.21	0.21	0.19
Limestone & Dolomite Use	0.00	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.03	0.03	0.02
Soda Ash Use	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urea Consumption	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste Management	**0.26**	**0.32**	**0.35**	**0.35**	**0.34**	**0.34**	**0.34**	**0.34**	**0.34**	**0.34**	**0.34**	**0.27**	**0.28**	**0.29**	**0.24**	**0.22**	**0.20**	**0.15**	**0.14**	**0.13**
Solid Waste	0.21	0.27	0.30	0.29	0.29	0.28	0.28	0.28	0.28	0.27	0.27	0.21	0.21	0.23	0.18	0.15	0.14	0.10	0.08	0.07
Wastewater	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Agriculture	**1.23**	**1.19**	**1.30**	**1.32**	**1.30**	**1.32**	**1.29**	**1.29**	**1.28**	**1.38**	**1.29**	**1.29**	**1.26**	**1.28**	**1.25**	**1.29**	**1.31**	**1.35**	**1.38**	**1.37**
Enteric Fermentation	0.70	0.67	0.69	0.68	0.67	0.66	0.65	0.63	0.63	0.64	0.64	0.64	0.62	0.63	0.62	0.64	0.64	0.63	0.64	0.64
Manure Management	0.18	0.19	0.26	0.29	0.30	0.32	0.31	0.33	0.32	0.33	0.34	0.33	0.33	0.33	0.32	0.32	0.32	0.34	0.36	0.35
Agricultural Soils	0.35	0.34	0.34	0.34	0.32	0.33	0.33	0.32	0.32	0.31	0.30	0.32	0.31	0.31	0.30	0.32	0.33	0.33	0.33	0.33
Liming and Urea Fertilization	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.01	0.01	0.00	0.00	0.01	0.03	0.05	0.05	0.05
TOTAL GROSS EMISSIONS	**8.64**	**9.15**	**9.54**	**9.69**	**9.49**	**9.89**	**10.39**	**9.97**	**9.68**	**9.43**	**8.75**	**8.94**	**8.79**	**8.79**	**8.81**	**8.88**	**8.98**	**9.54**	**9.10**	**8.67**
Change relative to 1990 (baseline)	**—**	**+ 6%**	**+ 10%**	**+ 12%**	**+ 10%**	**+ 14%**	**+ 20%**	**+ 15%**	**+ 12%**	**+ 9%**	**+ 1%**	**+ 3%**	**+ 2%**	**+ 2%**	**+ 2%**	**+ 3%**	**+ 4%**	**+ 10%**	**+ 5%**	**+ 0%**
Change relative to 2005 (baseline)	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**-3%**	**-5%**	**-12%**	**-10%**	**-12%**	**-12%**	**-12%**	**-11%**	**-10%**	**-4%**	**-9%**	**-13%**

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

[50] Semiconductor data from 2011 – 2016 are from the EPA FLIGHT Tool, projected back to 1990 based on trends from the National U.S GHG Inventory and EPA SIT module values.