VERMONT

Agency of Natural Resources

Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990 – 2020

April 2023

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Note to Readers

The format for the Greenhouse Gas Emissions Inventory and Forecast report has been updated in this release to make the document more accessible for public consumption, as well as to incorporate certain sensitivity analyses and other recommendations of the Vermont Climate Council (VCC) and Subcommittees, in line with the Global Warming Solutions Act. This report estimates greenhouse gas (GHG) emissions levels by sector, and includes important considerations related to emission estimates. Any significant methodology changes made since the previous inventory report are also discussed in this document. A separate methodology document - *Vermont Greenhouse Gas Emissions Inventory and Forecast – Methodologies* - is available and discusses the specific sector by sector methodologies and datasets utilized in greater depth. The *Methodologies* document will be updated with each inventory release as necessary when improvements to methods or datasets occur.

For additional information and resources on climate action in Vermont from adaptation and resilience to mitigation pathways and strategies, please visit our website: https://climatechange.vermont.gov/.

Executive Summary

The concentration of greenhouse gases (GHG) in the earth's atmosphere continue to increase due to anthropogenic emissions from different sectors and processes. Greenhouse gases absorb solar radiation and trap heat energy in the atmosphere which warms the planet. Global warming is already having impacts here in the Northeastern U.S. and around the globe[1], including impacts to communities and natural ecosystems, many of which are already marginalized or disproportionately impacted. 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 reducing emissions that contribute to global warming. The goal of this inventory is to provide an understanding of emissions sources in Vermont in a way that enables the tracking of emissions levels through time and to help inform decisions on future mitigation strategies and pathways that is consistent with other jurisdictions.

The Vermont Greenhouse Gas Emissions Inventory and Forecast reports are required pursuant to Vermont statute 10 V.S.A. § 582[2]. The Inventory quantifies historic 1990 and 2005 baseline GHG levels and tracks changes in emissions through time to determine progress toward the state's GHG reduction requirements in 10 V.S.A. § 578[3], which were updated with the passage of the Global Warming Solutions Act (GWSA)), (Act 153) in 2020.[4] The emissions reduction requirements of the GWSA are 26% below 2005 levels by 2025, 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050.

The methodology and data used to inform this inventory can be understood in detail in the *Vermont Greenhouse Gas Emissions Inventory and Forecast – Methodologies* companion document. This report provides emissions estimates, as well as general information and emissions trends for each sector. Updates to calculation methodologies and data that have been used to generate emissions estimates in the inventory are briefly described in the sections below and are discussed in greater detail in the Methodology document.

The official emissions totals in this inventory report are measured on a gross basis, meaning they do not account for any sequestration of CO_2 from the atmosphere. Supplemental information estimating sequestration totals from the Land-use, Land Use Change, and Forestry (LULUCF) sector are also included in this report, as well as estimates of biogenic CO_2 emissions from wood combustion in several sectors. For further discussion on the accounting of biogenic CO_2 and the LULUCF sector please refer to the Methodology document.

This inventory includes official estimates for three years (2018, 2019, and 2020) to provide as up-to-date data as possible. Overall emissions declined from 2017 through 2020 as shown in Figure 1, with variability within each sector. Estimates from 2020 are likely an outlier due to the

[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
[3] Vermont Statute 10 V.S.A. § 578: https://legislature.vermont.gov/statutes/section/10/023/00578
[4] Vermont Legislature - Global Warming Solutions Act (Act 153): https://legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT153/ACT153%20As%20Enacted.pdf

impacts of the COVID-19 pandemic, which had a substantial impact on the transportation/mobile sources sector, reducing emissions by approximately 15% from 2019 to 2020. Electricity sector emissions from the previous report have been adjusted upward for the years 2016 through 2019 due to a calculation error in the previous report which is explained in Sector 2.1.5. Total emissions in 2020 were 7.99 million metric tons of CO_2 equivalent ($MMTCO_2e$). Transportation/mobile sources sector totals are expected to rebound to some degree based on the rebound in both VMT and Fuel sales in 2021, but the extent of that rebound is unclear.

This report also provides 5 and 10 year emissions projections for 2025 and 2030. The 5 and 10 year emissions estimates projections are 8.55 $MMTCO_2e$ for 2025 and 7.32 $MMTCO_2e$ in 2030 and were calculated using the business as usual percent changes by sector from GHG mitigation pathway modeling values completed for the Vermont Climate Action Plan. Estimating future emissions levels depends on a multitude of factors that are difficult to predict and has been further complicated by the impact on the economy and social behaviors stemming from the COVID-19 pandemic.

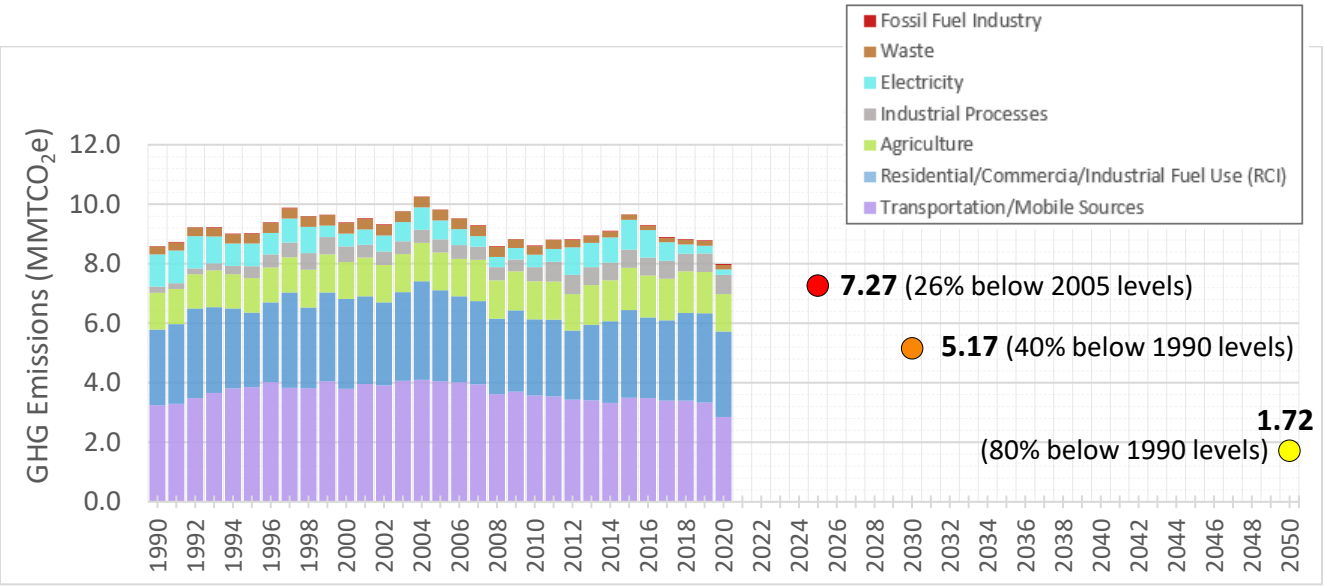

Figure 1: Vermont statewide greenhouse gas emissions levels and mandated reduction targets as defined in 10 V.S.A. § 578.

1. Introduction

The *Vermont Greenhouse Gas Emissions Inventory and Forecast* (Inventory) provides estimates of the amount of human caused (anthropogenic) greenhouse gas emissions produced within the state of Vermont in units of million metric tons of carbon dioxide (CO_2) equivalent ($MMTCO_2e$). The 100-year Global warming potential (GWP) values are used from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) per IPCC inventory guidelines, but additional estimates using the AR5 GWP values are included for select years as Appendix B of this report. Estimates of emissions using the AR4 20-year GWP values are available the select years in the companion Methodology document. The Inventory estimates and tracks the levels of greenhouse gas emissions for the state as accurately and consistently as possible through time and are generated using methods and datasets discussed in the *Vermont Greenhouse Gas Emissions Inventory and Forecast – Methodologies* companion document. This report includes estimates for the years 1990 – 2020 and supersedes estimates included in previous reports. Including the most current data is important to help understand our progress towards required emissions reductions levels. Data is currently available to span three years (2018, 2019, and 2020) and so this iteration of the Inventory covers the years 1990 – 2020.

1.1 Vermont and the U.S. GHG Comparisons

In comparing the sectoral contributions from Vermont to the U.S. as a whole, there are some significant differences to note. Vermont has a higher percentage of emissions from transportation, thermal use in buildings (RCI), and agriculture than the country as a whole, which is likely due to the rural nature of the state and the disproportionate use of heating fuel during the winter months. It also has a much lower percentage of emissions from electricity generation (Figure 2 and Figure 3) due to the large amounts of low or no carbon electricity in the state's portfolio.

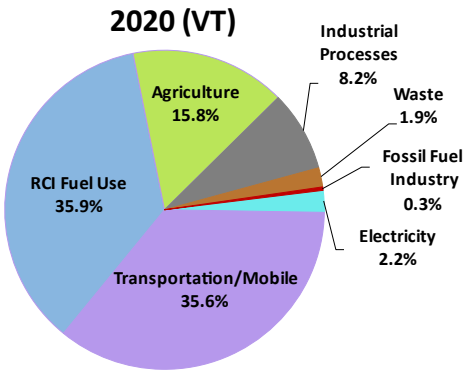

Figure 2: Vermont GHG percent contributions by sector.

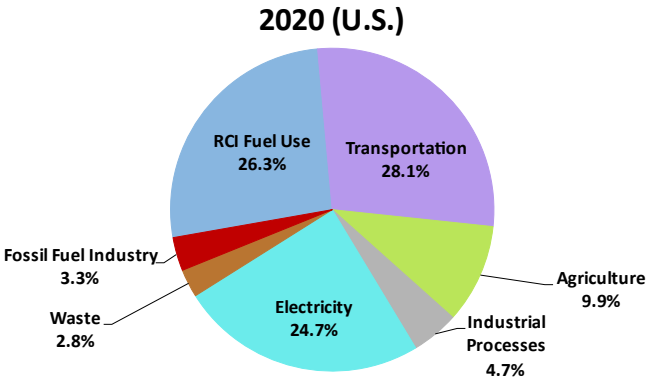

Figure 3: U.S. GHG percent contributions by sector. Data for the U.S. contributions by sector has been reallocated to match the Vermont sector categories in this report.

2 Vermont GHG Emissions by Sector

2.1 Overview

Tracking greenhouse gas emissions by sector helps us to understand each sector's share of emissions, and how those emissions levels are changing over time. This information is important for prioritizing and informing policy decision-making related to each sector and subsectors. The sectors in this report include transportation/mobile sources, residential/commercial/industrial (RCI) fuel use, agriculture, industrial processes, electricity consumption, waste, and the fossil fuel industry. The land-use, land use change, and forestry (LULUCF) sector is also included, but is not incorporated into the overall gross totals. Figure 4 below shows the estimates of GHG emissions by sector back to the 1990 baseline. Additional detail on each sector can be found in the subsections below with more information on the calculation methodologies and data sources located in the accompanying Methodology document.

Emissions of biogenic carbon dioxide, which are produced from the burning, breaking down, or processing of biologically-based material, are not included in the overall gross totals in the inventory based on IPCC inventory guidelines[5]. Those emissions are instead captured in the LULUCF sector through changes in land use and the amount of stored carbon on the landscape (carbon stocks and fluxes). Estimates of emissions of biogenic CO_2 have been included as additional information by sector where applicable and where the data exist. A detailed explanation of the accounting decisions and calculations for biogenic emissions in Vermont is included in the Methodology document.

[5] IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

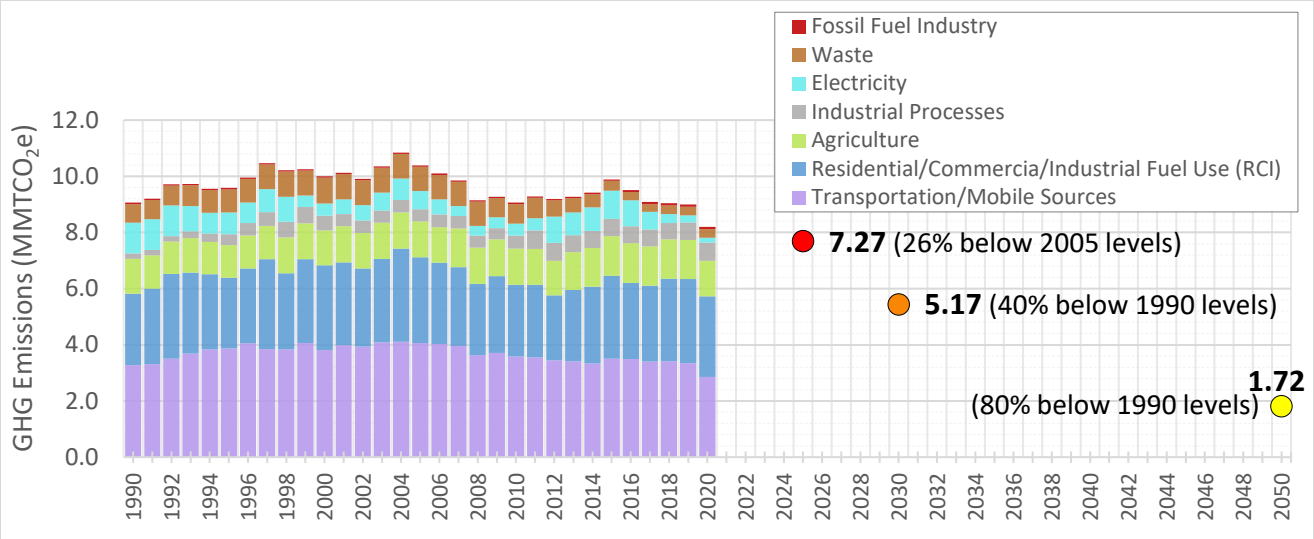

Figure 4: Total and sector-specific GHG emissions in Vermont, 1990-2020 with targets.

2.1.1 Transportation/Mobile Sources

The transportation and mobile sources sector estimates emissions of greenhouse gases related to the movement of people and goods through and around Vermont. The totals include emissions from the combustion of fuels used in cars and trucks on Vermont roads, the use of aviation gasoline and jet fuel for aircraft, and emissions from certain other non-road equipment like recreational vehicles, lawn equipment, boats, and rail (Table 1). The use of gasoline and diesel by vehicles on the roads of Vermont is the largest source of emissions in the sector (Table 2), with light duty gasoline vehicles being the largest source category within the onroad vehicle fleet (Table 3).

The transportation and mobile sources sector has consistently been the highest emitting sector in Vermont, but due to a significant decrease in 2020, emissions from the sector were lower than those from the residential, commercial and industrial fuel use sector. Reductions in transportation sector emissions in 2020 (Figure 5) were due to the COVID-19 pandemic and the resulting reductions in vehicle miles traveled (VMT) and sales of gasoline in the state. Statewide VMT (Figure 6) and sales of gasoline (Figure 7) both rebounded somewhat in 2021, but totals were still below pre-pandemic levels. Emissions levels in this sector depend on a number of complex factors including travel behaviors, fuel prices, vehicle consumer choices, vehicle fuel efficiency standards, and electrification policies and initiatives. These factors are difficult to predict and, in the case of travel behaviors, are likely to be permanently impacted by changes in behavior related to the COVID-19 pandemic.

Table 1: Mobile source contributions by fuel type.

Sector	Emissions in $MMTCO_2e$					
	1990	2005	2017	2018	2019	2020
Transportation/Mobile Sources (MMTCO2e)	**3.25**	**4.05**	**3.40**	**3.40**	**3.34**	**2.85**
Motor Gasoline (Onroad and Nonroad) (CO_2)	2.57	3.14	2.50	2.52	2.50	2.09
Diesel (Onroad and Nonroad) (CO_2)	0.45	0.65	0.76	0.75	0.71	0.65
Jet Fuel & Aviation Gasoline (CO_2)	0.08	0.13	0.06	0.07	0.07	0.06
Other sources (CO_2, CH_4, N_2O)	0.15	0.13	0.07	0.06	0.06	0.05
Ethanol (biogenic CO_2)*	0.00	0.01	0.17	0.16	0.17	0.14
Biodiesel (biogenic CO_2)*	0.00	0.00	0.05	0.03	0.02	0.02

** biogenic totals not included in gross total estimates*

Table 2: Percent contribution to transportation emissions from onroad and nonroad sources (2017 NEI)[6].

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

Table 3: Percent contribution to transportation emissions by vehicle type (2017 NEI)[9].

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%

[6] 2017 National Emissions Inventory (NEI) Data: https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data#dataq

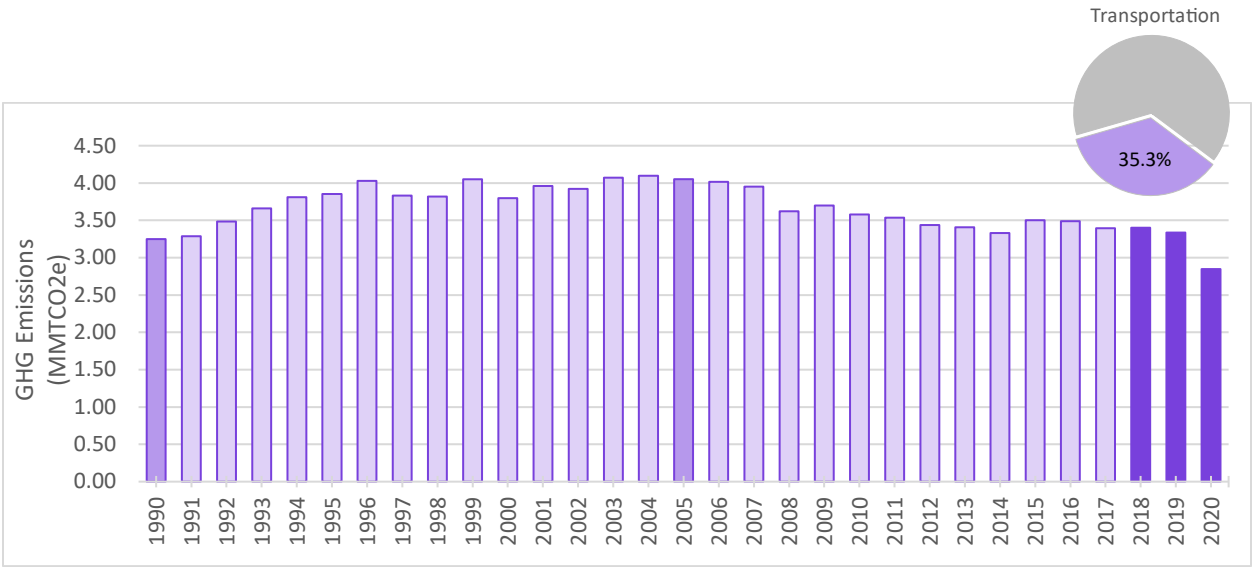

Figure 5: Vermont GHG emissions from transportation/mobile sources sector. Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in dark purple.

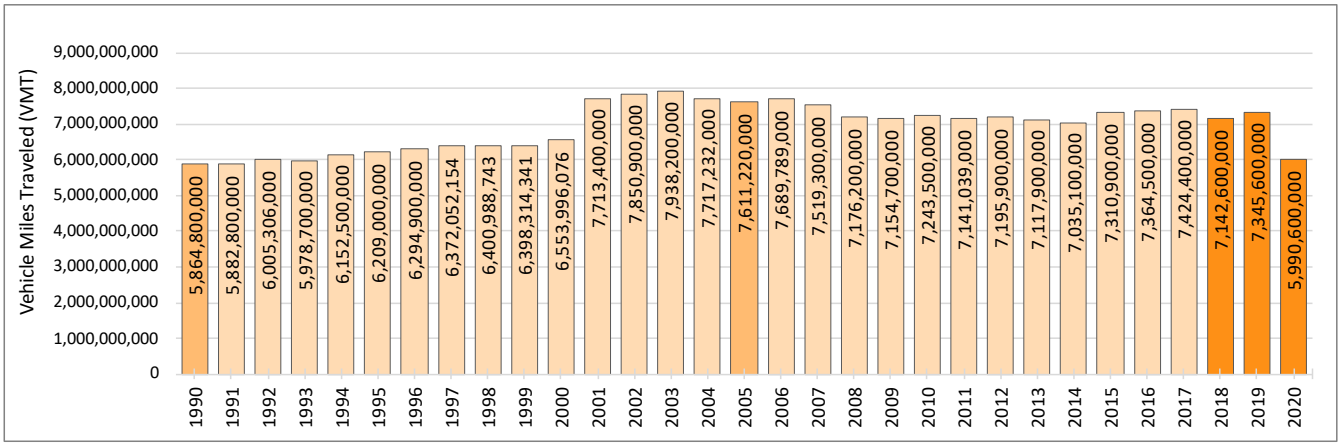

Figure 6: Vehicle miles traveled in Vermont by year (Source: VTrans). Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in darker orange.

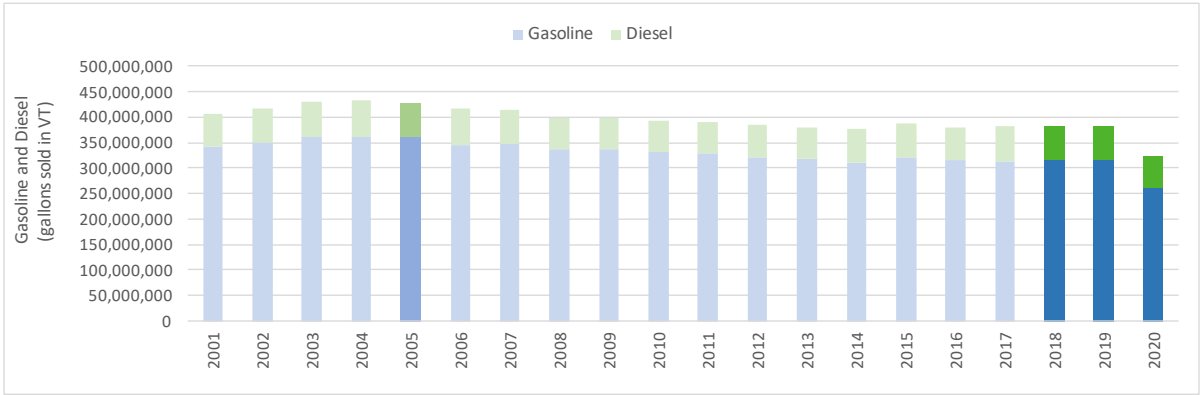

Figure 7: Gallons of gasoline and diesel sold in Vermont by year (Source: Joint Fiscal Office). Years from 2001-2020 are included with the 2005 baseline year highlighted and the updated 2018-2020 values shown in darker blue and green.

2.1.2 Residential/Commercial/Industrial (RCI) Fuel Use

The majority of greenhouse gas emissions from the Residential/Commercial and Industrial Fuel Use sector are related to the use of fossil fuels for space heating, water heating, and cooking, in residential, commercial, and industrial buildings. Emissions are mostly CO_2 from the use of fuel oil, propane, and natural gas but do include methane (CH_4) and nitrous oxide (N_2O) from burning fossil fuels and wood (Table 4). The industrial portion of the RCI sector also includes diesel fuel used in several non-road categories such as farm use, off-highway construction, and logging operations. Due to the decrease in emissions in the transportation sector in 2020, the RCI sector was the highest emitting sector in the state in 2020, barely surpassing the transportation sector total (Figure 2).

The residential subsector is responsible for the greatest share of emissions of the RCI sector at nearly 53% in 2020, followed by the commercial subsector at 30.8% and the industrial subsector at 16.7% (Table 5). The use of fuel oil in the residential subsector is the highest emitting source within the sector overall, followed by residential propane and the use of natural gas in the commercial subsector (Table 5). Overall emissions from the sector increased by 2% from 2018 to 2019 and then decreased by 4.4% between 2019 and 2020. The fluctuation of emissions levels (Figure 8) are caused mainly by winter heating season demand as well as fuel prices, but can also be impacted by weatherization initiatives, fuel switching, and increased efficiency of appliances. RCI sector emissions totals have been plotted with heating degree days in Figure 9, as an indicator of average winter temperatures, to illustrate the relationship between GHG emissions in the RCI sector and winter temperature fluctuations.

Table 4: GHG emissions from the RCI sector by subsector and fuel type.

Sector	Emissions in $MMTCO_2e$					
	1990	2005	2017	2018	2019	2020
Residential/ Commercial/ Industrial (RCI) Fuel Use	**2.54**	**3.06**	**2.70**	**2.94**	**3.00**	**2.87**
Residential - Oil, Propane, Natural Gas, and other	1.41	1.66	1.39	1.48	1.56	1.42
Residential - Wood (CH_4, N_2O)	0.06	0.07	0.09	0.09	0.09	0.08
Commercial - Oil, Propane, Natural Gas, and other	0.57	0.72	0.78	0.92	0.89	0.88
Commercial - Wood (CH_4, N_2O)	0.00	0.00	0.00	0.00	0.00	0.00
Industrial - Oil, Propane, Natural Gas and Other	0.47	0.60	0.44	0.44	0.45	0.48
Industrial - Wood (CH_4, N_2O)	0.00	0.00	0.00	0.00	0.00	0.00
Residential - Wood (biogenic CO_2)*	0.83	0.95	1.28	1.30	1.30	1.16
Commercial - Wood (biogenic CO_2)*	0.03	0.01	0.04	0.04	0.04	0.02
Industrial - Wood (biogenic CO_2)*	0.29	0.27	0.16	0.17	0.17	0.13
Renewable Natural Gas (RNG)*	0.000	0.000	0.000	0.000	0.001	0.002

** biogenic totals not included in gross total estimates*

As discussed previously, biogenic emissions are not included in the gross emissions totals in this inventory. The biogenic CO_2 values from the burning of wood (listed in Table 4) are included here for informational purposes only, and the methodology used for calculating these totals, as well as the IPCC guidance related to biogenic emissions, is discussed in the Methodology document.

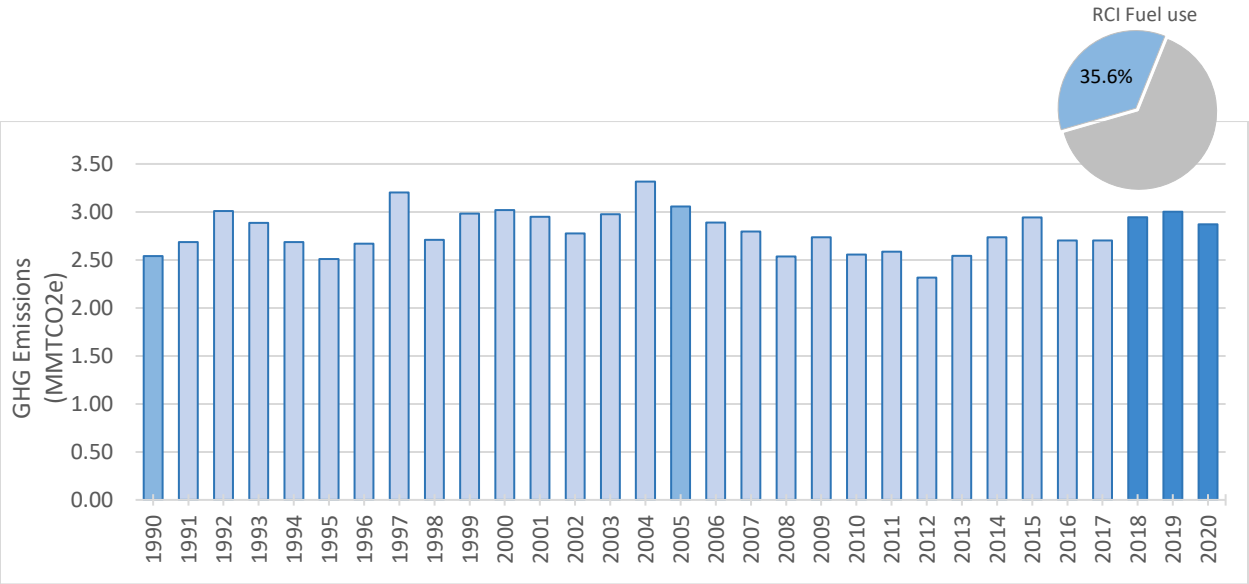

Figure 8: Vermont GHG emissions from the RCI sector. Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in dark blue.

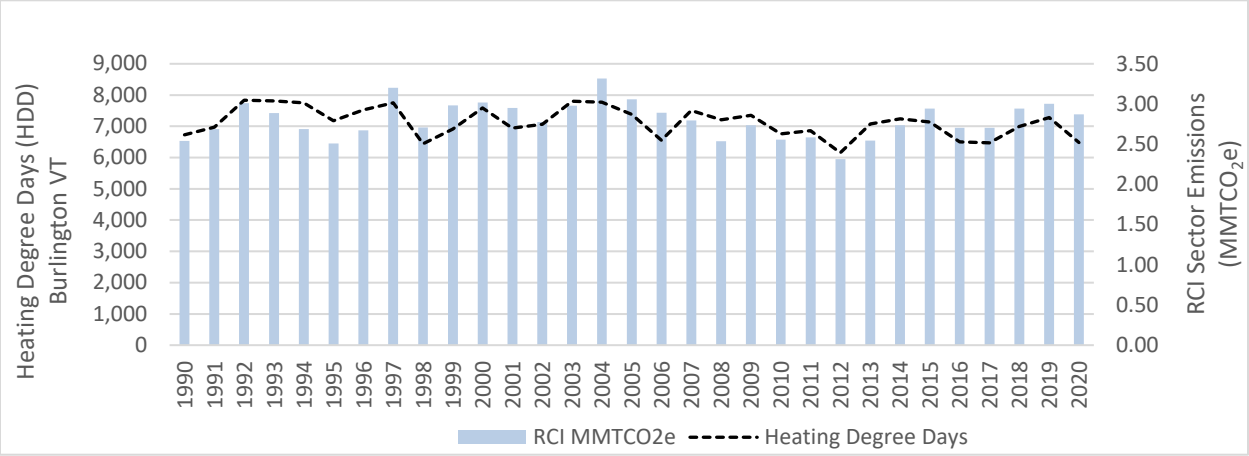

Figure 9: Vermont RCI sector emissions in $MMTCO_2e$ plotted with the heating degree days (the difference between 65 degrees and a day's average temperature if below 65 degrees) from 1990 – 2020.

Table 5: GHG emissions contributions by fuel type and subsector within the RCI sector (2020).

RCI Breakdown by Subsector and by Fuel (2020)	Subsector	Emissions ($MMTCO_2e$)	Percent of Subsector Total	Percent of Total by Subsector
Fuel Oil	Residential	0.80	53.2%	52.5%
Propane	Residential	0.38	25.4%	
Natural Gas	Residential	0.21	13.8%	
Wood ($CH_4 + N_2O$)	Residential	0.08	5.6%	
Other	Residential	0.03	2.0%	
Total	**Residential**	**1.51**	**100%**	
Fuel Oil	Commercial	0.23	25.4%	30.8%
Propane	Commercial	0.22	24.9%	
Natural Gas	Commercial	0.38	43.2%	
Wood ($CH_4 + N_2O$)	Commercial	0.00	0.2%	
Other	Commercial	0.06	6.3%	
Total	**Commercial**	**0.89**	**100%**	
Fuel Oil	Industrial	0.30	62.0%	16.7%
Propane	Industrial	0.01	2.2%	
Natural Gas	Industrial	0.12	24.3%	
Wood ($CH_4 + N_2O$)	Industrial	0.00	0.4%	
Other	Industrial	0.05	11.1%	
Total	**Industrial**	**0.48**	**100%**	
Grand Total	**All**	**2.87**		**100.0%**

2.1.3 Agriculture

The agriculture sector includes estimates of the emissions of CH_4 and N_2O from agricultural practices and activities in Vermont. These include emissions related to the digestive processes of animals, manure management, fertilizer application, and processes related to agricultural soils. Carbon dioxide emissions from this sector are almost entirely biogenic, and so are not included in the sector totals, with the exception of liming and urea fertilization (Table 6). Total emissions from the sector have remained relatively constant in the last several years (Figure 10), declining by about 1% from 2018 to 2019 and with a slightly larger decline of around 9% in 2020. This trend is likely due to decreases in emissions from fertilizer, and a slightly lower number of dairy cows.

Agricultural emissions totals in the Inventory do not account for any sequestration (removal of CO_2 from the atmosphere) by vegetation, storage in agricultural soils, or any emissions benefits from agricultural management practices such as no till or cover cropping. Many Vermont farmers are already working to reduce emissions from their farms by adopting agricultural conservation practices to reduce tillage and fertilizer use and these practices have benefits for both GHG emissions and water quality. As recommended by the Vermont Climate Council, ANR is currently working with the Agency of Agriculture Food and Markets (AAFM) through a

consultant process to investigate the availability of tools and datasets that will allow for more accurate accounting and a more holistic picture of greenhouse gas emissions and sinks associated with the agricultural sector in Vermont. Additional information related to data and emissions from the agricultural sector in the state can be found in the Vermont Carbon Budget report[7] that was completed as a part of the GWSA and Climate Action Plan process.

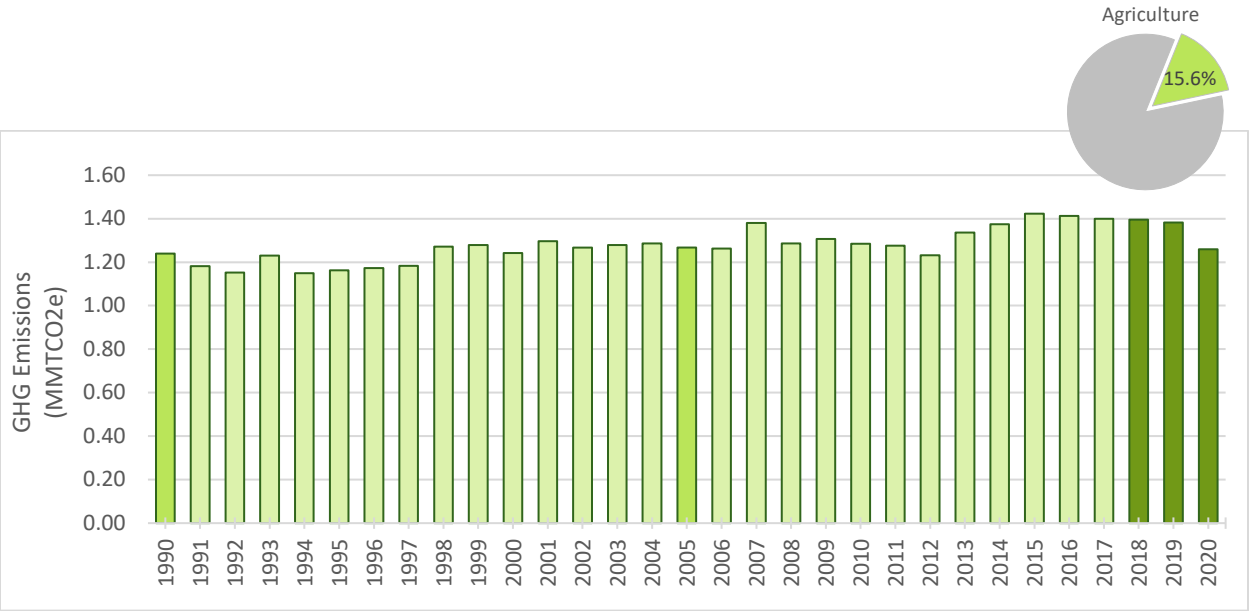

Figure 10: Vermont GHG emissions from the agriculture sector. Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in dark green.

Table 6: GHG emissions contributions of subsectors within the agriculture sector.

Sector	Emissions in $MMTCO_2e$					
	1990	2005	2017	2018	2019	2020
Agriculture	**1.24**	**1.27**	**1.40**	**1.40**	**1.38**	**1.26**
Enteric Fermentation (CH_4, N_2O)	*0.70*	*0.63*	*0.64*	*0.64*	*0.63*	*0.61*
Manure Management (CH_4, N_2O)	*0.18*	*0.33*	*0.35*	*0.36*	*0.35*	*0.33*
Agricultural Soils (CH_4, N_2O)	*0.36*	*0.30*	*0.35*	*0.36*	*0.37*	*0.29*
Liming and Urea Fertilization (CO_2)	*0.00*	*0.00*	*0.05*	*0.04*	*0.04*	*0.03*

[7] Vermont Carbon Budget Report: https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/Carbon%20Budget%20for%20Vermont%20Sept%202021.pdf

2.1.4 Industrial Processes

The Industrial Processes (IP) sector includes GHG emissions related to industrial manufacturing processes occurring in Vermont, as well as the use of high GWP gases in a number of applications. Many of the high emitting manufacturing categories generally covered in the IP sector of GHG inventories, such as the production of chemicals and materials like lime, ammonia, nitric acid, cement, iron, and steel, are not occurring in Vermont. The state does not have many large manufacturing facilities, which is evidenced by the fact that there are less than a dozen facilities in the state that report to EPA's Greenhouse Gas Reporting Program[8], which has a reporting threshold of 25,000 metric ton CO_2e. There are emissions of sulfur hexafluoride (SF_6) associated with the electric transmission system in Vermont, which have the potential to increase with additional electrification initiatives, however, emissions of high GWP fluorinated gases from ozone depleting substances (ODS) substitutes, and the manufacturing of semiconductors dominate emissions from the sector making up around 94% of the total (Table 7). Emissions estimates from the IP sector have remained fairly flat from 2018 to 2020, with a small increase in emissions from semiconductor manufacturing (Figure 11).

Ozone depleting substances substitutes are gases that are being used to replace gases that deplete the ozone layer. A number of these gases, mainly hydrofluorocarbons (HFCs), are very potent planet warming gases with high GWPs and their use and leakage into the atmosphere is a driver of global warming. These gases are used in refrigeration equipment, air conditioning equipment, aerosol propellants, and foams. The phase out and replacement of these substances with lower GWP alternatives is underway in Vermont through the passage of Act 65 (2019)[9] and Act 121 (2022)[10], which prohibits the use of high-GWP HFCs in certain end uses.

The manufacturing of semiconductors is a complex process that requires the use of very high GWP gases including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). These gases are used in the plasma etching and chemical vapor deposition process, as well as in heat transfer fluids. Emissions can be mitigated by adding destruction devices to combust some of the high GWP gases before they are released to the atmosphere, and by finding alternatives for the gases used in the processes themselves.

[8] EPA Greenhouse Gas Reporting Program: https://www.epa.gov/ghgreporting/learn-about-greenhouse-gas-reporting-program-ghgrp
[9] Vermont Act 65: https://legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT065/ACT065%20As%20Enacted.pdf
[10] Vermont Act 121: https://legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT065/ACT065%20As%20Enacted.pdf

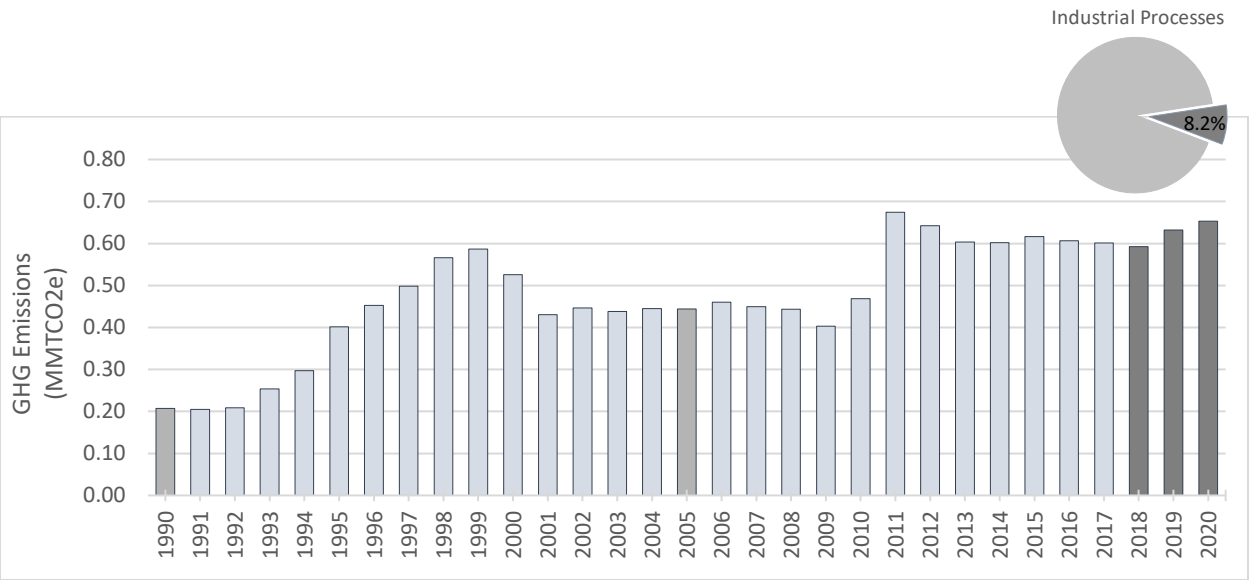

Figure 11: Vermont GHG emissions from the industrial processes sector. Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in dark grey.

Table 7: GHG emissions contributions of subsectors with the industrial process sector.

Sector	Emissions in $MMTCO_2e$					
	1990	2005	2017	2018	2019	2020
Industrial Processes	**0.21**	**0.44**	**0.60**	**0.59**	**0.63**	**0.65**
ODS Substitutes (HFCs, PFCs, NF_3 SF_6)	0.00	0.18	0.34	0.34	0.36	0.37
Electric Utilities (SF_6)	0.04	0.01	0.01	0.01	0.01	0.01
Semiconductor Manufacturing (HFCs, PFCs, NF_3 SF_6)	0.16	0.21	0.23	0.22	0.23	0.24
Limestone & Dolomite Use (CO_2)	0.00	0.03	0.02	0.02	0.03	0.03
Soda Ash Use (CO_2)	0.01	0.01	0.00	0.00	0.00	0.00
Urea Consumption (CO_2)	0.00	0.00	0.00	0.00	0.00	0.00

2.1.5 Electricity Consumption

The electricity sector includes emissions associated with all electricity used by Vermonters and is the only sector in the inventory where emissions that occur outside of the boundaries of the state are accounted for. This is because in Vermont we consume more than three times as much electricity as we generate in state[11] and also makes sense from the perspective of the interconnected nature of the New England electric grid. Emissions estimates are still only for emissions that occur at the point of generation and do not include estimates of any emissions that occur "upstream" of the sources themselves. Sources of electricity that are considered renewable have been assumed to have zero emissions within this accounting framework. Additional

[11] Energy Information Administration (EIA) – State Profile and Energy Estimates: https://www.eia.gov/state/?sid=VT

information on the methodologies for estimating emissions in the electric sector can be found in the Methodology document.

Electricity sector emissions reported previously from 2016 through 2019 have been updated in this report. Totals for those years were estimated artificially lower because the data utilized for the calculations was based on customer retail sales instead of total generation and load, and so did not include emissions from the electricity that was lost during transmission to customers. The correction of this error and the associated update increases the electricity sector totals for those years, as can be seen in Table 8 below.

Table 8: Difference in electricity sector totals from 2016 – 2019 from previous report.

Sector	Emissions in $MMTCO_2e$					
	2015	2016	2017	2018	2019	2020
Electricity Sector Previous Report (1990 - 2017)	1.00	0.81	0.49	0.18	0.13	NA
Electricity Sector Updated Values (including line losses)	1.00	0.92	0.62	0.31	0.25	0.18
Difference Resulting from Update	**0.00**	**0.11**	**0.13**	**0.13**	**0.13**	**0.00**

Even with the updates to the emissions totals to include line losses, the electricity sector remains one of the lowest emitting sectors in the state (Appendix A) and accounted for 2.2% of statewide emissions in 2020 with the majority of emissions associated with the residual system mix portion of the portfolio (Table 9). Low emissions totals from the sector are due mainly to our reliance on electricity from hydroelectric and nuclear generation. Declines in emissions in this sector (Figure 12) are attributed to distribution utilities meeting and exceeding Renewable Energy Standard (RES)[12] requirements for their electricity portfolios. In the last several years between 57% and 69% of the electricity in Vermont has been from hydroelectric generation with electricity and renewable energy certificates (RECs) from Hydro-Québec (HQ) being well over half of that total.

[12] Vermont Public Utility Commission – Renewable Energy Standard: https://puc.vermont.gov/electric/renewable-energy-standard

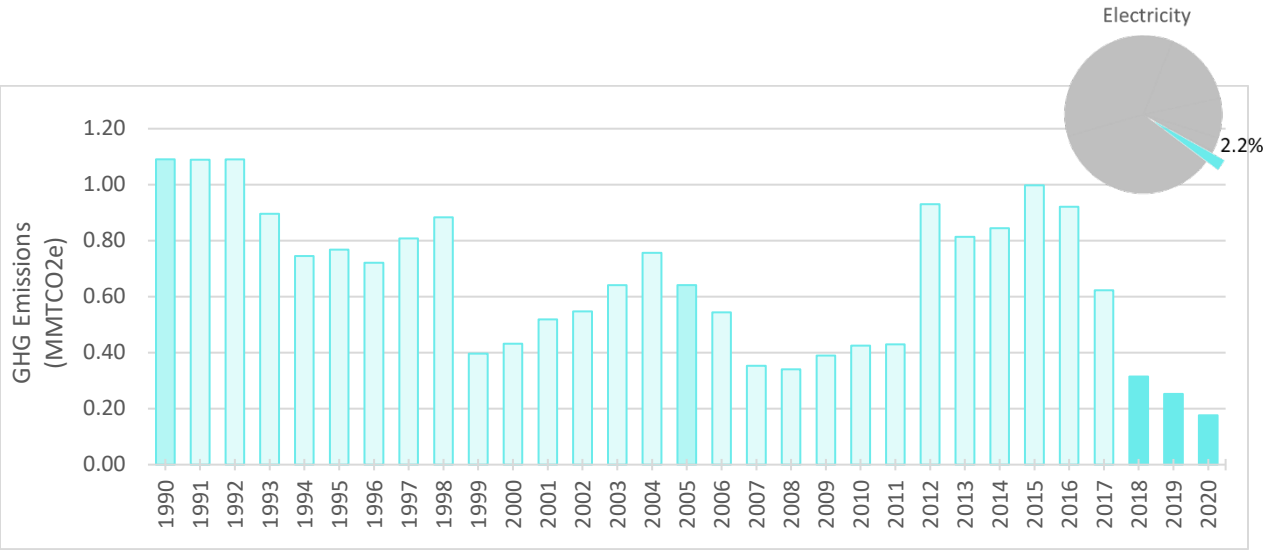

Figure 12: Vermont GHG emissions from the electricity sector. Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in bright blue.

Table 9: GHG emissions contributions by fuel and system mix in the electric sector.

Sector	Emissions in $MMTCO_2e$					
	1990	2005	2017	2018	2019	2020
Electricity Consumption	**1.09**	**0.64**	**0.62**	**0.31**	**0.25**	**0.18**
Coal	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.05	0.00	0.01	0.00	0.00	0.00
Oil	0.01	0.01	0.00	0.00	0.00	0.00
Wood (CH_4, N_2O)	0.00	0.01	0.01	0.01	0.01	0.01
Residual System Mix	1.03	0.62	0.60	0.30	0.24	0.16

* Biogenic CO_2 emissions are not included in totals[13]

2.1.6 Waste

Emissions of greenhouse gases associated with the waste sector include CH_4 and N_2O from both solid waste and wastewater. This includes emissions related to wastewater treatment systems, landfills, and composting. Carbon dioxide emissions from the waste sector are considered biogenic and are not included in the sector totals. Total emissions from both the solid waste and wastewater sectors remained flat from 2018 through 2020 (Figure 13), and the waste sector remains one of the smallest emitting sectors at 1.9% of the statewide total. Emissions estimates

[13] Biogenic emissions from wood combustion for the generation of electricity are not included in the Inventory totals. This includes emissions from the two main wood biomass electric generation facilities in the state, McNeil and Ryegate. Biogenic CO_2 emissions from these two facilities are significant, totaling approximately 0.86 $MMTCO_2e$ in 2020, but are not accounted for in the Inventory both because the emissions are biogenic and because the RECs produced by these two facilities are sold almost exclusively outside of Vermont. Additional information related to the accounting of biogenic CO_2 can be found in the Methodology document.

for the sector were updated in this inventory report using supplemental information from EPA for industrial wastewater and composting that had not been available until recently. The addition of these two subcategories has increased the totals from the sector since the previous report (Table 10). Vermont's Universal Recycling law (Act 148)[14] has helped to lower emissions in the solid waste sector by banning recyclable materials, leaf and yard debris, and food scraps from landfills which reduces the amount of landfill gas produced.

Table 10: GHG emissions contributions within the waste sector.

Sector	Emissions in $MMTCO_2e$					
	1990	2005	2017	2018	2019	2020
Waste	**0.27**	**0.35**	**0.15**	**0.16**	**0.16**	**0.16**
Solid Waste (CH_4, N_2O)	0.21	0.28	0.07	0.08	0.08	0.08
Composting (CH_4, N_2O)	0.00	0.01	0.01	0.01	0.01	0.01
Wastewater (CH_4, N_2O)	0.05	0.07	0.06	0.06	0.06	0.07

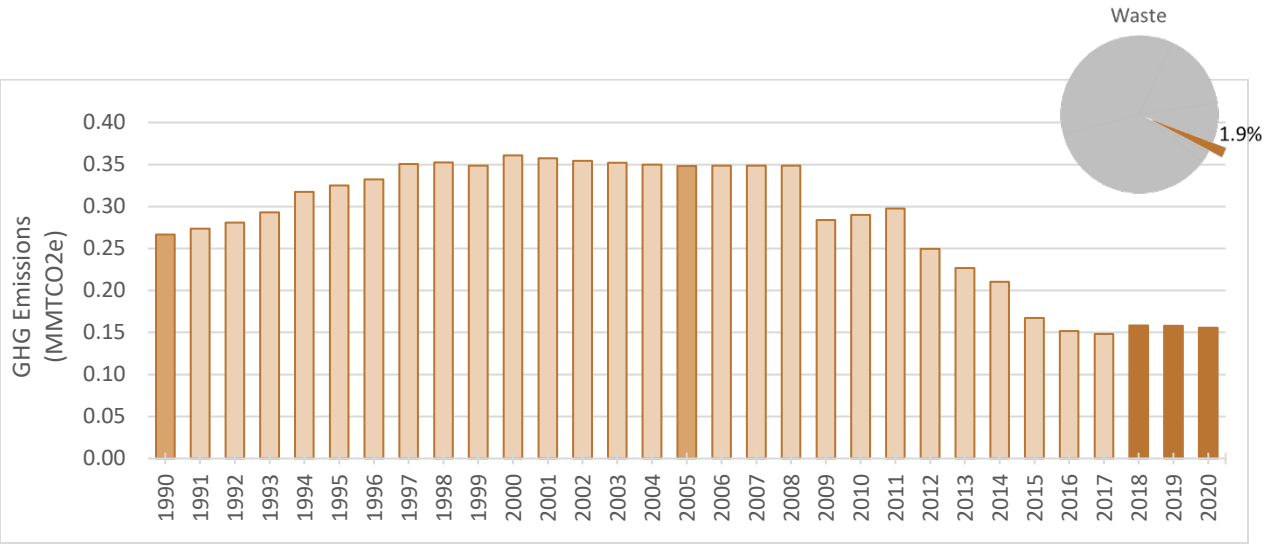

Figure 13: Vermont GHG emissions from the waste sector. Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in dark brown.

2.1.7 Fossil Fuel Industry

Emissions of greenhouse gases from the fossil fuel industry account for CH_4 emissions from natural gas leaks or fugitive emissions from the transmission and distribution pipelines and related services in Vermont. All of the emissions related to the combustion of fossil fuels is captured within other sectors in this inventory. Total emissions from the sector account for only

[14] Vermont Department of Environmental Conservation – Universal Recycling Law: https://dec.vermont.gov/waste-management/solid/universal-recycling

0.3% of the statewide total. Emissions in this sector increase as new natural gas services and lines are installed, but those increases are offset to some degree as older, and more leak prone pipe and service types are replaced with pipes and services made from updated and less leak prone materials (Figure 14). This offsetting effect has led to stable emissions levels in this sector in the last several years (Table 11) after the increase seen from the extension of Vermont Gas services to Addison County.

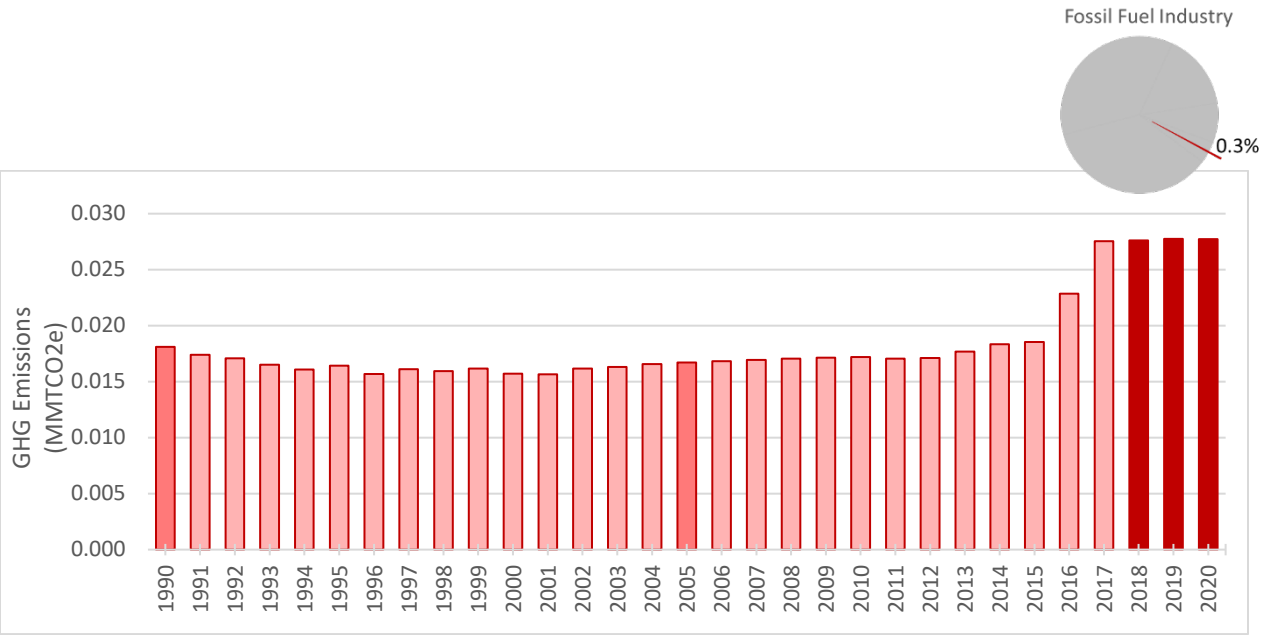

Figure 14: Vermont GHG emissions from the fossil fuel industry sector. Years from 1990-2020 are included with the 1990 and 2005 baseline years highlighted and the updated 2018-2020 values shown in dark red.

Table 11: GHG emissions contributions within the fossil fuel industry sector.

Sector	Emissions in $MMTCO_2e$					
	1990	2005	2017	2018	2019	2020
Fossil Fuel Industry	**0.018**	**0.017**	**0.028**	**0.028**	**0.028**	**0.028**
Natural Gas Distribution (CH_4)	0.007	0.003	0.004	0.004	0.004	0.004
Natural Gas Transmission (CH_4)	0.011	0.014	0.023	0.023	0.023	0.023

3 Additional Emissions Inventory Components

Discussion of estimates of emissions and sinks from sectors or portions of sectors that are not included in the official gross inventory totals published in the Inventory are provided below. For additional explanation of why certain emissions and sinks are not accounted for in the total gross emissions for Vermont, please refer to the *Methodologies* document.

3.1 Land Use, Land-Use Change, and Forestry (LULUCF)

Greenhouse gas emissions and sequestration resulting from changing or maintaining certain land uses as well as the cycling and storage of carbon in the forests of Vermont is a critical component to understanding a more holistic picture of GHG emissions in the state. Forests and other vegetation sequester CO_2 from the atmosphere and convert it into stored biological material through the process of photosynthesis, essentially removing or negating GHG emissions released into the atmosphere. Some of that sequestered carbon can also be transferred into soils for potentially longer-term storage in forests, agricultural lands, and other land types. Changes to land use can impact the carbon stored on that land either causing it to be emitted as CO_2 or potentially increasing sequestration, depending upon the change. Managing natural working lands (NWL) and conserving forests and other natural ecosystems is crucial to increase resilience to climate change, and to allow these systems to both retain and potentially store more carbon.

Accurately estimating the emissions and/or sequestration (sink) based on annual changes in the landscape and forests to determine an overall net emission or sink is challenging. Data are not readily available or high enough resolution to estimate these changes at the state level every year, and carbon cycling through these systems and ecosystems is complex and not always well understood. In the previous inventory report only sequestration by forests was included as supplemental information because estimates were available from the Forest Inventory and Analysis (FIA)[15] program. This inventory report includes newly released estimates[16] from the EPA of state-level emissions and sinks from land use conversions for land use types besides forests. This supplemental information was created by the EPA by downscaling estimates calculated for the National Inventory Report[17]. Estimates of the changes in carbon on the landscape (fluxes) and carbon emitted and sequestered by forests are shown in Table 12. The LULUCF sector in Vermont is a large emissions sink overall, meaning that it sequesters far more CO_2 than is emitted within the sector, but the annual sequestration has been declining steadily since 1990 as can be seen in the green bars in Figure 15 below. Sequestration in the state is dominated by forests as seen in Table 12, and the declining sequestration over time mirrors the loss of forested land in the state[18]. Additional information related to the LULUCF sector estimates can be found in the Methodology document.

[15] Forest Inventory and Analysis (FIA) Program: https://www.fia.fs.usda.gov/
[16] EPA State GHG Emissions and Removals: https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals
[17] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020
[18] Vermont Forest Parks and Recreation – Vermont Forest Carbon Inventory: https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Climate_Change/Files/VermontForestCarbonInventory_Mar2021.pdf

Table 12: Emissions and sinks for select years from the LULUCF sector in Vermont.

Land-Use, Land use change, and Forestry (LULUCF)	Emissions/Sequestration in $MMTCO_2e$								
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2018**	**2019**	**2020**
Forest Carbon Flux (Forest Land Remaining Forest Land)	(9.17)	(8.61)	(8.09)	(7.51)	(7.16)	(6.73)	(6.48)	(6.41)	(6.35)
Aboveground Biomass	*(4.12)*	*(4.11)*	*(4.12)*	*(4.14)*	*(4.17)*	*(4.02)*	*(3.95)*	*(3.92)*	*(3.88)*
Belowground Biomass	*(0.79)*	*(0.79)*	*(0.79)*	*(0.79)*	*(0.80)*	*(0.77)*	*(0.76)*	*(0.75)*	*(0.74)*
Deadwood	*(1.36)*	*(1.32)*	*(1.27)*	*(1.19)*	*(1.06)*	*(0.96)*	*(0.90)*	*(0.88)*	*(0.87)*
Litter	*(0.17)*	*(0.15)*	*(0.13)*	*(0.12)*	*(0.11)*	*(0.11)*	*(0.10)*	*(0.10)*	*(0.10)*
Soil (Mineral)	*(1.23)*	*(1.02)*	*(0.84)*	*(0.66)*	*(0.46)*	*(0.26)*	*(0.21)*	*(0.20)*	*(0.20)*
Soil (Organic)	-	-	-	-	-	-	-	-	-
Drained Organic Soil	-	-	-	-	-	-	-	-	-
Total wood products and landfills	*(1.50)*	*(1.22)*	*(0.94)*	*(0.61)*	*(0.56)*	*(0.61)*	*(0.56)*	*(0.56)*	*(0.56)*
Land Converted to Forest Land	(0.27)	(0.27)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)
Cropland Remaining Cropland (Ag soil carbon flux)	(0.18)	(0.20)	(0.10)	(0.15)	(0.15)	(0.10)	(0.09)	(0.09)	(0.11)
Land Converted to Cropland	0.38	0.42	0.42	0.42	0.44	0.48	0.48	0.48	0.48
Grassland Remaining Grassland	(0.04)	(0.05)	(0.04)	(0.01)	(0.01)	0.04	0.01	0.02	0.00
Land Converted to Grassland	(0.03)	(0.05)	(0.04)	(0.03)	0.00	(0.03)	(0.02)	(0.02)	(0.02)
Wetlands Remaining Wetlands	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Land Converted to Wetlands	0.00	0.00	0.00	0.00	0.00	-	-	-	-
Settlements Remaining Settlements	(0.37)	(0.36)	(0.37)	(0.38)	(0.40)	(0.41)	(0.40)	(0.40)	(0.40)
Land Converted to Settlements	0.55	0.60	0.65	0.68	0.71	0.73	0.74	0.74	0.74
LULUCF Net CO_2 Flux (w/ harvested wood products)	**(9.14)**	**(8.52)**	**(7.83)**	**(7.24)**	**(6.84)**	**(6.27)**	**(6.02)**	**(5.94)**	**(5.92)**

** Note that parentheses indicate net sequestration.*

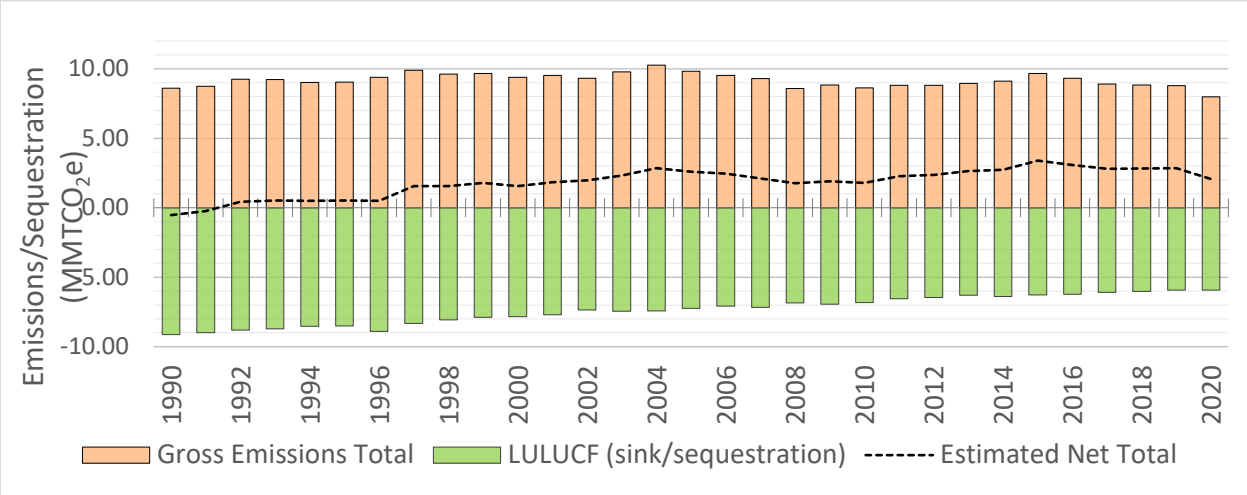

Figure 15: Estimated gross emissions, total sequestration, and net GHG levels in Vermont from 1990-2020.

3.2 Biogenic CO_2

Emissions of biogenic CO_2 are directly tied to the LULUCF sector. Wood use for energy is the largest source of human-caused biogenic CO_2 emissions in Vermont, but those emissions are not included in the inventory totals because the carbon (and releases of CO_2) from that wood is captured in the changes in carbon on the landscape and in the forests of Vermont as per IPCC guidelines. Estimating the carbon and CO_2 fluxes from changes in land use and from forests is not an exact science, nor are there currently accurate data on the amount of wood cut, imported, or combusted annually in Vermont to compare the LULUCF flux estimates to. Biogenic CO_2 estimates have been included in several of the inventory sectors in this report as supplemental information and to help provide a sense of scale of these emissions and transfer of carbon from the landscape. Additional work is ongoing with other states in the region to coordinate methodologies to estimate emissions and sinks in the LULUCF sector and related to forests and forest carbon.

3.3 GWP_{bio}

GWPbio is a factor that is used to account for a portion of biogenic CO_2 emissions at the point of combustion, specifically for the combustion of wood, while also giving partial emissions credit for the renewability of the resource. One of the main influences of GWP_{bio} factors are the rotation periods for the harvested biofuels. Essentially, the longer the rotation period for the vegetation that was cut and combusted to regrow, the higher the associated GWP_{bio} multiplier. These factors are meant to be applied to lifecycle emissions estimates but given the importance of emissions from wood combustion in Vermont and the acknowledgement that the pulse of CO_2 emitted when biomass is combusted leads to additional global warming before the CO_2 can be re-sequestered, providing an alternative accounting framework seems appropriate. A GWP_{bio} factor of 0.32 was taken from the Biogenic Carbon Footprint Calculator[19] for cool temperate climate and used to estimate the values shown in Table 13 below.

Table 13: GWP_{bio} Emissions estimates for the RCI sector.

RCI Sector - GWPbio	MMTCO$_2$e					
	1990	2005	2017	2018	2019	2020
Residential - Wood (biogenic CO2 - GWP_{bio})	0.27	0.30	0.41	0.42	0.42	0.37
Commercial - Wood (biogenic CO2 - GWP_{bio})	0.01	0.00	0.01	0.01	0.01	0.01
Industrial - Wood (biogenic CO2 - GWP_{bio})	0.09	0.09	0.05	0.06	0.05	0.04

[19] Biogenic Carbon Footprint Calculator – World Wildlife Federation: https://files.worldwildlife.org/wwfcmsprod/misc/climate_forest/Biogenic_Carbon_Footprint_Calculator_2020.xlsx

4 Emissions Forecasts

4.1 Projected GHG Emissions Levels for 2025 and 2030

As is seen in this inventory report, emissions of greenhouse gases come from a variety of different sectors and processes, and are influenced by many factors including the economy, markets, state and federal policies and regulations, personal and consumer choices, and unforeseen events such as the COVID-19 pandemic. Estimating what greenhouse gas emissions totals will be in a future year requires making many assumptions. Recent modeling completed through 2050 to inform the Vermont Climate Action Plan (CAP)[20] and the Comprehensive Energy Plan (CEP)[21] is used here to project emissions estimates in the Inventory. This is a change from the projection methodologies used in previous inventory reports because this Vermont specific CAP and CEP modeling was not available for those Inventory iterations. Greenhouse gas estimates and modeling performed as a part of the CAP/CEP process included business as usual (BAU) baseline estimates, which are estimates of emissions levels assuming similar trends continue into the future without any new policies to reduce emissions. The CAP/CEP modeling and assumptions differed from those used in this inventory report, so percent changes in the modeled BAU totals were used to project the emissions in this report for each sector as seen in Table 13 below.

The decline in emissions estimates for 2020 in this report are a very real example of the impact that social and economic events can have on GHG emissions, and why they are difficult to accurately predict. It is unclear to what extent, if any, the reductions seen in 2020 will maintain and become permanent behavioral changes, and this will likely have a real impact on future emissions levels in Vermont and globally. The data and tools needed to complete emissions estimates for 2021 are not yet available. However, based on fuel sales and VMT data for 2021 (Figure 16 and Figure 17) emissions in the transportation sector are expected to rebound somewhat.

[20] Vermont Climate Action Plan: https://climatechange.vermont.gov/readtheplan
[21] Vermont Comprehensive Energy Plan: https://publicservice.vermont.gov/about-us/plans-and-reports/department-state-plans/2022-plan

Table 14: GHG emissions projections using percent changes from CAP modeling[22].

Sector	2018 Inventory ($MMTCO_2e$)	Pathways BAU Percent Change (2018 - 2025)	Pathways BAU Percent Change (2018 - 2030)	2025 Projection ($MMTCO_2e$)	2030 Projection ($MMTCO_2e$)
Electricity	0.31	21.9%	-3.8%	0.38	0.30
Transportation/Mobile	3.40	-6.6%	-36.8%	3.18	2.15
Residential/Commercial/Industrial Fuel Use (RCI)	2.94	-4.9%	-10.1%	2.80	2.65
Agriculture	1.40	0.6%	1.3%	1.40	1.41
Industrial Processes	0.59	1.8%	4.1%	0.60	0.62
Waste	0.16	0.2%	0.5%	0.16	0.16
Fossil Fuel Industry	0.03	1.0%	1.6%	0.03	0.03
Total	**8.83**			**8.55**	**7.32**

Note: Percent changes in the transportation sector estimates are from the mitigation scenario modeling that uses higher electric vehicle adoption rates. The Advanced Clean Cars II regulation had not been adopted when the original BAU projections were made and so was not incorporated. Percent changes in the agricultural sector were used from 2020 – 2025 because of an artificial drop in emissions from that sector in the BAU modeling that was skewing the projections.

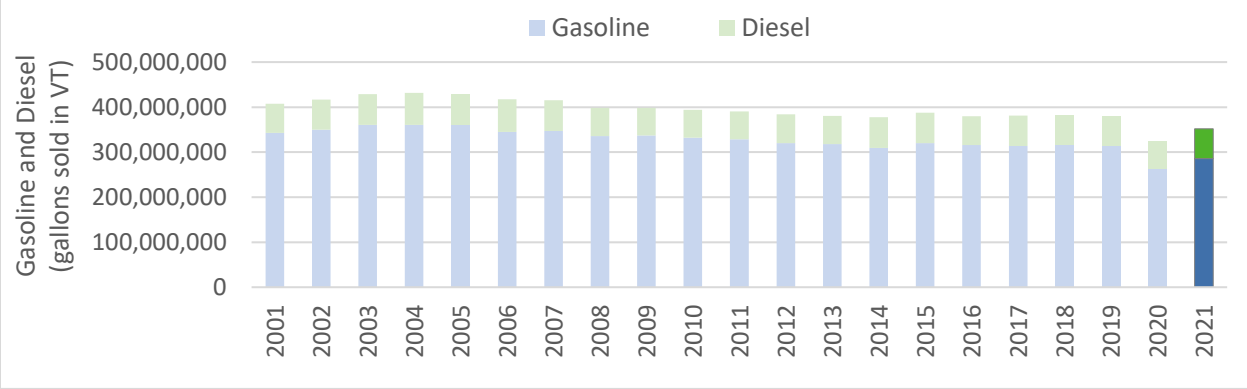

Figure 16: Gallons of gasoline and diesel sold in Vermont by year (Source: Joint Fiscal Office).

[22] Projections in Table 14 are based on an extrapolation of 2018 GHG inventory estimates. Because the BAU modeling was completed before the 2020 emissions estimates had been completed for this GHG Emissions Inventory report and before data related to the impacts of the COVID-19 pandemic were available, GHG emissions in 2020 in the transportation sector estimates in the BAU are larger than in reality. Since the projections in this table were based on 2018 GHG Inventory report values, which did not reflect decreases in transportation sector emissions related to the COVID-19 pandemic, and those emissions reductions were also not captured in the BAU modeling, the estimates in the table are artificially inflated. The amount to which they are inflated depends in large part on the extent emissions in the transportation sector rebound to pre-COVID levels in the coming years, however, the projections in the next iteration of the GHG Emissions Inventory and Forecast report are expected to be lower.

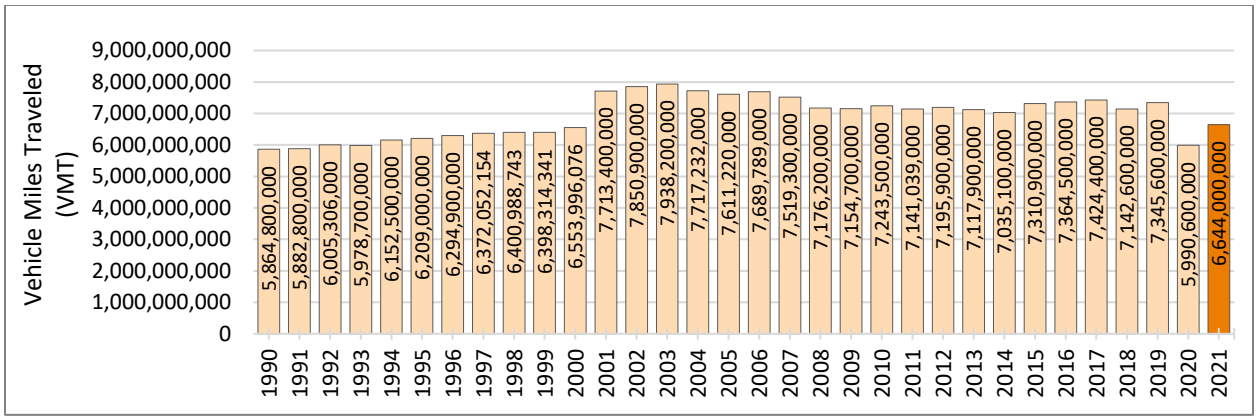

Figure 17: Vehicle miles traveled in Vermont by year (Source: VTrans)

5 Conclusion

The 1990-2020 Vermont Greenhouse Gas Emissions Inventory and Forecast report provides both current and historical estimates of GHG emissions in Vermont. Historical emissions totals serve as baseline values to track progress towards Vermont's mandated emissions levels and provide insights into which sectors to prioritize for mitigation policies. The three new years of data released in this report (2018-2020), show very slight declines in overall emissions. Emissions levels dropped again in 2020 but this was due mainly to decreases in the transportation sector related to impacts from the COVID-19 pandemic, which are expected to at least partially rebound based on 2021 fuel sales and VMT data.

This inventory report is one way to understand GHG emissions associated with Vermont and the actions of Vermonters. The approaches taken by the Agency of Natural Resources for this annual in-boundary inventory attempt to maintain consistency with other states in the region, as well as IPCC guidelines, and are based on data availability and the most current understanding of the various methods and tools to estimate GHG emissions. There are several analyses currently underway that will help to provide additional information and insights in the future on specific sectors and using alternative frameworks and assumptions. These analyses will inform policies and decisions related to GHG emissions and activities in the state, including a lifecycle emissions analysis to better understand the "upstream" and "downstream" emissions from energy use in Vermont, a consumption-based inventory that combines lifecycle emissions with consumption estimates for the state, an analysis to incorporate local data and more accurately quantify emissions and sequestration on a net basis from agricultural practices, and a project to improve estimates and tracking of forest carbon on a regional level. When these analyses and reports are completed they will provide additional information to supplement and expand upon estimates provided in this report.

Appendix A – Vermont Historic Greenhouse Gas Emissions by Sector [23]

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	2018	2019	2020
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**	**0.92**	**0.62**	**0.31**	**0.25**	**0.18**
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	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	0.00	0.00	0.00
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	0.00	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	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	0.90	0.60	0.30	0.24	0.16
Residential / Commercial / Industrial (RCI) Fuel Use	**2.54**	**2.51**	**3.02**	**2.95**	**2.78**	**2.98**	**3.32**	**3.06**	**2.89**	**2.79**	**2.54**	**2.74**	**2.56**	**2.58**	**2.32**	**2.54**	**2.74**	**2.94**	**2.70**	**2.70**	**2.94**	**3.00**	**2.87**
Coal	0.02	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	0.00	0.00
Natural Gas	0.31	0.37	0.50	0.42	0.44	0.45	0.47	0.45	0.43	0.48	0.46	0.46	0.45	0.46	0.43	0.51	0.57	0.64	0.65	0.65	0.75	0.76	0.71
Oil, Propane & Other Petroleum	2.14	2.05	2.45	2.46	2.27	2.46	2.78	2.53	2.38	2.24	2.00	2.20	2.02	2.04	1.80	1.94	2.07	2.20	1.96	1.96	2.10	2.15	2.08
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	0.10	0.10	0.09
Wood combustion (biogenic CO_2 - not included in gross totals)	1.15	1.24	1.11	1.10	1.06	1.04	1.10	1.23	1.26	1.22	1.21	1.23	1.28	1.32	1.32	1.37	1.43	1.43	1.44	1.47	1.52	1.51	1.32
Transportation	**3.25**	**3.85**	**3.80**	**3.96**	**3.92**	**4.07**	**4.10**	**4.05**	**4.02**	**3.95**	**3.62**	**3.70**	**3.58**	**3.54**	**3.44**	**3.41**	**3.33**	**3.50**	**3.49**	**3.40**	**3.40**	**3.34**	**2.85**
Motor Gasoline (Onroad and Nonroad) (CO_2)	2.57	2.77	3.03	3.00	3.07	3.21	3.17	3.14	3.02	3.02	2.77	2.73	2.68	2.64	2.56	2.53	2.46	2.55	2.52	2.50	2.52	2.50	2.09
Diesel (Onroad and Nonroad) (CO_2)	0.45	0.85	0.54	0.73	0.66	0.67	0.65	0.65	0.70	0.68	0.63	0.66	0.73	0.72	0.71	0.72	0.71	0.79	0.81	0.76	0.75	0.71	0.65
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.07	0.08	0.08	0.07	0.08	0.08	0.09	0.06	0.07	0.07	0.06
Non-Energy Consumption - Lubricants (CO_2)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	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	0.01
All Mobile (CH_4, N_2O)	0.13	0.15	0.14	0.15	0.14	0.14	0.13	0.12	0.11	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04
Ethanol + Biodiesel (biogenic CO2 - not included in gross totals)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.13	0.18	0.17	0.17	0.18	0.20	0.19	0.19	0.22	0.22	0.19	0.19	0.17
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**	**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	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	0.02	0.02	0.02
Industrial Processes	**0.21**	**0.40**	**0.53**	**0.43**	**0.45**	**0.44**	**0.45**	**0.44**	**0.46**	**0.45**	**0.44**	**0.40**	**0.47**	**0.67**	**0.64**	**0.60**	**0.60**	**0.62**	**0.61**	**0.60**	**0.59**	**0.63**	**0.65**
ODS Substitutes	0.00	0.05	0.13	0.15	0.15	0.16	0.17	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	0.34	0.36	0.37
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	0.01	0.01	0.01
Semiconductor Manufacturing (HFCs, PFCs & SF_6)	0.16	0.28	0.34	0.24	0.25	0.24	0.22	0.21	0.23	0.21	0.20	0.14	0.18	0.37	0.33	0.27	0.25	0.26	0.24	0.23	0.22	0.23	0.24
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	0.02	0.03	0.03
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	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	0.00	0.00	0.00
Waste Management	**0.27**	**0.33**	**0.36**	**0.36**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.28**	**0.29**	**0.30**	**0.25**	**0.23**	**0.21**	**0.17**	**0.15**	**0.15**	**0.16**	**0.16**	**0.16**
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	0.08	0.08	0.08
Composting	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Wastewater	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07
Agriculture	**1.24**	**1.16**	**1.24**	**1.30**	**1.27**	**1.28**	**1.29**	**1.27**	**1.26**	**1.38**	**1.29**	**1.31**	**1.28**	**1.28**	**1.23**	**1.34**	**1.37**	**1.42**	**1.41**	**1.40**	**1.40**	**1.38**	**1.26**
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	0.64	0.63	0.61
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	0.36	0.35	0.33
Agricultural Soils	0.36	0.31	0.28	0.32	0.29	0.29	0.32	0.30	0.30	0.31	0.30	0.33	0.33	0.31	0.28	0.37	0.39	0.40	0.37	0.35	0.36	0.37	0.29
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	0.04	0.04	0.03
TOTAL GROSS EMISSIONS	**8.61**	**9.03**	**9.39**	**9.53**	**9.33**	**9.77**	**10.27**	**9.83**	**9.54**	**9.30**	**8.59**	**8.84**	**8.62**	**8.82**	**8.82**	**8.95**	**9.12**	**9.66**	**9.31**	**8.90**	**8.83**	**8.79**	**7.99**
Land-use, Land Use Change, and Forestry (LULUCF)	**-9.14**	**-8.52**	**-7.83**	**-7.70**	**-7.36**	**-7.45**	**-7.43**	**-7.24**	**-7.09**	**-7.18**	**-6.84**	**-6.94**	**-6.84**	**-6.56**	**-6.46**	**-6.31**	**-6.39**	**-6.27**	**-6.22**	**-6.10**	**-6.02**	**-5.94**	**-5.92**
Estimated Net Emissions Total	**-0.53**	**0.52**	**1.56**	**1.83**	**1.97**	**2.32**	**2.84**	**2.59**	**2.45**	**2.12**	**1.76**	**1.90**	**1.78**	**2.26**	**2.36**	**2.64**	**2.73**	**3.39**	**3.09**	**2.80**	**2.82**	**2.86**	**2.07**

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

Appendix B: Gross Emissions Totals for select years using AR5 100-yr GWP values.

Sector	Emissions in $MMTCO_2e$								
	1990	1995	2000	2005	2010	2015	2018	2019	2020
Electricity Supply & Demand (consumption based)	**1.09**	**0.77**	**0.43**	**0.64**	**0.43**	**1.00**	**0.31**	**0.25**	**0.18**
Coal	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	0.00	0.01	0.02	0.00	0.00	0.00
Oil	0.01	0.01	0.06	0.01	0.04	0.01	0.00	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
Residual System Mix	1.03	0.75	0.35	0.62	0.36	0.96	0.30	0.24	0.16
Residential / Commercial / Industrial (RCI) Fuel Use	**2.55**	**2.51**	**3.03**	**3.06**	**2.56**	**2.95**	**2.95**	**3.01**	**2.88**
Coal	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.31	0.37	0.50	0.45	0.45	0.65	0.75	0.76	0.71
Oil, Propane & Other Petroleum	2.14	2.05	2.45	2.53	2.02	2.20	2.10	2.15	2.08
Wood (CH_4 & N_2O)	0.07	0.08	0.07	0.08	0.09	0.10	0.11	0.11	0.10
Transportation	**3.24**	**3.84**	**3.79**	**4.04**	**3.57**	**3.50**	**3.40**	**3.33**	**2.84**
Motor Gasoline (Onroad and Nonroad) (CO_2)	2.57	2.77	3.03	3.14	2.68	2.55	2.52	2.50	2.09
Diesel (Onroad and Nonroad) (CO_2)	0.45	0.85	0.54	0.65	0.73	0.79	0.75	0.71	0.65
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
Jet Fuel & Aviation Gasoline (CO_2)	0.08	0.06	0.07	0.13	0.07	0.08	0.07	0.07	0.06
Non-Energy Consumption - Lubricants (CO_2)	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.01
All Mobile (CH_4, N_2O)	0.12	0.13	0.12	0.11	0.07	0.05	0.04	0.04	0.03
Fossil Fuel Industry	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	**0.03**	**0.03**
Natural Gas Distribution	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas Transmission	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03
Industrial Processes	**0.21**	**0.40**	**0.53**	**0.44**	**0.47**	**0.62**	**0.59**	**0.63**	**0.65**
ODS Substitutes*	0.00	0.05	0.13	0.18	0.25	0.32	0.34	0.36	0.37
Electric Utilities (SF_6)	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Semiconductor Manufacturing (HFCs, PFCs & SF_6)	0.16	0.28	0.34	0.21	0.18	0.26	0.22	0.23	0.24
Limestone & Dolomite Use	0.00	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.03
Soda Ash Use	0.01	0.01	0.01	0.01	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
Waste Management	**0.30**	**0.36**	**0.40**	**0.39**	**0.32**	**0.18**	**0.17**	**0.17**	**0.17**
Solid Waste	0.24	0.30	0.33	0.31	0.24	0.11	0.09	0.09	0.09
Composting	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Wastewater	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Agriculture	**1.28**	**1.21**	**1.30**	**1.33**	**1.34**	**1.48**	**1.46**	**1.44**	**1.32**
Enteric Fermentation	0.78	0.75	0.77	0.71	0.69	0.71	0.72	0.71	0.69
Manure Management	0.18	0.19	0.27	0.35	0.35	0.36	0.38	0.37	0.35
Agricultural Soils	0.32	0.27	0.25	0.27	0.29	0.36	0.32	0.33	0.25
Liming and Urea Fertilization	0.00	0.00	0.00	0.00	0.01	0.05	0.04	0.04	0.03
Grand Total (gross)	**8.68**	**9.12**	**9.49**	**9.92**	**8.71**	**9.74**	**8.92**	**8.87**	**8.08**

Note *: It was not possible to update the ODS Substitutes category with AR5 100-yr GWP values because of how the estimates in that subsector are calculated. Updating GWP values only impacts emissions of gases other than CO_2, so many emissions totals remain unchanged.

Appendix C: Vermont Key Category Analysis by Scale Assessment.

Sector	Scale 1990	Key Category in 1990	Scale 2005	Key Category in 2005	Scale 2020	Key Category in 2020
Electricity Supply & Demand (Consumption - based)						
Coal	0.00%	No	0.00%	No	0.00%	No
Natural Gas	0.54%	No	0.00%	No	0.00%	No
Oil, Propane, & Other Petroleum	0.16%	No	0.11%	No	0.00%	No
Wood (CH_4, N_2O)	0.03%	No	0.14%	No	0.15%	No
Residual System Mix	11.93%	Yes	6.27%	Yes	2.05%	Yes
Residential/ Commercial/ Industrial (RCI) Fuel Use						
Coal	0.26%	No	0.02%	No	0.00%	No
Natural Gas	3.65%	Yes	4.59%	Yes	8.86%	Yes
Oil, Propane, & Other Petroleum	24.82%	Yes	25.75%	Yes	25.98%	Yes
Wood (CH_4, N_2O)	0.77%	No	0.75%	No	1.10%	No
Transportation/Mobile						
Motor Gasoline (Onroad and Nonroad) (CO_2)	29.84%	Yes	31.91%	Yes	26.13%	Yes
Diesel (Onroad and Nonroad) (CO_2)	5.23%	Yes	6.61%	Yes	8.11%	Yes
Hydrocarbon Gas Liquids, Residual Fuel, Natural Gas (CO_2)	0.03%	No	0.00%	No	0.00%	No
Jet Fuel & Aviation Gasoline (CO_2)	0.89%	No	1.36%	No	0.78%	No
Non-Energy Consumption - Lubricants (CO_2)	0.22%	No	0.13%	No	0.16%	No
All Mobile (CH_4, N_2O)	1.51%	No	1.21%	No	0.45%	No
Fossil Fuel Industry						
Natural Gas Distribution	0.08%	No	0.03%	No	0.05%	No
Natural Gas Transmission	0.13%	No	0.14%	No	0.29%	No
Industrial Processes						
ODS Substitutes	0.01%	No	1.84%	Yes	4.59%	Yes
Electric Utilities (SF_6)	0.47%	No	0.14%	No	0.08%	No
Semiconductor Manufacturing (HFC, PFC & SF_6)	1.86%	Yes	2.16%	Yes	3.06%	Yes
Limestone & Dolomite Use	0.00%	No	0.32%	No	0.36%	No
Soda Ash Use	0.07%	No	0.05%	No	0.05%	No
Urea Consumption	0.00%	No	0.00%	No	0.03%	No
Waste Management						
Solid Waste (CH_4, N_2O)	2.47%	Yes	2.81%	Yes	0.96%	No
Wastewater	0.62%	No	0.67%	No	0.82%	No
Agriculture						
Enteric Fermentation	8.09%	Yes	6.45%	Yes	7.68%	Yes
Manure Management	2.07%	Yes	3.37%	Yes	4.18%	Yes
Agricultural Soils	4.20%	Yes	3.04%	Yes	3.59%	Yes
Liming and Urea Fertilization	0.03%	No	0.04%	No	0.32%	No

Appendix D: Vermont Key Category Analysis by Trend Assessment

Sector	Subsector	Trend Assessment (1990-2020)	Contribution to the trend (1990 - 2020)	Cumulative total (1990-2020)
Electricity Supply & Demand	Residual System Mix	1.39	0.27	0.27
Residential/ Commercial/ Industrial (RCI) Fuel Use	Natural Gas	0.63	0.12	0.39
Industrial Processes	ODS Substitutes	0.59	0.11	0.50
Transportation/Mobile Sources	Diesel (Onroad and Nonroad) (CO_2)	0.32	0.06	0.56
Agriculture	Manure Management	0.12	0.02	0.59
Transportation/Mobile Sources	All Mobile (CH_4, N_2O)	0.15	0.03	0.62
Waste	Solid Waste (CH_4, N_2O)	0.22	0.04	0.66
Agriculture	Enteric Fermentation	0.25	0.05	0.70
Electricity Supply & Demand	Natural Gas	0.08	0.01	0.72
Industrial Processes	Semiconductor Manufacturing (HFCs, PFCs, SF_6, NF_3)	0.14	0.03	0.75
Residential/ Commercial/ Industrial (RCI) Fuel Use	Oil, Propane, & Other Petroleum	0.21	0.04	0.79
Transportation/Mobile Sources	Motor Gasoline (Onroad and Nonroad) (CO_2)	0.78	0.15	0.93
Industrial Processes	Electric Utilities (SF_6)	0.06	0.01	0.94
Residential/ Commercial/ Industrial (RCI) Fuel Use	Wood (CH_4, N_2O)	0.04	0.01	0.95
Transportation/Mobile Sources	Jet Fuel & Aviation Gasoline (CO_2)	0.02	0.00	0.96
Industrial Processes	Limestone & Dolomite Use	0.05	0.01	0.97
Agriculture	Agricultural Soils	0.04	0.01	0.97
Residential/ Commercial/ Industrial (RCI) Fuel Use	Coal	0.04	0.01	0.98
Electricity Supply & Demand	Oil	0.02	0.00	0.98
Fossil Fuel Industry	Natural Gas Transmission	0.02	0.00	0.99
Electricity Supply & Demand	Wood (CH_4, N_2O)	0.02	0.00	0.99
Waste	Wastewater	0.02	0.00	1.00
Transportation/Mobile Sources	Non-Energy Consumption - Lubricants (CO_2)	0.01	0.00	1.00
Transportation/Mobile Sources	Hydrocarbon Gas Liquids, Residual Fuel, Natural Gas (CO_2)	0.00	0.00	1.00
Fossil Fuel Industry	Natural Gas Distribution	0.00	0.00	1.00
Industrial Processes	Soda Ash Use	0.00	0.00	1.00
Industrial Processes	Urea Consumption	0.00	0.00	1.00
Electricity Supply & Demand	Coal	0.00	0.00	1.00