

Vermont Greenhouse Gas Emissions Inventory and Forecast

Methodologies **EXPANDED**

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Acronyms & Abbreviations

AAFM: Agency of Agriculture, Food and Markets

ACCII: Advanced Clean Cars II regulation

ACT: Advanced Clean Trucks regulation

AFOLU: Agriculture Forestry and Other Land Use

ANR: Agency of Natural Resources

AR4: Intergovernmental Panel on Climate Change Fourth Assessment Report

AR5: Intergovernmental Panel on Climate Change Fifth Assessment Report

BAU: Business As Usual

Btu: British thermal unit

CFCs: chlorofluorocarbons

CH₄: methane

CO₂: carbon dioxide

CO₂e: carbon dioxide equivalent

CO₂FFC: Carbon dioxide from Fossil Fuel Combustion SIT module

DEC: Vermont Department of Environmental Conservation

e-CFR: Electronic Code of Federal Regulations

EIA: Energy Information Administration

EPA: Environmental Protection Agency

EV: electric vehicle

F-gas: fluorinated gas

FHWA: Federal Highway Administration

FLIGHT: Facility Level Information on GreenHouse gases Tool

FPR: Vermont Department of Forests Parks and Recreation

GHG: greenhouse gas

GHGRP: GreenHouse Gas Reporting Program

GWP: global warming potential

HCFCs: hydrochlorofluorocarbons

HFC: hydrofluorocarbon

IP: industrial processes

IPCC: Intergovernmental Panel on Climate Change

ISO-NE: independent systems operator – New England

JFO: Joint Fiscal Office

kWh: kilowatt hour

LFG: landfill gas

LFGTE: landfill gas-to-energy

LEAP: Low Emissions Analysis Platform

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

MWh: megawatt hour

N₂O: nitrous oxide

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

NF₃: nitrogen trifluoride

NWL: Natural and Working Lands

ODS: ozone depleting substances

PFC: perfluorocarbon

PHMSA: Pipeline and Hazardous Materials Safety Administration

PSD: Public Service Department

RCI: residential/commercial/industrial

REC: renewable energy certificate

SEDS: State Energy Data System

SF₆: sulfur hexafluoride

SIT: State Inventory Tool

UNFCCC: United Nations Framework Convention on Climate Change

USCA: United States Climate Alliance

USDA: United States Department of Agriculture

VMT: vehicle miles traveled

VTrans: Vermont Agency of Transportation

1 Introduction

The *Vermont Greenhouse Gas Emissions Inventory and Forecast: Methodologies* report is a supporting document for the Vermont Greenhouse Gas (GHG) Emissions Inventory and Forecast report (GHG Inventory) completed by the Vermont Agency of Natural Resources. The Methodologies report provides details on the specific methodologies and datasets used to calculate the emissions totals in the inventory and will be updated as necessary when methodologies, datasets, or assumptions used in the inventory calculations change through time.

Foundational Information

Greenhouse gases 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 produced by the Environmental Protection Agency (EPA), are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF₆), and nitrogen trifluoride (NF₃). Some of these greenhouse gases do occur naturally in the atmosphere, such as CO₂, CH₄, and N₂O, but since the industrial revolution human activities have rapidly increased their concentrations leading to warming of the planet.¹

Some greenhouse gases are more effective at trapping heat in the atmosphere than others and remain in the atmosphere for different amounts of time (different atmospheric lifetimes). In order to make the gases comparable to each other for quantification purposes the Intergovernmental Panel on Climate Change (IPCC) developed a method using global warming potentials (GWPs), which account for the heat trapping efficiency and the atmospheric lifetime of gases other than CO₂ and set them relative to CO₂ on a per unit of mass basis. Emissions totals including applicable GWP adjustments are reported in units of CO₂ equivalent (CO₂e). The GWP values used in the Vermont GHG inventory 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 Fifth Assessment Report (AR5)¹. The GWP values are essentially multipliers that are applied to masses of non-CO₂ gases to make their climate warming impacts directly comparable to CO₂.

¹ 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.

Table 1: AR5 – 100-year Global warming potential values.²

GHG Category	AR5 100-year GWP Value	Atmospheric Lifetime (years)
CO ₂	1	Variable
CH ₄	28	12
N ₂ O	265	114
HFCs	up to 12,400	1 - 270
PFCs	up to 11,100	2,600 - 50,000
NF ₃	16,100	740
SF ₆	23,500	3,200

GWP values are updated over time as scientific estimates of the absorption of energy or the atmospheric lifetimes or relative concentrations of the gases change. Both the National Inventory of U.S. Greenhouse Gas Emissions and Sinks³, and the Vermont GHG Inventory are now using the AR5 100-year GWP values, since that is the recommendation in the most recent IPCC inventory guidelines document. This is an update to the values used in a previous Vermont GHG Inventory (1990-2020) report which were from the IPCC Fourth Assessment Report (AR4).

The choice of time horizon for the GWP values used is related to whether the emphasis of the data or analysis is on the speed of potential climate change or the eventual magnitude. If the speed at which climate change is occurring is the main focus, a shorter time horizon, such as 20 years, may be appropriate. However, if the overall magnitude of the changes in the climate are the focus, a longer duration time horizon is more appropriate. For the Vermont GHG Inventory the 100-year time horizon has been used to be consistent with the IPCC inventory guidelines, but it is important to strike a balance for mitigation strategies that prioritizes the mitigation of both short-lived and long-lived gases.

Biogenic CO₂ is another important foundational consideration when calculating a GHG inventory and is defined as carbon dioxide that is emitted as a part of the natural carbon cycle, related to the combustion or decomposition of biologically based materials (excluding fossil fuels).⁴ IPCC guidelines recommend excluding biogenic CO₂ from inventory totals within each sector because those emissions are captured in the net fluxes (transfers of carbon from one pool to another over a certain amount of time) within the Land-use, Land Use Change and Forestry (LULUCF) sector. This approach presents a challenge because of the lack of certainty in the data and flux estimates used and quantified in the LULUCF sector. State level emissions estimates⁵ disaggregated from the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022 report have been included as totals for the LULUCF sector, but no sequestration or estimated biogenic CO₂ emissions are included within sector specific totals. Estimates of

² Source: EPA Overview of Greenhouse Gases: <https://www3.epa.gov/climatechange/ghgemissions/gases/n2o.html>

³ EPA - Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2022:

<https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022>

⁴ EPA Science Advisory Board – Carbon Dioxide Accounting for Emissions from Biogenic Sources:

<https://www.epa.gov/sites/default/files/2016-08/documents/biogenic-co2-accounting-framework-report-sept-2011.pdf>

⁵ EPA - State GHG Emissions and Removals: <https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals>

biogenic CO₂ are provided in several inventory sectors for informational purposes including ethanol and biodiesel in the Transportation/Mobile Sources sector, wood combustion and renewable natural gas in the Residential/Commercial/Industrial Fuel Use (RCI) sector, and wood combustion in the Electric sector, that show the emissions of biogenic CO₂ if they were counted at the point of combustion. However, this calculation has not been completed for every sector in the inventory.

An important distinction when considering accounting practices for biogenic CO₂ is that 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 associated with biogenic sources which moves between pools on the order of months to centuries, meaning that combusting fossil fuels releases carbon that was in long term storage and effectively out of circulation into the atmosphere and into the more immediate carbon cycle.⁶ Carbon dioxide emitted from the combustion or decomposition of biogenic materials, which are a part of the faster carbon cycle, are assumed to be sequestered by the regrowth of the biogenic material that produced them, and are captured in the flux from the land use change as described above. The distinction between short-term and long-term carbon storage is important to understand; however, depending on the timescales of carbon movement within the faster carbon cycle, the sequestration of CO₂ emitted by the combustion or decomposition of biogenic materials may be on a longer timescale than would be required to meet Vermont's mandated GHG emissions reductions.

2 Inventory Development and Methodologies Overview

Greenhouse Gas Emissions Inventory and Forecast reports are required by Vermont state statute 10 V.S.A. § 582 to establish a periodic and consistent inventory of greenhouse gas emissions for the state of Vermont. The inventory is required to incorporate data from a number of state agencies through collaborative processes and must be compatible with the Governor's Commission on Climate Change final report⁷. The Greenhouse Gas Emissions Inventory and Forecast reports also establish the 1990 and 2005 baseline GHG levels set forth in the Vermont Global Warming Solutions Act (GWSA) and are the metric which determines progress towards the State's emissions reduction requirements.

Estimates of emissions in the Greenhouse Gas Emissions Inventory and Forecast reports have been calculated using methodologies largely based on methods used in, or developed for, the *Greenhouse Gas Inventory and Reference Case Projections, 1990-2030*⁷ report and are compatible with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories⁸ and the

⁶ California Greenhouse Gas 2000-2020 Emissions Trends and Indicators Report: https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/2000-2020_ghg_inventory_trends.pdf

⁷ Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030: https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/Vermont_GHG_Emissions_Inventory_and_Projection_2007GovCommission_Report.pdf

⁸ IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. <https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/>

2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories⁹. 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, several default federal datasets are used to inform the emissions calculations. Where Vermont-specific data exist, the potential additional accuracy and granularity of the dataset is balanced with the need to keep the methodologies consistent through time. This approach keeps the Inventory as historically accurate and comparable as possible. It is important to note that each additional year of the Vermont GHG Inventory updates *all* of the historical values back to 1990 as appropriate, due to updates in historical federal datasets, methodology updates or refinements, or the incorporation and backward projection of the impacts of more accurate and/or Vermont specific datasets.

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 from the Vermont Agency of Transportation (VTrans), data from the Vermont Department of Forest Parks and Recreation (FPR), data from the Department of Taxes, data from the Vermont Joint Fiscal Office (JFO), and data submitted to EPA through the Greenhouse Gas Reporting Program (GHGRP).

To assist states in the comprehensive quantification of statewide anthropogenic greenhouse gas emissions EPA has created a tool and framework that both allows for ease of estimation as well as promoting consistency across state estimates. This state inventory tool (SIT)¹⁰ has been utilized for many sectors to calculate emissions estimates. There are a number of different modules within the SIT tool that generally correspond directly to emissions from the different inventory sectors. These SIT methodologies 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 that meet the minimum data requirements. The inventory also incorporates additional estimates from EPA, the most recent versions of which were published in January 2025, of state level emissions derived from disaggregating National Emissions Inventory data to a state level¹¹.

⁹ IPCC (2019) - *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*: <https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html>

¹⁰ [State Inventory and Projection Tool | US EPA](#)

¹¹ EPA (2024) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, EPA 430-R-24-004. <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022>.

2.1 Vermont GHG Methodologies and Data by Sector

2.1.1 Transportation/Mobile Sources

The Transportation and Mobile Sources sector includes 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, trucks, and other vehicles on Vermont roads, the use of aviation gasoline and jet fuel for aircraft, and emissions from non-road equipment like recreational vehicles, construction, logging and agricultural equipment, lawn equipment, boats, and rail. The current methodology used to calculate GHG emissions in the sector for the entire 1990 – 2022 time series covered in the inventory is through the use of two EPA SIT modules, one to estimate the emissions of CO₂ and one to estimate the emissions of CH₄ and N₂O.

Carbon dioxide emissions estimates are based on fuel combustion totals for onroad and nonroad transportation and mobile sources and rely on the EPA CO₂ from Fossil Fuel Combustion (CO₂FFC) SIT module, which is also used for estimating emissions of CO₂ in the residential/commercial/industrial (RCI) fuel use sector. This tool uses estimates of energy consumption (based on fuel volumes) in the Transportation/Mobile Sources sector by fuel type and multiplies them by the carbon content of each fuel. The main fuels which contribute to the emission totals include motor gasoline, distillate fuel (diesel), and aviation gasoline and jet fuel, but also include smaller amounts of propane, natural gas, and the use of fossil fuels as lubricants.

The default data in the module are from the Energy Information Administration State Energy Data System (SEDS).¹² dataset, which is a federal source of comprehensive state energy statistics data that provides estimates of energy consumption by state. Input data is expressed in units of energy consumption by sector and fuel type in billions of British thermal units (Btu). The amount of gasoline and onroad (non-dyed) diesel fuel sold in Vermont is available and reported through the Joint Fiscal Office.¹³ JFO gasoline totals are available for 1993 onward and are used to derive energy use from motor gasoline utilized in the CO₂FFC module, after first adjusting the values to remove the approximate contribution from aviation gasoline and ethanol. Annual totals for 1990 through 1992 are projected backwards from 1993 based on percent changes in SEDS totals for the category. In previous versions of the GHG Inventory, onroad diesel estimates were taken from SEDS. However, in the 1990-2022 iteration of the GHG Inventory, diesel sales data from JFO have been incorporated into the inventory to capture the use of onroad diesel, after being adjusted to remove the estimated biodiesel component of the fuel, which is still taken from SEDS. Onroad diesel values from JFO are available from 2001 onward with the totals before 2001 also projected back to 1990 using percent changes from the corresponding SEDS dataset. With the incorporation of more granular data from the Vermont Department of Taxes into the latest Vermont GHG Inventory it has been possible to disaggregate and transfer the portion of GHG emissions related to nonroad diesel use that were previously included in the RCI industrial subsector into the transportation sector. Data enabling the disaggregation of the nonroad diesel (“other dyed diesel” category) from the heating fuel in the Tax Department data has only been

¹² Energy Information Administration – State Energy Data System (SEDS): <https://www.eia.gov/state/seds/>

¹³ Vermont Joint Fiscal Office – Gasoline and Diesel Gallons Sold: <https://ljfo.vermont.gov/subjects/transportation/monthly-data>

available since a recent update to reporting form FGR-615 and so disaggregated values have been available since July 2023. These data were used to determine an annual percentage of the total and applied to historical values to determine the nonroad diesel percentage to be added to the transportation component totals. Additional datasets from SEDS and the Energy Information Administration (EIA) were used to inform the Btu consumption estimates for remaining categories which include fuels such as jet fuel and aviation gasoline.

Emissions of CH₄ and N₂O are calculated differently from the CO₂ component. Estimation methods of some pollutants, such as CH₄ and N₂O, 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 CH₄ and N₂O Emissions from Mobile Combustion module. This module calculates emissions from onroad transportation using vehicle miles traveled (VMT) estimates 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 are used for the vehicle age distributions and engine emissions control technologies, but the default VMT data are adjusted using vehicle class percent compositions from the Federal Highway Administration (FHWA) and applying them to Vermont specific VMT data from VTrans that goes back to the 1990 baseline.

2.1.2 Residential/Commercial/Industrial (RCI) Fuel Use

The majority of greenhouse gas emissions from the Residential/Commercial and Industrial Fuel Use (RCI) sector are related to fossil fuels used for space heating, water heating, and cooking, in residential, commercial, and industrial buildings. Emissions are mostly CO₂ from the use of fuel oil, propane, and natural gas but also include methane (CH₄) and nitrous oxide (N₂O) from wood combustion, as well as GHG emissions from less common fuels like kerosene, and coal. The industrial subsector of the RCI sector previously included diesel fuel used in several nonroad categories such as off-highway construction, and logging operations, but with the incorporation of more granular data from the Vermont Department of Taxes it was possible to transfer this portion of fuel to the nonroad component of the transportation sector, as described in the Transportation/Mobile Sources sector. Emissions estimates in the RCI sector are calculated for the entire time series using two EPA SIT modules, one to estimate emissions of CO₂ and the other for emissions of CH₄ and N₂O. Emissions of CO₂ from wood combustion or the use of other biofuels is not included in the gross totals of the GHG inventory reports as it is considered biogenic. See Section *1 Introduction: Foundational Information* for additional discussion related to biogenic CO₂ emissions.

The SIT module used to calculate all the CO₂ emissions from the sector is the CO₂ from Fossil Fuel Combustion (CO₂FFC) module. The calculation methodology for this module multiplies the estimated total energy consumption in billion Btu for each applicable subsector (residential/ commercial/ industrial) and fuel type by a fuel specific emission factor and then by a combustion efficiency value. The input data for heating oil, propane, and kerosene used for the RCI sector in this module are now based on data from the Vermont Department of Taxes form FGR-615. This full dataset is available back to 2017 with partial data back to 2015. Related data prior to 2015

are not comparable and so were not utilized. For years prior to 2015 SEDS data from the different subcategories has been aggregated into totals by corresponding fuel (distillate, propane, kerosene) for the entire RCI sector and then the historical annual values have been adjusted based on the average percent difference between the SEDS values and Tax Department values for years where there was overlapping data (2017 – 2021). These adjusted SEDS values were then disaggregated into the original SEDS categories for incorporation into the CO₂FFC SIT module. Tax Department values for 2015 – 2022 were also disaggregated using SEDS percentages for input into the CO₂FFC SIT module since the data as reported is not allocated to the residential, commercial, and industrial subsectors. As mentioned above, the “other dyed diesel” category in the Tax Department data, which represents the nonroad diesel use, was removed from totals in the RCI industrial subsector. Additional datasets from SEDS and the Energy Information Administration (EIA) were used to inform the Btu consumption estimates for some of the smaller remaining categories which differ by fuel and by year but are generally based on national level reporting of sales data that are presented by state.¹⁴ Once all inputs are adjusted and entered into the CO₂FFC module, emissions estimates are calculated and converted into units of MMTCO₂e within the tool.

The SIT module utilized in the RCI sector to calculate emissions of CH₄ and N₂O is the Methane and Nitrous Oxide Emissions from Stationary Combustion module. The methodology to calculate emissions in this module is similar to the CO₂FFC module. Emissions are calculated by multiplying the estimated total energy consumption in billion Btu for each applicable subsector (residential/commercial/industrial) and fuel type by a fuel and GHG specific emission factor. Data utilized in this module are default data from the EIA SEDS dataset in billions of Btu. Energy estimates from wood combustion for the commercial and industrial subsectors are calculated from data submitted to the ANR-DEC Air Quality and Climate Division as a part of their Point Source Registration program¹⁵ and estimates of energy from wood combustion in the residential subsector are derived from Vermont Residential Fuel Assessment reports.¹⁶ Emissions estimates are then converted into units of MMTCO₂e within the SIT module by using conversion factors and multiplying by the GWP value for each gas as appropriate.

2.1.3 Agriculture

The agriculture sector of the GHG inventory accounts for emissions of CH₄ and N₂O from agricultural practices in the state, including animals and crop production. Carbon dioxide in this sector that is produced in processes like the management of manure in a solid form or from manure that is deposited on pasture, range, or on paddock lands and decomposes in the presence of oxygen, is almost exclusively biogenic, and so not included in the sector totals. The CO₂ that

¹⁴ EIA SEDS – “Technical notes & documentation - complete 2018” – Section 4: Petroleum:
https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf

¹⁵ VT Agency of Natural Resources – Air Quality and Climate Division – Point Source Registration Program:
<https://dec.vermont.gov/air-quality/point-source-registration>

¹⁶ 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

is included in the sector is the CO₂ associated with liming and urea fertilization. The subsectors of the agriculture sector include enteric fermentation (CH₄ produced as a part of the digestive process of ruminant animals), manure management, agricultural soils, rice cultivation, liming of soils, urea fertilization, and agricultural residue burning, although not all subsectors have associated values or emissions within Vermont.

Greenhouse gas emissions estimates in the Agriculture sector are calculated for the entire 1990 – 2022 time series using the Carbon Dioxide, Methane, and Nitrous Oxide from Agriculture SIT module. Most of the emissions in the sector are related to the size of animal populations and the enteric fermentation and management of manure associated with those animals, but emissions from agricultural soils are included that are based mainly on acres of crops and fertilizer use. Emissions from enteric fermentation are calculated using total animal populations by animal type multiplied by default region-specific per animal emission factors in the tool. Methane and nitrous oxide emissions related to manure management involve estimating the waste produced for the animal populations using the number of animals and assumptions of average animal mass and multiplying by emission factors for volatile solids production (the organic fraction of totals solids in manure that will oxidize and be driven off as a gas at a temperature of 1,112°F) and maximum CH₄ production potential, which depends on the associated manure management system. Agricultural soil emissions 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 SIT module are almost exclusively default data from various US Department of Agriculture datasets including livestock population and crop data from the National Agriculture Statistics Service. One adjustment is made to account for the CH₄ from waste that is estimated to enter anaerobic digester facilities. Manure in an anaerobic digester produces emissions of CH₄ but when that CH₄ is combusted in the process it produces CO₂, which per IPCC inventory guidelines is considered biogenic and so is not included in the inventory totals. In previous versions of this inventory, dairy cow population adjustments to account for anaerobic digesters were completed for the entire manure management subsector and resulted in lower emissions of both CH₄ and N₂O due to the way the EPA SIT calculations are performed. In this latest inventory, dairy cow population adjustments were only made to the CH₄ portion of the manure management calculations, thereby only reducing CH₄ emissions from manure managed in anaerobic digesters. This omission in previous inventories, which amounts to a small actual emission of N₂O, was flagged during a project completed by a contractor (ICF) to review agricultural tools and datasets for Vermont and to provide a recommendation for how to best account for emissions from the Agriculture sector using the most appropriate tools and datasets. This project was completed in collaboration between ANR, the Agency of Agriculture Food and Markets (AAFM) and a contractor.

Additional suggestions were made in the report for improving the Agriculture sector of the GHG Inventory but given the timing of the finalizing of the report and the creation of the latest iteration of the GHG Inventory (1990 – 2022) it was not possible to incorporate all of the suggested refinements. Based on recent discussions with AAFM staff, two refinements to the default SIT data were made for calculating the 1990 – 2022 GHG emissions from the Agriculture sector. These included modifying the default manure management storage percentages by storage type to account for the absence of the use of storage lagoons in Vermont, as well as zeroing out an erroneous spike in the liming data that occurred in the 2007 default data. These

modifications resulted in relatively small changes to emissions but improve the overall accuracy of the inventory. ANR will work with AAFM to implement additional changes to the extent possible and practicable in future inventories to update the current methodology, or develop a different methodology, to more accurately represent emissions from anaerobic digesters and other manure management practices in VT, as well as a method to capture impacts of additional agricultural management practices.

The agriculture sector is the only sector included within the current gross inventory framework where sequestration by vegetation and soils within the boundaries of the sector itself is a critical component. Because of the current gross emissions accounting framework, sequestration is not included in the inventory totals within the agriculture sector. If it were, it could be offsetting some portion of the gross emissions calculated using the SIT module. Sequestration and the potential to increase sequestration in the agriculture sector is important because reducing gross emissions within the sector is difficult while maintaining viable farms which are an important climate strategy for building resilience on the landscape. It is also important because many of these practices that enhance agricultural soils have both GHG emissions benefits as well as other co-benefits, such as improving water quality. The Land-use, Land Use Change, and Forestry (LULUCF) sector does include estimates of carbon fluxes related to agriculture, specifically in the cropland, remaining cropland, and land converted to cropland categories, but those net totals are provided as supplemental information which are not included in the official inventory totals for the sector and are currently coarse representations of the agricultural landscape in the state. Updated IPCC guidelines recommend including the Agriculture sector within the LULUCF sector as an Agriculture, Forestry, and Other Land Use (AFOLU) sector, but this has not yet been done in the Vermont GHG inventory. ANR is planning to collaborate with AAFM and to discuss options to provide additional or alternative accounting frameworks which would more clearly reflect the sequestration and emissions of agricultural management practices, land use changes, and soil carbon related to the agriculture sector. The Vermont Carbon Budget¹⁷ is an additional analysis that was completed as a part of the original Climate Action Plan process to produce and inform agriculture sector estimates in Vermont, as well as other land use related estimates, and is an important foundation for improving estimates in the sector.

2.1.4 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 hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF₃), sulfur hexafluoride (SF₆), and CO₂. Totals in this sector are estimated using two different methodologies which include the Industrial Processes SIT module and emissions data reported to

¹⁷ A Carbon Budget for Vermont: Task 2 in Support of the Development of Vermont's Climate Action Plan: [https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/\(10\)%20Carbon%20Budget.pdf](https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/(10)%20Carbon%20Budget.pdf)

EPA through the Greenhouse Gas Reporting Program (GHGRP) for the semiconductor manufacturing subsector.

Emissions related to substitutes for ODS are associated with HFCs present in end uses like refrigeration equipment, air conditioning equipment, aerosol propellants, and foams. High GWP HFCs have been incorporated into many of 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 often have very high GWP values, many of them thousands of times more potent than CO₂ in their ability to warm the planet.

Estimates of GHG emissions from the ODS Substitutes sector were previously derived from a tool developed by California for use by U.S. Climate Alliance (USCA).¹⁸ The tool was based on a detailed fluorinated gas (F-gas) model¹⁹ which estimated annual HFC emissions from equipment by type and apportioned them to a per capita value that could be applied to states and modified using several state specific variables. The tool is not being updated and is unable to incorporate, or be modified to account for, the change in GWP values from AR4 to AR5. Because of the inability of the CA tool to adjust to these GWP changes coupled with the fact that the EPA SIT IP module estimates for the sector have been improved, the SIT values are now being utilized in the GHG Inventory. The estimates in the SIT are sourced directly from the EPA state level GHG estimates disaggregated from the national inventory report. The methodology utilized in the Inventory of U.S. Greenhouse Gas Emissions and Sinks and the state level disaggregation²⁰ is similar to that previously utilized in the CA tool and relies on a Vintaging Model to generate estimates of the use of ODS substitutes (including HFCs, PFCs, CO₂, and blends that contain these substances) based on various equipment end uses and the amount of required chemicals and leakage or release values. These estimates are distilled to per capita values which are then modified at a regional level to produce values for individual states. These modifications are related to differing rates of equipment usage (e.g. rates of home air conditioning use are not equal across the country) and based on ground and air level measurement comparisons to expected emissions from inventory estimates.

Greenhouse gas emissions related to semiconductor manufacturing include HFCs, PFCs, SF₆, and NF₃ and are taken from emissions totals reported to EPA through the GHGRP which requires annual reporting of GHG emissions by applicable sources and facilities.²¹ Emissions of the F-gases in semiconductor manufacturing occur in the plasma etching and chemical vapor

¹⁸ The U.S. Climate Alliance is a bipartisan coalition of governors committed to reducing greenhouse gas emissions consistent with the goals of the Paris Agreement. <https://www.usclimatealliance.org/>

¹⁹ California Air Resources Board – California’s High Global Warming Potential Gases Emission Inventory – Emissions Inventory Methodology and Technical Support Document (2015 edition): https://www.arb.ca.gov/cc/inventory/slcp/doc/hfc_inventory_tsd_20160411.pdf

²⁰ Methodology Report for Inventory of U.S. Greenhouse Gas Emissions and Sinks by State - 3.4.2 Substitution of Ozone-Depleting Substances (NIR Section 4.24): <https://www.epa.gov/system/files/documents/2023-09/Methodology-Report-3-Industrial-Process-and-Product-Use.pdf>

²¹ EPA – Greenhouse Gas Reporting Program (GHGRP): <https://www.epa.gov/ghgreporting>

deposition processes²², and through the use of heat transfer fluids. It should be noted that historically a number of these high GWP gases were incorporated into the manufacturing process in order to phase out toxic gases that were more hazardous to human health.

The GHGRP emissions estimates for semiconductor manufacturing in the inventory are pulled directly from the EPA Facility Level Information on Greenhouse gases Tool (FLIGHT) for all available years (2011 through 2022).²³ Emissions totals from before 2011 are estimated by projecting reported 2011 emissions totals backwards through time to 1990 based on state level estimates⁵ disaggregated from the National Inventory of U.S. Greenhouse Gas Emissions and Sinks³ report for electronics manufacturing generated by EPA.

The remaining subsectors within the Industrial Processes sector in Vermont are 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 SIT IP 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 SF₆ used as an insulator in electric power transmission and distribution equipment are based on an estimate of the quantity of SF₆ consumed annually, multiplied by an assumed leakage emission factor.

2.1.5 Electricity Consumption

The electric sector is comprised of emissions estimates from electricity generation based on the amount of electricity purchased by Vermont utilities for consumption by Vermonters, 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 because of the interrelated nature of the New England power grid.²⁴ Calculations of the GHG emissions from the electricity sector are performed using a methodology previously developed in collaboration with the Vermont Public Service Department that incorporates information on electric purchases by generation type by megawatt hour (MWh) and emissions factors by generation type. The electric sector is the only sector in the inventory that accounts for emissions that are produced outside the boundaries of the state, but these out-of-state emissions only include emissions that occur at the point and time of electricity generation and, similar to all other sectors in the inventory, do not include any estimates of lifecycle or upstream emissions.

The after-the-fact deliveries of utilities by generation type and kilowatt hour (kWh) totaling the annual electric load for Vermont (Ownload) is provided by the Vermont PSD, which includes

²² EPA State Inventory Tools – User’s Guide for Estimating carbon dioxide, nitrous oxide, HFC, PFC, NF₃, and SF₆ emissions from Industrial Processes using the State Inventory Tool: <https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool>

²³ EPA FLIGHT Tool: https://ghgdata.epa.gov/ghgp/main.do?site_preference=normal

²⁴ Some states utilize the amount of in-state generation for determining GHG emissions from the electric sector. Currently, Vermont consumes more than three times as much electricity as it generates, on an annual basis. See, EIA – State Profile and Energy Estimates: <https://www.eia.gov/state/?sid=VT>

adjustments for renewable energy certificate (REC) retirements. These kWh totals are converted to MWhs and multiplied by annual average emission factors in pounds per megawatt hour MWh by generation type from the New England Power Pool Generation Information System (NEPOOL GIS).²⁵ Residual Mix reports. Renewable generation sources, including wind, solar photovoltaic, and hydropower, are considered to emit no GHG emissions at the point of generation for the purposes of this inventory, and nuclear generation is also considered to be zero GHG emitting. Carbon dioxide from electricity generated through biomass combustion is not included because the CO₂ is of biogenic origin, but CH₄ and N₂O emissions are included in the totals. States in the region differ on this accounting practice, however, it is consistent with IPCC inventory guidelines for the treatment of biogenic CO₂.

Historical emissions calculations in the electric sector are somewhat less certain than estimates after 2002. For totals before 2002, NEPOOL GIS Residual Mix emission factor data were not available, so emissions rates by fuel type were projected backwards to 1990. Utility Ownload data were available on a fairly consistent basis throughout the time series, with several gaps for which emissions estimates were interpolated, most notably from 2006 through 2009. The methodology is consistent through the entire time series, but the uncertainty in the emission factors applied increases farther back in time.

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.²⁶ Required renewability portfolio percentages increase from 55% in 2017 to 75% in 2032.²⁷ Modifications to the Renewable Energy Standard (Act 179) were passed by the Vermont legislature in June 2024 and contain more ambitious requirements around in-state renewable energy generation as well as requiring utilities to provide 100% renewable electricity to their customers by 2035.²⁸ the impacts from which should eventually be visible in the GHG Inventory. 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.

Renewable energy certificates, which are used by distribution utilities to meet the RES requirements, are a market-based tool that represent the environmental attributes of renewable electricity generation. A REC is issued when one MWh of electricity is generated by a defined and certified renewable generation unit and delivered to the grid. The market for RECs is separate from the energy market and they are the accepted legal mechanism for tracking, accounting for, and substantiating claims of renewable energy generation and use.²⁹ Accounting

²⁵ NEPOOL GIS – Public Reports – NEPOOL Residual Mix: <https://www.nepoolgis.com/public-reports/>

²⁶ Vermont Renewable Energy Standard: <https://legislature.vermont.gov/statutes/chapter/30/089>
Public Service Department website: https://publicservice.vermont.gov/renewable_energy/state_goals

²⁷ Vermont Public Utility Commission: <https://puc.vermont.gov/electric/renewable-energy-standard>

²⁸ No. 179. An act relating to the Renewable Energy Standard:
<https://legislature.vermont.gov/Documents/2024/Docs/ACTS/ACT179/ACT179%20As%20Enacted.pdf>

²⁹ EPA Green Power Partnership: <https://www.epa.gov/greenpower/renewable-energy-certificates-recs>

for REC retirements in quantifying emissions from electricity consumption acknowledges the regional nature of the electric grid. Specifically, because Massachusetts, Connecticut, and Rhode Island all include REC adjustments in their GHG inventory methodologies, attempting to quantify Vermont emissions using a methodology that doesn't account for REC adjustments would likely result in the Vermont inventory including the zero-emission generation that was also claimed as zero emission by another state in the region.

The accounting decisions associated with emissions of CO₂ from wood combustion for electricity generation in Vermont are related to issues surrounding biogenic CO₂ and the REC accounting methodology used in the electric sector. This issue is made more relevant because of two electric generation facilities that rely mainly on wood for their generation energy source. Even though the emissions from these two facilities occur within the state, they are not included in the inventory totals for two reasons. The first is because the combustion of wood for electricity generation produces CO₂ that is considered biogenic, and no biogenic CO₂ is included in the GHG inventory totals per IPCC inventory guidelines³⁰ because it is assumed that the carbon will be captured in the fluxes in the land-use, land use change and forestry sector, and that the CO₂ released will eventually be re-sequestered through the regrowth of the biogenic material. The other reason is that under the current methodology for the electric sector, which includes adjustments for REC purchases and retirements, there are very few MWhs in the electricity purchased for consumption associated with wood generation in Vermont as the RECs from these facilities are sold to utilities outside Vermont. Biogenic CO₂ emissions from these sources would be included in the GHG inventories of the other states in the region if they were accounted for at the point of combustion (and some are), but they would also be captured in the LULUCF sector of the Vermont inventory to the degree that the biomass used in these facilities was sourced within Vermont.

2.1.6 Waste

Emissions of greenhouse gases associated with the waste sector include CH₄ and N₂O 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. Emissions estimates for the sector are calculated and compiled using several tools and methodologies including the SIT modules, state level data disaggregated from the U.S. National inventory data and reported landfill gas totals.

Calculations of the CH₄ and N₂O emissions from the wastewater subsector are completed using the EPA SIT Wastewater module and include CH₄ from municipal wastewater, direct N₂O from municipal wastewater, and N₂O from biosolids. Currently the tool is being used with default values provided by EPA with the exception of Vermont-specific 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)³¹ The SIT

³⁰ IPCC Guidelines for National Greenhouse Gas Inventories (2006): <https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/>

³¹ WMPD report: <https://dec.vermont.gov/sites/dec/files/wmp/residual/RMSWhitePaper20180507.pdf>

methodology is population-based and depends on calculated per capita values and emission factors for variables such as percentage of organic content in wastewater, protein consumption and nitrogen content, and CH₄ and N₂O emission factors. Details on the methodologies and calculations can be found in the User's Guide for the Wastewater SIT module.³² Estimates for the industrial wastewater component have been extracted from the EPA state level GHG estimates⁵ which were disaggregated from the U.S. National Emissions Inventory totals, because no default data were available in the SIT module.

The GHG emissions estimates for the solid waste subsector are derived from two different methodologies. Totals from 2009 and later use a methodology based on reported landfill gas (LFG) totals, when the data first became available. The two largest landfills in Vermont are in Coventry and Moretown, but the Coventry landfill is the only remaining open landfill in the state. Both landfills have landfill gas to energy (LFGTE) systems and are also required to register with the Vermont DEC Air Quality and Climate Division, along with two other smaller closed landfills with LFGTE systems that have also provided data previously. Methane emissions are estimated based on the reported annual LFG totals for the reporting facilities and are used to estimate the total CH₄ combusted in engines or flares versus the amount that escapes as fugitive. Landfill gas is produced from the decomposition of organic materials in landfills and is composed of approximately 50% methane and 50% biogenic CO₂ by volume, with trace amounts of non-methane organic compounds and volatile organic compounds. When the LFG is combusted either in a flare or in the LFGTE engines the CH₄ component is converted to CO₂ and because the generated CO₂ emissions are related to the decomposition of biogenic material within the landfill, they are considered biogenic and are not included in the gross emissions totals for the sector per EPA and IPCC guidelines, but are instead at least partially captured in the LULUCF sector. Fugitive CH₄ emissions and the portion not actually combusted by the flares or LFGTE systems is converted to MMTCO₂e to come up with an emissions value. In earlier versions of the inventory, the solid waste emissions for 2009 onward were increased by 15% each year, which was a previously recommended value from the Waste Management and Prevention Division, to account for all of the smaller closed landfills in the state that may still be emitting some level of fugitive LFG. An alternative method was used in the previous and in this most recent inventory in an attempt to more accurately estimate annual emissions from 2009 through 2022 from these smaller closed landfills. The U.S. EPA Landfill Gas Emissions Model (LandGEM version 3.03) was populated with available data for the smaller closed landfills including parameters such as landfill open date, landfill closure date, and total waste in place. Lacking more granular data, the tonnage of waste in place at each closed landfill was divided by the number of years of operation and assumed to be deposited in equal amounts each year from open date to closure date to estimate annual waste acceptance rates, which were needed to model the emissions in LandGEM. Further assumptions were made wherever sufficient data were lacking for a specific landfill to successfully run LandGEM. A small number of these closed landfills were noted to have onsite LFG combustion control devices, such as passive flares. For these six closed smaller landfills, an assumption was made that methane emissions are reduced by 50 percent. Due to the large number of closed landfills in Vermont and the relatively coarse level of data available for these estimates the closed landfills were grouped together with

³² EPA State Inventory Tool – Wastewater User's Guide: https://www.epa.gov/sites/production/files/2020-10/documents/wastewater_users_guid.pdf

landfills with similar open and closure dates to allow for fewer overall runs of the LandGEM model while maintaining a reasonable level of accuracy. Emissions estimates from these closed landfills were then summed and added to the post 2009 totals from the LFGTE calculations in place of the previously utilized 15% adder.

Historical estimates from before 2009 are from calculations completed for the 2007 *Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030* report using a previous version of the EPA SIT module for solid waste that have been adjusted for changes in GWP values since that report was released. The SIT module is based on LFG generation estimates that rely on waste-in-place totals, rather than on reported LFG values based on an amount of gas passing through engines or flares and already include estimates for closed landfills. The calculation methodology used for estimates before 2009 are not the same as those after 2009 but reported LFG totals were assumed to be more accurate than attempting to estimate the LFG generation based on waste in place data, so the methodology change was adopted.

Estimates of CH₄ emissions from composting have also been included and were taken from the EPA state level data based on the disaggregation of the National Inventory of U.S. Greenhouse Gas Emissions and Sinks report totals.

Emissions from the waste sector, and specifically the solid waste sector, are important to understand in a more holistic way. IPCC inventory guidance calls for the CO₂ emitted from the decomposition of materials in landfills to be considered biogenic and omitted from gross inventory totals. The more products and materials people consume and throw away the greater these biogenic CO₂ emissions will become. Materials recycling and diversion efforts can therefore impact overall GHG emissions from the waste sector, even though not accounted for in this inventory. Understanding details of consumption habits and the GHG emissions implications of personal choices will be critical to enable meaningful and lasting emissions reductions in this space. Work has continued through a collaborative project with EPA and several states in the northeast region to produce a consumption-based inventory that will provide information related to emissions from consumption in the state.

2.1.7 Fossil Fuel Industry

Emissions of greenhouse gases from the fossil fuel industry sector are relatively low in Vermont because there is no production or refining of petroleum occurring in the state. 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.

Emissions of CH₄ from the transmission subsector are related to leakage of NG from transmission lines in the state and are calculated using the Natural Gas and Oil SIT module. The total miles of transmission lines are multiplied by an emission factor as a leakage rate per mile by 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).³³

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 by material type are developed by EPA, as published in the Electronic Code of Federal Regulations (e-CFR).³⁴ and are multiplied by the number of services and miles of applicable distribution line from PHMSA to come up with annual emissions of CH₄ from the NG distribution system. This CH₄ total is then converted to MMTCO₂e for a total from the subsector.

2.1.8 Land Use, Land-Use Change, and Forestry

The Land-use, Land use Change, and Forestry (LULUCF) sector is an important component for understanding a more holistic picture of greenhouse gas emissions in the state of Vermont, but is also very difficult to accurately quantify. This is the main reason that the official GHG emissions inventory totals use a gross accounting framework instead of a net framework (which excludes carbon sinks). A large amount of carbon is sequestered by forests and other vegetation types as they remove CO₂ from the atmosphere and convert it into stored biological material through photosynthesis, but forest processes and changes in land use can also emit CO₂ as well as other GHGs like CH₄ and N₂O. Changes between land use types, such as converting areas to forest, draining wetlands, converting areas to agricultural land, and clearing forests for development, all have impacts on the amount of carbon and CO₂ either emitted to the atmosphere or sequestered within a system. Because these carbon fluxes from land use and land-use change are related to complex systems and ecosystems, reliable, accurate, and repeatable quantification on a statewide scale and on an annual basis is difficult. The difficulty in understanding and quantifying the changes and carbon fluxes from these complex systems is exacerbated by other factors that affect landscapes and ecosystems such as drought, heat, and flooding, that impact the health of forests, soils, crops, and overall ecosystem functionality.

Based on the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 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. Updated 2006 IPCC inventory guidelines and the 2019 refinement to those guidelines recommend incorporating the agriculture sector into the LULUCF sector for the creation of an Agriculture, Forest, and Other Land Use sector recognizing that processes and practices related to emissions and sequestration in the natural and working lands (NWL) space often influence both of these

³³ PHMSA – 2010+ Pipeline Miles and Facilities: <https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-mileage-and-facilities>

³⁴ 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

sectors. This aggregation of the two sectors has not yet been incorporated into the Vermont GHG inventory because of the challenge to accurately quantify emissions and fluxes from land-use and land use change, especially on an annual basis. Emissions estimated exclusively for the agriculture sector on a gross basis using methodologies consistent with the previous IPCC guidelines are based on data that is more concrete, such as animal populations and fertilizer application, and can be quantified and tracked more accurately. This separation has also been maintained within the EPA SIT modules for Agricultural emissions and LULUCF calculations. Understanding that there is a very real connection between the agriculture sector and the carbon fluxes related to land use changes a project has been completed in collaboration with AAFM where a contractor investigated tools and datasets and provided recommendations to ANR on ways to improve and enhance the agriculture sector of the GHG Inventory both within the current framework and also suggestions regarding the use of a net framework and the utilization of additional tools and datasets. This report will be available on ANR's website (<https://climatechange.vermont.gov/>) A previous investigation into a net framework methodology and the creation of an AFOLU for the state has been completed in the Vermont Carbon Budget that was used to help inform the Vermont Climate Action Plan and certain components of the LULUCF sector of the inventory.

In historic GHG Inventory reports only estimates of net sequestration associated with forests were included as opposed to emissions or fluxes from land-use change or processes from other land use classifications. A more complete LULUCF sector has been included in the previous (1990 – 2021) GHG inventory report and the current 1990 – 2022 report based on state level data now being estimated and released by EPA. Forest data estimates used in this sector are produced by the U.S. Department of Agriculture, Forest Inventory and Analysis program³⁵ and are related to carbon flux estimates for Forest Land Remaining Forest Land, Land Converted to Forest Land, Forest Land Converted to Land, and Urban Trees in Vermont. Values for the carbon fluxes from the remaining land use categories and land use conversions between types, including croplands, grasslands, wetlands, and settlements, are taken from calculations for the Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990 – 2021) report that have been disaggregated to state levels by EPA¹¹. Detailed information on the methodology for these estimates can be found in the Methodology Report for Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990 – 2021 document from EPA²⁰.

Several changes were made to the methodology compared to last year's report to improve alignment with EPA guidance and better reflect Vermont-specific data. This year's net forest carbon flux values include three land use and land use change categories: Forest Remaining Forest, Land Converted to Forest, and Forest Converted to Other Land, as outlined in the EPA's State Inventory Tool (SIT). Similarly, updates were made to the Agricultural Soil Carbon Flux methodology. The 2025 inventory includes four land use categories: Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, and Land Converted to

³⁵ Domke, Grant M.; Walters, Brian F.; Giebink, Courtney L.; Greenfield, Eric J.; Smith, James E., Nichols, Michael C.; Knott, Jon A.; Ogle, Stephen M.; Coulston, John W.; Steller, John. 2023. Greenhouse gas emissions and removals from forest land, woodlands, urban trees, and harvested wood products in the United States, 1990-2021. Resour. Bull. WO-101. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 10 p. <https://doi.org/10.2737/WO-RB-101>.

Grassland. Lastly, Vermont-specific data were incorporated to improve estimates of carbon storage in landfilled yard trimmings and food scraps. Data from the 2022 Diversion and Disposal Report³⁶, published by the Waste Management and Prevention Division, along with composition percentages from the 2018 Vermont Waste Composition Study³⁷, were used to quantify the carbon content of landfilled yard trimmings and food scraps. Because the SIT module requires input data dating back to 1960, historical disposal values were extrapolated using percent changes from the SIT default dataset for the period 1960 to 1987. These adjusted values were then used as inputs to the SIT module for carbon storage calculations.

3 Alternative Methodologies and Emissions Forecasts

3.1 20-Year GWP Values

One other framework for understanding emissions impacts is to assess emissions on different timescales, rather than the 100-year timescale. The 20-year GWP is one such alternative that was recommended as a sensitivity analysis in the Vermont Climate Action Plan. Using 20-year GWP values prioritizes gases that have atmospheric lifetimes shorter than that of CO₂, because the values are focusing the warming impact of the gas to a timeframe closer to the atmospheric lifetime of the gas, rather than spreading the warming impact of the gas over a greater number of years. Methane is the GHG in the inventory for which this change has the most dramatic effect with a change from the AR5 100-year GWP multiplier value of 28 to an AR5 20-year GWP of 84. Other short-lived and high GWP gases, such as those in the ODS Substitutes and Semiconductor Manufacturing portions of the Industrial Processes sector also show substantial increases in emissions totals in the 20-year GWP scenario.

³⁶ [2022 Diversion and Disposal Report | Department of Environmental Conservation](#)

³⁷ <https://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/2018-VT-Waste-Characterization.pdf>

Table 2: GHG Estimates by Sector for select years using AR5 20-year GWP values.

Sector	Emissions in MMTCO ₂ e									
	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Electricity Supply & Demand (consumption based)	1.09	0.77	0.44	0.64	0.43	1.01	0.32	0.25	0.18	0.22
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	0.02	0.00	0.01	0.02	0.00	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	0.00
Wood (CH ₄ & N ₂ O)	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Residual System Mix	1.03	0.75	0.35	0.62	0.37	0.97	0.30	0.24	0.17	0.21
Residential / Commercial / Industrial (RCI) Fuel Use	2.40	2.41	2.89	2.96	2.50	2.75	2.94	2.99	2.81	2.78
Coal	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.32	0.38	0.50	0.44	0.45	0.64	0.75	0.76	0.71	0.72
Oil, Propane & Other Petroleum	1.86	1.80	2.20	2.30	1.80	1.83	1.89	1.94	1.79	1.78
Wood (CH ₄ & N ₂ O)	0.19	0.22	0.19	0.22	0.25	0.28	0.30	0.30	0.31	0.27
Transportation	3.51	4.05	4.08	4.35	3.68	3.58	3.52	3.51	3.02	3.25
Motor Gasoline (Onroad and Nonroad) (CO ₂)	2.54	2.74	3.00	3.05	2.63	2.48	2.44	2.42	2.01	2.19
Diesel (Onroad and Nonroad) (CO ₂)	0.72	1.07	0.84	1.02	0.88	0.94	0.95	0.95	0.89	0.92
Hydrocarbon Gas Liquids, Residual Fuel, Natural Gas (CO ₂)	0.00	0.00	0.00	0.00	0.00	0.01	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	0.09
Non-Energy Consumption - Lubricants (CO ₂)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
All Mobile (CH ₄ , N ₂ O)	0.15	0.16	0.14	0.12	0.08	0.05	0.05	0.05	0.04	0.05
Fossil Fuel Industry	0.06	0.06	0.05	0.06	0.06	0.06	0.09	0.09	0.09	0.09
Natural Gas Distribution	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Natural Gas Transmission	0.04	0.04	0.04	0.05	0.05	0.05	0.08	0.08	0.08	0.08
Industrial Processes	0.16	0.32	0.43	0.39	0.39	0.54	0.49	0.49	0.53	0.59
ODS Substitutes*	0.00	0.05	0.14	0.19	0.21	0.31	0.30	0.29	0.32	0.33
Electric Utilities (SF ₆)	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Semiconductor Manufacturing (HFCs, PFCs & SF ₆)	0.12	0.20	0.25	0.16	0.14	0.19	0.16	0.17	0.18	0.19
Limestone & Dolomite Use	0.00	0.03	0.02	0.03	0.02	0.03	0.01	0.02	0.02	0.05
Soda Ash Use	0.01	0.01	0.01	0.01	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	0.84	1.03	1.14	1.08	1.11	0.70	0.64	0.62	0.61	0.62
Solid Waste	0.71	0.90	1.00	0.93	0.95	0.55	0.48	0.47	0.45	0.45
Composting	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Wastewater	0.13	0.13	0.14	0.14	0.15	0.14	0.14	0.14	0.15	0.15
Agriculture	2.93	2.82	3.13	3.16	3.13	3.34	3.42	3.43	3.26	3.21
Enteric Fermentation	2.27	2.17	2.26	2.06	2.01	2.07	2.12	2.11	2.02	2.00
Manure Management	0.37	0.41	0.65	0.87	0.87	0.92	0.98	0.99	0.94	0.90
Agricultural Soils	0.29	0.24	0.23	0.23	0.24	0.30	0.28	0.29	0.25	0.25
Liming and Urea Fertilization	0.00	0.00	0.00	0.00	0.01	0.05	0.04	0.04	0.05	0.06
Grand Total (gross)	11.00	11.46	12.16	12.64	11.29	11.99	11.41	11.39	10.51	10.76

* Totals may not sum due to independent rounding

3.2 Lifecycle Assessments and Consumption Based Inventories

There are multiple ways and frameworks by which to look at GHG emissions associated with an area or attributable to a population. The 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. For example, the Inventory accounts for the emissions associated with computer chips manufactured in Vermont, but not the cars or other products in which these chips are used that are manufactured outside of the state.

and sold into Vermont. Because this inventory is a snapshot of annual 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 upstream emissions were already accounted for either within Vermont's own inventory in another sector or by another jurisdiction in their GHG inventory.³⁸

Greenhouse gas emissions estimates using lifecycle assessments attempt to evaluate all of the associated emissions of a process or production (most often a consumer product), including the emissions related to the inputs, manufacturing, transport, use, and disposal.³⁹ 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 a highly complex exercise that requires the setting of specific accounting boundaries that depend on the desired analysis but can provide important information for informing decisions on policies or mitigation strategies. ANR contracted for the completion of a Vermont energy Sector Life Cycle Assessment which produced upstream emissions factors and GHG emissions totals for energy sectors within the GHG Inventory that can be added to the GHG Inventory totals to provide life cycle emissions totals. For additional information please see Section 3.5.2.

Consumption-based inventories incorporate lifecycle emissions factors but focus on the entirety of emissions associated with a consumed good or service and assign those to the final consumer of that good or service, 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 with a greater focus on consumer choices and behaviors.⁴⁰ A consumption-based inventory does not include emissions associated with the production of goods or services within a state, unless they are also consumed within the state. Whether a consumption-based inventory for Vermont would show higher emissions totals than seen in the sector based in-boundary framework of the current inventory would depend on factors including the emissions profiles of Vermont's imports vs exports, how they net out, and which GWP timescale was chosen for the analysis. Oregon has produced a consumption-based emissions inventory⁴¹ to supplement their sector-based inventory, which is an illustrative example of how a consumption-based emissions inventory can

³⁸ 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>

³⁹ 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

⁴⁰ Oregon DEQ – Oregon's Greenhouse Gas Emissions through 2015:

<https://www.oregon.gov/deq/FilterDocs/OregonGHGreport.pdf>

⁴¹ Oregon Consumption-based Emissions Inventory: <https://www.oregon.gov/deq/mm/Pages/Consumption-based-GHG.aspx>

help to inform a more complete picture of how the state contributes to climate change. For information related to ongoing work in this space please see Section 3.5.3.

3.3 Biogenic Carbon Calculator and GWP_{bio}

The growing recognition of the need for immediate reductions in GHG emissions has led to investigations to better understand and appropriately account for biomass combustion. As mentioned above, emissions of biogenic CO₂ are captured within carbon fluxes in the LULUCF sector and are assumed to be re-sequestered by the regrowth of new biogenic material. One of the difficulties with this assumption is that when biomass is combusted, much of the carbon stored in that material is emitted directly to the atmosphere as CO₂. That pulse of CO₂ then remains in the atmosphere for as long as it takes for new vegetation to regrow and store that same amount of carbon. The longer the vegetation takes to regrow the longer that pulse of CO₂ remains in the atmosphere and contributes to the warming of the planet. The Biogenic Carbon Footprint Calculator⁴² from the World Wildlife Federation, which utilizes the concept of GWP_{bio}, is a method that adjusts emissions from biomass, including biomass combustion, to account for the regrowth rotation period of the fuel. GWP_{bio} factors are designed to be applied as lifecycle emissions factors but are an interesting and potentially useful lens to provide an alternative view between a fully carbon neutral approach of accounting for biogenic CO₂ and a full accounting of biogenic CO₂ at the point of combustion. This approach acknowledges both the issues around timescales of carbon neutrality and the difference between CO₂ from fossil fuels and from biogenic sources. Factors for GWP_{bio} for biomass combustion depend on a number of factors, but especially on climate, tree species, and baseline forest assumptions. The Biogenic Carbon Footprint Calculator and GWP_{bio} acknowledge the importance, as well as the challenge, of accounting for biogenic CO₂ emissions in an annual inventory in a way that accurately reflects the short-term fate of those emissions.

3.4 Emissions Forecasts

The greenhouse gas emissions forecast reported in the inventory is generated from a model of the Vermont economy developed in the Stockholm Environment Institute's Low Emission Analysis Platform (LEAP).⁴³ LEAP is an integrated, scenario-based modeling tool that can be used to track energy consumption, production and resource extraction in all sectors (e.g. transportation, buildings, electricity, industrial processes, agriculture, waste) of an economy. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks. The Vermont Pathways model in the LEAP platform contains detailed state-specific data on those economic sectors and other parameters such as population. Based upon those inputs, and assumptions regarding the rates of change over time, the model calculates emissions

⁴² Biogenic Carbon Footprint Calculator for Harvested Wood Products – World Wildlife Fund:

https://files.worldwildlife.org/wwfemspord/misc/climate_forest/Biogenic_Carbon_Footprint_Calculator_2020.xlsx

⁴³ <https://leap.sei.org>

for each sector. The forecast presented in the inventory report is based upon a baseline/business-as-usual scenario that reflects existing programs and policies in place but no new actions.

3.5 Supplemental Analyses

There have been several supplemental analyses that have been either ongoing or completed in the past year that both give additional insights into a sector within the GHG Inventory or to provide a different view or framework by which to understand emissions totals attributable to Vermont. These analyses include the Agricultural Tool Review project, the Vermont Energy Sector Life Cycle Assessment project, and the Consumption-based emissions inventory which is currently ongoing. Additional detail is available in the reports themselves which will be available on the ANR website (<https://climatechange.vermont.gov/>).

3.5.1 Agricultural Tool Review project⁴⁴

The Agricultural Tool Review project report evaluates the existing Vermont GHG Inventory, existing GHG accounting tools, and datasets to offer recommendations for optimizing GHG inventory practices within Vermont's agriculture sector. A comprehensive overview and definitions of climate-smart agricultural practices is provided along with a detailed examination and analysis of existing tools for quantifying agricultural emissions. This detailed examination focused on adherence to IPCC Guidance for the Agriculture, Forestry, and Other Land Use (AFOLU) sector, ease of use of the tool, tool completeness and evaluation of components, and ability to account for the impacts of management practices in Vermont.

3.5.2 Vermont Energy Sector Life Cycle Assessment⁴⁵

The Vermont Energy Sector Life Cycle Assessment project combines emissions from the energy sector components of the existing Vermont GHG Inventory with the upstream emissions occurring due to the use of that energy in the state to estimate total Vermont energy sector life cycle emissions total for the time series (1990 – 2020). In order to produce these energy sector life cycle emissions estimates the contractor reviewed and identified energy pathways used in Vermont and compiled and calculated upstream emission factors, which were mainly from the Argonne National Laboratory Greenhouse Gases, Regulated Emissions, and Energy Used in Technologies (GREET) model. Where appropriate and where data was available, the study configured GREET parameters to reflect conditions specific to Vermont. Since the objective of the study was to produce life cycle emissions totals when combined with totals in the Vermont GHG Inventory the emission factors for the different energy pathways do not include the emissions at the point of combustion and so are not themselves life cycle emission factors. The

⁴⁴ Review of Agricultural Greenhouse Gas Emissions and Sequestration in Vermont: Inventory Tools and Methodological Recommendations:

https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/1990-2021_GHG_Inventory_Uploads/Final_VT_Agricultural_GHG_Sequestration%20Inventory%20Recommendations_April2024.pdf

⁴⁵ Vermont Energy Sector Life Cycle Assessment:

https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/1990-2021_GHG_Inventory_Uploads/VT_GHG_EnergySector_LCA_May2024.pdf

analysis and corresponding workbook include totals both with and without biogenic CO₂, which are accounted for in the emissions totals in the report through the inclusion or exclusion of estimates of biogenic CO₂ that are provided in the GHG Inventory in the applicable sectors for data tracking purposes. The Vermont energy sector life cycle emissions total has been updated for the time series 1990 – 2022. The update utilizes the latest 1990 – 2022 GHG inventory data combined with upstream lifecycle emission factors from 1990 – 2021 that were provided by the contractor. Upstream lifecycle emission factors for 2022 were not available and 2021 upstream data were used to approximate upstream GHG emissions in this latest inventory year.

3.5.3 Consumption-based Emissions Inventory

Vermont has been a part of an EPA pilot project to develop consumption-based greenhouse gas (GHG) emission inventories (CBEI) for states utilizing EPA’s U.S. Environmentally-Extended Input-Output (USEEIO) model⁴⁶. The USEEIO is a model that couples economic input-output data with environmental data to derive sector-based information for potential life cycle environmental and economic impacts. The EPA, with assistance from a contractor, is developing state-specific data and outputs to provide environmental and economic information on sectors that is reflective of state economies. These models can help to account for and understand a more complete picture of emissions caused by the consumption of goods in a state or region. This project is ongoing, but results will be reviewed and posted on the ANR climatechange.gov website when they become available.

⁴⁶ U.S. EPA Environmentally – Extended Input-Output (USEEIO) Models: <https://www.epa.gov/land-research/us-environmentally-extended-input-output-usecio-models>