VERMONT

DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Agency of Natural Resources

Vermont Greenhouse Gas Emissions Inventory and Forecast

Methodologies

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Contents

List of Tables

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

CH_4: methane

CO_2: carbon dioxide

CO_2e: carbon dioxide equivalent

CO_2FFC: 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

N_2O: nitrous oxide

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

NF_3: 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

SF_6: 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 – Methodology* report is a supporting document for the Greenhouse Gas (GHG) Emissions Inventory and Forecast report completed by the Vermont Agency of Natural Resources. The Methodology 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 (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Some of these greenhouse gases do occur naturally in the atmosphere, such as CO_2, CH_4, and N_2O, but since the industrial revolution human activities have rapidly increased their concentrations leading to warming of the planet.[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 (atmospheric lifetime). 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 CO_2 and set them relative to CO_2 on a per unit of mass basis. Emissions totals including applicable GWP adjustments are reported in units of CO_2 equivalent (CO_2e). 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 Fourth Assessment Report (AR4).[2] The GWP values are essentially multipliers that are applied to masses of non-CO_2 gases to make their climate warming impacts directly comparable to CO_2.

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[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.

[2] IPCC Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013: Addendum; Part two: Action taken by the Conference of the Parties at its nineteenth session (2014): http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

Table 1: AR4 – 100-year Global warming potential values.[3]

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

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 Sinks[4], and the Vermont GHG inventory continue to use the AR4 100-yer GWP values, because that is the recommendation in the most recent IPCC inventory guidelines document. However, those values have been updated in more recent IPCC Assessment Reports and the inventory guidelines are expected to be updated in the next iteration of the National GHG inventory to include the use of GWP values from the AR5 report. 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, but 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 CO_2 is another important foundational consideration when calculating GHG inventory totals 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).[5] IPCC guidelines recommend excluding biogenic CO_2 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 is difficult because of the lack of certainty in the data and flux estimates used and quantified in the LULUCF sector. State level emissions estimates[6] disaggregated from the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020[4] report have been included to inform LULUCF totals, but the net values including the LULUCF totals are not the official GHG inventory totals. Estimates are provided in several inventory sectors for informational purposes including ethanol and biodiesel in the Transportation/Mobile

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[3] Source: EPA Overview of Greenhouse Gases: https://www3.epa.gov/climatechange/ghgemissions/gases/n2o.html
[4] 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
[5] 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
[6] EPA - State GHG Emissions and Removals: https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals

Sources sector, wood combustion and renewable natural gas in the RCI sector, and wood combustion in the Electric sector, that show the emissions of biogenic CO_2 if it were counted at the point of combustion, however, this calculation has not been completed for every sector in the inventory. This Inventory also does not include sequestration estimates from land use activities in the official totals, as discussed in the LULUCF discussion.

An important distinction when considering accounting practices for biogenic CO_2 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 which moves between pools on the order of months to centuries, which means that combusting fossil fuels adds more carbon that was in long term storage and effectively out of circulation into the atmosphere and into the more immediate carbon cycle.[7] 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 timescale of carbon movement within the faster carbon cycle, the sequestration of CO_2 emitted by the combustion or decomposition of biogenic materials may still be on a longer timescale than would be required to meet mandated GHG emissions reductions.

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 report[8]. 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*[8] report and are compatible with IPCC GHG inventory guidelines.[9] Data availability is a key factor influencing methodology decisions with the intention of providing the most accurate emissions estimates

[7] 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

[8] 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

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

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 more detailed 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.

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 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) 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 published in 2022 of state level emissions derived from disaggregating National Emissions Inventory data to a state level[10].

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 certain other non-road equipment like recreational vehicles, lawn equipment, boats, and rail. The current methodology used to calculate GHG emissions in the sector for the entire 1990 – 2020 time series covered in the inventory is through the use of two EPA SIT modules, one to estimate the emissions of CO_2 and one to estimate the emissions of CH_4 and N_2O.

[10] EPA State GHG Emissions and Removals: https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals

Carbon dioxide emissions estimates are based on fuel combustion totals for onroad and nonroad transportation and mobile sources and rely on the EPA CO_2 from Fossil Fuel Combustion (CO_2FFC) SIT module, which is also used for estimating emissions of CO_2 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), aviation gasoline and jet fuel, but also include 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)[11] dataset, which is a federal source of comprehensive state energy statistics data that provides estimates of energy consumption by state. This default data is expressed as estimated 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[12] and is used to derive energy use from motor gasoline utilized in the CO_2FFC module, after first adjusting the values to remove the approximate contribution from aviation gasoline and ethanol. Diesel sales data from JFO have not been incorporated into the inventory because it is unclear to what extent the nonroad end uses covered by the JFO data match those covered in the default SEDS dataset in the tool, which could lead to under or over counting of emissions. Default SEDS data have been used for the transportation distillate fuel portion of the calculation after removal of the estimated biodiesel component of the fuel, which is also estimated in the SEDS dataset. Ethanol and biodiesel totals are removed from the emissions estimates due to their biogenic origin. Default SEDS data are also utilized for the remaining categories in the CO_2FFC module.

Emissions of CH_4 and N_2O are calculated differently from the CO_2 component. Estimation methods of some pollutants, such as CH_4 and N_2O, are technology dependent and so have differing emissions factors depending on the type and age of the vehicle producing them. Estimates of these GHGs were calculated using the EPA SIT CH_4 and N_2O Emissions from Mobile Combustion module. 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.

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[11] Energy Information Administration – State Energy Data System (SEDS): https://www.eia.gov/state/seds/
[12] Vermont Joint Fiscal Office – Gasoline and Diesel Gallons Sold: https://ljfo.vermont.gov/subjects/transportation/monthly-data

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 CO_2 from the use of fuel oil, propane, and natural gas but do include methane (CH_4) and nitrous oxide (N_2O) from wood combustion, as well as GHG emissions from less common fuels like kerosene, and coal. The industrial subsector of the RCI sector also includes diesel fuel used in several non-road categories such as farm use, off-highway construction, and logging operations. Emissions estimates in the RCI sector are calculated for the entire time series using two EPA SIT modules, one to estimate emissions of CO_2 and the other for emissions of CH_4 and N_2O. Emissions of CO_2 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 CO_2 emissions.

The SIT module used to calculate all the CO_2 emissions from the sector is the CO_2 from Fossil Fuel Combustion 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 data for all of the fossil fuel input values used for the RCI sector in this module are default values from the EIA SEDS dataset. Datasets used to inform the Btu consumption estimates in SEDS for this sector differ by fuel and by year but are generally based on national level reporting of sales data that is presented by state.[13] Emissions estimates are then converted into units of $MMTCO_2e$ within the tool using conversion factors as appropriate.

The SIT module utilized in the RCI sector to calculate emissions of CH_4 and N_2O is the Methane and Nitrous Oxide Emissions from Stationary Combustion module. The methodology to calculate emissions in this module is similar to the CO_2FFC 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 also 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 program[14] and estimates of energy from wood combustion in the residential subsector are derived from Vermont Residential Fuel Assessment reports[15]. Emissions estimates are then converted into units of $MMTCO_2e$ within the SIT module by using conversion factors and multiplying by the GWP value for each gas as appropriate.

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[13] EIA SEDS – "Technical notes & documentation - complete 2018" – Section 4: Petroleum: https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf

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

[15] 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

2.1.3 Agriculture

The agriculture sector of the GHG inventory accounts for emissions of CH_4 and N_2O from agricultural practices in the state, including animals and crop production. Carbon dioxide in this sector 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 CO_2 that is included in the sector is the CO_2 associated with liming and urea fertilization. The subsectors of the agriculture sector include enteric fermentation (CH_4 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 – 2020 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 CH_4 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 modify the population of dairy cows in the manure management portion of the tool to remove the waste that is estimated to enter anaerobic digester facilities. Manure in an anaerobic digester produces emissions of CH_4 but when that CH_4 is combusted in the process it produces CO_2, which per IPCC inventory guidelines is considered biogenic and so is not included in the inventory totals. The number of animals to remove from the manure management totals is informed by ANR point source registration data and the EPA AgSTAR database[16] for anaerobic digesters.

The agricultural 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 agricultural sector. If it were, it would likely be offsetting some portion of the gross emissions calculated using the SIT module. Sequestration and the potential to increase sequestration in the agricultural sector is important because reducing

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

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 and are currently coarse representations of the agricultural landscape in the state. Updated IPCC guidelines recommend including the Agricultural sector within the LULUCF sector as a Agriculture, Forestry, and Other Land Use (AFOLU) sector, but this has not been done in the Vermont GHG inventory because of a lack of confidence and high uncertainty in the LULUCF sector emissions and flux estimates. A project is about to begin for a contractor to evaluate tools and datasets for quantification of emissions from the agricultural sector that will include both net and gross estimates and incorporate Vermont specific data and management practices to the extent possible. This analysis will provide a tool to quantify net emissions in the agricultural sector and will be one component to enable the creation of an AFOLU sector as the LULUCF sector data and flux estimates improve. The Vermont Carbon Budget[17] was an additional analysis that was completed to produce and inform agricultural sector estimates in the Vermont, as well as other land use related estimates, and is an important foundation for improving estimates in the sector.

The use of the SIT module for calculating GHG emissions from the agriculture sector produces gross emissions estimates limited in terms of the inputs and considerations it can account for, specifically in terms of GHG implications of agricultural management practices.

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 (NF_3), sulfur hexafluoride (SF_6), and CO_2. Totals in this sector are estimated using several different methodologies depending upon the subsector but include the Industrial Processes SIT module, a tool developed by California for U.S. Climate Alliance (USCA)[18] states for estimation of emissions of ODS substitutes, and emissions data reported to EPA through the Greenhouse Gas Reporting Program (GHGRP).

[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

[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/

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 CO_2 in their ability to warm the planet.

Estimates of GHG emissions from the ODS Substitutes sector are derived from a tool developed by California for use by USCA states. When this methodology was adopted the California tool was considered to be a more robust and detailed methodology than the calculations contained in the SIT module. The tool is based on a detailed fluorinated gas (F-gas) model[19] which estimates annual HFC emissions from equipment by type and subtype using extensive data from research and from the California refrigerant management program including leakage rates from charging new and used equipment, leakage rates from existing equipment, and end of life equipment loses. These HFC emissions estimates for California are then apportioned to a per capita value (or per vehicle) and adjusted based on state-specific factors such as the percentage of households with air conditioning units or using heat pumps. Per capita values are then applied to the population of Vermont to produce an estimated business as usual baseline value that is incorporated into the GHG inventory. The California tool does not include estimates back to 1990 and only contains data for 2005 onward, so for all years prior to 2005 the SIT Industrial Processes module estimates for ODS substitutes have been used in the inventory. Because the California model is based on a per capita value it is not feasible to reflect on the ground changes to emissions levels based on mitigation strategies to reduce ODS substitutes on a more granular level. Reductions in emissions can really only be reflected in the tool outputs using the pre-calculated mitigation scenarios included in the tool. Because of this limitation in the tool methodology, there is a plan to explore additional calculation methods that would allow for the incorporation and use of local data.

Greenhouse gas emissions related to semiconductor manufacturing include HFCs, PFCs, SF_6, and NF_3 and are taken from emissions totals reported to EPA through the GHGRP which requires annual reporting of GHG emissions by applicable sources and facilities.[20] Emissions of the F-gases in semiconductor manufacturing occur in the plasma etching and chemical vapor deposition processes[21], 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

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

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

available years (2011 through 2020).[22] Emissions totals from before 2011 are estimated by projecting reported 2011 emissions totals backwards through time to 1990 based on state level estimates[6] disaggregated from the National Inventory of U.S. Greenhouse Gas Emissions and Sinks[4] 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 SF_6 used as an insulator in electric power transmission and distribution equipment are based on an estimate of the quantity of SF_6 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. [23] 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 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)[24] 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 CO_2 is of biogenic origin, but CH_4 and N_2O emissions are included in the

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[22] EPA FLIGHT Tool: https://ghgdata.epa.gov/ghgp/main.do?site_preference=normal
[23] Some states utilize the amount of in-state generation for determining GHG emissions from the electric sector. Currently, Vermont consumers 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
[24] NEPOOL GIS – Public Reports – NEPOOL Residual Mix: https://www.nepoolgis.com/public-reports/

totals. States in the region differ on this accounting practice, however, it is consistent with IPCC inventory guidelines for the treatment of biogenic CO_2.

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.[25] Required renewability portfolio percentages increase from 55% in 2017 to 75% in 2032.[26] 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[27]. Accounting 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 CO_2 from wood combustion for electricity generation in Vermont are related to issues surrounding biogenic CO_2 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 CO_2 that is considered biogenic, and no biogenic CO_2 is included

[25] Vermont Renewable Energy Standard: https://legislature.vermont.gov/statutes/chapter/30/089
Public Service Department website: https://publicservice.vermont.gov/renewable_energy/state_goals
[26] Vermont Public Utility Commission: https://puc.vermont.gov/electric/renewable-energy-standard
[27] EPA Green Power Partnership: https://www.epa.gov/greenpower/renewable-energy-certificates-recs

in the GHG inventory totals per IPCC inventory guidelines[28] 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 CO_2 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 CO_2 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 CH_4 and N_2O from solid waste and wastewater. Carbon dioxide associated with the waste sector is considered biogenic and is not included in the totals for the sector. 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 CH_4 and N_2O emissions from the wastewater subsector are completed using the EPA SIT Wastewater module and include CH_4 from municipal wastewater, direct N_2O from municipal wastewater, and N_2O 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).[29] The SIT 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 CH_4 and N_2O emission factors. Details on the methodologies and calculations can be found in the User's Guide for the Wastewater SIT module.[30] Estimates for the industrial wastewater component have been extracted from the EPA state level GHG estimates[6] 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 of these landfills have landfill gas to energy (LFGTE) systems and are also required

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[28] IPCC Guidelines for National Greenhouse Gas Inventories (2006): https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/
[29] WMPD report: https://dec.vermont.gov/sites/dec/files/wmp/residual/RMSWhitePaper20180507.pdf
[30] EPA State Inventory Tool – Wastewater User's Guide: https://www.epa.gov/sites/production/files/2020-10/documents/wastewater_users_guid.pdf

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 CH_4 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 CO_2 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 CH_4 component is converted to CO_2 and because the generated CO_2 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 captured in the LULUCF sector. Fugitive CH_4 emissions and the portion not actually combusted by the flares or LFGTE systems is converted to $MMTCO_2e$ to come up with an emissions value. Because there are a number of smaller closed landfills in Vermont that are not captured in this methodology, the total is increased by 15%, 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. Because the LFG emissions from closed landfills decline over time with no new waste being added, this multiplier will need to be revisited in future iterations of the Inventory.

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. 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 CH_4 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 CO_2 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 CO_2 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. There is currently work being done 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 CH_4 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).[31]

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) [32] and are multiplied by the number of services and miles of applicable distribution line from PHMSA to come up with annual emissions of CH_4 from the NG distribution system. This CH_4 total is then converted to $MMTCO_2e$ 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 CO_2 from the atmosphere and convert it into stored biological material through photosynthesis, but forest processes and changes in land use can also emit CO_2 as well as other GHGs like CH_4 and N_2O. 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 CO_2 either emitted to the atmosphere or sequestered within a system. Because these carbon fluxes, the transfer of carbon from one pool to another over a certain amount of time, from land use and land-use change are related to

[31] PHMSA – 2010+ Pipeline Miles and Facilities: https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-mileage-and-facilities
[32] 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

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 agricultural 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 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 agricultural 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 Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990 – 2020) report and the EPA SIT modules for Agricultural emissions and LULUCF calculations. Understanding that there is a very real connection between the agricultural sector and the carbon fluxes related to land use changes, work is being completed through a contract process to investigate a number of tools and datasets that would enable the calculation of agricultural emissions in a net framework (including emissions and sequestration). This work will provide a more in depth understanding of agricultural emissions in a net framework, and specifically focus on incorporating the benefits of different agricultural management practices into the estimates. 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.

Historically the GHG inventory has only included estimates of net sequestration associated with forests and has not included emissions or fluxes from land-use change or processes from other land use classifications. A more complete LULUCF sector has been included in the current (1990 – 2020) GHG inventory report based on recently released state level data from EPA. Forest data estimates used in this sector are produced by the U.S. Department of Agriculture, Forest Inventory and Analysis program[33] 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

[33] USDA – Forest Service - Domke, Grant M.; Walters, Brian F.; Nowak, David J.; Greenfield, Eric. J.; .Smith, James, E.; Nichols, Michael C.; Ogle, Stephen M.; Coulston, John. W.; Wirth, Tom C. 2022. Greenhouse gas emissions and removals from forest land, woodlands, urban trees, and harvested wood products in the United States, 1990 2020. Resource Update FS 382. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 10 p. https://doi.org/10.2737/FS-RU-382

settlements, are taken from calculations for the Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990 – 2020) report that have been disaggregated to state levels by EPA[10]. 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 – 2020[34] document from EPA.

3 Alternative Methodologies and Emissions Forecasts

3.1 20-Year GWP Values

One other option for understanding emissions impacts is to assess the emissions values 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 CO_2, 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 AR4 100-year GWP multiplier value of 25 to an AR4 20-year GWP of 72. 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.

[34] EPA – Methodology Report for Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990-2020: https://www.epa.gov/system/files/documents/2022-08/StateGHGI_Methodology_Report_August_2022.pdf

Table 2: GHG Estimates by Sector for select years using AR4 20-year 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**	**0.44**	**0.64**	**0.43**	**1.00**	**0.32**	**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	0.02	0.02	0.02	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
Residential / Commercial / Industrial (RCI) Fuel Use	**2.66**	**2.64**	**3.13**	**3.19**	**2.70**	**3.11**	**3.12**	**3.18**	**3.03**
Coal	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.32	0.38	0.51	0.45	0.45	0.65	0.75	0.76	0.71
Oil, Propane & Other Petroleum	2.15	2.07	2.46	2.54	2.03	2.22	2.11	2.16	2.09
Wood (CH_4 & N_2O)	0.17	0.19	0.16	0.19	0.22	0.25	0.26	0.26	0.23
Transportation	**3.28**	**3.87**	**3.82**	**4.07**	**3.59**	**3.51**	**3.41**	**3.34**	**2.85**
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)	0.16	0.17	0.15	0.13	0.08	0.06	0.05	0.05	0.04
Fossil Fuel Industry	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.08**	**0.08**	**0.08**
Natural Gas Distribution	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Natural Gas Transmission	0.03	0.03	0.04	0.04	0.04	0.04	0.07	0.07	0.07
Industrial Processes	**0.20**	**0.46**	**0.70**	**0.68**	**0.80**	**1.04**	**1.05**	**1.11**	**1.15**
ODS Substitutes*	0.00	0.12	0.31	0.42	0.58	0.74	0.81	0.84	0.86
Electric Utilities (SF_6)	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
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	**0.75**	**0.91**	**1.01**	**0.96**	**0.79**	**0.44**	**0.41**	**0.40**	**0.39**
Solid Waste	0.61	0.77	0.86	0.80	0.62	0.28	0.24	0.23	0.22
Composting	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Wastewater	0.14	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16
Agriculture	**2.70**	**2.59**	**2.85**	**2.90**	**2.89**	**3.08**	**3.09**	**3.05**	**2.87**
Enteric Fermentation	2.01	1.92	1.99	1.82	1.78	1.83	1.85	1.82	1.77
Manure Management	0.34	0.38	0.58	0.78	0.78	0.81	0.86	0.84	0.80
Agricultural Soils	0.35	0.30	0.27	0.29	0.32	0.39	0.35	0.36	0.28
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)	**10.73**	**11.30**	**12.00**	**12.49**	**11.24**	**12.23**	**11.48**	**11.42**	**10.55**

Note *: GWP values for the ODS Substitutes category have not been adjusted directly like the other categories but have instead been scaled using a ratio from California Air Resources Board (CARB) Short Lived Climate Pollutant (SLCP) HFC inventories with AR4 100-year and AR4 20-year GWP values. Several of the 20-yr GWP values for gases in the semiconductor manufacturing process could not be found and where that was the case the AR4 100-yr values were used. Updating GWP values only impacts emissions of gases other than CO_2, so many emissions totals remain unchanged. Using 20-yr GWP values greatly increases the potency of CH_4.

3.2 Lifecycle Assessments and Consumption Based Inventories

There are multiple ways 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.[35]

Greenhouse gas emissions estimates using lifecycle assessments attempt to evaluate all of the associated emissions of the process or production (most often a consumer product), including the emissions related to the inputs, manufacturing, transport, use, and disposal.[36] 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.

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.[37] 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

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[35] 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

[36] 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

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

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 inventory[38] to supplement their sector-based inventory, which is an illustrative example of how a consumption-based emissions inventory can help to inform a more complete picture of how the state contributes to climate change.

3.3 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, biogenic CO_2 is considered carbon neutral because the emissions 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 CO_2. That pulse of CO_2 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 CO_2 remains in the atmosphere and contributes to the warming of the planet. 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 to lifecycle emissions estimates but are applied to biogenic CO_2 estimates in the GHG inventory to provide an alternative view between a fully carbon neutral approach and a full accounting of biogenic CO_2 at the point of combustion. This acknowledges both the issues around timescales of carbon neutrality and the difference between CO_2 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. For the GHG inventory an estimated factor of 0.32 has been used based on a GWP_{bio} tool[39] from the World Wildlife Federation with assumptions for a cool temperate climate. The use of a GWP_{bio} factor acknowledges the importance, as well as the challenge, of accounting for biogenic CO_2 emissions in an annual inventory in a way that accurately reflects the short-term fate of those emissions. This is a key issue that ANR plans to work to better understand and incorporate as appropriate.

3.4 Emissions Forecasts

Estimating emissions levels in future years requires many assumptions related to a number of societal factors including the economy, personal and consumer choices, policies and regulations impacting emissions levels, and unforeseen events such as the COVID-19 pandemic, many of which are difficult to predict. Some of this detailed projection work was completed to help inform the Climate Action Plan using the Low Emissions Analysis Platform (LEAP)[40], which is

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[38] Oregon Consumption-based Emissions Inventory: https://www.oregon.gov/deq/mm/Pages/Consumption-based-GHG.aspx

[39] Biogenic Carbon Footprint Calculator for Harvested Wood Products – World Wildlife Fund: https://files.worldwildlife.org/wwfcmsprod/misc/climate_forest/Biogenic_Carbon_Footprint_Calculator_2020.xlsx

[40] Low Emissions Analysis Platform (LEAP): https://leap.sei.org/default.asp?action=introduction

an integrated energy planning and climate change mitigation assessment model. The modeling process produced business-as-usual (BAU) scenario estimates as well as several scenarios with possible mitigation pathways by which Vermont might meet the state's mandatory GHG emissions reduction requirements out to 2050. Because the LEAP model does not utilize the same methodologies as the GHG inventory, emissions projections in the Inventory for 2025 and 2030 are based on percent changes in the LEAP modeling values applied to the Inventory estimates for the applicable sector. Percent changes from LEAP outputs were used from 2018 to 2025 and from 2018 to 2030 and applied to the 2018 Inventory totals because 2018 was the most current year of historical data when the LEAP model was run. The projections utilize the percent changes in the BAU LEAP scenario for all sectors besides the Transportation/Mobile Sources. For the Transportation/Mobile Sources sector one of the mitigation scenarios was used that incorporated a higher electric vehicle (EV) adoption rate that roughly corresponds to the potential influx in EVs from the adoption of the of the Advanced Clean Cars II (ACCII) and Advanced Clean Trucks (ACT) rulemaking. The projections in the Inventory do not incorporate the percent changes from the LEAP mitigation scenario for the electric sector, even though these would be impacted by the adoption of ACCII and ACT, because it was not possible to parse out the contribution to emissions projections in the electric sector attributable to increases in EV adoption from those related to other sectors that rely on beneficial electrification as their main mitigation strategy.