Evaluation of Projected and Inventoried Vermont Greenhouse Gas Emissions

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EXECUTIVE SUMMARY

This report was prepared by Synapse Energy Economics for Conservation Law Foundation, to summarize the results of Synapse's review of the State of Vermont's analysis of expected greenhouse gas emissions in calendar year 2024, as well as earlier years. Emissions in 2024 are important under the Vermont Global Warming Solutions Act because the Agency of Natural Resources is obligated to take action to ensure that these emissions fall at least 26 percent below calendar year 2005 emissions by January 1, 2025. On July 1, 2024, the Secretary of Natural Resources issued a letter to the Vermont Climate Council stating her determination that it is not necessary for ANR to update rules because the State is "generally on track" to meet the 2025 GHG emission requirements.[1] The Secretary's determination rested upon analysis conducted by a consultant group using a Vermont Pathways model built upon the Low Emissions Analysis Platform (LEAP).

Synapse compared the modeled Vermont greenhouse gas emissions (from the Pathways model in LEAP) with the State's inventory of emissions through 2020, for each sector of the economy. We find that, contrary to the State's contention that Vermont can be expected to meet its January 1, 2025, reduction requirement by 13,000 metric tons of CO_2-equivalent, inventoried emissions are likely to be about 240,000 to 320,000 metric tons greater than the model projects for calendar year 2024.

Table ES-1. Sectoral and cumulative approximate corrections to the Pathways model estimate, along with the estimate for context. Units are thousands of metric tons.

Sector	Pathways 2024 Estimate (kMT)	Approx. Correction to 2024 Emissions Estimate (kMT)
Electricity	120	-40 to -120*
Thermal/RCI	2,287	+80
Transportation	2,954	net 0
Fossil Fuel T&D	21	0
Industrial Process	565	+50
Waste	125	+30
Agriculture	1,190	+200
TOTAL	7,262	+320 to +240
Relation to 7,275 kMT Limit	13 below	230 to 310 over

** This range correction reflects the likely treatment of biogenic CO_2 from wood electricity generation and possible renewable energy credit ownership effects.*

If the differences between the Pathways model and the inventory had been addressed in or before early 2024, the State would have projected missing the January 1, 2025, GWSA emissions reduction requirement by 230,000 to 310,000 metric tons, and the Secretary's July 1, 2024, letter would have reflected different findings.

[1] Moore, Julia S. July 1, 2024. Letter to Vermont Climate Council.

1. INTRODUCTION

This report was prepared by Synapse Energy Economics (Synapse) for Conservation Law Foundation (CLF). CLF requested that Synapse examine analysis conducted by the State of Vermont regarding expected greenhouse gas (GHG) emissions according to the State's inventory methodology in calendar year 2024, as well as earlier years. Emissions in 2024 are important under the Vermont Global Warming Solutions Act (the GWSA, amending 10 V.S.A. § 578 and codifying 10 V.S.A. chapter 24) because the Agency of Natural Resources (ANR) is obligated to take action to ensure that these emissions fall at least 26 percent below calendar year 2005 emissions by January 1, 2025 (2025 GHG emissions requirement). On July 1, 2024, the Secretary of Natural Resources issued a letter to the Vermont Climate Council stating her determination that it is not necessary for ANR to update rules because the State is "generally on track" to meet the 2025 GHG emission requirements.[2] The Secretary's determination rested upon analysis conducted by Energy Futures Group (EFG), Stockholm Environment Institute (SEI), and Cadmus Group using a Vermont Pathways model built upon the Low Emissions Analysis Platform (LEAP). The purpose of this report is to summarize the results of Synapse's analysis comparing both the methods and results of the State's inventory and the Pathways modeling conducted for the EFG analysis.

1.1. Structure of this report

Section 2 of this report provides a summary of Vermont's GHG inventory and a summary of the Vermont Pathways model the State used to make estimates of the 2024 emissions level.

Sections 3 through 9 of this report step through each sector of the Vermont economy, as characterized in the Inventory and Pathways modeling. For each sector, we present the inventory methodology, followed by a discussion of how that sector is modeled in the Pathways model and the resulting projections for 2024 emissions. Each section concludes with an evaluation of the inventory and Pathways model results, with a focus on the extent to which the Pathways model is a rigorous and suitable tool to use for estimating 2024 emissions under the State's inventory method, based primarily on comparison of inventory and Pathways model results for the period 2015 to 2020.

Section 10 concludes the report with a cross-sectoral summary, including implications for the likelihood of the State meeting its 2025 GHG emissions requirement.

[2] Moore, Julia S. July 1, 2024. Letter to Vermont Climate Council.

2. VERMONT'S GREENHOUSE GAS INVENTORY AND PROJECTIONS

2.1. State Greenhouse Gas Emissions Inventory through 2020

The *Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990–2020*[3] (the Inventory, in reference to any year, and April 2023 Inventory in reference to the Inventory for 1990–2020) is, per the Vermont Global Warming Solutions Act of 2020, the established baseline by which the State's progress in meeting its 2025, 2030, and 2050 GHG emissions requirement is measured. The Inventory is required pursuant to 10 V.S.A. § 582. Gross emissions data reported in the Inventory does not account for any sequestration as a result of land use, land-use change, and forestry (LULUCF).ANR's April 2023 Inventory includes inventories for emissions from 2018, 2019, and 2020. The Inventory is compiled based on data from State agencies along with federal datasets and tools.

The State's inventory process continuously updates data for previous years, with data from the 2023 Inventory superseding previously reported data. The April 2023 Inventory also provides 2025 and 2030 emissions projections using a business-as-usual (BAU) percent change by sector from the GHG mitigation pathway modeling completed for the Vermont Climate Action Plan. The projected GHG emissions in the BAU pathway are 8.55 million metric tons of CO_2-equivalent ($MMTCO_2e$) in 2025, and 7.32 $MMTCO_2e$ in 2030 (see Figure 1). The Inventory uses 100-year global warming potential (GWP) emissions factors from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). The Inventory notes that given the 2020 Covid-19 pandemic's effects on energy use generally, 2020 inventory data may not be indicative of long-term trends.

The April 2023 Inventory breaks down annual emissions into seven primary sectors. These are: transportation and mobile sources (collectively transportation); residential, commercial, and industrial fuel use (RCI); agriculture; industrial processes; electricity; waste; and in-state fossil fuel industry emissions.

[3] Vermont Agency of Natural Resources. April 2023. *Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990-2020*. Available at: https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2020_Final.pdf.

Figure 1. Historical and BAU projected emissions by sector, from the 2023 Inventory

The largest sector of emissions has historically been transportation. This sector includes all liquid fuels used in trucks and cars on state roads, aviation and jet fuel for aircraft, and certain non-road equipment such as fuels used in recreational vehicles, lawn equipment, boats, and rail. On-road and nonroad gasoline and diesel made up 96 percent of in-state transportation emissions. Emissions from this sector have been trending down since their 2004 peak.[4] The second-largest emitting sector is fossil fuels used in RCI spaces and water heating and cooking. These fuels include fuel oil, propane, natural gas, and wood. Methane and nitrous oxide (N_2O) emissions from wood are included and converted to CO_2e using their global warming potentials (GWP), but biogenic CO_2 emissions from wood combustion are not included. This sector fluctuates in response to the number of heating degree days (HDD). Agricultural emissions represent the third-largest sector of emissions and include emissions related to digestive processes of animals, manure management, fertilizer production, and agricultural soils management. Agricultural emissions are largely methane and N_2O emissions. Industrial processes represent the fourth-largest sector and are made up primarily of a few sources of high GWP emissions such as sulfur hexaflouride (SF_6) used in electrical transmission systems and hydrofluorocarbons used in semiconductor manufacturing. These long-lasting, high GWP emissions have largely remained constant from 2015 through 2020.

[4] In 2020, as a result of Covid-19, transportation emissions were notably reduced.

The Inventory accounts for electricity emissions outside the state that are emitted to generate electricity for use inside the state, given the small number of generators inside the state and the interconnected nature of the ISO-New England (ISO-NE) grid. The electric sector emissions include estimated line losses, which increase total sector emissions. The waste sector emissions are primarily methane and N_2O emissions from wastewater treatment facilities, landfills, and composting. The estimate does not include biogenic CO_2 emissions from the waste sector. Finally, the Inventory accounts for methane emissions from the state's natural gas transmission and distribution system based on the size, length, type, and age of the installed pipelines.

Although not in the Inventory, the Methodology report does list emissions using the higher 20-year AR4 and 100-year AR5 (fifth IPCC Assessment Report) GWP emission factors, which primarily increase the emissions values for methane, N_2O, and other heat-trapping molecules.[5] Because some gases trap more heat in the atmosphere than others and have shorter or longer lifespans in the atmosphere, it is necessary to convert all GHGs to a standard metric. The Inventory uses a methodology recognized by the IPCC to convert GHGs into CO_2 equivalents on a 100-year time scale. However, using higher emissions factors under the 20-year GWP factors would result in gross emissions being approximately 30 percent higher than with the 100-year AR4 GWP emission factors. The IPCC periodically updates the GWP emissions factors, as it did between AR4 and AR5. Between AR4 and AR5, the GWP emissions factor for CH_4 increased while it decreased for N_2O. The Inventory relies on the U.S. EPA's GHG Emissions and Sinks methodology.

The Inventory provides a BAU emissions forecast for 2025 and 2030. The Inventory used the change in emissions from 2018 to 2025 and 2030 in the State's implementation of the LEAP model to produce the BAU trajectory. Because the LEAP model accounts for GHG inventories differently, the BAU forecast applies a percent change value taken from LEAP to the Inventory estimates for each sector rather than using the absolute values from the LEAP model. The BAU LEAP case was applied to all sectors other than the transportation fuel sector. That sector utilized a high-EV LEAP case in order to account for a higher projected adoption for electric vehicles. (The BAU trajectory used for the electric sector does not include projected increases in the electric sector resulting from increasing transportation electricity demand.)

2.2. Pathways 3.27 Model

The State of Vermont contracted with a team of consultants, including EFG, Cadmus, and SEI, to develop a statewide emissions model using the LEAP model. LEAP is a software package developed by SEI that tracks emissions across an economy and ensures that all energy demands are met by appropriately transformed energy supplies. Aside from a crude electric sector model, LEAP does not use the economics of the different sectors to make projections. It does not model the impacts of a policy or regulation. Instead, it accurately accounts for the implications of the inputs and projections provided by

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[5] Vermont Agency of Natural Resources. 2023. *Vermont Greenhouse Gas Emissions Inventory and Forecast – Methodology.* https://web.archive.org/web/20240711102738/https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/_Methodology_Vermont_Greenhouse_Gas_Emissions_Inventory_1990-2020_Final.pdf.

the user. For example, LEAP cannot project how many electric vehicles will be sold with and without a rebate—instead, the user makes a projection of the impact of that policy and provides that as an input to LEAP. LEAP then accounts for the increased electricity demand, reduction in gasoline demand, and the resulting changes in emissions from those changes in inputs.

Vermont's Pathways model was originally developed to support the State's Climate Action Plan in 2021. It was updated to version 2.0 in 2022 in response to stakeholder comments. In 2023, the State contracted with the EFG team to develop a deeper and updated analysis of decarbonization pathways in the thermal sector, resulting in the publication of *The Analysis of Buildings/Thermal Energy Sector Emissions Reduction Policies for Vermont* (EFG Report) in November 2023. The purpose of this analysis was to inform the State regarding the relative impact of different policy approaches to building decarbonization, with a focus on achieving reductions to meet the January 1, 2030, GHG emissions reduction requirement. In that process, EFG and collaborators implemented some changes outside the thermal sector, with the objective of bringing the overall LEAP model up to date. These changes included accounting for programs funded by the *Inflation Reduction Act* and *Infrastructure Investment and Jobs Act*, as well as the *Advanced Clean Cars II* and *Advanced Clean Trucks* Rules. The EFG Report included the results of this revised BAU case, as well as the results of the policy cases focused on the thermal sector. The BAU case from that LEAP model is referred to as providing the "Pathways 3.27" model results. Throughout the remainder of this report, we refer to the Pathways 3.27 model and its results as "Pathways 3.27," "Pathways," "Pathways 3.27 model," "Pathways 3.27 LEAP model," or the "Model."

ANR states that it relied upon the Pathways 3.27 model when making its July 1, 2024, determination regarding the statutory January 1, 2025, GHG emissions reduction requirement. Figure 2 shows a slide from a June 13, 2024, presentation to the Vermont Climate Council showing the Pathways 3.27 results (Pathways 3.27 2025 (CY 2024)) compared with the statutory target levels for calendar year 2024 (GWSA 2025). This slide indicates that the Model shows Vermont meeting the statutory level, with a buffer of 13,000 metric tons (or 0.18 percent). Any shortfall between projected and actual calendar year 2024 GHG emissions would indicate that the State has not met its 2025 GHG emissions reduction requirement, and more importantly is off-track in meeting its 2030 GHG emissions reduction requirement.

Figure 2. Slide from Climate Council presentation, June 13, 2024, comparing Pathways 3.27 model results with GWSA compliance levels by sector and in total

Pathways 3.27 v. GWSA

	Pathways 3.27 2025 (CY 2024)	GWSA 2025	Pathways 3.27 2030 (CY 2029)	GWSA 2030
Agriculture	1,190	1,153	1,217	819
Electricity Generation	120	255	164	181
R/C/I	2,287	2,423	1,888	1,720
Residential	1,025	1,302	709	924
Commercial	856	758	773	538
Industrial	406	363	406	257
Industrial Processes	565	486	580	345
Transmission and Distribution	21	25	19	17
Transportation	2,954	2,801	2,626	1,989
Waste	125	132	126	94
TOTAL	7,262	7,275	6,620	5,166
		- 13		+ 1,454

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VERMONT AGENCY OF NATURAL RESOURCES

3. ELECTRIC SECTOR EMISSIONS

3.1. Inventory methodology

Vermont bases its electric sector emission inventory on accounting for ownership of environmental attributes of electric power. Renewable energy certificates (or credits, referred to as RECs) track ownership of attributes and are the accounting tool used for compliance with Vermont's renewable energy standard (RES), as well as the equivalent policies in other New England states. REC ownership is tracked in the NEPOOL Generator Information System (GIS). Power purchased and imported from HydroQuébec by Vermont utilities is assumed to be hydroelectric in origin, even if the NEPOOL GIS system does not fully track Québec generation.

At the end of each year (and after allowing for several months for REC ownership to be locked in the NEPOOL GIS), Vermont utilities own certain attributes, and these attributes are used to inventory the emissions associated with that portion of the utilities' power. Fixing ownership of attributes for the year is referred to as "retiring" RECs. To the extent that utilities sold more power than is accounted for in retired RECs, emissions for the remaining power is inventoried by assigning the emissions rate from the regional "residual mix." The residual mix is the mix of generation that was not claimed or retired by any load-serving entity in the NEPOOL system. It generally consists of fossil fuel, nuclear, and imported generation, although it does include other sources.

The NEPOOL GIS system accounts for GHGs independently, and Vermont accounts for non-carbon GHGs (namely methane and nitrous oxides) for biomass and other biogenic electric sources, while not counting CO_2 emissions from these sources.

3.2. Pathways model and Vermont's 2024 projections

Pathways 3.27 lists 2024 emissions of 120 thousand metric tons (kMT) of CO_2e, sourced primarily from sources listed as "ISONE Natural Gas Fired Combined Cycle," "ISONE Petroleum Liquids," "ISONE Wood_Wood Waste Biomass," and "Vermont Wood_Wood Waste Biomass."

Table 1 shows the composition of the 2024 Pathways 3.27 emissions projection.

Table 1. Electric sector pathways emissions (kMT CO_2e)

Source	***2024 Emissions***
ISONE Landfill Gas	0.77
ISONE Natural Gas Fired Combined Cycle	60.94
ISONE Petroleum Liquids	10.99
ISONE Wood_Wood Waste Biomass	13.39
Vermont Landfill Gas	0.01
Vermont Petroleum Liquids	0.95
Vermont Wood_Wood Waste Biomass	33.09
Total	**120.14**

3.3. Evaluation

Table 2 shows the electric sector GHG emissions from the Inventory as well as from the Pathways 3.27 LEAP model. For this table, and the tables throughout the Report that note average differences between the Inventory and Model values from 2015 through 2020, average difference ("Avg. Dif.") is calculated by subtracting the Model's emissions from the April 2023 Inventory emissions for each year from 2015 to 2020, then averaging over the six years, rounded to the nearest whole digit.

Table 2. Electric sector emissions comparison (kMT CO_2e)

		2015	*2016*	*2017*	*2018*	*2019*	*2020*	***Avg Dif.***
a. Coal	Inventory	-	-	-	-	-	-	-
	Model	-	-	-	-	-	-	
b. Natural Gas	Inventory	16	5	7	0	0	0	(9)
	Model	0	0	0	0	0	81	
c. Oil	Inventory	7	4	4	0	0	0	(18)
	Model	18	20	20	19	24	21	
d. Wood and Waste	Inventory	15	15	14	14	12	12	(46)
	Model	57	56	55	57	59	74	
e. Residual System Mix	Inventory	960	898	598	301	240	164	381
	Model	191	181	174	168	162	0	

Table 2 shows that the Pathways 3.27 model is not well aligned to the state's electric sector GHG emissions as inventoried in the Inventory over the period from 2015 through 2020. While we do not have sufficient information to detail exactly how and why the Pathways 3.27 model is not well aligned with the Inventory, we believe there are two drivers which could be substantial contributors to the difference: treatment of emissions from biogenic sources, and the nexus of utility RES compliance and clean energy actions with the regional residual mix.

Treatment of wood and waste

The Pathways 3.27 model is likely overstating inventoried emissions from the combustion of wood and waste. In 2020, for example, the Pathways 3.27 model attributes 74 kMT of CO_2e emissions to Vermont or regional (ISO-NE) electric generation from landfill gas and wood/waste/biomass. The Inventory's method counts only emissions of CH_4 and N_2O from these biogenic sources and does not count CO_2 emissions. Pathways 3.27 provides the CH_4 and N_2O emissions for each of these sources, which sum to just 13 kMT in 2024. This implies that the Pathways 3.27 model must be counting about 60 kMT of emissions from biogenic CO_2 in 2020. Correcting the Pathways 3.27 results for this misalignment of methods would reduce expected 2024 electric sector emissions by about 40 kMT.

REC ownership and residual mix

Vermont enacted its RES in 2015, and the first compliance year was 2017. The fall in inventoried emissions from 2015 to 2017 and beyond reflects the impact of this policy, as Vermont's electric utilities acquired the required zero- or low-emission renewable RECs for RES compliance. The Pathways 3.27 model does not appear to reflect this change—it significantly underestimates emissions in these early years. This means that Pathways 3.27 has not been aligned to match reported attribute ownership in the past, and likely is not built to reflect attribute ownership for its projections. Looking forward, this means it is likely that the Pathways 3.27 model will overstate emissions because Vermont's utilities are rapidly increasing their utilization of zero-emission attributes.

Two Vermont utilities (Burlington Electric Department—BED—and Washington Electric Coop—WEC) have, for several years, procured only renewable electricity, and they retire renewable RECs equal to or greater than their sales each year.[6] Green Mountain Power's (GMP) final portfolios have not been fully renewable, but have been zero emission due to the retirement of nuclear attributes.[7] GMP has committed to maintaining its zero-emission portfolio, including in 2024. Vermont Electric Cooperative (VEC) was also 84 percent renewable and 100 percent zero-emissions in 2023.[8]

The combined effect of the RES and utility commitments is that 2024 inventoried emissions for BED, WEC, and GMP should be very close to zero, while 63 percent of electricity from other utilities (VEC and smaller municipal utilities) will need to be renewable under the RES. This means that 2024 electric sector emissions should be no greater than an estimate based on the application of the regional residual mix to 37 percent of the electricity supplied by VEC and the smaller municipal utilities; if VEC remains zero emission in 2024 then the only emissions would be from the small municipal utilities.[9] If Vermont electric utilities were to fully eliminate their emissions for 2024 through REC ownership, the maximum correction to apply to the Model would be to subtract the 120 kMT that the model projects from the electric sector for 2024.

4. Thermal (RCI) Sector Emissions

4.1. Inventory methodology

Vermont's thermal sector emissions are made up of emissions from fossil fuels used in the RCI subsectors. The primary fuels by emission totals are fuel oil, natural gas, and propane. The Inventory also accounts for methane and N_2O emissions from wood combustion but does not account the biogenic CO_2 emissions from wood. The Inventory relies on U.S. Energy Information Administration (EIA) State Energy Data System (SEDS) datasets for fossil fuel inputs used in each sector, with state emissions calculated from EPA State Inventory Tool (SIT) modules: one for CO_2 emissions and another for CH_4/N_2O emissions. EIA data are national sales data presented at the state level. This is supplemented with fuel

[6] Burlington Electric Department. N.d. "Our Energy Portfolio." Accessed at https://www.burlingtonelectric.com/our-energy-portfolio on July 29, 2024. Washington Electric Cooperative. N.d. "2023 Sources and Costs of Power." Accessed at https://www.washingtonelectric.coop/wp-content/uploads/2024/03/2024-Power-Source-Chart.pdf on July 29, 2024. Vermont Department of Public Service. January 15, 2024. *2024 Annual Report on the Renewable Energy Standard*. Available at: https://publicservice.vermont.gov/sites/dps/files/documents/Appendix%20B_2024%20Renewable%20Energy%20Standard%20Report%20FINAL.pdf

[7] Green Mountain Power. N.d. "Annual Energy Mix." Accessed at https://greenmountainpower.com/energy-mix/ on July 29, 2024

[8] Vermont Electric Coop. N.d. "Power Supply." Accessed at https://vermontelectric.coop/electric-system/power-supply on July 29, 2024.

[9] The Vermont Public Power Supply Authority website indicates that VPPSA utilities in 2022 met the RES requirements and no more. See https://vppsa.com/energy/renewable-energy-standard/.

data for wood combustion coming from the State's Residential Fuel Assessment and the ANR-DEC Air Quality and Climate Division Point Source Registration program.[10]

4.2. Pathways model and Vermont's 2024 projections

Pathways 3.27 lists 2024 emissions of 2,289 kMT of CO_2e, across all three RCI subsectors, with emissions coming primarily from fuel oil, natural gas, and propane.

Table 3 shows the composition of the 2024 Pathways 3.27 emissions projection broken out by fuel. Pathways 3.27 breaks down the RCI categories by appliance fuel type, whereas we have summed up by primary fuel type in the table below. The largest use of fuels in the RCI sector is for space heating, which is largely dependent on the number of HDDs that the state experiences in a given year. HDDs are the difference between 65 degrees and a day's average temperature below 65 degrees and a measure of how cold the temperature was. The Pathways 3.27 HDD assumption hovers around 7,900 HDDs per year but has trended down slightly in recent years. Beyond HDDs, state RCI fuel use is driven by fuel prices, weatherization improvements, fuel-switching from more to less emissions-intensive fuels or electricity, and improving appliance efficiency.

Table 3. RCI subsector pathway emissions by fuel source (kMT CO_2e)

Source	***2024 Emissions***			
	Residential	**Commercial**	**Industrial**	***Total***
Diesel	-	-	228	228
Gasoline	-	50	32	83
Propane	308	191	-	499
Kerosene	-	-	1	1
LPG	-	-	11.72	12
Natural Gas	169	385	115	668
Fuel Oil	525	226	8	760
Wood	23	15	0	38
Total	**1025**	**868**	**397**	**2289**

Totals may not sum due to rounding.

4.3. Evaluation

Table 4 breaks out use by RCI subsector, as the April 2023 Inventory does. Emissions in each RCI subsector are largely related to fuel use for space and water heating, cooking, and other heat applications. The industrial subsector also includes diesel fuel for non-road equipment such as farming,

[10] This report is based on the April 2023 Inventory. The State updated parts of its methodology for the Inventory released in 2024 (covering the period 1990 through 2021), and those changes are not reflected in the Inventory results presented in this report. The April 2023 Inventory was the most recent completed Inventory at the time the Secretary made her determination.

construction, and logging equipment. It shows that the largest source of the underestimation of emissions comes from the residential sector (see row *a*), where actual average emissions were approximately 80 kMT CO_2e more than modeled.

Table 4. Residential, commercial, and industrial (RCI) sector emissions comparison

		2015	*2016*	*2017*	*2018*	*2019*	*2020*	***Avg Dif.***
a. Residential	Inventory	1528	1418	1480	1570	1650	1500	79
	Model	1458	1330	1402	1499	1569	1417	
b. Commercial	Inventory	1007	870	780	920	890	880	(3)
	Model	1009	874	786	927	903	867	
c. Industrial	Inventory	407	415	440	440	450	480	2
	Model	401	408	445	445	447	474	

Table 5 shows the RCI sector GHG emissions by fuel from the April 2023 Inventory as well as from the Pathways 3.27 LEAP model.

Table 5. RCI emissions comparison by fuel (kMT CO_2e)

		2015	*2016*	*2017*	*2018*	*2019*	*2020*	***Avg Dif.***
a. Coal	Inventory	-	-	-	-	-	-	
	Model	-	-	-	-	-	-	
b. Natural Gas	Inventory	645	652	649	748	756	708	3
	Model	638	645	647	749	756	703	
c. Oil, Propane, and Other Petroleum	Inventory	2202	1956	1957	2097	2147	2076	25
	Model	2189	1925	1944	2083	2126	2017	
d. Wood	Inventory	94	96	97	99	99	88	58
	Model	38	39	39	38	36	36	

Table 5 shows that the Pathways 3.27 model is not well calibrated to the State's RCI sector Inventory over the period from 2015 through 2020. The Pathways 3.27 model consistently underestimates sector emissions by approximately 80 kMT per year. It is unclear exactly how and why the Model consistently underestimates RCI sector emissions because the Model overestimates the number of HDDs as compared to historical data. The model could be improved by more completely accounting for CH_4 and N_2O emissions from wood combustion, primarily in the residential sectors. The Model reports CO_2e values between 36 and 39 kMT per year, while reporting CO_2e from CH_4 and N_2O emissions of approximately 1 kMT per year. It is not clear whether the Model is counting CO_2 emissions (contrary to the Inventory treatment of biogenic CO_2) or otherwise miscounting CH_4 and N_2O emissions.

5. TRANSPORTATION SECTOR EMISSIONS

5.1. Inventory methodology

Vermont's transportation sector emissions are made up of emissions from fossil fuels used in on-road, aviation, rail, and non-road transportation.[11] The primary fuels by emission totals are gasoline, diesel, and jet fuel. The Inventory also accounts for methane and N_2O emissions from liquid fuel combustion but does not account for biogenic CO_2 emissions from ethanol or biodiesel. The Inventory relies on EIA SEDS datasets for fossil fuel inputs used in each sector, with state emissions calculated from EPA SIT modules: one for CO_2 emissions and another for CH_4/N_2O emissions. EIA data are national sales data that are presented at the state level. This is supplemented with gasoline sales data from the State's Joint Fiscal Office with adjustments made to remove approximate contributions from aviation gasoline and ethanol. A large variable in total transportation sector emissions is state vehicle-miles traveled (VMT). For example, emissions fell by as much as 15 percent between 2019 and 2020 as a result of the Covid-19 pandemic in which total VMT fell dramatically. Total VMT have not rebounded to their pre-Covid-19 levels.

CH_4 and N_20 emissions for transportation fuels depend on a number of different factors including average age of the state's vehicle fleet, vehicle turnover, emissions control technology, and total VMT. These data are based on Federal Highway Administration estimates and state-specific VMT data from the State Agency of Transportation. Non-road emissions also include emissions from lubricants, recreational vehicles, and lawn equipment.

5.2. Pathways model and Vermont's 2024 projections

Pathways 3.27 lists 2024 emissions of 2,964 kMT of CO_2e, across all fuels, with emissions primarily coming from on-road gasoline and diesel use. Table 6 shows the composition of the 2024 Pathways 3.27 emissions projection broken out by fuel, with gasoline and diesel making up the vast majority of emissions.

[11] This report is based on the April 2023 Inventory. The State updated parts of its methodology for the Inventory released in 2024 (covering the period 1990 through 2021), and those changes are not reflected in the Inventory results presented in this report. The April 2023 Inventory was the most recent completed Inventory at the time the Secretary made her determination.

Table 6. Transportation sector pathway emissions (kMT CO_2e)

Source	*2024 Emissions*
Gasoline	2222
Diesel	615
Aviation	114
Non-energy: Lubricants	9
Other	4
Total	**2964**

5.3. Evaluation

Table 7 shows the transportation sector GHG emissions from the Inventory as well as from the Pathways 3.27 LEAP model.

Table 7. Transportation sector emissions comparison (kMT CO_2e)

		2015	*2016*	*2017*	*2018*	*2019*	*2020*	*Avg Dif.*
a. On & Off Road Gasoline	Inventory	2553	2516	2498	2525	2501	2088	14
	Model	2571	2565	2554	2352	2497	2057	
b. On & Off Road Diesel	Inventory	793	813	765	749	709	648	(9)
	Model	801	823	775	755	714	660	
c. Jet Fuel	Inventory	81	88	64	69	69	62	(42)
	Model	113	128	104	114	114	114	
e. All Mobile (CH_4/N_2O)	Inventory	21	20	18	16	16	13	17
	Model	-	-	-	-	-	-	
f. Non-energy: Lubricants	Inventory	51	50	47	42	41	36	35
	Model	12	11	10	9	8	8	
g. Other Fuels	Inventory	-	-	-	-	-	-	(7)
	Model	11	13	7	3	3	3	

Table 7 shows that the Pathways 3.27 model is well calibrated, overall, to the State's transportation sector GHG inventory from 2015 through 2020. The Model consistently underestimates emissions from the lubricants sector by about 35 kMT, but overestimates jet fuel emissions by a similar 40 kMT. The Model on average underestimates emissions from gasoline but in some years it overestimates, meaning there is more likely to be noise than a systematic factor to correct. The net result is a model with data for the transportation sector that is reasonably well aligned with historical averages, although it could be improved by having jet-fuel and lubricant data reflect actual emissions from those sectors.

6. FOSSIL FUEL TRANSMISSION AND DISTRIBUTION

6.1. Inventory methodology

Vermont's fuel transmission and distribution (T&D) emissions include fugitive emissions related to natural gas T&D in the state. There is no indigenous fossil fuel industry in the state. Emissions from the combustion of natural gas are accounted for in each respective sector. Emissions from T&D are estimated based on total miles of natural gas pipeline and the EIA Natural Gas and Oil SIT module. An emissions factor for leakage rate per mile by pipeline material type is used to estimate total T&D emissions. CH_4 is accounted for by using EPA emission factors per service and per mile of distribution pipeline by material type. The Inventory relies on federal T&D pipeline mile data to determine how many miles of particular type of pipeline there is in state. These data are provided by the Pipeline and Hazardous Materials Safety Administration (PHMSA).

6.2. Pathways model and Vermont's 2024 projections

Pathways 3.27 lists 2024 emissions of 21 kMT of CO_2e, all attributed to the state's natural gas transmission network and no emissions associated with the distribution system. Table 8 breaks down emissions by each subsector; there are no modeled emissions associated with natural gas distribution. The model relies on historical methane emissions data from 2000 and does not assume any methane emissions losses (leakage) for the transmission or the distribution system.

Table 8. Fossil fuel pathway emissions (kMT CO_2e)

Source	***2024 Emissions***
Transmission	21
Distribution	0
Total	21

6.3. Evaluation

The Model is fairly well aligned with the Inventory. Table 9 compares Inventory and Model emissions for the state's natural gas T&D sector. However, the Model could be improved by including estimates of fugitive emissions from the T&D sector. This is, in total, a relatively small sector of emissions in the state and does not account for much of the total difference in emissions between the Inventory and Model. Adding distribution emissions to the Model would more accurately reflect how Inventory emissions are associated with the natural gas T&D sector.

Table 9. T&D sector emissions comparison (kMT CO_2e)

		2015	2016	2017	2018	2019	2020	Avg Dif.
a. Distribution	Inventory	3.9	4.0	4.1	4.2	4.3	4.3	4
	Model	-	-	-	-	-	-	
b. Transmission	Inventory	14.7	18.8	23.4	23.4	23.4	23.4	1
	Model	10	20	20	23	23	22	

7. INDUSTRIAL PROCESS EMISSIONS

7.1. Inventory methodology

Vermont's industrial process emissions come from a diverse range of sectors and pollutants. The sector includes emissions from the use of ozone depleting substance (ODS) substitutes, semiconductor manufacturing, limestone and dolomite use, electric power T&D systems, soda ash, and urea (fertilizer) consumption. The primary pollutants include hydrofluorocarbons (HFC), perfluorocarbons (PFC), nitrogen trifluoride (NF_3) sulfur hexafluoride (SF_6), and CO_2. Methods for estimating each industrial sector's emissions differ, with estimates largely derived from the Industrial Processes SIT module. The estimates for ODS substitutes are derived from a tool developed by California for the U.S. Climate Alliance. This ODS tool includes estimated leakage rates for existing equipment and end-of-life disposal leakage estimates.

The Inventory also relies on data submitted to the U.S. EPA GHG Reporting Program to estimate emissions from semiconductor manufacturing. There is one semiconductor manufacturing facility in the state, and it reports annual emissions of all GHG pollutants to the EPA. The pollutants, beyond CO_2, in the industrial sector have widely different GHG GWP factors used to convert them into CO_2e values. The Inventory relies on 100-year GWP AR4 factors.

7.2. Pathways model and Vermont's 2024 projections

Pathways 3.27 lists 2024 emissions of 565 kMT of CO_2e, with most emissions split between ODS substitutes and semiconductor manufacturing.

Table 10 breaks out emissions by subsector in the industrial process sector. The sector's modeled emissions remain relatively constant over the years with little variability in subsector emissions. For limestone and dolomite production, soda ash use, and urea consumption, the Model relies on historical industrial product use value for each of those products and multiplies it by a coefficient of less than 1. For ODS substitutes and electric utilities' sulfur hexafluoride, values extrapolated from historical emissions data from the Inventory are used. Semiconductor manufacturing data in the Model is directly taken from the EPA SIT from 1990 to 1999, with an extrapolated growth rate in emissions through 2019.

Table 10. Industrial process sector pathway emissions (kMT CO_2e)

Source	***2024 Emissions***
ODS Substitutes	333
Electric Utilities (SF6)	5
Semiconductor Manufacturing (HFCs, PFCs, SF6)	198
Limestone & Dolomite	23
Soda Ash Use	4
Urea Consumption	2
Total	565

7.3. Evaluation

The Model is not well aligned with the Inventory. Table 11 compares emissions by subsector between the Inventory and Model. The Model consistently underestimates emissions by approximately 20 kMT in the ODS substitute sector (see row *a*) and approximately 30 kMT from the semiconductor manufacturing sector (see row *c*). The Model could be improved by more accurately representing emissions from the semiconductor manufacturing sector. Modeled emissions in this subsector are falling, whereas the Inventory shows emissions to be generally stable or increasing. Because there is only one facility in Vermont that reports its data annually to the EPA, the Model could more closely reflect actual historical emissions in this subsector. We recognize that ODS substitute sector emissions are likely more difficult to model accurately given that there is likely not complete data on this sector. However, closer calibration is possible.

Table 11. Industrial process sector emissions comparison (kMT CO_2e)

		2015	2016	2017	2018	2019	2020	Avg Dif.
a. ODS Substitutes	Inventory	315	326	337	345	359	367	20
	Model	323	323	321	321	321	323	
b. Electric Utilities	Inventory	6	6	6	6	6	6	0
	Model	6	6	6	6	6	6	
c. Semiconductor Manufacturing	Inventory	256	239	228	220	231	245	33
	Model	210	210	206	201	197	197	
d. Limestone & Dolomite Use	Inventory	33	29	23	15	29	29	1
	Model	33	25	24	23	23	23	
e. Soda Ash Use	Inventory	4	4	4	4	4	4	0
	Model	4	4	4	4	4	4	
f. Urea Consumption	Inventory	1	2	2	2	3	3	0
	Model	1	2	2	2	2	2	

8. Waste Management Emissions

8.1. Inventory methodology

Vermont's waste sector emissions only include CH_4 and N_2O from solid municipal waste, wastewater treatment facilities within the state, and composting. The Inventory does not include biogenic CO_2 emissions from this sector, in line with IPCC inventory guidelines. For the wastewater sector, the Inventory uses the EPA SIT Wastewater module alongside direct measurement data for CH_4 and N_2O from the facilities. The emissions data from the solid waste subsector come from two different methodologies. There are two large landfills in the state that both have landfill gas to energy systems and report their emissions data to the State's DEC Air Quality and Climate Division. There are also two smaller closed solid waste facilities with similar systems that have reported their data to the State. Captured CH_4 that is then combusted and emitted as CO_2 is not counted in the Inventory because it is considered biogenic in source. To account for a number of smaller, closed facilities that still emit CH_4 and N_2O, the total solid waste subsector emissions are increased by 15 percent, a figure recommended by the State's Waste Management and Prevention Division, in the Inventory. Methane emissions from composting are included in the Inventory and are taken from EPA state level data from the U.S. GHG Emissions and Sinks report.

Key variables in determining total sector emissions include waste prevention and diversion through recycling programs and overall state consumption data.

8.2. Pathways model and Vermont's 2024 projections

Pathways 3.27 lists 2024 emissions of 125 kMT of CO_2e, with the majority of emissions coming from the state's wastewater facilities. Table 12 breaks out the Model's emissions for the state's waste sector. The sector's estimated emissions have remained relatively constant over the years with little variability in subsector emissions. The Model does not separate or identify compost-related emissions. The Model arrives at solid waste emissions estimates by multiplying estimated short tons[12] of waste by historical reported emissions as reported in the Inventory, extrapolated out to 2019. For wastewater, state population estimates are multiplied by a constant coefficient for both methane and N_2O.

Table 12. Waste sector pathway emissions (kMT CO_2e)

Source	***2024 Emissions***
Solid Waste	55
Wastewater	69
Total	125

8.3. Evaluation

The Model is not well calibrated to actual historical state waste emissions as detailed in the Inventory. Table 13 compares emissions by subsector in the waste sector between the Inventory and the Model.

First, the solid waste sector calculations in the Model consistently underestimate actual reported emissions by about 25 kMT (see row *a*). Second, the Model does not account for composting emissions (see row *b*), while the wastewater facility subsector calculations consistently overestimate emissions by approximately 5 kMT (see row *c*). Together, the Model underestimates total sector emissions by an average of 33 kMT.

Table 13. Waste sector emissions comparison (kMT CO_2e)

		2015	*2016*	*2017*	*2018*	*2019*	*2020*	***Avg Dif.***
a. Solid Waste	Inventory	96	78	72	82	81	77	26
	Model	54	55	55	55	55	55	
b. Composting	Inventory	8	11	12	12	13	14	12
	Model	-	-	-	-	-	-	
c. Wastewater	Inventory	63	63	64	64	64	65	(5)
	Model	69	69	69	69	69	69	

[12] A short ton is equivalent to 2,000 pounds (lbs.). A metric ton is equivalent to 1,000 kilograms, or approximately 2,204 pounds.

The Model could be improved by including historical estimates for composting or including composting emissions within the solid waste subsector. Additionally, the wastewater facility subsector could be improved by using State provided facility-level emissions data, which is more accurate.

9. AGRICULTURE EMISSIONS

9.1. Inventory methodology

Vermont uses the U.S. EPA's SIT to inventory agriculture sector emissions. These emissions are entirely CH_4 and N_2O emissions, because the CO_2 released in the agriculture sector is biological in origin and is not counted in the Inventory. The SIT is populated by data from federal sources, such as USDA information regarding the number of cows or total volume of various crops produced. The State amends the inputs to the SIT to account for cow manure that is estimated to be processed in anaerobic digesters to reduce the resulting emissions in the Inventory. For the April 2023 Inventory, Vermont made this correction by adjusting the number of cows in the manure management portion of the SIT. The State also inputs data regarding the estimated use of different fertilizers. The State's fertilizer use estimates in the Inventory are unchanged from at least as far back as 2014, through 2020.

9.2. Pathways model and Vermont's 2024 projections

The Model breaks down agricultural sector emissions into four primary categories: enteric fermentation, manure management, agricultural soils, and liming and urea fertilization. For enteric fermentation, the Model multiples a total estimated herd size by estimated CH_4 emissions factor. Twelve different types of common agricultural animals are accounted for with varying emission factors. Similarly, for manure management, the Model breaks out emissions for CH_4 and N_2O by animal and multiplies total herd size by an emissions factor. The agricultural soils subsector is broken down into direct and indirect emissions. Direct emissions include a constant value for fertilizer N_2O emissions and an emissions factor. The same is true for agricultural soils indirect emissions. For liming and urea fertilization, N_2O emissions are modeled at a constant rate using historical data with slight downward variations.

The EFG team cut emissions in the Pathways 3.27 model by a factor of two starting in 2020, in order to reflect insights about net emissions from a carbon cycle study. However, this change is not reflected in the Inventory so the State has adjusted the Pathways results back to their original levels when presenting modeled results. We have replicated that process here to show the 2024 Pathways results.

Table 14. Agriculture sector pathway emissions (kMT CO_2e)

Source	*2024 Emissions*
Enteric Fermentation	641
Manure Management	172
Agricultural Soils	309
Liming and Urea Fertilization	47
Total	1170

9.3. Evaluation

We have identified two areas of concern regarding comparing the Inventory and the Model for the agriculture sector. The first has to do with errors in the execution of the Inventory, which result in incorrect emissions values for comparison. The second is that the Model sustains differences with the Inventory over the full 2015 to 2020 period without any indication of calibration.

Inventory errors for 2020

In the 2022 Agriculture Sector SIT module used to calculate the Inventory, the emissions from fertilizers are understated for 2020 due to a spreadsheet error. The SIT makes an adjustment between reporting or data years and calendar years, assigning 65 percent of the growing year emissions to one year of emissions and 35 percent to the next year. The SIT module spreadsheet used by the State for the Inventory does not include the 2021 growing year emissions, meaning that the 2020 calendar year fertilizer emissions are understated by 35 percent.

This error is compounded by missing data on the National Adjustment sheet. This sheet adjusts state-specific numbers each year to ensure that all state emissions add up to national emissions. The SIT module used by the State for the Inventory includes National Adjustments for 2019 but not for 2020. The National Adjustment generally results in an increase in emissions, so its absence results in inappropriately lower emissions in the Inventory.

In its presentation to the Climate Council on January 29, 2024, ANR stated that the improvement of the agriculture sector model for 2020, compared with earlier years, was an indication of improvements in the Model.[13] Instead, it appears that this reduction in difference is simply a result of Inventory errors.

[13] Poor, TJ, Jane Lazorchak, and Brian Woods, *Updated Vermont Pathways Baseline Emissions: Presentations to the Vermont Climate Council*, Vermont Agency of Natural Resources (ANR), January 29, 2024.

Pathways model is not well calibrated to Inventory

Table 15 shows the Inventory and model emissions for each year from 2015 through 2020 for each subsector.

Table 15. Agriculture sector emissions comparison (kMT CO_2e)

		2015	*2016*	*2017*	*2018*	*2019*	*2020*	***Avg Dif.***
a. Enteric Fermentation	Inventory	635	643	645	643	630	614	6
	Model	634	643	645	643	643	638	
b. Manure Management	Inventory	341	357	348	355	347	334	162
	Model	180	189	186	191	191	171	
c. Agricultural Soils	Inventory	400	366	354	359	367	287	45
	Model	312	314	312	309	309	307	
d. Liming and Urea Fertilization	Inventory	48	47	52	38	38	25	(6)
	Model	48	47	47	47	47	47	

The Model consistently underestimates total agricultural sector emission by around 200 kMT CO_2e through 2020. Enteric fermentation appears to be relatively well calibrated in the early years (through 2018), before drifting off in 2019 and 2020 (see row *a*). It is unclear from the Model why the modeled and actual values begin to diverge. These latter years are when the Model transitions to modeling the BAU case rather than hosting historical data, indicating that the Model inputs may not be up to date with the Inventory's sources.

Manure management shows a difference between the Inventory and the Model of almost a factor of two (see row *b*). The two sources appear to move in concert: the same years are highest and lowest emissions in both documents. It appears likely that the factors that transform inputs to outputs in the Model do not align with those used by the Inventory. The Model's agricultural soils emissions (see row *c*) show a steady underestimate of the Inventory values, aside for 2020 (where the error discussed above changes the balance). The Model and Inventory values do not move in concert, so there may be differing inputs as well as differing conversion factors. Finally, liming and urea fertilization is relatively well calibrated on average, although the Model appears to be almost fixed while the Inventory reflects some variation in input parameters. Across all four categories, the Model consistently underestimates Inventory emissions by about 200 kMT CO_2e per year.

10. EVALUATION SUMMARY

Vermont's Pathways 3.27 model has not been calibrated to correct for systematic differences between the Model and the Inventory. These differences result in an overall underestimate of emissions by the Pathways model throughout the 2015 to 2020 comparison period. There is no evidence in the Model that its systematic differences from the Inventory change between 2020 and 2024. We therefore expect that the Pathways 3.27 model estimate of 2024 emissions retains these systematic differences and therefore understates the inventoried 2024 emissions by a comparable amount. Table 16 shows the cumulative impacts of these differences.

Table 16. Sectoral and cumulative approximate corrections to the Pathways 3.27 model estimate, along with the estimate for context

Sector	Pathways 2024 Estimate (kMT)	Approx. Correction to 2024 Emissions Estimate (kMT)
Electricity	120	-40 to -120*
Thermal/RCI	2,287	+80
Transportation	2,954	net 0
Fossil Fuel T&D	21	0
Industrial Process	565	+50
Waste	125	+30
Agriculture	1,190	+200
TOTAL	7,262	+320 to +240
Relation to 7,275 kMT Limit	13 below	230 to 310 over

** This range correction reflects the likely treatment of biogenic CO_2 from wood electricity generation and possible renewable energy credit ownership effects.*

The differences between the Model and Inventory were all present in the Model used throughout 2023 and 2024. If they had been addressed in or before early 2024, the State would have projected missing the January 1, 2025, GWSA emissions reduction requirement by 230 to 310 kMT, and the Secretary's July 1, 2024, letter would have reflected different findings.