Scientific Underpinning of Emissions Reductions

In drafting this update to the Climate Action Plan, the Agency of Natural Resources produced or commissioned the following reports and technical studies, prioritized by the Council, that sought to clarify and improve our understanding of key components of climate action.

Greenhouse Gas Inventory Review and Forecast

The Vermont Greenhouse Gas Inventory and Forecast[1], is published annually by the Agency of Natural Resources (ANR), as required by Vermont statute 10 V.S.A. § 582 and following guidelines for GHG accounting from the Intergovernmental Panel on Climate Change (IPCC) and Environmental Protection Agency (EPA). Vermont's GHG Inventory establishes historic 1990 and 2005 baseline greenhouse gas (GHG) levels for Vermont and tracks changes in GHG emissions through time. The Inventory is the primary means of determining progress toward Global Warming Solutions Act (GWSA) statewide emissions reduction obligations. It is important to note that, historically, there has been a three-year lag in emissions inventory reporting, primarily due to delays in calculating agriculture sector emissions (i.e., the Inventory covering 1990-2022 GHG emissions was published in 2025).

[1] https://climatechange.vermont.gov/climateactionoffice/greenhouse-gas-inventory

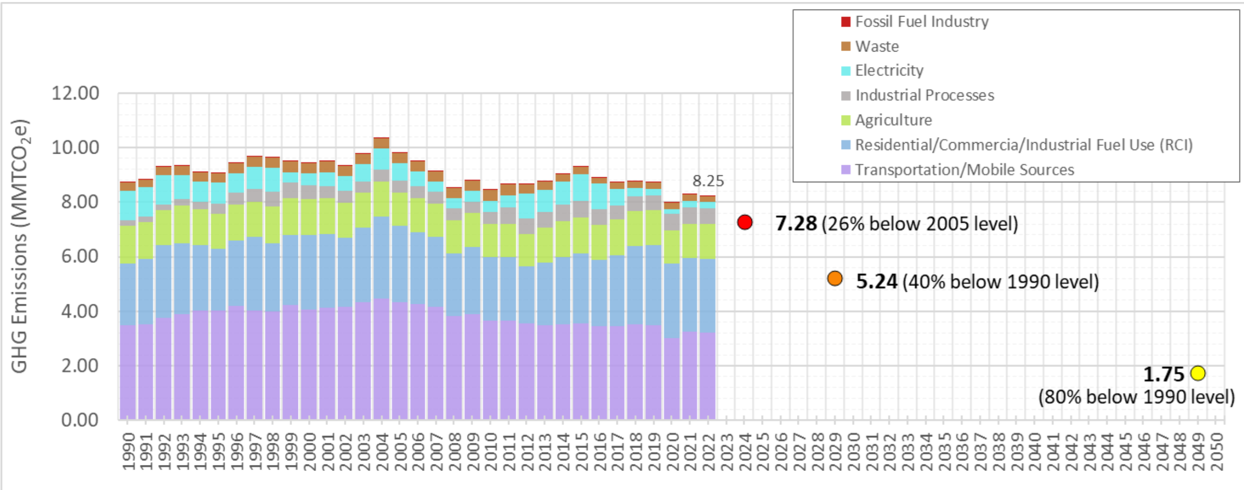

Figure 18: Vermont Greenhouse Gas Inventory historical emissions and future requirements

Vermont's annual statewide GHG emissions from 1990 through 2022 are shown by sector on Figure 18 as reported in the *Vermont Greenhouse Gas Inventory and Forecast*. The red dots indicate the maximum statewide emissions consistent with the Vermont Global Warming Solutions Act requirements to be achieved by January 1st of 2025, 2030, and 2050.

Beginning in 2024, a supporting companion document was published with the annual Inventory, detailing the methodologies and data used to inform the Inventory. This methodology document also discusses data and methods for supplemental analysis related to Land Use and Land Use Change (LULUCF) sources and sinks, providing links to relevant reports.[2] The Science and Data Subcommittee of the Council is responsible for reviewing and providing feedback on any updates to the inventory methodology. To ensure that Vermont fulfills its legal obligations, it is important that our tracking methods continue to be as transparent and accurate as possible.

Vermont Pathways / LEAP

In support of the 2020 Comprehensive Energy Plan and the 2021 Climate Action Plan the state commissioned development of the Vermont Pathways model in the Stockholm Environment

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[2] https://climatechange.vermont.gov/climateactionoffice/greenhouse-gas-inventory

Institute’s Low Emission Analysis Platform (LEAP). In contrast to the *Vermont Greenhouse Gas Inventory and Forecast* which presents historic emissions, the Vermont Pathways model utilizes existing data and projections of activity across a wide range of economic sectors to forecast emissions of greenhouse gases and other pollutants. It includes representations of numerous greenhouse gas reduction measures, including data related to their installation and operational costs and their energy use. The model includes a baseline case (often referred to as “business-as-usual”) that projects future emissions based on the on-going effects of current policies, as well scenarios developed from that baseline designed to explore the changes in emissions and costs of implementation of different approaches to reduce emissions. The model also provides estimates of key indicators such as the number of weatherization projects completed, the number of electric vehicles in service, and the number of heat pumps installed by year and in total necessary to achieve the emissions target for a given scenario.

Since its initial development, the Vermont Pathways model has been significantly updated twice: once in support of the Analysis of Buildings/Thermal Energy Sector Emissions Reduction Policies for Vermont (discussed below); and a second time in support of this update of the Climate Action Plan (“2025 update”).

The 2025 update includes a comprehensive update of the baseline scenario assumptions for all the sectors represented in the model, which mirror the sectors accounted for in the *Vermont Greenhouse Gas Inventory and Forecas*t. The model results presented below were provided to the Agency of Natural Resources just as this Climate Action Plan was being published and have not been reviewed by the Climate Council.

The updated baseline incorporates two changes from the previous version worth noting. First, the calibration factors for each sector were updated so that modeled emissions aligned with reported emissions from the 2024 *Vermont Greenhouse Gas Inventory and Forecast* report. Second, implementation of the Advanced Clean Cars II and Advanced Clean Trucks regulations was removed from the baseline scenario due to uncertainty regarding the waiver granted to California, and by extension to other states, to allow those regulations to become effective. As a result emissions are 0.887 million metric tons carbon dioxide equivalent (MMT CO_2e) / 13.4% higher in 2029 and 0.420 MMT CO_2e / 8.8% higher in 2049 as compared to the previous version of the baseline scenario.

The update also includes four mitigation scenarios. These scenarios implemented the twenty-six mitigation measures[3] represented in the model on different schedules in order to explore the potential effects on emission reduction trajectories and net costs or savings. Those scenarios and their emission reductions relative to 1990 emissions, along with the GWSA target reductions and the revised baseline reductions are presented below.

Table 9: Percent Greenhouse Gas Emission Reductions as compared to 1990

	2029	**2034**	**2049**
GWSA Requirement	40%	N/A	80%
Baseline	14%	26%	41%
Scenario 1: all mitigation measures implemented over the entire modeling period (2024-2050)	29%	53%	78%
Scenario 2: societally cost-effective measures[4] implemented over the modeling period, with non-cost-effective measures implemented 2039-2050	25%	44%	72%

[3] Mitigation measures are increased behind-the-meter solar PV, B100 in heavy-duty vehicles, manure management, wastewater methane abatement, ozone-depleting substances substitution, semiconductor manufacturing measures, enhanced agricultural soil sequestration, reduced enteric fermentation, commercial building advanced wood heat, fossil water heating phase-out by 2040, fossil cooking phase-out by 2040, district heating projects, commercial building heat pumps, managed EV charging, residential building heat pumps, E15 ethanol blending in gasoline, vehicle-to-grid technology, B20 biodiesel, B100 heating fuel, sustainable aviation fuel, B100 for industrial processes, renewable natural gas for industry, biogas, light duty internal combustion motor vehicle sales phase-out by 2035, vehicle miles traveled reductions, weatherization at scale

[4] Social cost includes measure implementation costs, operational costs or savings as compared to baseline, and the social cost of avoided greenhouse gas emissions. Societally cost-effective mitigation measures are increased behind-the-meter solar PV, B100 in heavy-duty vehicles (implemented 2034-2050), B100 heating fuel, B100 for industrial processes, B20 biodiesel, sustainable aviation fuel, E15 Ethanol, manure management, wastewater methane abatement, ozone-depleting substances substitution, semiconductor manufacturing measures, enhanced agricultural soil sequestration, reduced enteric fermentation, commercial building advanced wood heat, fossil water heating phase-out by 2040, fossil cooking phase-out

Scenario 3: implementation of societally cost-effective measures only through 2050	28%	49%	69%
Scenario 4: societally cost-effective measures plus weatherization implemented over the entire modeling period, with the remainder of the non-cost-effective measures implemented 2039-2050	25%	44%	72%

The results of the scenario analysis illustrate the challenge with achieving the 2030 requirement currently established in state statute. Scenarios 2, 3, and 4 also present the progress anticipated by 2035 to provide context for the impact of implementation over time.

Although Scenario 1 fully implements all twenty-six of the mitigation measures represented in the model in all sectors, as noted above the emission reductions achieved are less than the GWSA emissions reduction requirements for both 2030 and 2050. To achieve a 40% reduction by 2030 would have required increasing the assumed measure adoption/implementation rates for one or more mitigation measures. Tables showing the level of implementation of selected measures are presented later in this section. This scenario results in cumulative savings of $6.06 billion in 2050 as compared to the baseline scenario with the primary benefit being savings from avoided fuel costs. This scenario becomes net cost beneficial in 2031. In 2030 it is $9 million more costly than the baseline.

Scenario 2 delays implementation of measures that are not cost-effective until 2039. This results in a 44% reduction by 2035 with cumulative savings of $2.65 billion as compared to the baseline. Cost savings as compared to baseline in 2050 are $7.52 billion, approximately 25% more than Scenario 1.

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by 2040, district heating projects, commercial building heat pumps, managed EV charging, residential building heat pumps

Scenario 3 implements only societally cost-effective measures over the entire modeling period. As expected, this results in the greatest net savings of all scenarios - $1.01 billion by 2030, $2.92 billion by 2035, and $10.17 billion by 2050. This scenario does not achieve a 40% reduction until 2032 and does not achieve the 80% reduction by 2050 target.

Scenario 4 adds weatherization retrofits to the list of cost-effective measures being implemented over the entire modeling period. This scenario results in nearly identical emission reductions as compared to Scenario 2 in all years. Including weatherization projects throughout the modeling period results in cumulative net savings by 2035 of $2.18 billion, approximately $474 million less than Scenario 2. However, the effect of early weatherization projects results in cumulative net savings by 2050 of $7.6 billion, $85 million greater than Scenario 2.

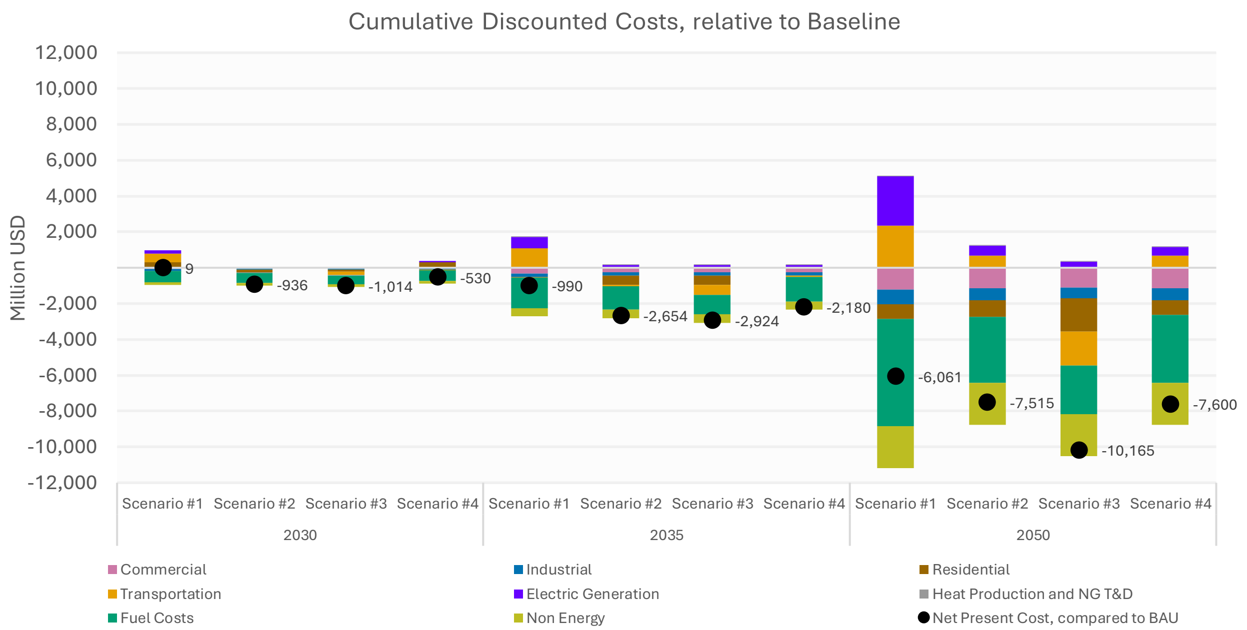

Figure 19: Costs/Savings of Scenarios versus Baseline, including social costs of GHGs

Note that the costs/savings results from the model are inclusive of the social cost of greenhouse gases, which is described in more detail below. Among the costs that the social cost of greenhouse gases estimates are the increased costs due to negative health outcomes related to pollutant emissions, but those costs are not specific to Vermont. In addition, several measures (e.g. weatherization, EVs) produce health benefits to Vermonters that are not related to greenhouse gas emissions. Those benefits were not included in the benefit-cost analysis. However, a health benefits study performed in support of a prospective regional transportation sector cap-and-invest program in the northeast United States concluded that positive health outcomes would likely result from decreased combustion emissions from motor vehicles and an increase in non-motorized transport modes.[5]

Given that the social cost of greenhouse gases estimates the avoided costs of emissions that accrue to society worldwide over decades, the cumulative net cost analysis was performed minus that adjustment in an effort to present a rough estimate of the costs/benefits at the state scale of the various mitigation scenarios. The analysis likely overestimates costs to some extent as there are benefits embedded in the social cost of greenhouse gases that do accrue to Vermonters, but development of state-level cost of greenhouse gas emissions values was beyond the scope of this modeling effort. As expected, net costs increase in all scenarios as compared to the analysis with the social cost of greenhouse gases included. Scenario 3 (cost-effective measures) results in net benefits from 2030 onward with $1.66 billion in net benefits by 2050. Scenario 2 (delayed implementation) is net beneficial by 2030 and 2035 but has cumulative net cost of $1.26 billion by 2050. Scenario 4 has a net cost of $307 million by 2030, is net beneficial ($9 million in net savings) by 2035, and has a cumulative net cost of $1.2 billion by 2050. Scenario 1 shows net costs over the entire modeling period, with a cumulative net cost of $5.73 billion by 2050; over 4 times the average net cost of scenarios 2 and 4 ($1.23 billion).

[5] Fallon Lambert, K. et al, "Air Quality, Health and Equity Impact Assessment of the Transportation Climate Initiative", American Geophysical Union, Fall Meeting December 2020, abstract accessed at https://ui.adsabs.harvard.edu/abs/2020AGUFMA111.0003F/abstract

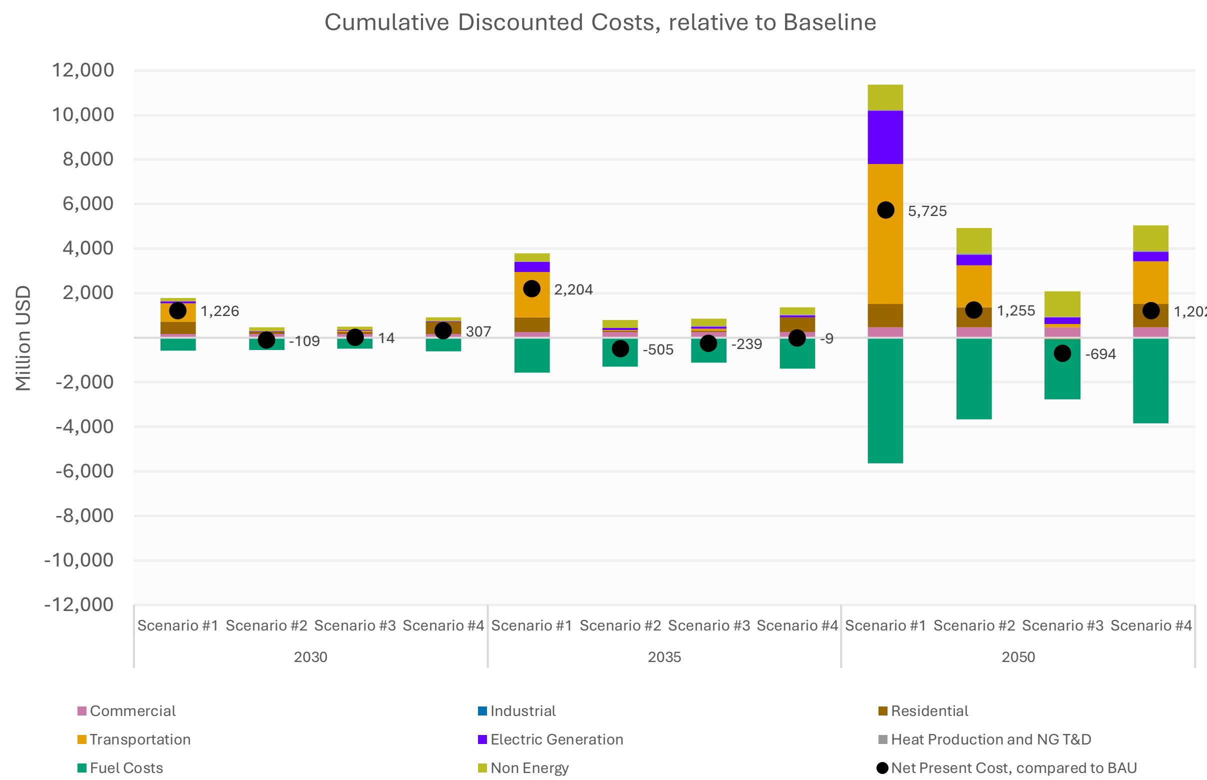

Figure 20: Costs/Savings of Scenarios versus Baseline, excluding social costs of GHGs

Indicators from the two sectors that make up the majority of the state's emissions, transportation and residential/commercial/industrial heating, illustrate the level of mitigation measure adoption necessary to achieve the emission reductions noted above:

Table 10: EV/PHEVs

	Number of Vehicles					Percent of Fleet			
	2025	**2029**	**2034**	**2050**		**2025**	**2029**	**2034**	**2050**
Baseline	21,870	66,543	153,342	281,920		4.0%	12.2%	29.3%	64.0%
Scenario 1	22,633	79,075	187,724	418,759		4.1%	14.5%	35.9%	95.0%
Scenario 2	21,870	66,543	153,342	339,341		4.0%	12.2%	29.3%	77%

Table 11: Heavy-Duty EV/PHEV- Number of Vehicles / Percent of Fleet

	Number of Vehicles					Percent of Fleet			
	2025	**2029**	**2034**	**2050**		**2025**	**2029**	**2034**	**2050**
Baseline	510	784	1,957	4,246		1.0%	1.4%	3.3%	6.7%
Scenario 1	793	4,727	15,044	51,343		1.5%	8.3%	25.1%	80.1%
Scenario 2	525	834	2,050	20,878		1.0%	1.5%	3.4%	32.9%

Table 12: Residential Weatherization Retrofits

	Average Annual Retrofits					Cumulative Retrofits			
	2025	**2026-2029**	**2030-2034**	**2045-2049**		**2025**	**2029**	**2034**	**2049**
Baseline & Scenario 3	5,845	3,969	2,254	2,199		5,845	21,722	32,992	65,719
Scenarios 1 & 4	11,613	11,613	7,262	6,174		11,613	58,064	94,373	186,987
Scenario 2	2,345	2,345	2,345	20,591		2,345	11,726	23,452	166,243

Table 13: Heat Pump Installations

	Average Annual Housing Units Switching to Heat Pumps					Cumulative Housing Units			
	2025	**2026-2029**	**2030-2034**	**2045-2049**		**2025**	**2029**	**2034**	**2049**
Baseline	5,003	1,118	4,927	2,362		5,003	9,474	34,108	96,430
Scenario 1	6,018	1,859	5,973	3,147		6,018	13,452	43,317	117,502
Scenario 2	5,251	1,086	5,558	3,759		5,251	9,594	37,384	117,049
Scenario 3	5,538	1,218	5,552	3,242		5,538	10,409	38,168	113,721

Marginal Abatement Cost Analysis[6]

This report, released in 2022, provided additional analysis and information on the emissions abatement potential and costs for each of the mitigation measures represented in the original version of Vermont Pathways. The analysis examined two timeframes. The first scenario implemented the measures only through 2030 but accounted for savings realized through 2050. The second implemented the measures through 2050 and accounted for savings and costs through 2050. The results showed a wide range of both emission reduction potential for each measure and their cost. Three measures, all in the residential sector (fossil cooking phase-out, fossil water heating phase-out, and heat pump space heating) had savings in the range of $140-$400 per metric ton reduction in both scenarios. Two transportation measures (internal combustion sales phase-out by 2035 and E15 motor fuel) had costs ranging from $0.32 to $50.04 per metric ton reduction in both scenarios. Four measures across three sectors (transportation, residential, industrial) had costs ranging from $132 to $972 per metric ton reduction. Two residential sector measures (weatherization at scale and advanced wood heating) had significant savings in the 2030 scenario but significant costs in the 2050 scenario, due in part to decreasing opportunities for savings for measures implemented after 2030 due to ongoing decarbonization of energy.

Analysis of Buildings / Thermal Energy Sector Emissions Reduction Policies for Vermont[7]

In 2023 ANR released a study of a suite of policies for reduction of greenhouse gas emissions in the buildings/thermal energy sector. The study utilized the Vermont Pathways model and several external spreadsheet workbooks to explore the efficacy and comparative cost of three

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6 https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/MAC%20Curve%20Deliverable%20Memo%20Clean%20Version.pdf

7 https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/VT%20Thermal%20Analysis%20Final%20Report%2011_28%20revisions.pdf

overarching policy options (expansion of existing programs in the buildings/thermal energy sector, a clean heat standard, and a cap-and-invest program) under two different emission trajectory scenarios (40% reduction in emissions from 1990 level by 2030, and the same reduction by 2035). It also examined a bundle of regulatory measures that would achieve the 40% reduction in emissions by 2030. The study made several findings, including:

- Achievement of reductions were made easier due to availability of federal and state funding, however additional policies and programs were required to meet emission reduction targets;
- Many of the emission reduction measures considered would reduce energy costs for consumers that are able to implement them; and
- The cost of fossil fuels would need to increase to recover program costs.

Transportation Carbon Reduction Study[8]

In 2023 the Vermont Department of Transportation (VTrans) released their Carbon Reduction Study, analyzing a collection of mitigation measures in the transportation sector to understand how current programs affect greenhouse gas emissions and to assess future policy options and investment strategies towards the reduction of transportation emissions. The baseline forecast from this analysis indicated transportation sector emissions in carbon dioxide equivalents would be 0.4 million metric tons over the transportation sector's target emissions to achieve a 40% reduction from 1990 levels by 2030 and 0.1 million metric tons over the 80% reduction by 2050 target. The majority of transportation emissions are from and are forecast to continue to be from motor vehicles (cars and trucks) operating on Vermont's roadways. The study concluded that achieving transportation sector emission reductions consistent with the Global Warming Solutions Act targets requires measures beyond the simple expansion of current programs and projects. Development and implementation of additional innovative policies and programs is necessary to move towards more rapid decarbonization

[8]https://vtrans.vermont.gov/sites/aot/files/climate/VTrans%20Carbon%20Reduction%20Strategy%20Final.pdf

Life Cycle Emissions Study[9]

Act 18 of 2023 amended 10 V.S.A. §582 Greenhouse Gas Inventories; Registry to require aa annual supplemental accounting of upstream and lifecycle greenhouse gas emissions from liquid, gaseous, solid geologic and biogenic fuels combusted in Vermont. Subsequently the ANR commissioned an analysis of the life cycle emissions from sources of energy, both electricity and thermal, used in Vermont. The study was delivered in April 2024. The analysis combined emissions from the existing Vermont Greenhouse Gas Emissions Inventory for the energy sector with the upstream emissions occurring due to use of energy in the state to determine total Vermont energy sector life cycle emissions for the time series 1990-2020. It concluded that the percentage of total energy sector emissions from upstream sources ranges from 17% to 21%. Upstream emissions from petroleum products were consistently the highest contributor to the transport and RCI sectors.

Clean Heat Standard Assessment of Thermal Sector Carbon Reduction Potential in Vermont (CHS Potential Study)

The Affordable Heat Act (Act 18 of 2023) required the Department of Public Service to undertake a study to assess and quantify the technical, economic, and maximum achievable potential for greenhouse gas emission reductions in the building thermal energy sector. In September 2024 PSD's contractor, NV5, delivered their report[10] which analyzed those three scenarios and a fourth scenario that prioritized implementation of cost-efficient life cycle emission reductions to meet the sector reductions specified in Act 18. The study developed a mix of mitigation measures that achieved the by 2030 and by 2050 building thermal sector proportional share of the reductions required in Vermont's Global Warming Solutions Act. This scenario relied heavily on a rapid transition to biofuels in the short-term to achieve the by 2030 reductions coupled with a steadily increasing number of buildings switching to heat pumps to

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

[10] https://publicservice.vermont.gov/clean-heat-standard/public-service-department-thermal-sector-carbon-reduction-potential-study

achieve the by 2050 target. The estimated cumulative societal net benefits of this scenario were $124 million through 2029 and $2.14 billion through 2049. The majority of the benefits are generated by avoided social economic and environmental damages and avoided fossil fuel (fuel oil and propane) consumption, while the majority of the costs are due to incremental mitigation measure costs (e.g. cost associated with heat pump installation) and increased consumption of biofuels and renewable fuels.

The report also included an analysis of the state's workforce's ability to deliver clean heat measures. While the results vary by measure, in general the state's clean energy workforce will require expansion through 2049, with the most significant need for single-family home weatherization workers.

Cap-and-Invest Study[11]

In early 2025 VTrans released a study, developed cooperatively with ANR, analyzing the effect of Vermont's participation in a multi-jurisdictional cap-and-invest program covering the state's transportation sector and potentially the thermal energy sector. The two candidate programs considered were the linked California and Quebec programs (the Western Climate Initiative or WCI) and the prospective New York Climate Initiative (NYCI). The study concluded that Vermont's participation in either of these programs would support additional progress toward meeting the state's emission reduction targets. However, due to the time required to develop and promulgate regulations, develop other program support measures, and ultimately link with another program that cap-and-invest would not enable Vermont to reduce emissions to the level required by the GWSA by 2030. As directed by statute, the Treasurer's Office reviewed this study. The Treasurer recommended Vermont not consider joining WCI as this time given concerns about work needed to insulate low- and moderate-income Vermonters from the resulting increased fuels costs but rather wait for and analyze the details of the NYCI when they become available.

[11]https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/Vermont_Climate_Council/VT%20Cap-and-Invest%20Report_Final.pdf

Social Cost of Greenhouse Gases

<u>Background:</u> As part of the Initial Vermont Climate Action Plan (CAP) adopted by the Vermont Climate Council (VCC) in December of 2021, estimates of the Social Cost of Carbon (SCC) and of other greenhouse gases were recommended for use in Vermont.[12] At the time the Initial Vermont Climate Action Plan was adopted, the federal government was in the midst of a comprehensive update to Social Cost of Greenhouse Gases (SC-GHG) estimates to reflect the latest science.

The SC-GHG puts a dollar value on the harm caused by releasing one ton of greenhouse gases into the air. The SC-GHG estimates the value of all future climate impacts (both negative and positive) – like farm productivity, health effects, flood damage and other forms of extreme weather, energy disruptions, conflicts, migration, and ecosystem harm – on society worldwide.

However, current estimates miss some impacts because of data gaps and modeling limits. When certain damages can't currently be quantified, they're essentially counted as zero. This means the real cost of climate pollution is likely higher than is currently reflected in the SC-GHG. The SC-GHG gives policymakers a way to compare the economic benefits of cutting emissions against the costs of climate action, though the true benefits are probably underestimated.

<u>Adopted recommendation</u>

Based on a) the EPA's updated Social Cost of Greenhouse Gases (SC-GHG) estimates developed in response to the National Academies of Sciences, Engineering, and Medicine (NASEM) recommendation to incorporate the latest science in estimates of SC-GHG values and b) consistent with the 2021 Initial CAP recommendation to "update[e] the Social Cost of Carbon and discount rate on a regular basis, taking into account new research", the Science & Data

[12] See pages 52-55. Initial Vermont Climate Action Plan, Vermont Climate Council, December 2021

Subcommittee unanimously advanced and the Vermont Climate Council unanimously adopted the following recommendations:

1) Vermont should utilize the EPA's updated SC-GHG estimates as provided in the Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances from November, 2023[13] for benefit cost analysis of activities that impact greenhouse gas (GHG) emissions and for GHG emissions-related rules adopted or amended pursuant to 10 V.S.A. chapter 24 and the Climate Action Plan.

2) The EPA's Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances from November, 2023 shares SC-GHG estimates calculated with 1.5%, 2%, and 2.5% discount rates, with 2% selected as the central discount rate. For clarity, we recommend a central discount rate of 2%, as used by the EPA and recommended by a leading panel of economists in the United States.[14] While the estimated social cost per ton of emissions varies by greenhouse gas and the year it is emitted, for reference, the 2023 EPA report establishes an estimated social cost of $190 per ton of CO_2 emitted in 2020 when utilizing a 2% near-term discount rate.[15]

3) The Science & Data Subcommittee of the VCC will continue to track the latest and most relevant scientific literature regarding social cost of greenhouse gas estimates, including any updates released by the federal Interagency Working Group on the Social Cost of Greenhouse Gases or its successors that are in line with NASEM recommendations. What Vermont uses for SC-GHG should continue to be based on NASEM recommendations and the best available science.

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[13] https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf
[14] Rennert, K., Errickson, F., Prest, B.C. *et al.* Comprehensive evidence implies a higher social cost of CO2. *Nature* 610, 687–692 (2022). https://doi.org/10.1038/s41586-022-05224-9
[15] See page 4, https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf Note: for comparison, among the SCC values adopted as part of the 2021 Climate Action Plan, the estimated social cost of CO_2 emitted in 2020 when utilizing a 2% near-term discount rate was $121 per ton.