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# Vermont Pathways Analysis Report 2.0

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**Prepared for:**

Vermont Agency of Natural Resources

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# Acronyms and Abbreviations

| Acronym | Definition |
| --- | --- |
| ACC II | Advanced Clean Cars II |
| ACT | Advanced Clean Trucks |
| CAP | Climate Action Plan |
| CEP | Comprehensive Energy Plan |
| CHS | Clean Heat Standard |
| CO2 | Carbon dioxide |
| CSM Subcommittee | Cross-Sector Mitigation Subcommittee |
| EV | Electric vehicle |
| EVSE | Electric vehicle supply equipment |
| GHG | Greenhouse gas |
| GWhs | Gigawatt hours |
| GWP | Global warming potential |
| GWSA | Global Warming Solutions Act |
| HFC | Hydrofluorocarbon |
| ICEV | Internal combustion engine vehicles |
| ISO-NE | Independent System Operator of New England |
| LEAP | Low Emissions Analysis Platform |
| LULUCF | Land use, land use change, and forestry |
| ODS | Ozone depleting substance |
| MMTCO2e | Million metric tons of carbon dioxide equivalent |
| Project Team | Cadmus, Energy Futures Group, and the University of Vermont |
| RES | Renewable Energy Standard |
| RPS | Renewable Portfolio Standard |
| SAFE Vehicles | Safer Affordable Fuel-Efficient |
| SEI | Stockholm Environment Institute |
| TCI | Transportation Climate Initiative |
| TMTCO2e | Thousand metric tons of carbon dioxide equivalent |
| TWhs | Terawatt hours |
| VCC | Vermont Climate Council |
| VMT | Vehicle miles traveled |

# Preface: Summary of Revisions to Vermont Pathways Analysis Report Version 2.0

In November 2021, the Cadmus/EFG team completed and delivered the first version of the Pathways Analysis Report ("Version 1.0") to inform the Climate Action Plan (CAP) adopted by the Vermont Climate Council on December 1, 2021. The updated Pathways Analysis Report Version 2.0 ("Version 2.0"), submitted February 11, 2022, includes new and amended content based on Low Emissions Analysis Platform (LEAP) and IMPLAN modifications, as well as language changes for clarity of intent. These changes were made in response to stakeholder comments received between November 2021 and January 2022. The Cadmus/EFG team appreciates and acknowledges the feedback and review from stakeholders on Version 1.0. The CAP will be an ongoing endeavor, spanning decades with major changes across all segments of Vermont's economy and energy systems. Maintaining regular updates and revisions to the Pathways Analysis and the CAP will help to inform policy and decision-makers on the progress and challenges presented by the transitions as more information becomes available.

The following summary of the analytic changes and revisions to our Pathways Analysis Report is intended to help the readers understand the amendments made based on stakeholder engagement on Version 1.0 in winter 2021-2022.

## Analysis and Results Revisions in Version 2.0

Adjustments made to LEAP and IMPLAN and incorporated into Version 2.0 are summarized in Table 1 and described in more detail below.

**Table 1. Summary of Version Revisions**

| Item | Version 1.0 | Version 2.0 |
|---|---|---|
| Transportation | Linear adoption of electric vehicles (EVs) to Internal combustion engine vehicles (ICEV) phase out in 2033. | Reduced early adoption of EVs to reflect manufacturer compliance with Advanced Clean Cars II (ACC II). |
| Advanced Wood Heat | Did not include high-efficiency pellet and wood stoves. Share of heating declined to 8% by 2050. | Incorporates high-efficiency pellet and wood stoves. Wood provides 13% of heating by 2050. |
| Environmental Externality Values | Externality costs for road transport branches not calculated. | LEAP update corrects calculation error by increasing the value of avoided emissions by $3.6 billion. |
| Biofuels Focused Pathway | Biofuels focused scenario included higher levels of B100 heating oil and distributed renewable natural gas. High efficiency pellet and wood stoves not included in analysis. | To meet GWSA requirements following EV reduction (see above), elements from biofuels focused scenario from version 1.0 were included in main mitigation scenario. High efficiency advanced wood heating also included. |
| IMPLAN – Inputs | Based on version 1.81 of LEAP model, reflecting net investments of approximately $500 million. | Adjusted based on version 2.04 of LEAP model, reflecting net investments of $1.1 billion. |
| IMPLAN – Opportunity Costs | Reduction of spending on non-CAP items not analyzed. | Opportunity costs of net investment in CAP assessed. |

1. The profile of EV adoption was adjusted downward. In Version 1.0 of the report, the adoption of light-duty EVs followed a linear path from 2020 to a phase out date for ICEVs in the year 2033. Based on analysis of supply constraints in the vehicle market and of the latest developments in the ACC II regulation, the Cadmus/EFG team modified light-duty vehicle adoption rates. The combined stock of electric (battery EV and plug-in hybrid EV) passenger cars and light trucks by 2025 is now 20,000, whereas in Version 1.0 the combined stock by 2025 was 43,000. This slower adoption of EVs results in three key impacts to the modeling: (1) slightly lower EV stock in later time periods, (2) lower magnitude of emissions reductions from EVs, and (3) slightly lower electricity demand. The assumed adoption of a zero emissions memorandum of understanding for medium- and heavy-duty vehicles was removed from the baseline and is also not modeled in the mitigation scenarios.
2. Adjustments to advanced wood heating were made to maintain a higher share of residential heating load served by wood and wood pellets. In Version 1.0 of the report, the share of residential space heating provided by wood fuels declined to approximately 8% by 2050. In response to comments from stakeholders, the share of residential space heating was adjusted to be consistent with the levels maintained in the biofuels-focused scenario developed for the Comprehensive Energy Plan. This results in wood fuels providing 13% of residential space heating needs in 2050. In addition, the share of high-efficiency wood and pellet stoves were increased so that 50% of these units are high efficiency by 2030, and 80% of the units are high efficiency by 2050.
3. The environmental externality costs for the transportation branches of the analysis were not being counted in the version of LEAP used for the Version 1.0 Pathways Analysis Report. An update of the LEAP model (version 2020 1.54) from the Stockholm Environment Institute (SEI) addressed this issue and externality costs for transportation are now properly calculated and included in the Version 2.0 results. As a result, the total value of social, economic, and environmental damages avoided by the mitigation pathway increases significantly in Version 2.0 of the report, increasing from a present value of $3.8 billion ($2019) in Version 1.0 to a present value of $7.4 billion in Version 2.0.
4. The modifications listed above resulted in a net increase in emissions, primarily due to the slower adoption of EVs. Combined, the changes listed above resulted in gross greenhouse gas (GHG) emissions being higher than Global Warming Solutions Act (GWSA) requirements by roughly 2% in 2030 and by 5% in 2050. Therefore, the team made additional modifications to the model so the CAP mitigation scenario would meet the GWSA requirements in all time periods:
    a. Adjusted the share of renewable natural gas in distributed gas (consumed in households and the commercial sector) to be the same as that in the biofuel-focused scenario (now 80% in 2050 instead of 30%).
    b. The B100 heating measure, which was previously only in the biofuel-focused scenario, is now also included in the CAP mitigation scenario. This assumes that 100% of the

remaining (post-electrification) heating oil is B100 with a steady ramp in the share of B100 reaching 100% by 2040.

c. Further adjusted the market penetration (share of new sales) for gasoline light-duty vehicles while accounting for the earlier modifications based on ACC II regulations.
    i. For passenger cars, reduced the sales share for gasoline vehicles to be 80%/32% in 2025/2030, instead of 90%/37%.
    ii. For light trucks, reduced the sales share for gasoline vehicles to be 70%/27% in 2025/2030, instead of 77%/32%.

5. The revisions listed above were also used to create a new set of values used by the Cadmus/EFG team to conduct an economic impact analysis using the IMPLAN model.
    a. The IMPLAN analysis in Version 2.0 of the Pathways Analysis Report includes an assessment of the opportunity costs of household spending foregone due to investments required to meet the GWSA requirements in the CAP mitigation scenario.

These revisions highlight that there are a range of ways to achieve the GWSA targets but amending any one element in the pathway requires other revisions to ensure compliance with the law. The final inputs and modifications in Version 2.0 represent our best understanding of Vermont's available pathways based on analysis done to date. As we learn more, continued adjustment of this analysis will be beneficial to ensure VT is using most up to date information in its decision-making processes.

# Executive Summary

To address the challenges, opportunities, and risks posed by global climate change, Vermont established a Climate Council charged with developing an initial Climate Action Plan (CAP) by December 1, 2021. This Plan will provide guidance for meeting the requirements of the Global Warming Solutions Act (GWSA) enacted by the Vermont Legislature in 2020.[1]

This *Vermont Pathways Analysis Report* was prepared by a team of decarbonization and energy planning professionals from The Cadmus Group and Energy Futures Group, under contract with the Agency of Natural Resources, to provide technical support to the Vermont Climate Council and its subcommittees and task groups as they prepared the CAP by December 1, 2021. It was subsequently revised with stakeholder input received November 2021 through January 2022, resulting in this updated Version 2.0. This report provides analysis and detailed scenario modeling using the Low Emissions Analysis Platform (LEAP) model, presenting details on the pathways, strategies, policies, and actions that meet the requirements of the GWSA across three time periods: 2025, 2030, and 2050. LEAP is an energy accounting framework-based tool that enables users to compare elements across user-defined scenarios that represent alternative future energy pathways. While not predictive, LEAP is beneficial for visualizing the scale and pace of transformation necessary to achieve emissions reductions. Results presented throughout this report are intended to inform design of GWSA compliant policies.

To meet the GWSA requirements it is necessary to take deep, sustained, and flexible actions across all sectors. Policies, regulatory rules, public messaging, technical support, financing, incentive programs, training, education, and workforce development are all necessary to help drive the pace and scale of the actions needed to meet the requirements in each time- period. Specifically, it will be important for policies and programs to be designed to work in tandem with markets and consumer actions to achieve the scale and pace of change assumed by the CAP and guided by the benchmarks presented in this Pathways Analysis Report. For this reason, Vermont has prioritized developing a clear tracking system to ensure adequate progress implementing or expanding identified programs and policies over time. If it becomes clear that Vermont will fall short of achieving some benchmarks by their recommended date—say, for instance, 116,000 light duty EVs registered by 2030—the GHG impact of this will need to be evaluated to help determine if other actions must be scaled up in order to make up for any shortfall to achieve an equivalent amount of emissions reductions. Stated differently, the activity benchmarks highlighted in this Pathways Analysis Report and reflected in the CAP (such as the number of EVs, heat pumps, heat pump water heaters, and homes weatherized) are both individually and collectively critical to achieving the GWSA requirements. Given the way this analysis was designed, LEAP does not present a menu of options to choose between, but rather a unified pathway intended to achieve emissions reductions. Vermont will likely need all of the actions detailed in this analysis, or their equivalent, working in tandem at the scale and pace presented to achieve the requirements of the GWSA.

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1 General Assembly of the State of Vermont. "Vermont Global Warming Solutions Act of 2020." VT LEG #350685 v.1. https://legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT153/ACT153%20As%20Enacted.pdf

In passing the GWSA, the Vermont Legislature acknowledged that acting to address climate change is essential for Vermont's future. Indeed, multiple rationales and justifications support reducing emissions and meeting GWSA requirements:

- **Economic** – In comparison to the baseline or "business as usual," by 2050 the mitigation scenario modeled in LEAP offers $ 6.4 billion of net benefits.[2] The mitigation scenario avoids $14.8 billion of fossil fuel costs and $7.4 billion of avoided economic, health, and environmental damages,[3] for a combined total savings of $22.2 billion.

  The present value of additional costs for the mitigation scenario are $15.9 billion above the baseline for investments in more efficient buildings and heating systems, EVs and EV charging infrastructure, practices to reduce the emissions of GHGs from agriculture and industrial processes, and investments in increased renewable electric generating stations and transmission and distribution systems.

  When the savings from fossil fuels and avoided damages are combined with the additional costs and investments required to reduce emissions, the net economic benefits between now and 2050 are projected to be approximately $6.4 billion, which is roughly equivalent to two years of Vermont's spending on all energy sources.
- **Social Equity** – Vermont has taken important steps in recognizing the importance of addressing the "energy burden," or the total spending on energy for transportation and housing, for low- and moderate-income households. Many strategies and actions that reduce emissions can also reduce this energy burden, and can be supported by programs, education, outreach, and job opportunities that are targeted toward potentially underserved or marginalized segments of the population. Actions that reduce a household's energy use and emissions can also improve the longevity and affordability of the building, and can improve indoor air quality, safety, and comfort, thereby providing health and well-being benefits. Affordable and clean transportation alternatives, such as EVs and improving bike and pedestrian infrastructure, also supports improved health and well-being while reducing emissions.
- **Environment** – By meeting the GWSA requirements, Vermont will reduce emissions by 26% below 2005 levels by 2025, 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050, accompanied by sufficient sequestration for Vermont to be net zero in 2050. These levels of reduction are consistent with scientific and political consensus on what is required to avoid potentially catastrophic impacts from climate change. Even with reductions that meet the GWSA requirements, Vermont and the rest of the world will face increased damages and disruptions from climate change for decades to come. However, the nature and scale of the threat if these reductions are not achieved by Vermont and other jurisdictions are much greater and threaten the health, stability, and well-being of the entire planet.

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2 These results are the net present value benefits in 2019 dollars, using a 2% discount rate, for the mitigation scenario compared to the baseline from 2015 through 2050.

3 Based on a social cost of greenhouse gases estimated using a damage-based approach starting at a level equivalent to $122 per metric tonne of carbon dioxide equivalent.

- **Technical/Institutional** – Meeting the GWSA requirements relies and builds upon technical solutions and organizations that exist in Vermont today. Advances across many industries, both directly related to energy and related to advanced computing, communications, material sciences, and control systems have enabled the development of a full palette of affordable and clean solutions for meeting every sector's energy service needs. Vermont's utilities, private fuel dealers, private businesses, financers, and public and non-profit organizations can grow and evolve to meet the challenges of deploying modern energy technologies.
- **Legal** – Unlike a policy target or goal, the GWSA establishes emissions reductions as requirements with potential legal recourse if the state fails to keep pace. Recognizing that emissions reductions are contingent on individual decision-making and private investments that are not directly controlled by the state, there is nevertheless a legal requirement for the state to develop and enact a plan for reducing emissions to meet the requirements. Success will depend on using the leverage of policies, public messaging, leading by example, regulations, and investment of public funds to catalyze and support the myriad of private decisions required.

## *Sector Overview*

To meet the GWSA requirements it is necessary to catalyze actions that will reduce emissions from each of the major sectors that currently contribute to GHG emissions. The mitigation scenario modeling conducted by the Project Team for this report is not predictive or prescriptive about exactly how the emissions reductions will be achieved over the coming decades. Instead, it provides valuable information on the scale and pace of changes that need to be considered in each sector. A brief synopsis of the type and scale of action needed in each sector is outlined below.

### Transportation

Emission reductions in the mitigation scenario come, in large part, from the electrification of the vehicle fleet. EVs produce fewer emissions than conventional gasoline and diesel cars and trucks because they are more efficient and they use cleaner fuel. A global and national transition toward EVs is underway, but Vermont will need to be on the leading edge of adoption to meet the GWSA requirements. The prospects for rapid adoption and transformation of the vehicle fleet are aided by favorable performance and economics for EVs. Over time, EVs can provide individual customers with financial savings and a lower total cost for operations (see Box 2, p. 23). Nevertheless, higher upfront costs (before incentives) are a near-term barrier, and care must be taken to ensure equitable access to clean transportation options.

While investments in reduced transportation demand management, biofuels, and alternative modes of transportation also contribute to reduced emissions, most of the savings are realized through the benefits of fleet electrification. By 2025 the mitigation scenario includes about 27,000 total EVs (across all vehicle classes) on the road, with EVs accounting for 17% of total vehicle sales and 5% of the statewide total vehicle miles traveled (VMT). By 2030, the mitigation scenario includes close to 126,000 EVs on the road, with EVs accounting for more than 68% of vehicle sales and 23% of the statewide total VMT.

The challenges to undertaking a transition at this pace and scale include increasing public and private infrastructure for vehicle charging and the availability of EVs based on manufacturing capacity and Vermont's ability to present as an attractive market for EV sales (see Box 6, p. 42). Revenues to assist with the transition in the transportation sector are expected to come largely from federal resources and potentially from participation in a regional initiative, such as the Transportation Climate Initiative (TCI; should that initiative move forward in the future).

## Buildings

In the building sector, the mitigation scenario relies on a combination of policies, strategies, and actions to reduce emissions. Modernizing the energy performance of Vermont's buildings means improving their thermal performance by insulating and air sealing to reduce the heating and cooling loads. It also involves taking advantage of the opportunity to improve the efficiency and emissions of heating systems by replacing conventional combustion-based equipment with modern and efficient cold-climate heat pumps. To further reduce emissions, buildings with more efficient thermal shells and heating equipment can also use electricity, solar, and/or biofuels, which create fewer emissions than conventional fossil fuels such as heating oil, propane, or natural gas. As building heating loads are increasingly electrified, electric system costs can be met through flexible load management and by coordinating multiple loads within and across large numbers of buildings. Advanced flexible load management can include thermal and battery storage, which offer resilience and back-up power benefits.

The mitigation scenario includes more than 96,224 residential heat pump installations by 2025 and 177,107 residential heat pump installations by 2030. In many cases, the opportunities for enhanced building energy performance and reduced emissions will save customers money. An example of the savings for an individual Vermont customer using propane is to use heat pumps, weatherization, and biofuels, as presented in Box 4, p. 29. Financing, incentives to overcome upfront cost barriers, education, and outreach are all necessary to promote the pace of adoption necessary to meet emission reduction requirements.

In the mitigation scenario an additional 90,000 housing units are weatherized by 2030, with a focus on serving low- and moderate-income households including those in rental units and mobile homes. The challenge of increasing the pace of delivery for weatherization services is discussed in Box 7, p. 44.

A Clean Heat Standard (CHS, see Box 3, p. 27) is a market based, flexible, and technology neutral approach to reduce emissions across all residential, commercial, and industrial buildings. As a performance-based standard, the CHS would require providers of heating fuels to procure a specified level of clean heat credits each year. Initiatives to improve the performance of rental properties and to set net zero standards for new construction also contribute to emissions reductions. Federal funds, both existing funds through historical programs funding weatherization and new funds related to infrastructure and climate objectives, will be essential complements to private and state-level investments in the building sector.

## Non-Energy

While more than three-quarters (76%) of Vermont's GHG emissions are attributed to energy use, there are significant non-energy emissions from agriculture and industrial processes. In Vermont's 2018

Greenhouse Gas Inventory,[4] non-energy emissions accounted for 24% of the total emissions, mostly from gases (such as methane and fluorinated gases) that have much higher impacts than carbon dioxide on warming for each physical unit of gas released.

In the mitigation scenario, non-energy emissions are reduced by 11% by 2025, 20% by 2030, and 38% by 2050. In the agriculture sector, management practices can reduce emissions, most importantly methane emissions, from enteric fermentation and manure management.[5] The sequestration of carbon by agricultural soils can also be promoted through alternative cropping and tillage patterns. Reducing methane emissions was recently identified as an international priority at the 26th Conference of the Parties at Glasgow Scotland,[6] and Vermont can benefit from increased attention and funding directed toward the reduction of methane emissions, demonstrating how natural and working lands can be managed to reduce direct emissions and increase sequestration. Meeting the GWSA requirement of net zero carbon emissions by 2050 requires steps to protect and maintain the landscape's capacity for sequestration. Even after meeting the reductions in gross emissions for the GWSA requirements, achieving a net zero requirement in 2050 will require Vermont to maintain sequestration rates of roughly 2 million metric tonnes of carbon dioxide equivalent (MMTCO2e) per year.

In Vermont, the non-energy emissions from industrial processes are primarily related to the use of substitutes for ozone depleting substances (ODS) as refrigerants and to the leakage of these gases (which have global warming impacts). In the mitigation scenario, emissions from ODS substitutes are reduced by more than 40% by 2030, based on the adoption of alternative refrigerants and enhanced refrigerant management and recycling. The direct non-energy emissions of fluorinated gases with high global warming impacts from semiconductor manufacturing are also reduced in the mitigation scenario, with an 8% decline by 2030.

## Electricity

The mitigation scenario relies heavily on the use of clean electricity in efficient buildings and transportation to offset the use of fossil fuels. Vermont has already made significant progress in shifting its electricity portfolio to clean resources, and the mitigation scenario includes continuing to increase renewable electricity, from 75% in 2032 to 100% by 2050. As the transportation and buildings sectors electrify, there will be significant increases in total electricity consumption. As the demand for electricity and reliance on intermittent renewable sources both increase, the value and importance of coordinated and flexible load management also grows. The LEAP modeling for the mitigation scenario includes a

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4 Vermont Department of Environmental Conservation. May 2021. *Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990–2017*. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf

5 Non-energy emissions are compared to 2020 as a baseline. The Carbon Budget Report conducted by the Cadmus and UVM team earlier in 2021 estimated lower agriculture sector emissions than the Greenhouse Gas Inventory, and the Carbon Budget values were used to calculate reductions in the Pathways analysis.

6 BBC News. November 2, 2021. "COP26: US and EU Announce Global Pledge to Slash Methane." https://www.bbc.com/news/world-59137828

limited amount of load control and coordination, for EV charging as an example, but does not represent the full potential of measures and strategies to promote load coordination. Therefore, the peak loads and generation requirements as modeled are illustrative, but likely higher than requirements in a system where demand response and load management are optimized. In the mitigation scenario, demand for electricity increases by 13% from 5.5 terawatt hours (TWh) in 2020 to 6.2 TWh in 2025, and by 34% to 7.4 TWh by 2030. By 2050 the total annual electricity demand in the mitigation scenario is almost 12 TWh. To meet these increased electricity demands, the mitigation scenario includes significant expansions in offshore wind, onshore wind, and solar generation, with Vermont continuing its reliance on electricity from the regional electric grid as well as generating resources in the state.

As electric demand grows and the uses of electricity are expanded, it is essential to address potential barriers that can prevent equitable access to the electric services and end uses that help to reduce emissions. Assuring equitable access to clean energy will entail upgrades to individual and community infrastructure, and consideration of the adequacy of electric service for individual housing units to support conversions to electric heat pumps and EV charging. Coordinated and flexible load management is a critical strategy to reduce the overall costs for new electric generation, transmission, and distribution infrastructure needs as electrification proceeds.

## *Meeting the Global Climate Imperative*

This report identifies and provides analytical support for the strategies, policies, and actions for each sector that, when combined in the mitigation scenario, can enable Vermont to meet the GWSA emission reduction requirements. Vermont, in isolation, cannot solve or abate the looming potential threats of climate change. No single jurisdiction or country can do that. Nevertheless, Vermont can adopt and implement a CAP that takes actions across all sectors of the economy to do its part to reduce emissions, demonstrating the social, technical, and economic feasibility of transformative solutions. The mitigation scenario analyzed in this report identifies key questions, milestones, and guideposts to inform this journey. This report and its analyses are not predictive or prescriptive about exactly how Vermont will meet the requirements of the GWSA. There is still a great deal of planning and work ahead.

This report and the supporting analyses indicate that meeting the GWSA requirements will not be easy, but it is possible based on technologies, market trends, and resources that exist today. Efforts in every sector will need to be increased far beyond what has been done in the past. It will be critical to provide ongoing tracking, reporting, and evaluating of the impacts for meeting requirements so that strategies and actions can be adapted in response to changing conditions. This report and analyses can be used and built upon for decades to come as Vermont strives to reduce emissions at a scale that meets the GWSA requirements- in a manner that benefits its citizens, its economy, and its natural and built environment.

# Introduction

## *Project Background and Context*

Since 2008, Vermont's Air Quality and Climate Division has released a series of briefs, updates, and comprehensive reports inventorying the state's GHG emissions across seven sectors, per Intergovernmental Panel on Climate Change guidelines: (1) transportation mobile sources, (2) residential, commercial, and industrial fuel use, (3) agriculture, (4) industrial processes, (5) electricity consumption, (6) waste, and (7) fossil fuel industry. Vermont's 2017 GHG inventory was released in May 2021 and demonstrates that, as of 2018, Vermont GHG emissions remained close to 1990 baseline levels and that the state's three largest sources of emissions are transportation, building energy use, and agriculture.

In 2020, the Vermont Legislature passed the GWSA, codifying an important set of emissions reduction targets and processes to ensure the state achieves at least an 80% gross emissions reduction from 1990 levels by 2050. Over the course of 2021, the Vermont Climate Council (VCC) has been working to develop the pathways, strategies, and actions necessary to set the state on a path to achieving this long-term emissions reduction target, as well as a 26% reduction from 2005 levels by 2025 and a 40% reduction from 1990 levels by 2030. Pursuant with the GWSA, the CAP also details strategies for natural working lands to support long-term sequestration and storage of carbon such that the state achieves net zero emissions by 2050 across all sectors. The CAP also includes approaches to increase resilience and equity throughout the state.

To support this effort, Vermont's Agency of Natural Resources contracted with Cadmus, Energy Futures Group, and the University of Vermont (the Project Team) to conduct a set of technical services related to the VCC. This included analyzing the pathways recommended by the VCC and its subcommittees to achieve the emissions reductions required in the GWSA. This report summarizes the Project Team's findings on the transformations necessary to achieve emissions reductions using the approaches developed by the Cross-Sector Mitigation (CSM) Subcommittee for the transportation, buildings, non-energy, and electricity sectors.

## *Analytical Approach*

To support the development of a CAP that aligns with the GWSA requirements, the Project Team conducted modeling using the LEAP, developed by the Stockholm Environment Institute (SEI), to analyze scenarios, pathways, strategies, and actions that combine to result in Vermont meeting the emissions reduction targets established by the GWSA statute.

LEAP is an energy accounting framework-based tool, developed over decades to aid with integrated demand and supply-side planning. The LEAP model is demand driven, in that users define energy use branches in the demand module (such as residential buildings or road transportation), then the model uses processes in the transformation module (such as electric generation or natural gas distribution) and energy supplies in the resource module (such as solar, wind, and primary and secondary petroleum products) to meet demand. The structure is well-suited for long-term planning horizons, cost accounting, and assessing social and environmental impacts. LEAP enables users to compare these elements across user-defined scenarios that represent alternative future energy pathways.[7]

The Project Team built its LEAP modeling upon versions of the Vermont Pathways model developed during late 2020 and 2021 in support of Vermont's *Comprehensive Energy Plan* (CEP).[8] This foundational work was conducted by SEI, under contract with the Vermont Department of Public Service. The model SEI developed to inform and support first the CEP and then the CAP has hundreds of branches and thousands of inputs. For example, the demand tree in the model represents significant levels of detail for each sector on the types of buildings or vehicles, end uses within buildings, and devices and vehicles used to provide services.

The Project Team's scope of work was to assess and build upon the LEAP modeling conducted for the CEP and to support the Cross-Sector Mitigation Subcommittee (CSM Subcommittee) of the Vermont Climate Council (VCC) as they used the modeling and modeling results to inform their findings and recommendations for inclusion in the CAP. While executing this scope, we worked closely with the CSM Subcommittee to understand their priorities for achieving emissions reductions in each sector, as well as for achieving cost-effectiveness and enhancing equity across Vermont. It is important to highlight that the LEAP model is not predictive of Vermont's future energy supply and demand, nor does it select the best pathways for Vermont to pursue its goals. Instead, by aligning model inputs with the prioritized strategies of experts and stakeholders, the model's quantitative results on equipment stock, turnover, and costs helped to inform the policies, programs, and other initiatives the CSM Subcommittee recommended for achieving the scale and pace of transformation required by the GWSA. While we have highlighted quantitative findings throughout, we have also developed key insights from the modeling. We encourage the CSM Subcommittee, VCC, and others involved in the CAP implementation process to focus on these insights, particularly because it may seem difficult to achieve the full scale of transformations included in the model in the near term. Yet, the modeling results indicate how Vermont can begin reducing emissions now, while scaling the market and continuing to identify additional avenues for emissions reductions over time.

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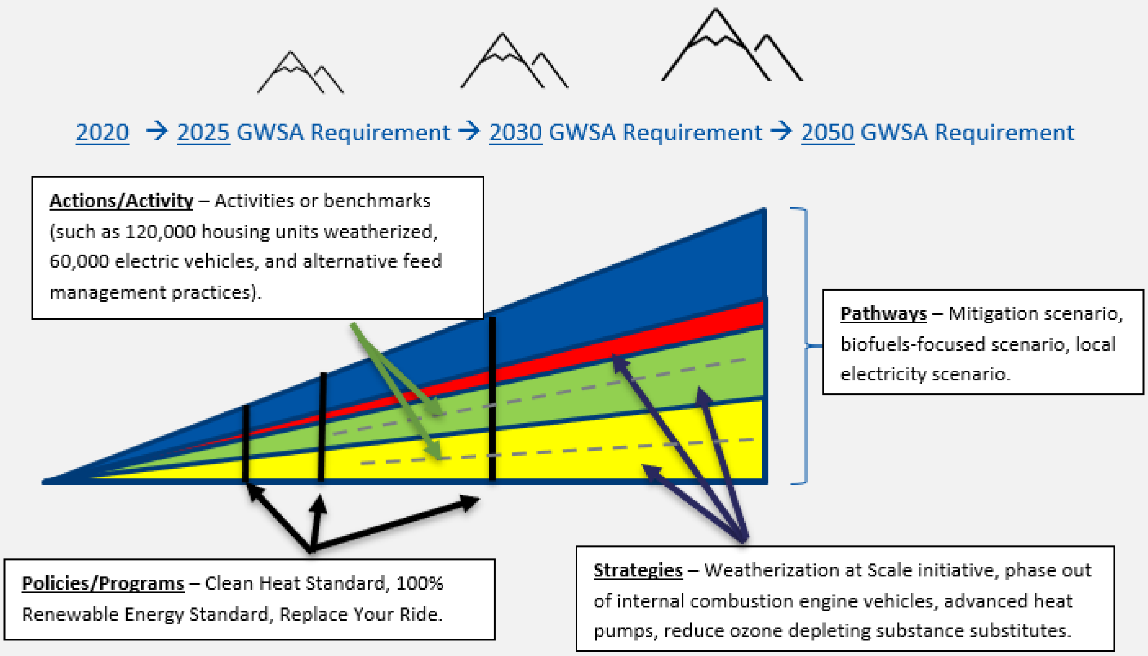
7 More information on LEAP and resources are available at https://leap.sei.org/Default.asp.

8 State of Vermont Department of Public Service. To be completed in January 2022. *Comprehensive Energy Plan: 2022 Plan Update*. https://publicservice.vermont.gov/publications-resources/publications/energy_plan

**Box 1. Terminology**

This document uses several terms to refer to the inter-related components of the analyses and their contributions to meeting the objectives and targets of the CAP.




**Climate Action Plan** – The overarching orientation and map of how the state meets GWSA requirements in three discrete time periods. (Note that a completely different orientation or different set of reduction targets could rely on nuclear power and carbon capture and sequestration: that would not just be a different scenario of Vermont's CAP, but an alternative way to reach the same target).

**Pathways** – The modeled scenarios representing bundles of strategies, policies and programs, and actions and activities that reach each time periods' target reductions. This report is focused on the mitigation scenario and how it meets the GWSA requirements by sector and time period in comparison to the baseline. The report also includes the comparative results for biofuels-focused and local renewable energy production scenarios.

**Strategies** – The components (represented by colored wedges in the diagram above) that are combined into pathways to meet the targets. Each strategy in the model includes information and assumptions on variables such as adoption rates, costs, fuel types, efficiencies, and emissions.

**Policies/Programs** – Legislative or regulatory actions or program initiatives adopted in a discrete or continuous manner, serving to support strategies.

**Activities/Actions** – The number of measures (activity) to reduce emissions from the baseline that are implemented and adopted throughout the planning period. Generally, these will be a combination of natural adoption rates based on market conditions and preferences, along with measures that are incentivized and supported by public funding and can be measured with benchmarks or waypoints.

## *Key Findings*

The mitigation scenario exceeds the GWSA requirements for the reduction of gross GHG emissions in 2025, and subsequently meets the requirements for 2030 and 2050. Figure 1 illustrates the reduction of emissions by sector for each time period. The arrows indicate the not-to-exceed emissions levels required by GWSA in 2025, 2030, and 2050.

Meeting the GWSA requirements will require significant reductions across all sectors of Vermont's economy, particularly from transportation and building heating and cooling. A large share of the mitigation scenario emissions reductions for transportation and buildings are the result of electrification displacing fossil fuels. The emissions reductions are the result of two factors: (1) the electric technologies (such as heat pumps and EVs) are more efficient than the equipment they replace (such as fossil fuel–powered boilers and internal combustion engines) and (2) the GHG emissions associated with Vermont's electric supply are much less than those from the fossil fuels they displace. Vermont has the advantage of having the cleanest electricity portfolio in the county, meaning the high-level results in the mitigation scenario are distinct from many other states where the GHG emissions from the electricity sector are more significant. However, given the role of electrification in meeting the GWSA requirements, the electric sector will need to continue to increase its proportion of clean electricity to meet and manage the demand of new electric equipment.

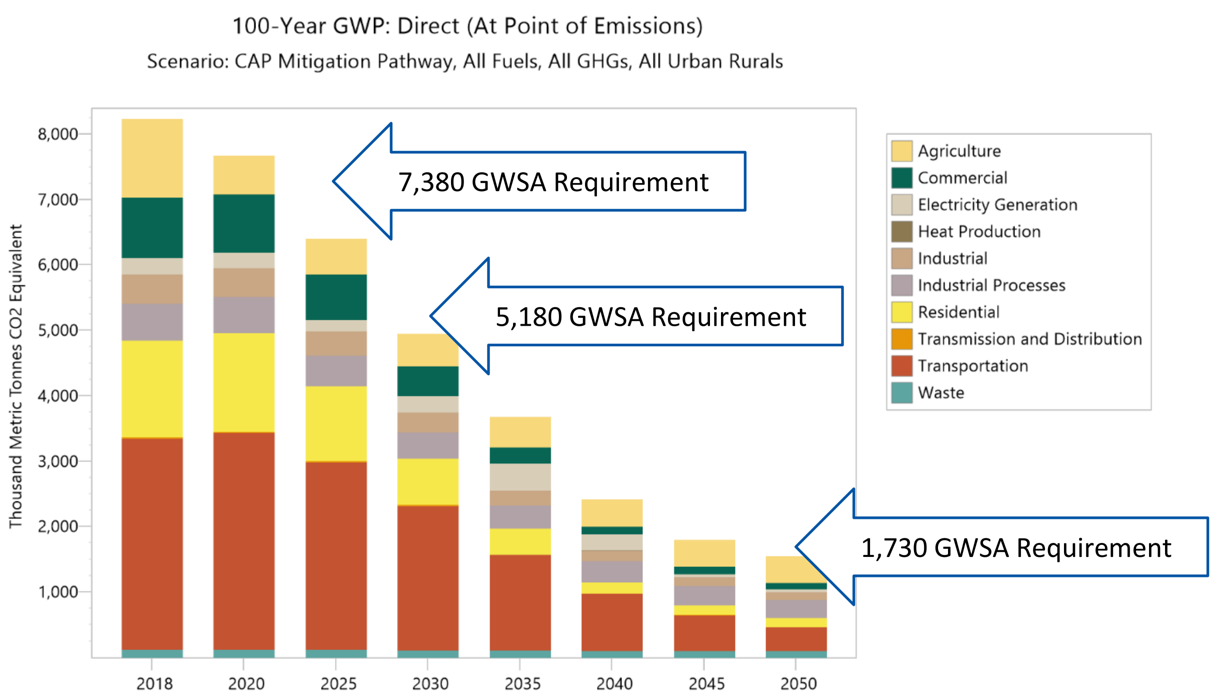



**Figure 1. Mitigation Scenario Greenhouse Gas Emissions by Sector and GWSA Targets**

The following sections summarize the emissions reduction for each major sector.

## Transportation

The transportation sector is the largest source of GHG emissions in Vermont, and accordingly has the largest absolute reduction of emissions in the mitigation scenario. Compared to the estimated 2018 levels, the sector emission reductions are 11% by 2025, 31% by 2030, and 88% by 2050. Emissions decline primarily due to the expansion of EVs in the light-duty sector and the parallel decarbonization of the electricity grid. The mitigation scenario's associated decline in transportation emissions from gasoline and diesel consumption is illustrated in Figure 2. Note that upstream emissions (those associated with the electricity grid) are counted in other sectors. The pace of the transition is significant, particularly in the near term, as necessary to achieve the requirements set forth in the GWSA and required by the science of climate change.

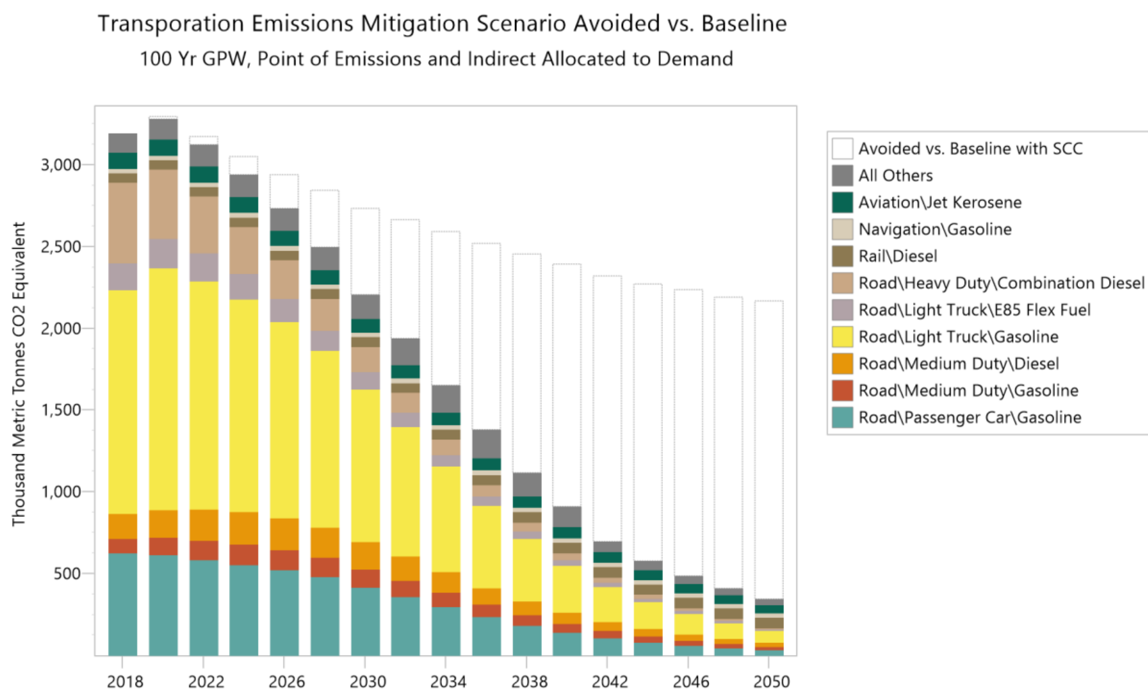



**Figure 2. Transportation Sector Greenhouse Gas Emissions in Mitigation Scenario by Fuel Type**

Increasing fuel economy, increasing use of biofuels, and lowering VMT relative to the baseline scenario further lower the sector's GHG emissions. This analysis is consistent with the pathways, strategies, policies, and actions recommended by the CSM Subcommittee, including participation in the TCI (if that were to move forward), a low carbon fuel standard, and associated initiatives such as Replace Your Ride, increased transit investment, Smart Growth, transportation demand management, and feebates for EVs and fuel-efficient vehicles.

Modeling the mitigation scenario in LEAP for the transportation sector involved modifying the baseline for several elements: the share of sales and vehicle stocks for all vehicle types, the efficiency of vehicles for each class, the number of VMT, and shares of biofuels.

Table 2 summarizes key indicators for the transportation sector in the mitigation scenario for 2025 and 2030.

**Table 2. Transportation Key Indicators for 2025 and 2030**

| Transportation | 2025 | 2030 |
|---|---|---|
| Number of EVs | 27,000 | 126,000 |
| EV Share of Sales | 17% | 68% |
| VMT Reduction from Baseline | 1.9% | 3.5% |
| EV share of VMTs | 5% | 23% |
| EV Managed Charging | 27% | 50% |

## Buildings

The buildings sector is the second largest source of GHG emissions in Vermont and, accordingly, is a major contributor in the mitigation scenario to meeting the GWSA targets. Figure 3 illustrates the emissions reductions from buildings by sector and year in comparison to the baseline. Residential buildings provide the largest emissions reductions, followed by commercial buildings. In both cases, space heating is the largest energy end use and the primary avenue by which emissions can be reduced, through a combination of more efficient building shells, higher-efficiency heating systems (including heat pumps versus combustion-based systems), and cleaner fuels (including biofuels and electricity replacing fossil fuels).

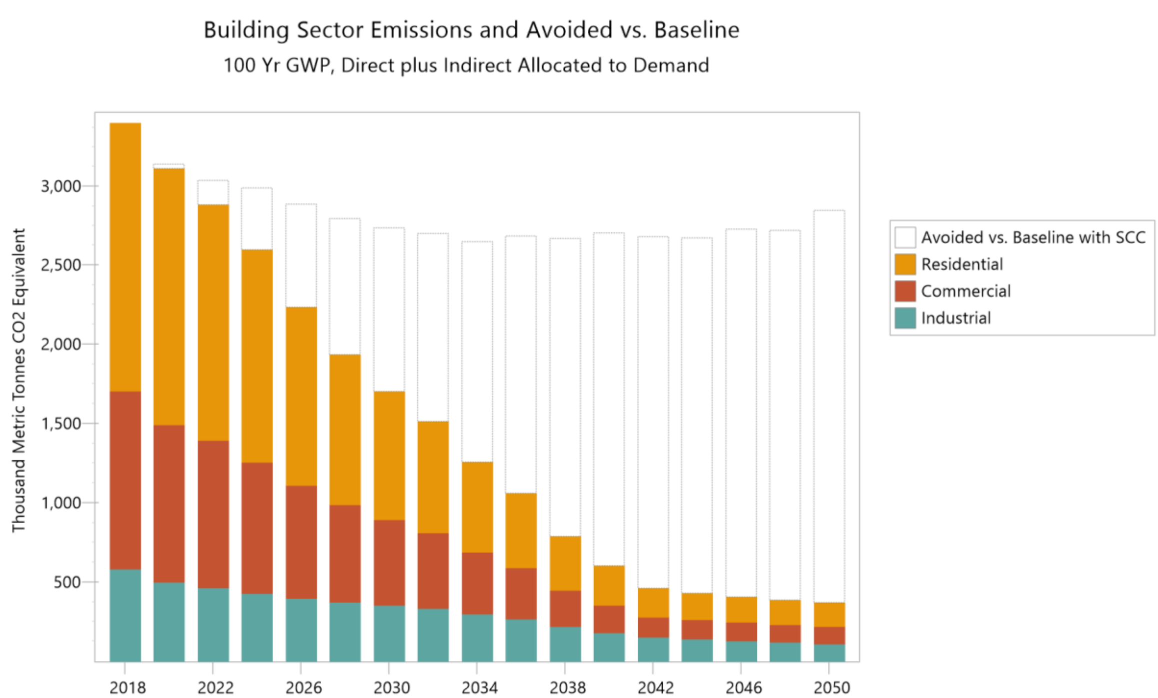



**Figure 3. Mitigation Scenario Building Sector Greenhouse Gas Emissions and Avoided Emissions versus Baseline**

This analysis is consistent with the pathways, strategies, policies, and actions recommended by the CSM Subcommittee, including the development and implementation of a Clean Heat Standard (CHS), Weatherization at Scale,[9] a Rental Property Efficiency Standard, net zero new construction standards for residential and commercial buildings, and increased demand response and coordinated load management for electric water heating.

Modeling the mitigation scenario in LEAP for the building sector involved modifying the baseline for several elements: reduced loads for space heating and cooling, increased adoption of high-efficiency heat pumps for space and water heating, updated for electricity replacing combustion fuels, and increased blending of biofuels. Solar thermal was not included in the model but could serve as a potential emissions reduction strategy in the building sector and as an eligible measure in meeting a CHS.

Table 3 summarizes key indicators for 2025 and 2030 for residential buildings.

**Table 3. Residential Buildings Key Indicators for 2025 and 2030[10]**

| Residential | 2025 | 2030 |
|---|---|---|
| Homes Weatherized | 69,000 | 120,000 |
| Heat Pumps Installed | 96,224 | 177,107 |
| Heat Pump Water Heaters Installed | 63,247 | 136,558 |
| Homes with Advanced Wood Heat | 12,898 | 14,992 |
| Homes with Biofuels | 12,112 | 21,086 |

## Non-Energy

Most of Vermont's GHG emissions are associated with energy use. However, roughly 17% of Vermont's emissions in 2020[11] came from direct GHG emissions from agriculture, industrial processes, and waste systems, or what is referred to as "non-energy" emissions. It is important that the CAP address opportunities to reduce non-energy emissions. Figure 4 illustrates how non-energy emissions from these sectors decrease in the LEAP model by 11% by 2025, 20% by 2030, and 38% by 2050.

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9 The mitigation scenario is based on a linear increase of annual weatherizations with a total of 90,000 units weatherized by 2030. An alternative pace of increase is discussed in Box 7, which allows for a more gradual rate of increase as the weatherization industry gears up for the tremendous growth in homes needing to be weatherized in the future. This alternative profile anticipates that by 2025, about 18,000 housing units will be weatherized with a balance of 72,000 homes to be weatherized in the five years from 2025 to 2030.

10 The residential building key indicators are installed stock in each year, inclusive of new retrofits and installations to date.

11 Non-energy emissions are compared to 2020 as a baseline. The Carbon Budget Report conducted by the Cadmus and UVM team earlier in 2021 estimated lower agriculture sector emissions than the Greenhouse Gas Inventory, and the Carbon Budget values were used to calculate reductions in the Pathways analysis.

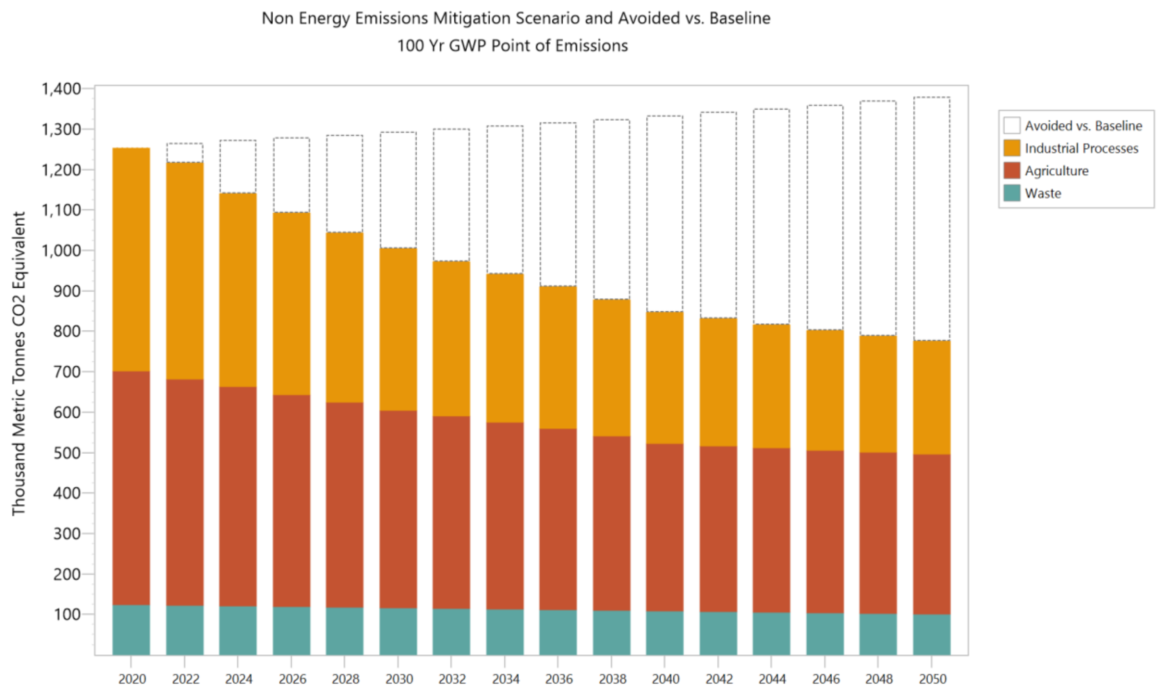


**Figure 4. Mitigation Scenario Non-Energy Sector Greenhouse Gas Emissions and Avoided Emissions versus Baseline**

Within the non-energy sector, the CSM Subcommittee recommended reducing direct agricultural emissions, increasing agricultural sequestration, reducing direct emissions from refrigerants, and addressing direct industrial process emissions as important contributions to achieving the GWSA targets. Non-energy emissions can also be reduced by ensuring that all flaring systems at waste and wastewater facilities are operational to reduce direct methane emissions and that, where possible, they also provide energy recovery from that flaring. Preliminary findings indicate that there are viable strategies to reduce enteric fermentation emissions, encourage best practices for manure management and soil sequestration, reduce ODS substitutes through refrigeration management, and increase efficiencies in semiconductor manufacturing, each of which are poised to be key drivers of emissions reductions and were incorporated into the LEAP model inputs. More research and analysis are required to further understand the cost and scale of these potential reductions, particularly from the agricultural sector.

Modeling the mitigation scenario in LEAP for the non-energy sector involved modifying the baseline for several elements: reduced the direct methane and nitrous oxide emissions from enteric fermentation and manure management, increased rates of soil carbon sequestration, and reduced direct emissions from refrigerants and from semiconductor manufacturing.

Table 4 summarizes the percentage emissions reduction from 2020 levels for key indicators in 2025 and 2030 for the non-energy sector.

**Table 4. Non-Energy Key Indicators for 2025 and 2030 - Percent Emissions Reductions from 2020**

| Non-Energy | 2025 | 2030 |
|---|---|---|
| Enteric Fermentation | 20% | 39% |
| Manure Management | 29% | 57% |
| Agricultural Soils | 9% | 19% |
| ODS Substitutes | 25% | 41% |
| Semiconductor Manufacturing | 4% | 8% |

## Electricity

In contrast to the previous sectors (transportation, buildings, and non-energy), the focus on the electric sector is not primarily on further reducing emissions, but rather on cost-effectively, reliably, efficiently, and equitably meeting significant growth in future demand using clean resources. In the mitigation scenario, the role of the electric sector in helping Vermont meet the GWSA targets is to provide an increasing amount of clean electricity, with total demand for electricity doubling from roughly 5.5 TWh in 2020 to 11.9 TWh by 2050. Figure 5 illustrates that transportation electrification accounts for most of this increased demand, followed by electrification of space heating in the residential and commercial sectors.

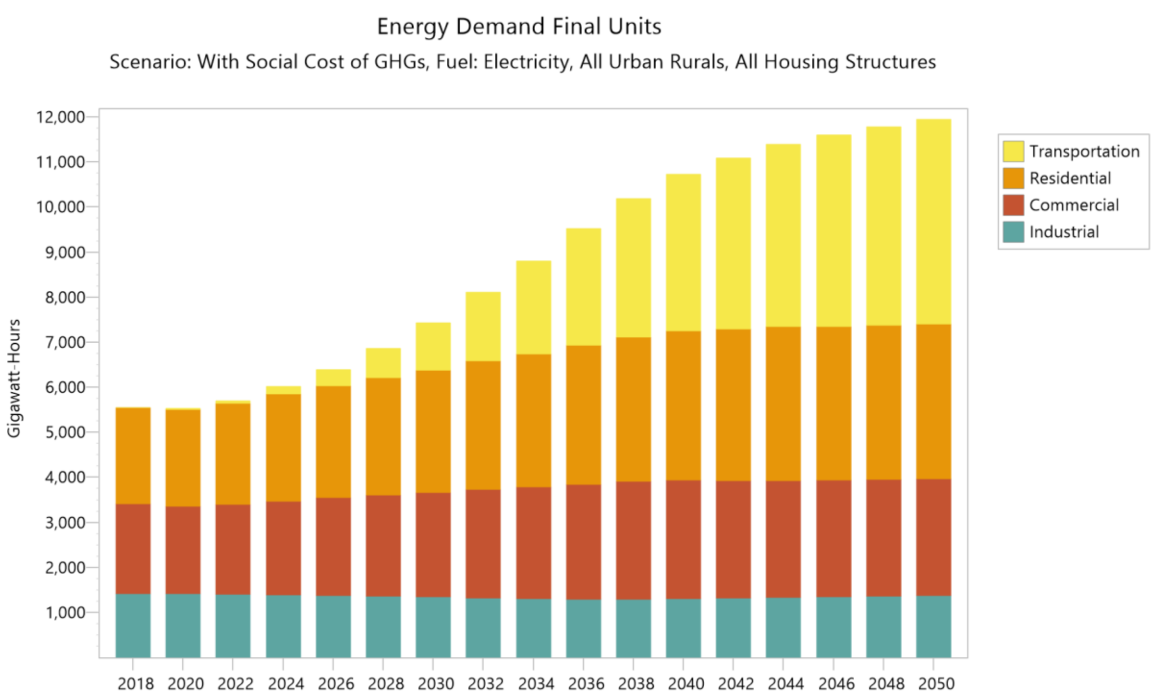


**Figure 5. Electricity Demand (GWh) for all Sectors through 2050**

Our analysis is consistent with the pathways, strategies, policies, and actions recommended by the CSM Subcommittee, including expanding the Renewable Energy Standard to 100% after 2032, conducting demand response, having flexible and coordinated load management (via managed EV charging and other solutions) and storage to address curtailment, ensuring that electrification is accessible to all, creating strategic electrification of industry, and focusing on increased clean electricity generation. Ultimately, ongoing planning and detailed analysis will need to occur to ensure optimization of all of the strategies, from investing in demand management activities (such as time-of-use rates, incentives, regulations, and code updates) to participating in the regional wholesale market and investing in more hardware (such as renewables and distribution and transmission upgrades) or other activities.

To model the mitigation scenario in LEAP for the electricity sector, the Project Team relied on the analysis conducted by SEI to support the CEP. In the LEAP model structure, the electricity demands are exogenous from the optimization routine for the sector. The use of coordinated and flexible load management is limited to a preliminary analysis of managed charging for EVs. Greater coordination across multiple loads and sites has significant potential to reduce the total increase in electricity peak demand and associated costs. The LEAP model uses capital, fixed, and variable operating costs for existing and potential new generating sources, both in Vermont and in the broader region served by the Independent System Operator of New England (ISO-NE), to reliably meet electricity demand in each time period throughout the day and over the course of each year. The modeling reflects both variations in electricity demand as well as the seasonal and diurnal variability of renewable energy output.

Table 5 summarizes key indicators for the electric sector in 2025 and 2030.

**Table 5. Electric Sector Key Indicators for 2025 and 2030**

| Electric Sector | 2025 | 2030 |
| --- | --- | --- |
| Electricity as Share of Energy | 20% | 30% |
| Total Demand (GWh) | 6,182 | 7,436 |
| Peak Demand (MW) | 1,374 | 1,652 |
| Share of EV Managed Charging | 27.3% | 50% |

# Detailed Pathways Findings

## *2025 Greenhouse Gas Emissions Reductions*

The GWSA requires a 26% GHG emissions reduction below a 2005 baseline by 2025. The mitigation scenario highlights the significant ramp up in activity required to meet this target, including in weatherization, clean heating and cooling technology deployment, and EV adoption, described in more detail below. In addition to implementing these strategies in the very near term, it is also essential to use this time period to gain momentum toward achieving 40% reduction by 2030, as the pace and scale of adoption must accelerate in the latter half of this decade to remain on-target. This is particularly imperative given the stock turnover cycles of many of the building and transportation technologies driving reductions in the mitigation scenario, as vehicles and heating equipment purchased or installed this decade are likely to still be in service in 2030. It will also be important to use the time period between now and 2025 to assess the feasibility of emissions reductions in the non-energy sector, including conducting research and monitoring of agricultural emissions and practices, as well as sequestration potential.

More details on the key actions within each sector for this time period are included below.

### Transportation

By 2025, Vermont’s transportation GHG emissions decline in the mitigation scenario by 11% relative to 2018, led in large part by reductions in gasoline emissions from light-duty trucks and light-duty passenger vehicles (Figure 6). Reductions are driven by rapid EV adoption and the improving fuel economy of internal combustion engine vehicles (ICEV). By 2025, the mitigation scenario has about 27,200 EVs on the road (Figure 7), with a new EV sales share of approximately 17%. All major automakers have invested in EV technology and are expected to release a diversity of EV models in the next three years, including new electric pickup trucks and sports utility vehicles, which are currently underrepresented in the EV market. Fuel economy in the mitigation scenario improves at 1.5% per year, which is consistent with the Safer Affordable Fuel-Efficient (SAFE) Vehicles rule.

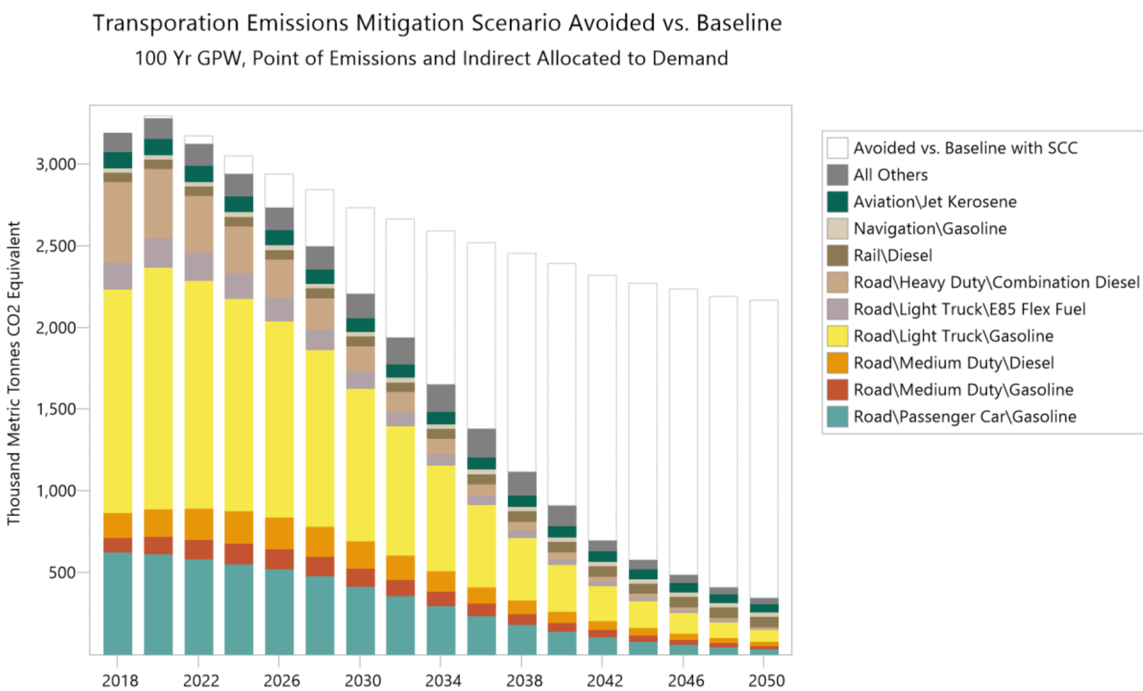


**Figure 6. Transportation Greenhouse Gas Emissions Climate Action Plan and Avoided versus Baseline**

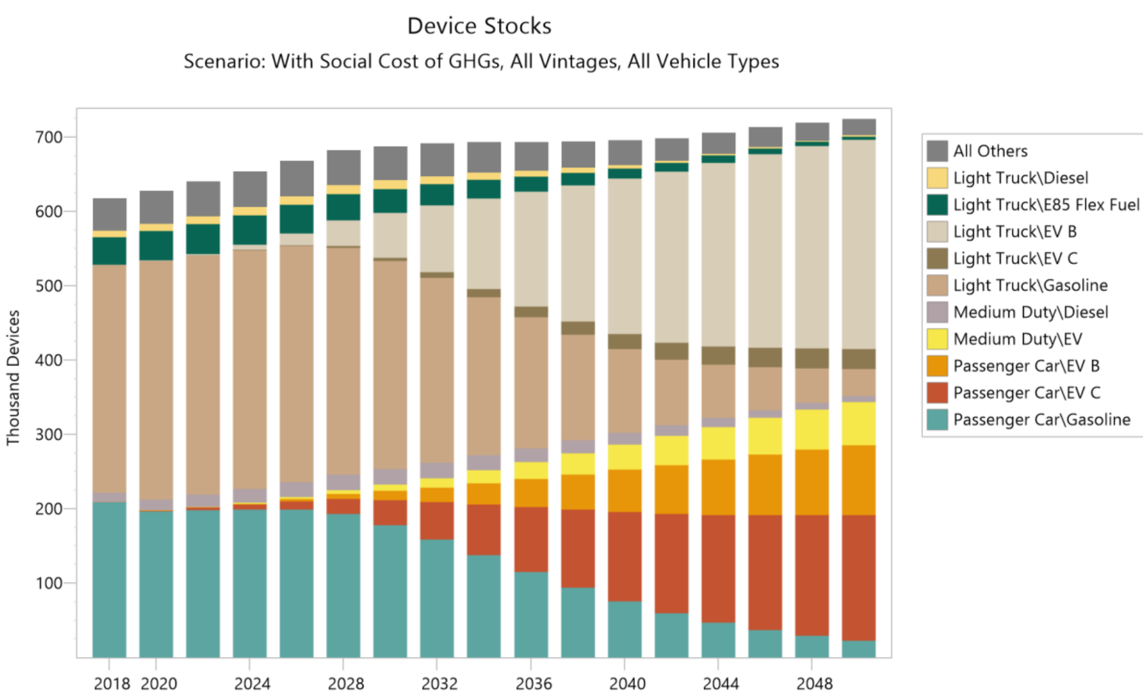


**Figure 7. Forecasted Vehicle Stock by Type: Mitigation Scenario Vehicle Stock by Type**

The costs of EVs have fallen quickly over the past decade, driven largely by battery cost reductions. Analysts expect the upfront cost of many light-duty EV segments to be compared to gasoline and diesel-fueled to the ICEV counterparts by the mid- to late-2020s.[12] Cost parity based on the total cost of ownership will reach parity sooner for most drivers given the savings on fuel and maintenance of driving an EV compared to a gasoline or diesel-fueled vehicle. LEAP modeling assumes that the upfront cost of EVs declines over the next decade while the cost of ICEV increases slightly. Upfront cost parity for passenger EVs is assumed to be reached in 2028. Upfront vehicle costs do not change between the baseline and mitigation scenarios since those costs are largely driven by forces outside of Vermont. The degree to which EV costs will continue declining over the next decade is a key uncertainty in the LEAP modeling. The higher upfront cost of EVs over the next few years suggests the need to continue providing vehicle rebates in Vermont, particularly for low- and moderate-income households.

12 International Council on Clean Transportation (Lutsey, Nic, and Michael Nicholas). 2019. *Update on Electric Vehicle Costs in the United States through 2030.* https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

**Box 2. Electric Vehicles and the Potential to Reduce Households Transportation Costs**

According to the U.S. Bureau of Labor Statistics, in 2018 and 2019 U.S. households spent an average of 12% to 13% of before-tax income on transportation, including for vehicles, fuel, maintenance, and repairs. This fraction varies by income level, with the-lowest income households spending as much as 40% on transportation and the highest-income households only spending 1% to 2%.

A transition to EVs could reduce this burden through savings on fuel and vehicle maintenance, and eventual savings on the upfront cost of vehicles. For example, an EV in Vermont that charges on a residential rate of $0.17 per kilowatt-hour costs approximately $0.06 per mile, whereas a gasoline vehicle with a fuel economy of 25 miles per gallon and a fuel cost of $3 per gallon pays double that: $0.12 per mile. Consumer Reports compared EVs and gasoline vehicles of similar size and from the same segment and found that most EVs saved drivers between $6,000 and $10,000 over the typical vehicle lifetime.

Analysts suggest that EVs will offer further savings in future years as upfront vehicle prices decline. According to Consumer Reports, EVs are currently 10% to 40% more expensive upfront than gasoline vehicles. Since 2018, automakers have released more luxury EV models than mainstream models, which masks upfront price declines. Price parity is expected to be reached in the mid- to late-2020s and battery costs are expected to continue declining, thus making EVs generally cheaper to purchase than gasoline vehicles within the next decade (or less). The California Air Resources Board expects sustained reductions in the cost of batteries through 2035, from about $100 per kilowatt-hour in 2025 to $56 per kilowatt-hour by 2030.

Yet, several cost-related barriers remain. The reliance of EV owners on public charging is expected to increase in coming years as the fraction of those without the ability to charge overnight at home increases. Public charging is generally more expensive than charging at home and makes the economics of personal EV ownership less attractive. Additionally, it remains unclear whether automakers will use savings from batteries to add all-electric range to vehicles rather than for reducing the upfront price for the consumer.

Sources: Harto, Chris. October 2020. *Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers.* https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf
U.S. Bureau of Labor Statistics. September 9, 2021. "Consumer Expenditures--2020." USDL-21-1617. https://www.bls.gov/news.release/cesan.nr0.htm
Hardman et al. 2021. "Perspective on Equity in the Transition to Electric Vehicles." *MIT Science Policy Review*, vol. 2.
California Air Resources Board. October 13, 2021. "Public Workshop on Advanced Clean Cars II." Webinar. https://ww2.arb.ca.gov/events/public-workshop-advanced-clean-cars-ii-1

**Transportation Key Insights for 2025**

There are several key transportation sector insights for 2025:

- Adopt ACC II and Advanced Clean Trucks (ACT) regulations and invest in strategies beyond these regulations (as these regulations alone are insufficient to achieve the needed level of electrification).
- Continue to monitor and explore regional initiatives around funding mechanisms, such as TCI and a low carbon fuel standard.
- Continue to expand charging availability throughout the state, with a particular focus on filling spatial gaps with fast charge stations.
- Study residential charging needs across Vermont to understand how best to balance at-home versus public charging solutions. The study should segment vehicle owners by those who can currently charge vehicles at their home or building, those who could feasibly install charging at their home or building, and those who do not have access to home charging and therefore need to rely on public stations.

## Buildings

GHG emissions from buildings in Vermont account for a bit more than one-third of the total emissions, making buildings the second largest source of GHG emissions (after transportation).

As Figure 8 shows, the residential sector currently accounts for more than half the GHG emissions from Vermont buildings, mostly from burning fuel oil and propane. Another one-third of emissions are from the commercial sector, while about 15% are from the industrial sector.

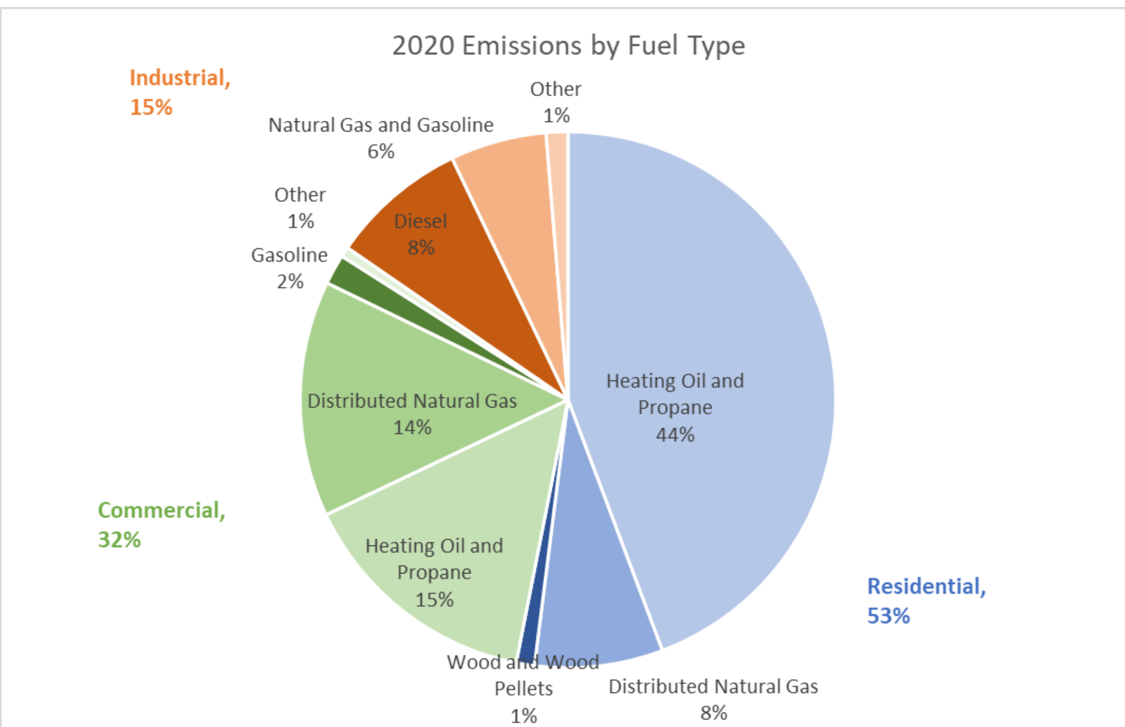


**Figure 8. Vermont Thermal Greenhouse Gas Emissions by Sector and Fuel Type**

There are several main ways to reduce emissions from the building sector captured in the mitigation scenario. These include improving the thermal performance of the building shell through improved insulation and reduced air leakage and drafts. This weatherization reduces the energy loads for heating and cooling the building, increases comfort, and can help to improve a building's longevity. Vermont has a strong history and base of experience for providing weatherization services and the mitigation scenario builds on this to improve and enhance the performance of residential buildings.

Using heat pumps (which use electricity and compression expansion cycles to transfer heat, rather than the combustion of fuels) for space heating and cooling provides the largest potential for reducing emissions from buildings. Cold-climate heat pumps have high efficiencies of more than 200%, so they are more efficient than typical combustion equipment (which has efficiencies in the range of 85% to 95%). Using clean electricity for heat pumps further reduces emissions in comparison to conventional heating systems.

To help reduce overall costs, it is important to manage building loads to more closely match the time-varying outputs of renewable generating systems, and to coordinate building loads to reduce their peak demands.

The use of biofuels, including renewable natural gas, biodiesel, and advanced wood heating systems, provides another means for reducing emissions. The lifecycle emissions from biofuels need to be considered, and not all sources result in reduced emissions; however, in many situations, biofuels provide significant reductions in comparison to fossil fuels.

By 2025 emissions from residential buildings in the mitigation scenario are reduced by 27% from 2018 levels. These savings come from a combination of increased weatherization, increased use of heat pumps for water and space heating, and increased use of biofuels. Reductions and the avoided emissions in comparison to the baseline by building type are illustrated in Figure 9.

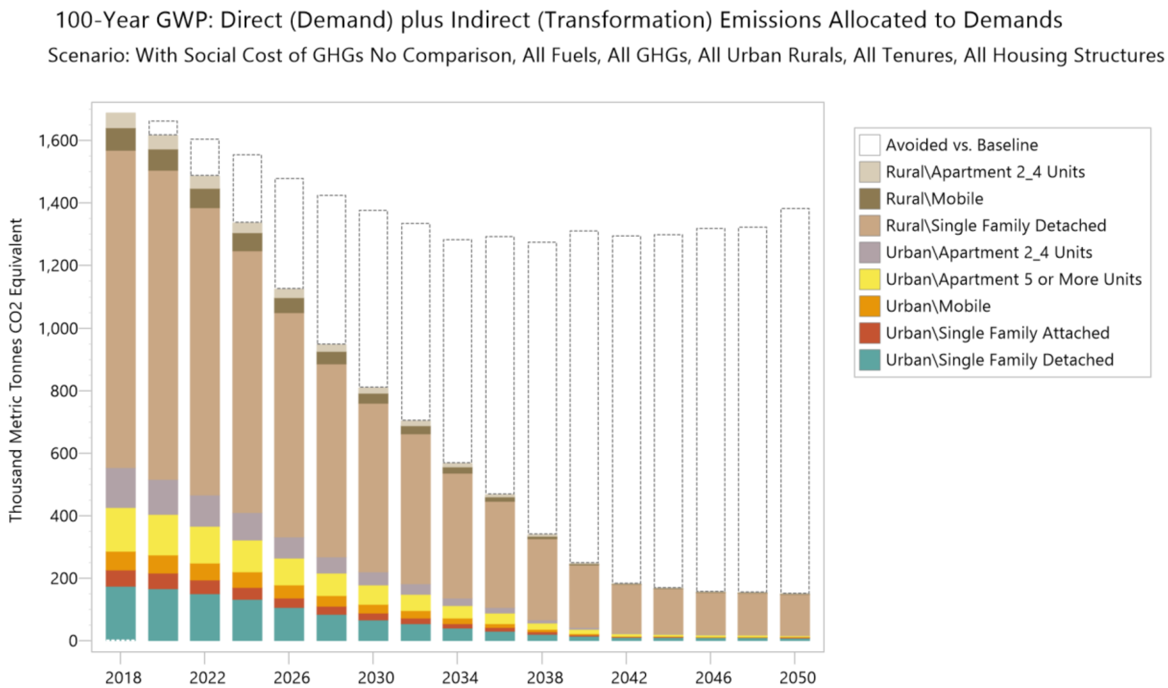


**Figure 9. Residential Building Greenhouse Gas Emissions Reductions by Housing Type**

It is generally anticipated that it will be easier and less expensive to reduce emissions from residential and commercial buildings than from industrial buildings, where energy needs are often related to industry specific process needs. Though some industrial end uses can be relatively easily converted to clean sources—as evidenced by a variety of custom industrial projects pursued by Vermont's electric utilities under existing Tier 3 requirements of the state's Renewable Energy Standard (RES)—others will likely be more difficult to convert.[13] Since residential and commercial buildings account for most of the building sector emissions, these sectors will also be the most likely to result in the largest emissions reductions. However, the adoption of a CHS as a performance standard for building sector emissions will allow for flexibility, both in terms of which sectors are affected and in terms of what activities and strategies are deployed. See Box 3 for an overview of the CHS.

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13 Tier 3 of the RES requires distributed utilities to achieve fossil fuel savings from energy transformation projects or to retire Tier 2 Renewable Energy Credits. Energy transformation projects include weatherizing buildings; installing air-source or geothermal heat pumps, biomass heating systems, and other high-efficiency heating systems; switching industrial processes from fossil fuel to electric; increasing the use of biofuels; and deploying EVs or related charging infrastructure.
Source: Department of Public Service, "Renewable Energy Standard," https://publicservice.vermont.gov/renewable_energy/state_goals

**Box 3. The Clean Heat Standard: A Flexible, Performance-Based Approach to Reducing Emissions from Building Sector**

The CHS is a performance standard, much like the RES currently imposed on Vermont's electric utilities, that would require Vermont Gas Systems and wholesale distributors of fuel oil, propane, and other fossil fuels sold to homes and businesses in Vermont to meet increasing annual GHG emission reduction requirements. Those requirements could be met through investments in a range of potential clean heat alternatives including heat pumps and other electrification technologies, weatherization and other efficiency investments that reduce fossil fuel consumption, renewable district heating systems, advanced wood heating systems, solar thermal, and sustainably produced liquid, or gaseous biofuels with lower lifecycle GHG emissions than the fossil fuels they replace. The amount of GHG reduction that each measure is credited with providing would be determined through a technical advisory group process analogous to those currently in place to determine whether Efficiency Vermont is achieving its energy savings goals and to determine whether the state's electric utilities are achieving their RPS Tier 3 requirements to reduce their customers' consumption of fossil fuels. The Vermont Public Utilities Commission would oversee compliance with the CHS.

Because the CHS is a performance standard, Vermont Gas Systems and other fossil fuel wholesalers would have the flexibility to determine the mix of clean heat measures they want to use to meet their annual requirements. They would also have the flexibility to decide how to acquire clean heat credits, whether through their own sales of biofuels in Vermont, by running programs to promote Vermont customers' investments in clean heat measures, or by buying clean heat credits from other parties (or some combination). Entrepreneurial fuel dealers, HVAC contractors, weatherization contractors, vendors of pellet stoves, solar thermal companies, and other businesses could generate clean heat credits by selling and installing energy efficiency and clean heat technologies in Vermont homes and businesses. They could then earn revenue from selling those credits, either through bilateral agreements with one or more fossil fuel wholesalers or on the open market. Also, because the CHS is a performance standard, with annual GHG emission reduction requirements based on the state's GWSA, emission reductions resulting from existing Vermont policies and programs—including Efficiency Vermont's efforts and the electric utilities' RPS Tier 3 programs—would all count and could be sold to obligated fossil fuel wholesalers. This could create a new revenue stream to defray the costs of those existing policies and programs.

Just as no Vermont home or business is required to install solar panels to help Vermont's electric utilities meet their RPS requirements or is required to install efficiency measures to help Efficiency Vermont meet its energy savings targets, no Vermont home or business would be required to do anything under the CHS. Instead, they would have the option to invest in heat pumps, pellet stoves, weatherization, biofuels, solar thermal, or other clean heat measures, and would have the cost of such investments defrayed through program rebates or price discounts. Fossil fuel wholesalers would need to ensure that rebate levels or price discounts are high enough to attract voluntary participation by homes and businesses at levels necessary to meet the wholesalers' growing annual GHG emission reduction requirements. Importantly, the CHS would include minimum requirements for clean heat pumps, pellet stoves, solar thermal, weatherization, and other measures provided for low-income homes that would otherwise not be able to participate.

As Figure 10 shows, a combination of activities and strategies contribute to reducing residential building emissions by 2025 in the mitigation scenario. This includes significant electrification—of nearly 96,000 heat pumps and over 60,000 heat pump water heaters compared to the period from 2015 through 2020, when Vermonters installed about 30,000 heat pumps and 13,000 heat pump water heaters.[14] Heat pump sales are growing exponentially (by over 11,000 in 2020 alone) absent new climate policies. It is generally easier to ramp up and expand existing efforts, such as the heat pump incentives currently offered through Efficiency Vermont, that already have some traction in the market than to get substantial emission reductions from new areas that currently have relatively low levels of market adoption. Another reason for the rapid increase in market share is that heat pump retrofits have the potential to lower energy bills for many homes and businesses currently heating with fuel oil or propane. It is critical to understand clean heat options and other opportunities to reduce emissions from the customer's financial perspective to help determine the need for incentive programs and to support accelerated adoption rates. Box 4 provides an example of how heat pumps and weatherization can help to reduce energy costs for a Vermont household that currently uses propane as its primary heating fuel.

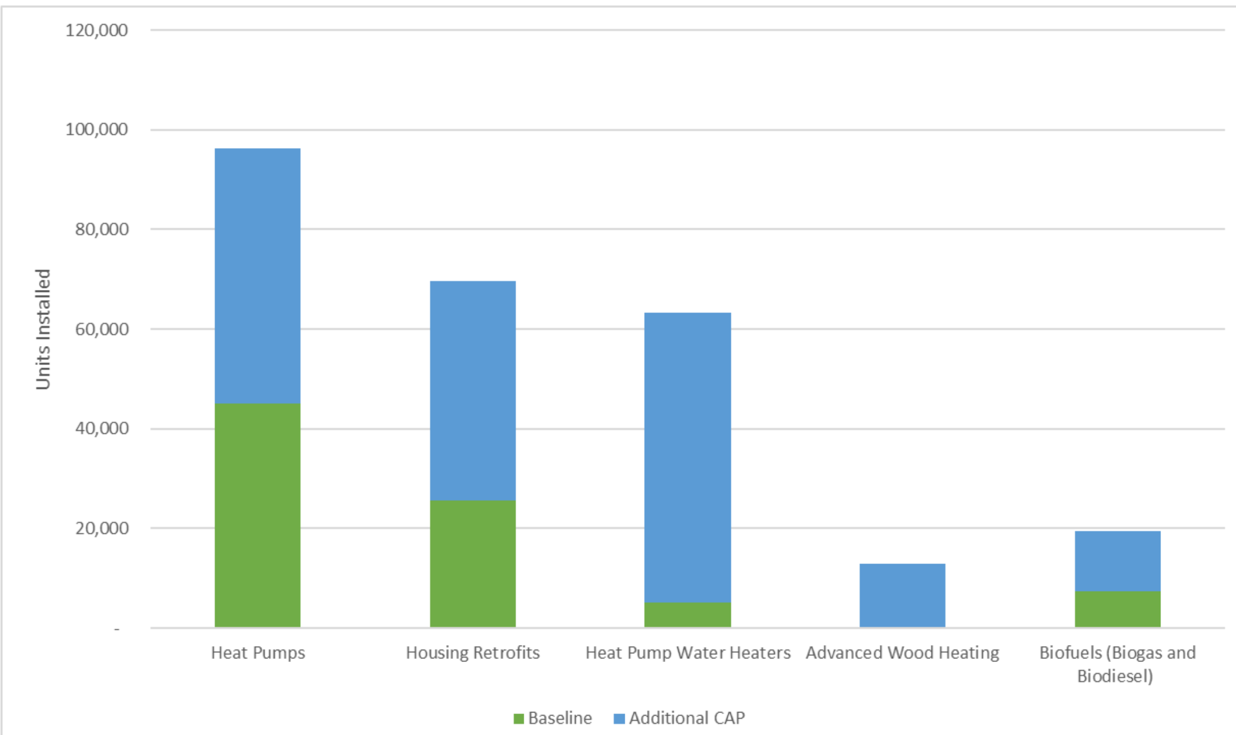


**Figure 10. Residential Building Measures Installed by 2025**

14 Energy Action Network. Community Energy Dashboard. *Community Progress Maps*. https://www.vtenergydashboard.org/statistics

Advanced wood heating includes high-efficiency pellet stoves and high-efficiency wood stoves. Biofuels include biogas and biodiesel (including B100 biodiesel). Advanced wood heating and biofuels reflect the number of households, rather than the number of units installed.

**Box 4. Clean Heat Options for Vermonters Who Heat with Propane**

Propane is the primary heating fuel in about 23% of Vermont homes. Since there are currently no direct biofuel alternatives for propane, it is useful to understand the options for propane customers as we seek to transition away from burning fossil fuels.

Building weatherization is an option for all customers, regardless of the fuel used for heating. Weatherization energy savings range from 13% to 45%, with an average of about 22% for Vermont program participants. In addition to energy cost savings, customers also benefit from health and safety improvements while preparing their building for a heat pump installation. Heat pumps operate more effectively in weatherized buildings.

In addition to weatherization, propane customers are also able to reduce fuel costs by displacing propane with heat pumps, biomass, and/or solar thermal. Table 6 shows the results of an analysis of four scenarios. Three different Vermont homes were analyzed and used as a baseline for savings comparisons. The low use customer burns about 486 gallons of propane per year, while the medium use customer burns 971 gallons, and the high use customer burns 1,457 gallons. Using November 2021 average rates, the annual propane costs for these customers would be $1,535, $3,070, and $4,605 respectively.

**Table 6. Clean Heat Options' Effect on Propane Costs and Savings**

| Scenario | Low Use | | Medium Use | | High Use | | Load Served |
|---|---|---|---|---|---|---|---|
| | *Annual Cost* | *Gallons* | *Annual Cost* | *Gallons* | *Annual Cost* | *Gallons* | |
| Baseline Propane Customer | $ 1,535 | 486 | $ 3,070 | 971 | $ 4,605 | 1,457 | 100% |
| Single-Head Heat Pump | $ 1,288 | | $ 2,576 | | $ 3,863 | | 40% |
| *Savings* | $ 247 | | $ 494 | | $ 741 | | |
| Pellet Stove | $ 1,230 | | $ 2,461 | | $ 3,691 | | 50% |
| *Savings* | $ 304 | | $ 609 | | $ 913 | | |
| Two-Head Heat Pump | $ 1,041 | | $ 2,081 | | $ 3,122 | | 80% |
| *Savings* | $ 494 | | $ 988 | | $ 1,482 | | |
| Central Heat Pump | $ 917 | | $ 1,834 | | $ 2,752 | | 100% |
| *Savings* | $ 618 | | $ 1,235 | | $ 1,853 | | |

The four scenarios examined for reducing propane use were installing (1) a single-head heat pump, (2) a pellet stove, (3) a two-head heat pump (or, preferably for better performance, two single-head heat pumps), and (4) a central heat pump system. As shown in Table 6, the heating load served for each of these options increases from 40% in option 1 to 100% in option 4. This means, for example, that the home with the two-head heat pump that provides 80% of the building's heating load will still rely on propane for 20% of the heating load. The table includes the blended energy costs of the heat pump (or pellet stove) and the propane system, along with the savings (highlighted in peach) relative to heating the home exclusively with propane. The central heat pump assumes 100% electricity and no propane use.

The customer will experience cost savings under low, medium, and high use conditions in all the scenarios. For a single-head heat pump meeting 40% of the home's load, savings would range from \$247 to \$741 per year. For the pellet stove meeting 50% of the load, savings would range from \$304 to \$913 per year. For the two-head heat pump meeting 80% of the load, savings would range from \$494 up to \$1,482 per year. For the central heat pump providing all the home's heat, savings relative to the home heated only with propane would range from \$618 to \$1,853 per year. These savings will vary according to the individual utility rates for a customer and savings will be less in utility territories with higher electric rates.

Customer savings from all these options can be significant, but there is also a cost to installing the new equipment. Rebates can reduce clean equipment costs and financing can help spread the payments over time so the resulting energy savings can either offset the investment altogether or help defray the cost significantly. The cost per heat pump or pellet stove system after rebates is approximately \$4,000 (plus or minus about \$1,000 depending on the house layout and other particulars). A central heat pump system can be two to three times that cost for a house with existing ductwork where a central heat pump can be added to the system. Of course, specific costs will vary.

The bottom line is that there are multiple options for propane-heated homes. Weatherization will reduce the heating needs of any building. Heat pumps and biomass systems are available that will displace a portion—or even all—the more expensive propane heat, providing savings that can be redirected to pay for modernizing the heating system in any home while using available rebates and taking advantage of affordable financing options for a cleaner energy future for everyone.

Sources: NMR Group, February 27, 2019. *Vermont Single-Family Existing Homes Overall Report*.
Vermont Department of Public Service. December 29, 2020. *2019 Annual Report on Vermont's Progress toward Building Energy Fitness Goals.*
Vermont Department of Public Service. 2021. "Retail Prices of Heating Fuels."
https://publicservice.vermont.gov/content/retail-prices-heating-fuels

As Figure 10 above illustrates, the mitigation scenario also includes significant ramping up of weatherization activity, roughly doubling the current total of 30,000 units treated to date. Increasing support for weatherization has received significant emphasis recently, along with committed funding from the Vermont Legislature, state agencies, and the federal government. Multiple state agencies, organizations, and businesses have stepped up to engage with the Weatherization at Scale initiative in support of weatherizing a total of 120,000 homes by 2030 (or 90,000 more than today's level) with an emphasis on low- and moderate-income homes and buildings.

Weatherizing older Vermont homes not only helps reduce energy costs, but also improves health and safety for the occupants and prepares the house for installing heat pumps, which work much better in tighter, insulated homes. The mitigation scenario reflects the interest and momentum for Weatherization at Scale and for preparing Vermont's homes for heat pumps with a focus on serving low-and moderate-income homes. The pace of increasing weatherization services at scale is further discussed in Box 7 (in the 2030 emissions reduction from buildings section of this report).

By 2025 the mitigation scenario also includes the use of 1.95 trillion Btu's of biofuels, which includes biodiesel and biogas. This is equivalent to the average total fossil fuel consumption of about 12,000 single family detached homes in the state.[15] The mitigation scenario also includes the equivalent of almost 13,000 homes with advanced wood heating, which includes high-efficiency pellet stoves and high-efficiency wood stoves.

**Building Sector Key Insights for 2025**

By 2025, initiatives that ensure meeting the 2030 goals will need to be well underway. There are several key building sector insights for 2025:

- Adopt a Clean Heat Standard and other building sector policies and programs that will result in modernizing our building stock through weatherization, electrification, and other approaches.
- Ramp up delivery of biofuels to homes and businesses significantly.
- Weatherize 18,000 more homes than done to date and install 96,000 heat pumps and over 60,000 heat pump water heaters in residential buildings.
- Install advanced wood heating systems for both residential and commercial buildings and make progress building out renewable district heating systems, in addition to some industrial electrification and other strategies beyond what Tier 3 currently provides.

## Non-Energy

**Emissions Reductions from Non-Energy Sector in 2025**

Total GHG emissions from the non-energy sector are 1,253 thousand metric tons of carbon dioxide equivalent (TMTCO2e) in 2020 and are reduced to 1,116 TMTCO2e in the LEAP model in 2025. This represents a reduction of 11%, or about 137 TMTCO2e, between 2020 and 2025, distributed across all aspects of the non-energy sector: industrial processes, agriculture, and waste. Most of the emissions reductions (65%) modeled in the non-energy sector during this time period come from industrial processes, while 33% of emissions reductions come from agriculture and about 3% come from waste. Figure 11 illustrates the emissions from the non-energy sector in 2020 and 2025.

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[15] This is based on an assumption that the average single-family home consumes approximately 75 MMBtu to 80 MMBtu per year for space heating and 20 MMBtu to 25 MMBtu per year for water heating, cooking, drying, and other end uses.

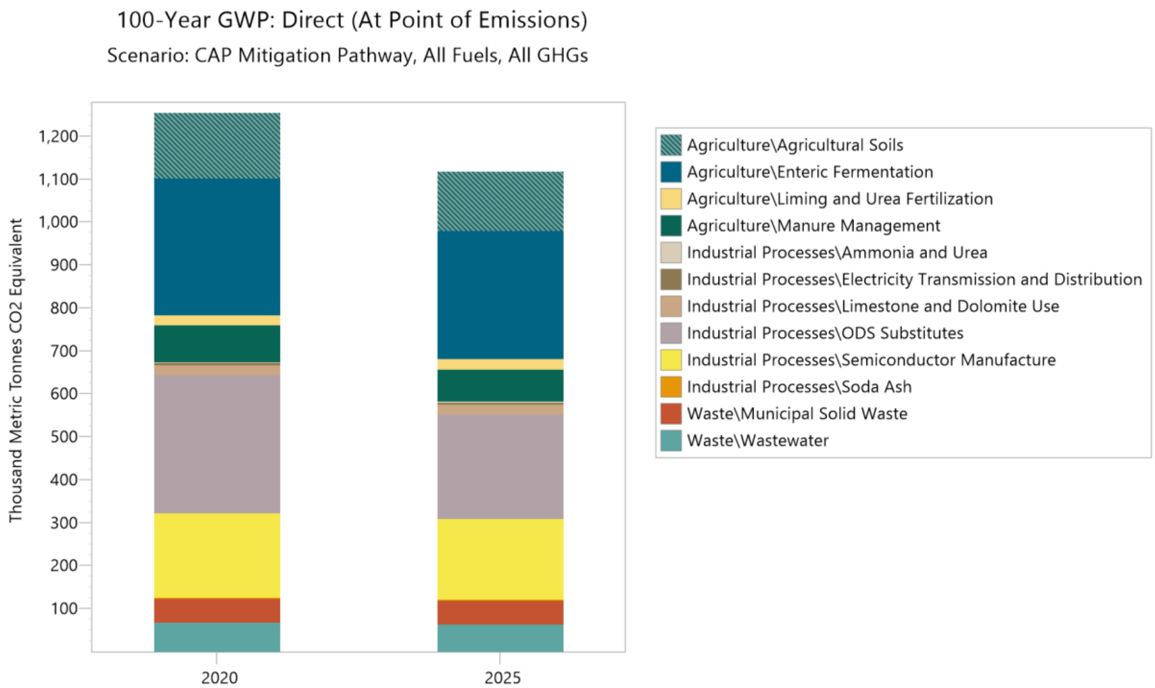


**Figure 11. Emissions Reductions from Non-Energy Sector in 2020 and 2025 in Current LEAP Model**

Industrial processes as modeled by LEAP include several categories: limestone and dolomite use, soda ash, ammonia, and urea, ODS substitutes, semiconductor manufacturing, and electricity transmission and distribution. In 2025, industrial process emissions are projected to be 463.5 TMTCO2e, which is a reduction of 88.6 TMTCO2e from emissions in 2020. Most of the emissions reductions from industrial processes come from ODS substitutes, from which emissions are reduced from 322.1 TMTCO2e to 243.0 TMTCO2e. There is also a slight reduction in emissions from semiconductor manufacturing, from 195.4 TMTCO2e in 2020 to 187.2 TMTCO2e in 2025.

Agriculture is the second largest sectoral source of non-energy emissions. In the mitigation scenario emissions from agriculture are reduced from 578.1 TMTCO2e in 2020 to 533.5 TMTCO2e in 2025, or 44.6 TMTCO2e over this time period. These reductions come from advanced management practices to reduce methane and nitrous oxide emissions from enteric fermentation and manure management, and to increase carbon sequestration rates for agricultural soils. Liming and urea fertilization, which represents the smallest emitting process within agriculture, does not have reductions during this time period. Enteric fermentation is the largest emitting process within agriculture, with emissions reduced from 318.8 TMTCO2e in 2020 to 298.7 TMTCO2e in 2025. Emissions from agricultural soils are reduced from 150.2 TMTCO2e in 2020 to 136.0 TMTCO2e in 2025. Emissions from manure management are reduced from 85.7 TMTCO2e in 2020 to 75.1 TMTCO2e in 2025.

The waste sector in LEAP includes municipal solid waste and wastewater. There is a slight decrease in emissions from waste, from 123.2 TMTCO2e in 2020 to 119.4 TMTCO2e in 2025.

**Non-Energy Key Insights for 2025**

The primary driver of the 11% reduction in emissions from the non-energy sector from 2020 to 2025 is industrial processes, particularly ODS substitutes. The emissions reductions from ODS substitutes reflected in in the mitigation scenario are consistent with Vermont's refrigerant management efforts, and these provide a major way for Vermont to reduce its hydrofluorocarbon (HFC) emissions. More information about efforts to reduce emissions through refrigerant management is outlined in the *Policy Implications* section.

Emission reductions from agriculture in the mitigation scenario from 2020 to 2025 result from advanced management practices for enteric fermentation, manure management, and agricultural soils. Emission reductions from enteric fermentation are based on alternative feed practices, including feed additives that reduce the methane produced from ruminants. Emission reductions from manure management are based on anticipated manure management practices and uptake of these practices by Vermont farmers, including waste digestors. Emission reductions from agricultural soils stem from altered agricultural soil management practices, which could include, for example, cover crops and no-till practices. Each of these strategies are discussed further in the *Policy Implications* section.

Waste is not a significant emitter relative to industrial processes and agriculture and there is only a slight reduction in emissions from wastewater management from 2020 to 2025, while emissions from municipal solid waste stay steady. This could be due to improvements in wastewater management technologies to reduce fugitive methane emissions from wastewater treatment.

## Electric

**Electricity Sector Modeling in LEAP**

Before presenting the electric sector findings, it is important to briefly discuss the approach to electricity sector modeling in LEAP, including key terms to help understand the analysis.

The key terms "energy" and "capacity" are frequently used in the electricity sector. Energy reflects the number of kilowatts used over a certain time frame (kilowatt-hour, or kWh), and can be viewed similarly to the number of gallons of gasoline used to drive a certain distance. Capacity reflects how much electricity is needed at a specific point in time (kilowatt, or kW), and can be viewed similarly to the amount of gasoline used when a driver puts their foot on the accelerator (also referred to as "peak load"). Utilities are required to meet the needs of both, and Vermont utilities assess these needs every three years through a planning process referred to as an "Integrated Resource Plan." The ISO-NE requires there to be enough generators on standby to meet capacity (the amount of electricity needed by the entire region, similar to when a driver accelerates), even though the region does not need this much electricity most of the year. These capacity needs drive the cost and build out of future generation, transmission, and distribution. Additionally, efforts to strategically electrify while also increasing variable renewable generation (wind and solar) require the use of other strategies, such as demand management and flexible coordinated load management and storage to ensure we meet future capacity as cost-effectively as possible.

The electric sector outputs from the LEAP model are uniquely different from those in the transportation, buildings, and non-energy sectors, because they are essentially a response to the electricity demands created by the other sectors. As described earlier, the Project Team developed the outputs from the transportation, buildings, and non-energy sectors by determining, for example, how many EVs or heat pumps (or other technology) would be needed to achieve the required emission reduction targets by a specific year.

To meet increasing electricity demand, in 2025 and beyond, SEI conducted the LEAP modeling for the electricity sector mitigation scenario based on existing and planned Vermont generating plants (as well as existing contracts). Requirements exceeding the contracted and planned supplies were met using a dispatch model of ISO-NE, allowing the model to estimate future capacity needs across the regional grid required to meet Vermont's needs. This provides an idea of the resources deployed to meet Vermont's increased electricity demand recognizing that Vermont is part of the regional grid.

For electric sector modeling, SEI obtained underlying data assumptions and forecast sources (pertaining to existing and planned capacity, system reserve and capacity adequacy, plant generation characteristics, plant costs, current and projected system load, and GHG emissions) from recognized entities such as the U.S. Energy Information Administration, ISO-NE, National Renewable Energy Laboratory, the U.S. Environmental Protection Agency, the Vermont Department of Public Service, and VEPP Inc. The capital costs (using data from the U.S. Energy Information Administration and National Renewable Energy Laboratory) for each generation source are shown in Figure 12.

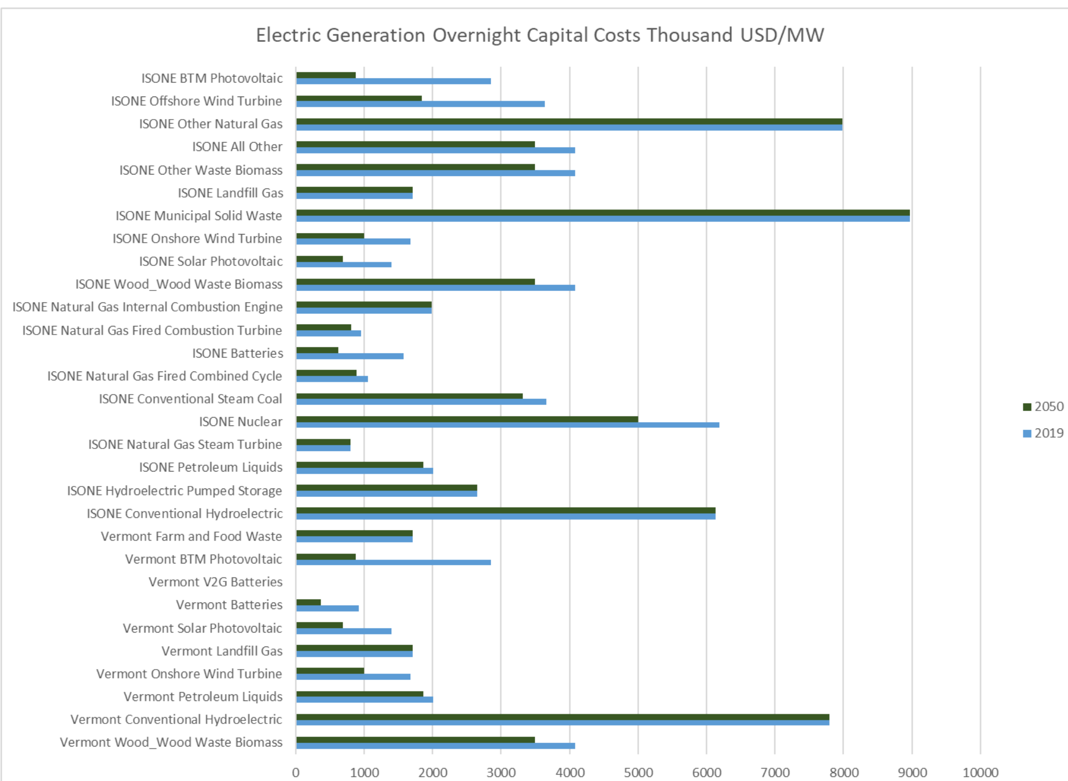


**Figure 12. Electric Generating Capital Cost Assumptions in Mitigation Scenario**

The least-cost capacity expansion and dispatch in the model is also subject to several constraints:

- Demand (and 8% energy loss from transmission) must be satisfied.
- The planning reserve margin must be maintained.
- There must be sufficient renewable energy production to meet Vermont's Tier I and Tier II RPS (but there is no representation of renewable energy credits separate from the renewable kilowatt-hours).
- The existing energy purchase contracts must be enforced and are assumed to expire on the current end date.

There are several strategies, activities, and other factors considered critical for meeting the mitigation scenario for the greater amount of electricity needed to meet Vermont's GWSA requirements:

- Ensuring that access to opportunities for the electrification of transportation and buildings to reduce emissions is equitably available to all (see Box 5, p. 36).
- Enabling Vermont to continue increasing the share of electricity generated by renewable resources, expanding beyond the current renewable energy standard level of 75% by 2032, to reach 100% renewable by 2050.
- Further market and technical research and demonstration of the potential for flexible loads (including battery and thermal storage) to be connected, coordinated, and managed to reduce system peak loads, costs, and to improve reliability and resilience (see Box 9, p. 52).

**Box 5. Ensuring Access to Clean Energy for All**

Technology changes such as strategically shifting to electrified heating and driving ultimately save the end user in the dollars spent on energy as well as the energy itself. Similarly, investing in distributed energy resources such as solar and batteries can stabilize fluctuating energy costs and ensure reliability when the power goes out. But for many Vermonters, making these investments may not be possible unless policy makers proactively address a variety of barriers, such as:

- **An inability to pay the upfront cost.** For those who simply cannot afford the investment, increased incentives are needed. For others, the solution may be to support financing products that recognize the value of the investment, using the cost savings incurred over the lifetime of the project to pay for the loan.
- **Lack of property ownership.** For those who rent, policies must be developed to address barriers for renters. This may include identifying ways to ensure that EV charging stations are available at rental properties (recognizing that multifamily properties pose particular challenges). It may also include developing products such as to-the-meter on-bill financing or requiring that rental properties be improved through mechanisms such as building energy code or rental ordinances.
- **Challenges with existing infrastructure.** Infrastructure challenges are various. Vermiculate in a home may need to be addressed prior to improving the building's envelope through air sealing and insulation. Installing heat pumps in a leaky home is inefficient and can lead to comfort issues for the occupant. Similarly, a property owner often must upgrade the electrical panel before installing technologies such as heat pumps or a Level II EV charger. These types of investments are not usually supported by entities that provide incentives for energy efficiency and strategic electrification. Policy makers must consider whether and how to modify current program designs to address these technical barriers.

Some clean energy shifts, such as the New England power grid becoming cleaner over time, will be applied to all who use electricity. Other activities, such as "going solar," weatherizing a home, installing heat pumps, or purchasing an EV, may not be available to all unless policy makers prioritize that the clean energy future be accessible to all.

### Electricity Sector Needs by 2025

As the mitigation options of increasing EVs and heat pumps are adopted, Vermont's electricity consumption will increase. The increase in electricity demand between the baseline and mitigation scenario is illustrated in Figure 13. In the mitigation scenario electricity demand grows from 5.5 TWhs in 2020 to 6.4 TWhs in 2025. In comparison, in the baseline scenario electricity demand by 2025 increases only modestly to 5.6 TWhs.

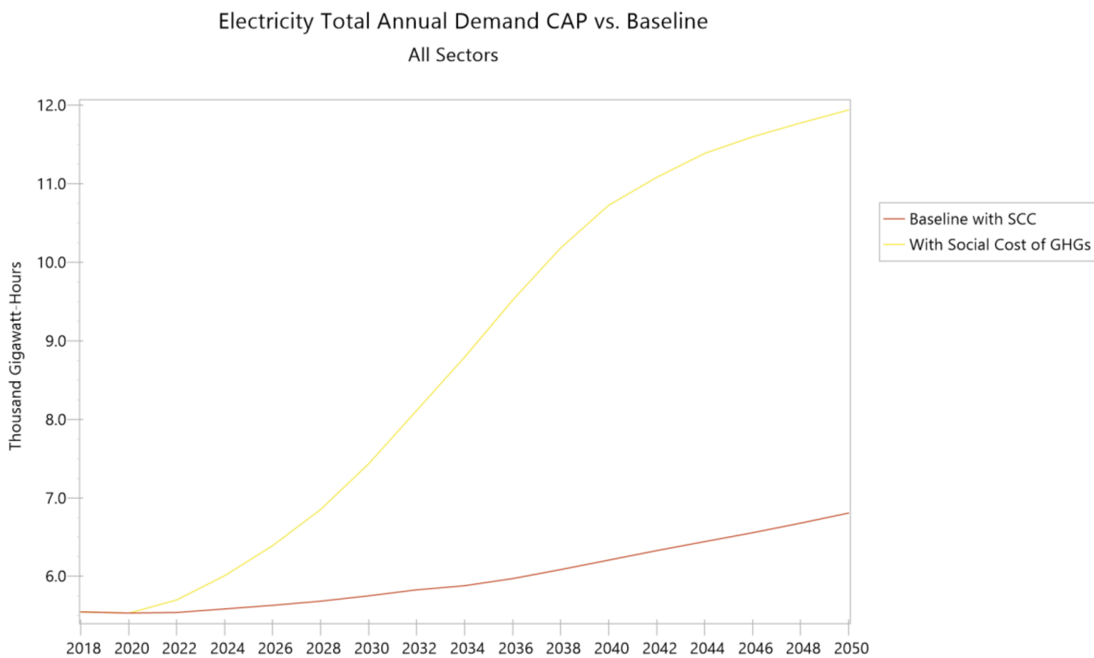


**Figure 13. Electricity Total Annual Demand (GWh) Mitigation Scenario versus Baseline Scenario**

Figure 14 shows where this increased demand is coming from. As of 2025, increases can be seen as electrification occurs in the residential and transportation sectors, with a slight increase in the commercial sector.

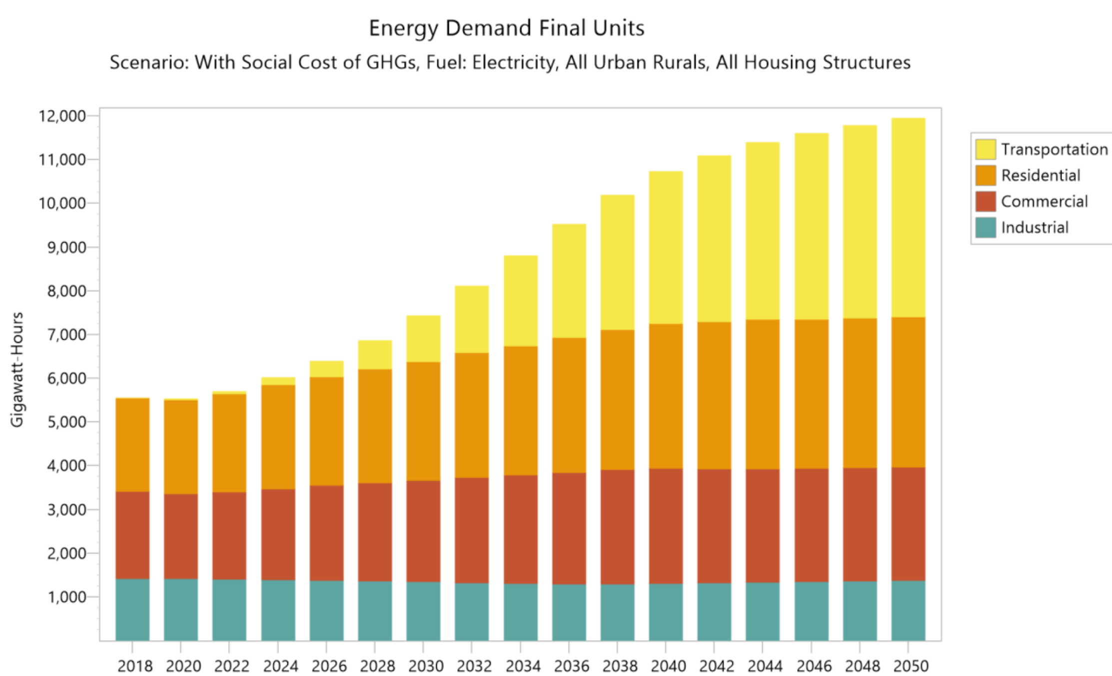


**Figure 14. Mitigation Scenario Electricity Demand (GWh) by Sector**

Based on the modeling approach, inputs, and constraints described above, the electric generating mix for the mitigation scenario is presented in Figure 15.

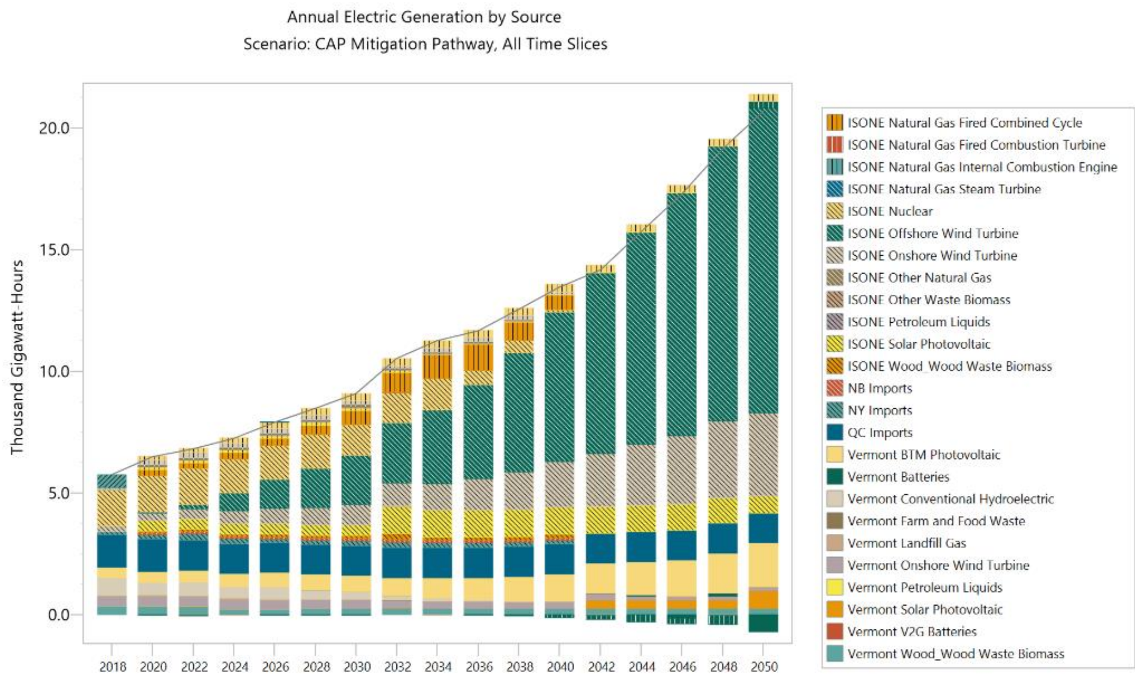


**Figure 15. Annual Electric Generation (GWh) by Source in Mitigation Scenario**

Offshore and onshore wind from outside of Vermont and a combination of in-state and out-of-state solar are the largest contributors to meeting increased electricity demand in the mitigation scenario. As mentioned above, the Project Team inputted contract terms and current policies such as Vermont's Renewable Energy Standard (RES) into LEAP, and the LEAP model then selected what is likely to be the most cost-effective resource available at the time it is needed. Therefore, the 2020 through 2025 timeframe shows decreases in biomass (Ryegate contract expiration), nuclear, and hydro, with increases in behind-the-meter solar (Vermont RES) and significant increases in regional solar and regional onshore and offshore wind.

With regards to peak, by 2025 peak demand is expected to grow by nearly 250 MWs in the mitigation scenario (as compared to 25 MWs under the baseline scenario).

As described above, the current structure of the model selects more generation to meet peak, rather than selecting other options. The opportunity for utilities to save on generation, distribution, and transmission costs through ongoing exploration and implementing flexible load management and non-wires alternatives cannot be emphasized enough.

**Electricity Sector Key Insights for 2025**

Key insights for the electricity sector include several critical needs and opportunities:

- Ensure that strategic electrification is accessible to all through education, incentives, rental policies, and the development of financing products that allow for longer-loan terms that fully capture the value in shifting to more efficient, electrified technologies.
- Examine the potential for rate designs that incentivize and optimize electricity consumption for transportation, space, and water heating.
- Carefully investigate how best to prepare for future significant load growth as the electrification of other sectors occurs, such as by researching and piloting favorable electric rates to incentivize activities aligned with chosen policy (and ensuring that all Vermonters, regardless of income, can participate and are not indirectly penalized, per the bullet above), as well as flexible demand management, assessing a 100% RES, and evaluating the costs and benefits of the location (local versus regional), type (wind, solar, batteries, hydro, biomass, or biofuels), and size.
- Continue deploying and analyzing the results of demand management tools and techniques.
- Continue reviewing current and future generation contracts and projects.
- Continue identifying future grid upgrades and non-transmission alternatives so that, when significantly more renewables, flexible load, and demand management are actively and regularly deployed, the grid can integrate these resources.

## *2030 Greenhouse Gas Emissions Reductions*

Meeting Vermont's GWSA requirement for 2030 is likely to be more difficult than meeting the 2025 requirement, as the gross reduction in GHG emissions required is nearly three times larger (3.46 MMTCO2e versus 1.26 MMTCO2e net reduction from 2018 levels). Reflecting this, the mitigation scenario overachieves emissions reductions by 2025, in the interest of being able to meet the 2030 requirements. The critical strategies, activities, and interventions for each sector remain generally the same, but the scale of activities and the impacts will have to have to be expanded greatly (such as needing more than 125,000 EVs, 120,000 total weatherized homes, and over 177,000 residential heat pumps).

Some of these changes are likely to be supported by non-Vermont technology and market evolutions. For example, the EV market will be significantly advanced by 2030 by the California and federal standards under development today, and both battery storage and coordinated controlled loads and management are expected to improve. This will be to Vermont's benefit, but also removes some level of control from the state. If the standards are weaker than anticipated or removed in the future, Vermont will have to determine ways to make up for those lost emissions reductions. This section provides details on how the mitigation scenario meets the GWSA 2030 requirements for each sector.

### Transportation

By 2030, transportation sector GHG emissions are modeled to decline by 31% in the mitigation scenario relative to 2018. This reduction is driven by greater EV adoption and modest reductions in VMT. The electrification of light-duty vehicles in particular greatly accelerates between 2025 and 2030. As shown in Figure 16, by 2030 the mitigation scenario anticipates 116,500 light-duty EVs on the road and 9,200 medium- and heavy-duty EVs.

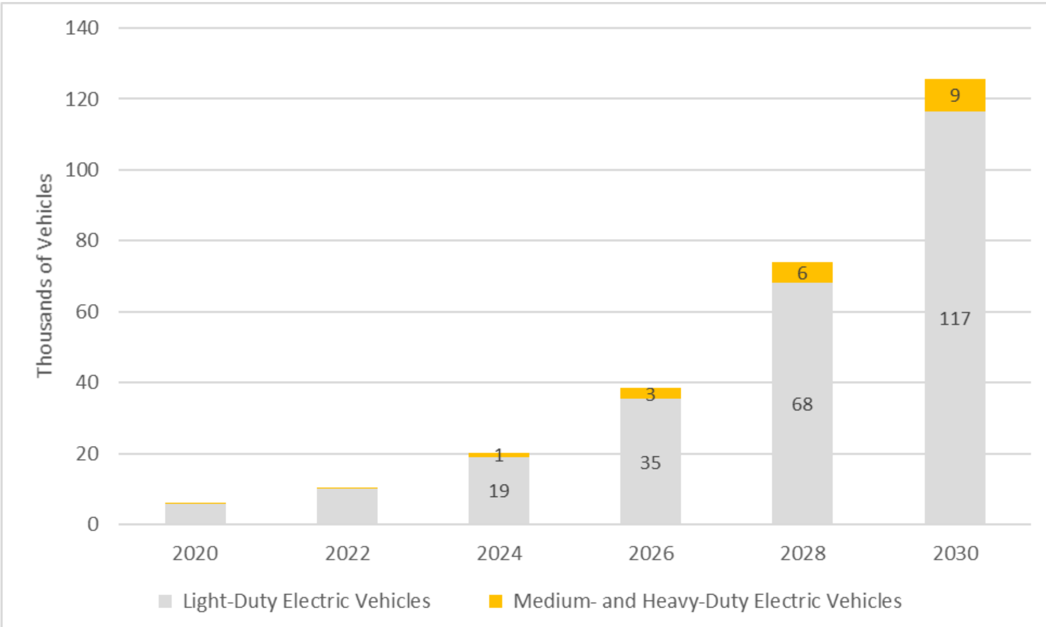


**Figure 16. Electric Vehicles on Vermont Roads by Year**

With these adoption rates, by 2030 EVs will account for 23% of all on-road VMT, as illustrated in Figure 17.

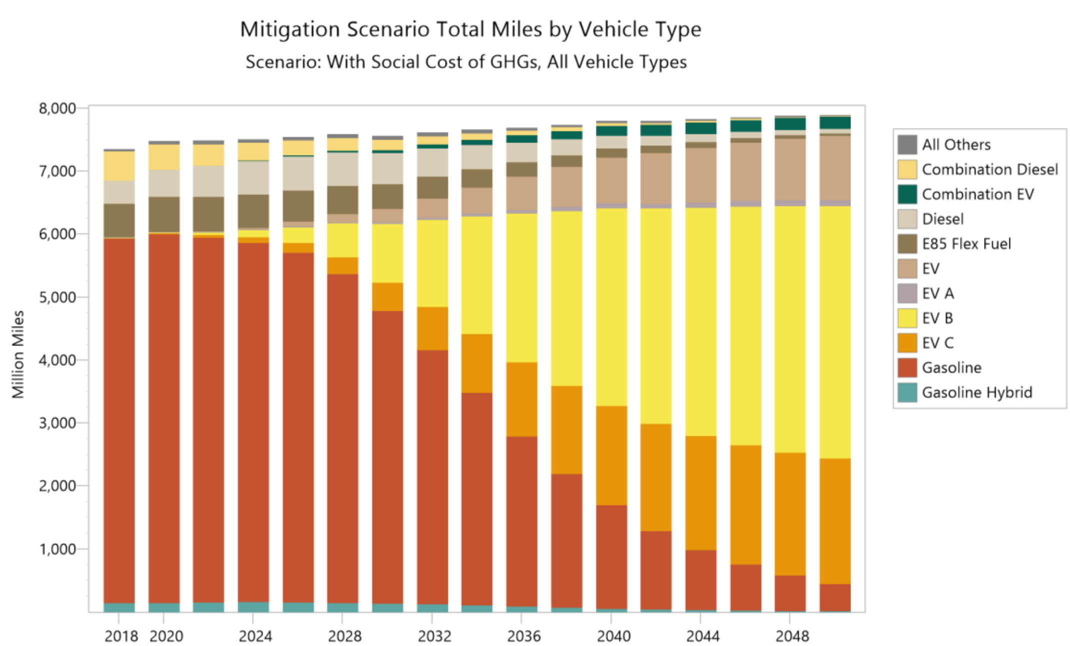


**Figure 17. Electric Vehicles Share of Total Vehicle Miles Traveled**

The cost projections in the mitigation scenario assume that by 2030 the upfront and operating costs of EVs are lower than for ICEVs in all light-duty segments. This means households and fleets save money on transportation expenses relative to today and can spend money on other goods and services. Medium-duty vehicles are not far behind light-duty vehicles in terms of cost. In the mitigation scenario, by 2030 most medium- and heavy-duty EVs reach cost parity with comparable ICEVs on a total cost of ownership basis, although some vehicle segments reach that point earlier. The exact year of cost parity will depend on vehicle-specific factors, such as daily mileage, duty cycle, battery size, and charging speed. The electrification of medium- and heavy-duty vehicles represents a monumental shift in how fleets will manage, operate, maintain, and dispose of their vehicles. To ensure success in this transition, the state of Vermont will need strategies for sustainable funding mechanisms, tariff structures, make-ready infrastructure programs, and advisory services aimed at medium- and heavy-duty vehicle fleets.

Another key consideration in 2030 is the growing market for used, light-duty EVs. Approximately two-thirds of all vehicle sales in Vermont in a given year are used vehicles.[16] Many EVs today are initially leased, which means they are sold after the lease expires, when they are two or three years old. Although not explicitly modeled in LEAP, used EVs will help low- and moderate-income households save money on transportation expenses and benefit from reduced vehicular emissions. State governments in the Northeast U.S. may compete for used EVs by providing incentives.

By 2030, the mitigation scenario also reflects increased investments in Smart Growth, Complete Streets, and transit expansion, with a 3.5% reduction in VMT compared to the baseline scenario but about a 0.5% increase relative to today. Note that LEAP is not an advanced transportation planning model and is therefore relatively unsophisticated in its modeling of VMT reductions. Changes in VMT are based on literature that isolates the link between VMT and urban densification, transit expansion, and other similar programs on VMT.[17]

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16 Energy Action Network. n.d. “Transportation Electrification in Vermont.” Slide 11. https://www.eanvt.org/featured-news/transportation-electrification-in-vermont/

17 Salon, D et al. 2012. “How do Local Actions Affect VMT? A Critical Review of the Empirical Evidence.” *Transportation Research* Part D (17) 495-508.
Ewing, R et al. 2014. “Structural Equation Models of VMT Growth in US Urbanized Areas.” *Urban Studies* Vol 51 (14) 3079-3096.

**Box 6. Advanced Clean Cars II and Advanced Clean Trucks Regulations**

The two most important regulatory drivers of the electrification of Vermont's on-road vehicles in the next decade are expected to be ACC II and ACT. Both regulations are on track for adoption in Vermont following adoption within California. ACC II requires that an increasing fraction of new vehicles deliveries in Vermont are electric - starting at 20% to 30% in 2026, hitting 49% to 70% in 2030, and ending at 100% by 2035 (based on Northeast States for Coordinated Air Use Management calculations for the maximum and minimum required sales for automakers). The exact number of EV deliveries will depend on the automakers' use of pooling and historical and environmental justice credits under the program.

Exceeding the ACC II and ACT standards could be challenging. Automakers typically have a three-to-five-year planning horizon for new vehicle models to enable setting up new supply chains and retooling of factories. This suggests that the available EV models for 2025 are being determined at the time of this writing (and it remains unclear whether automakers will have sufficient vehicles to over-comply with ACC II and ACT). Regardless of what automakers do, the state of Vermont can maximize its EV population by creating a strong ecosystem of policies and incentives that simultaneously attract automakers and infrastructure providers to Vermont and encourage an inflow of used EVs into the state.

**Transportation Sector Key Insights for 2030:**

There are several critical needs and opportunities for the electricity sector:

- Identify strategies that exceed the pace of electrification in ACC II and ACT regulations, as suggested in Box 6.
- Continue expanding charging infrastructure across Vermont in an equitable fashion, with a particular focus on multi-unit dwellings, on-street charging, and fast charge stations.
- Ensure that low- and moderate-income families have access to affordable EVs through targeted incentive programs of new and used EVs.
- Support the electrification of fleets by supporting distribution make-ready system upgrades,[18] incentivizing the upfront cost of medium- and heavy-duty vehicles,[19] providing free advisory services for fleet electrification,[20] and/or providing all-inclusive charging-as-a-service to fleets.
- Develop a thriving used EV market by working with auto dealerships and ensuring that the proper set of incentives exist to maximize EV sales.
- Create rates and incentives to promote equitable access to vehicle electrification or clean transportation services.

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18 State of New York. 2021. "EV Make-Ready Program." https://jointutilitiesofny.org/ev/make-ready

19 California HVIP. 2021. "Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project." https://californiahvip.org/

20 National Grid. 2021. "Fleet Advisory Services Program." https://www.nationalgridus.com/ev-fleet-hub/Get-Started/Fleet-Advisory-Services-Program

## Buildings

Total emissions from the building sector in the mitigation scenario are modeled to decline by 48% from 2.86 MMTCO2e in 2018 to 1.48 MMTCO2e in 2030. Roughly half the reductions by 2030 come from residential buildings, with about 30% from commercial buildings, while industrial buildings contribute about 20% of the reductions. The reductions primarily come from space heating and, as mentioned in the 2025 section on buildings, from a combination of improved shell efficiency, more efficient equipment, and cleaner fuels (such as electricity as compared to fossil combustion).

Figure 18 illustrates that residential building emissions in the mitigation scenario decline by 52% from 2018 levels, mostly from space and water heating measures.

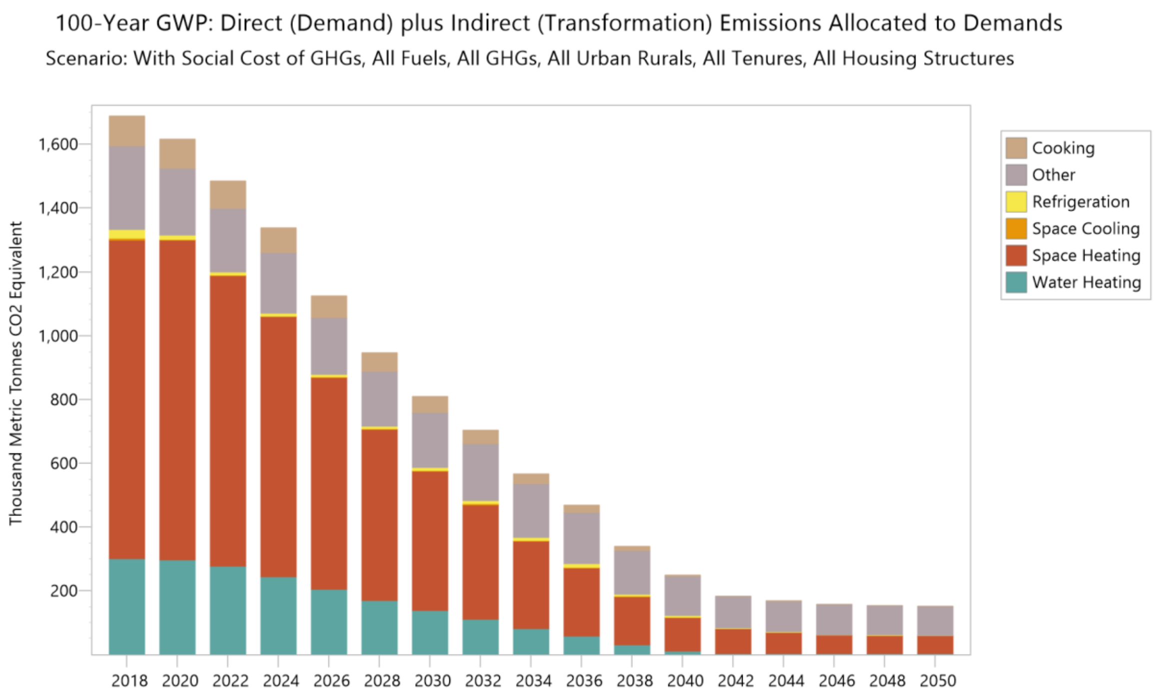


**Figure 18. Mitigation Scenario Decline in Residential Building Emissions by End Use**

To meet the 2030 GWSA requirements, the mitigation scenario requires roughly a doubling of the number of heat pumps, heat pump water heaters, and home weatherization retrofits, as well as a near doubling of biofuel fuel sales relative to 2025, as illustrated in Figure 19.[21]

Though not shown in the graph, various other strategies would also provide savings by 2030, including additional renewable district heat serving primarily commercial customers, some industrial electrification, and a few additional strategies.

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[21] The baseline scenario assumes almost no growth in heat pump water heaters. This most likely underestimates their growth, as market awareness and acceptance have started to increase.

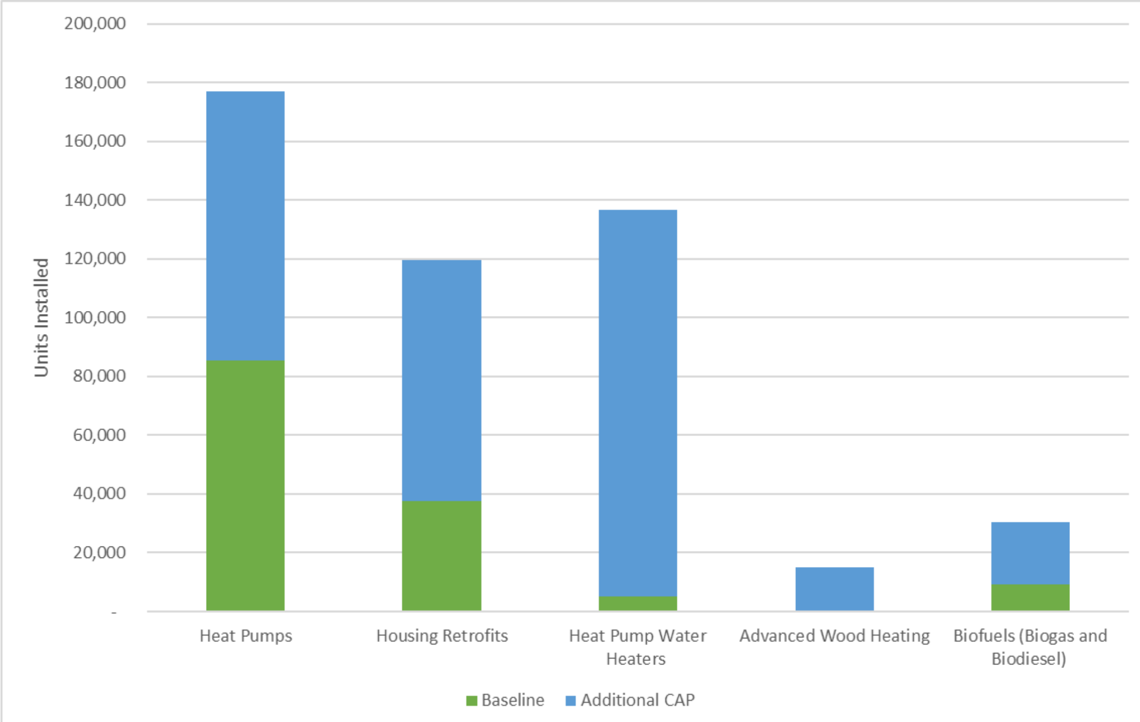


**Figure 19. Residential Building Measures Installed by 2030**

Advanced wood heating includes high-efficiency pellet stoves and high-efficiency wood stoves. Biofuels include biogas and biodiesel (including B100 biodiesel). Advanced wood heating and biofuels reflect the number of households, rather than the number of units installed.

The total number of weatherization units completed by 2030 is 120,000 or approximately 90,000 more than Vermont has accomplished to date. This is consistent with the objectives of both the Weatherization at Scale initiative and the statewide multifamily rental property efficiency standard compliance deadline of 2030. See Box 7 for more details about the trajectory and number of weatherization projects in the Weatherization at Scale initiative.

**Box 7. Weatherization at Scale Trajectory**

The Weatherization at Scale Working Group has been pursuing funding, financing, and programmatic efforts toward a target of 120,000 total homes weatherized by 2030. This initiative would be comprised of 90,000 new weatherization projects on top of the 30,000 homes weatherized to date in Vermont. It is proposed that the primary focus of this effort be directed toward low- and moderate-income homeowners and renters, who can benefit most from the energy cost savings and additional health and safety benefits that weatherization provides.

Figure 20 shows a trajectory of the cumulative total weatherization jobs required to achieve 120,000 homes weatherized by 2030, starting with the 30,000 completed to date. Note that while the pace of increase illustrated by the trajectory below is slower than the mitigation scenario, which reaches a cumulative total of 69,000 projects complete by 2025, both achieve 120,000 ahead of 2030.

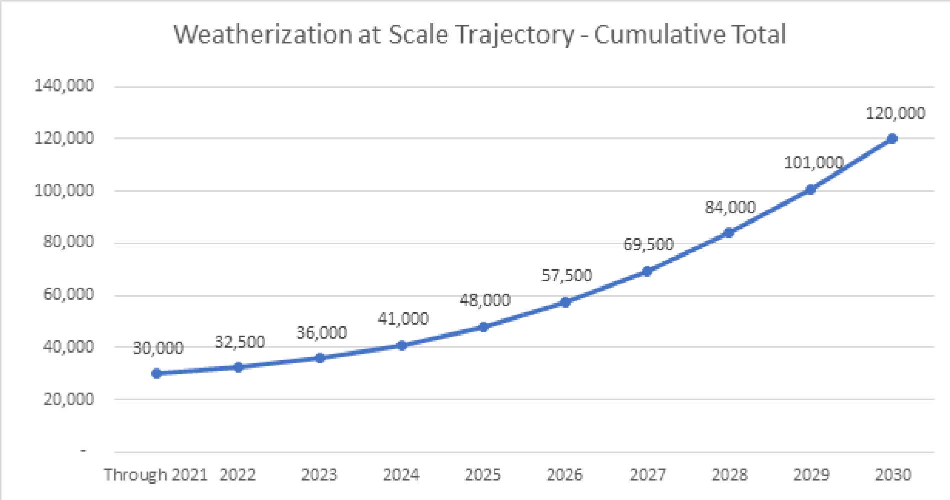


**Figure 20. Cumulative Weatherization Projects 2022 through 2030**

As shown in Figure 21, achieving 120,000 cumulative weatherization projects by 2030 will require a significant annual increase over today's approximately 2,000 annual weatherization jobs, reaching 25% to 43% through 2027 as the industry ramps up, followed by year-over-year project completion growth rates of 21% and down to 12% by 2030. However, the project completion trajectory will still need to continue to grow beyond 2030 until 2050, when 243,500 homes will need to have been weatherized, almost three-quarters of Vermont's housing units, to meet the GWSA targets. The Weatherization at Scale Working Group acknowledges that achieving the goal of 90,000 additional homes weatherized is ambitious, but it can and likely must be accomplished as an important component of meeting the GWSA goals for both reducing thermal energy use and for enabling clean heat pumps to operate more effectively in tight buildings.

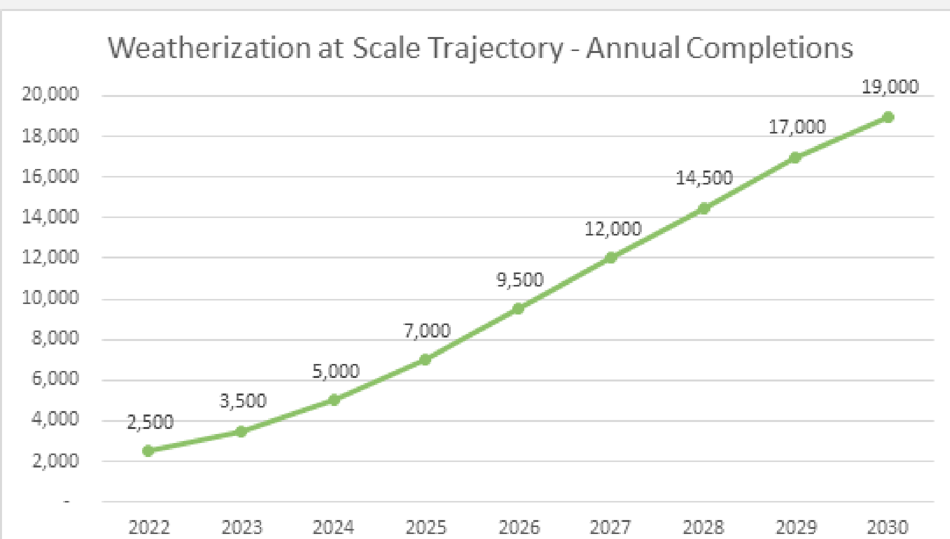


**Figure 21. Annual Weatherization Projects 2022 through 2030**

Workforce and supply chain issues are real and will need focused attention to enlist new workers and businesses into the weatherization industry and to ensure that sufficient insulation and air sealing equipment and supplies are available. With a focus on the low- and moderate-income community, the Vermont Office of Economic Opportunity and their Weatherization Assistance program providers will likely carry a significant share of this initiative. They currently deliver about half the state's annual weatherization jobs and would likely be asked to carry at least this share of new projects going forward. The Weatherization Assistance program providers are trusted entities within the low- and moderate-income community and have a proven record of quality and effective weatherization project delivery. However, like much of the construction industry, they are currently struggling to find workers.

Securing workers and businesses to meet this volume of activity is going to require innovation, fresh thinking, increased funding, and hard work. To lure more workers and entice construction businesses to get into the weatherization business, there needs to be dedicated funding streams for grants and incentives and a clear long-term commitment to the weatherization goals. Construction or other businesses are not going to enter this line of services without some assurances that funding, financing, and marketing will be provided to drive consumer demand and interest for years to come. With this significant commitment in place, we will likely see many of the larger construction and contracting firms diversify into the weatherization space. Providing them with the ability to offer higher wages to their workers, along with the recognition that weatherization can provide a climate-friendly career path for their employees, may create more businesses.

Other creative means of enlisting workers and businesses should also be considered including, but certainly not limited to, recruiting immigrants, developing automation and IT solutions (including robots, drones, and remote imaging), and other approaches.

By 2030 heat pumps remain the most important strategy for the residential sector, contributing 50% of total emissions reductions. However, other strategies will also contribute significant reductions, most notably biofuels (primarily biodiesel, but some biogas as well), along with weatherization. Weatherization will serve to reduce the costs of heat pumps by reducing the amount of heat needed and related electricity costs. Second, because the Weatherization at Scale initiative is targeted to low- and moderate-income households, it is addressing an important equity concern by lowering heating bills—regardless of whether the heat is supplied by electric heat pumps or by a combination of biofuels and fossil fuels.

There will be numerous challenges to meeting the level of building performance upgrades in the mitigation scenario by 2030, including the pace and scale for heat pumps and the pace for delivery of weatherization. Another important element for consumers to make modifications to their homes and businesses will be financing to help make the initial costs of upgrades affordable, and to permit payment over time as the savings from reduced energy consumption are realized. Box 8 describes the Weatherization Repayment Assistance program, an example financing strategy for residential customers.

**Box 8. On-Bill Repayment (or Weatherization Repayment Assistance Program)**

Through the collaboration led by Vermont Housing Finance Agency, several Vermont utilities expect to file a pilot on-bill payback tariff in early 2022. The pilot would allow customers to "finance" weatherization and clean heating systems directly on their monthly energy bill, which greatly simplifies payback for the improvements and increases customer uptake. Through this to-the-meter pilot, the obligation to pay back the home modernization retrofits would stay with the electric or natural gas meter and would not follow the owner or renter if they move. Customer heating costs would decrease from pre-weatherization levels due to the energy savings. All fuels (including oil and propane) could be financed as part of the electric bill. At the completion of the pilot, policymakers will be asked to consider increased funding to make the program a self-supporting revolving fund.

By 2030 the combined emissions from commercial and industrial buildings are projected to decline by 45%, from 1.38 MMTCO2e in 2018 to 0.76 MMTCO2e through implementation of the strategies, policies, and actions discussed above. As illustrated in Figure 22, most of these reductions are related to commercial space heating. As discussed earlier, a Clean Heat Performance Standard will allow for a variety of actions to contribute to meeting these levels of reductions.

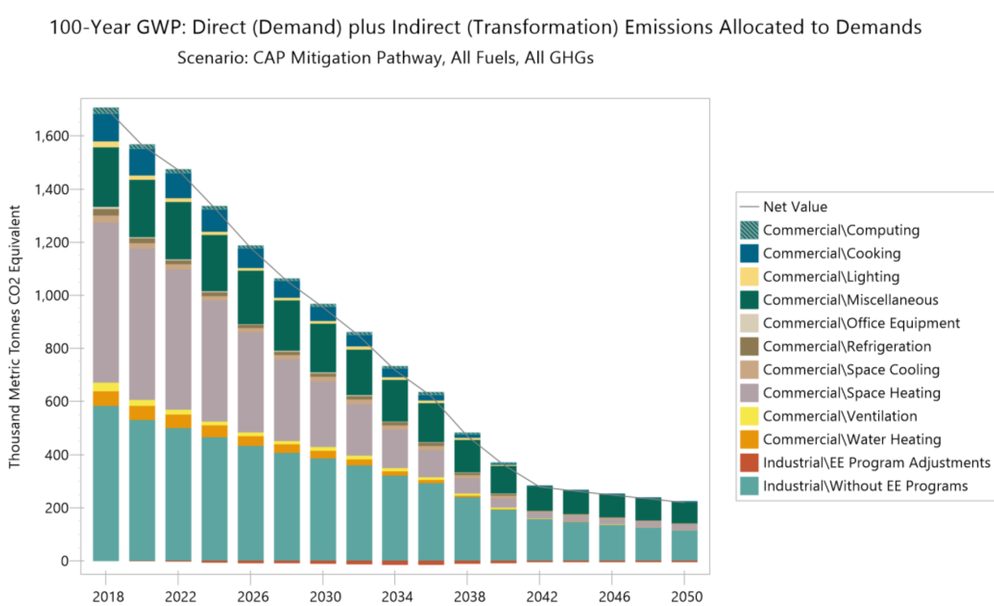


**Figure 22. Commercial and Industrial Building Energy Emissions in the Mitigation Scenario**

**Building Sector Key Insights for 2030**

Meeting the 2030 reduction goals will require sustained policy signals and funding support. Key insights for the building sector for 2030 include:

- Require net zero ready new construction through the energy codes,
- Weatherize existing buildings and modernize the way buildings are heated and cooled.
    - Heat pumps provide the greatest contribution
    - Delivery of biofuels resulting from the Clean Heat Standard also has a significant role.
    - The state will need to have weatherized 120,000 low- and moderate-income Vermont housing units, which will provide energy reductions, health, and safety benefits, and pave the way for more effective heat pump installations.
    - Heat-pump water heaters and electric induction cooking contribute to the reductions in the CAP mitigation scenario as well.
- To aid in paying for this modernization, widely available and easily accessible financing solutions will need to be available.
- Adding all of the electric demand to the grid will require smart controls and flexible load management.

## Non-Energy

**Emissions Reductions from Non-Energy Sector in 2030**

In the mitigation scenario, emissions from the non-energy sector are reduced significantly, by 20% between 2020 and 2030, or 248.5 TMTCO2e. Between 2025 and 2030, emissions are reduced by 10%, or 111.4 TMTCO2e. These levels of reduction require a significant ramp-up in emissions reductions activities from this sector. Total emissions from the non-energy sector are 1,004.9 TMTCO2e in 2030. In the 2025 to 2030 period, most non-energy emissions reductions (61%) come from the industrial processes, while 36% come from agriculture and 3% come from waste. Figure 23 illustrates the emissions from the non-energy sector in 2020 and 2030.

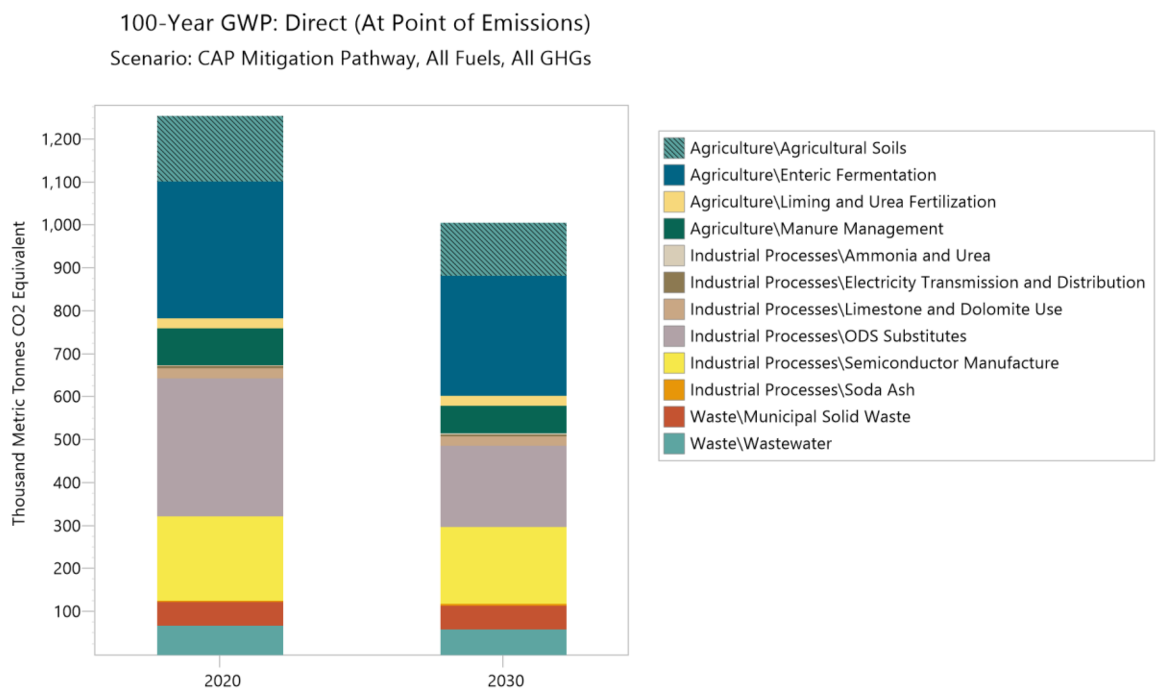


**Figure 23. Emissions Reductions from Non-Energy Sector in 2020 and 2030 in Current LEAP Model**

Industrial process non-energy emissions are reduced from 463.5 TMTCO2e in 2025 to 400.0 TMTCO2e in 2030, or 14%. Most of these come from ODS substitutes, which reduce emissions from 243.0 TMTCO2e in 2025 to 188.8 TMTCO2e in 2030.

Emissions from agriculture are reduced from 533.5 TMTCO2e in 2025 to 489.3 TMTCO2e in 2030, or 8%. These emissions reductions come from proportional reductions in three agriculture categories: enteric fermentation (reduction of 20.1 TMTCO2e), manure management (reduction of 10.6 TMTCO2e), and agricultural soils (reduction of 13.6 TMTCO2e). As with the 2025 emissions, there is a slight decrease in emissions from waste, all of which comes from reductions in emissions from wastewater.

### Non-Energy Key Insights for 2030

Reductions in 2030 rely on a continuation of policies and actions that achieved emissions reductions in 2025, with increased emissions reductions from increased adoption of measures and increased implementation of policies and programs.

The reduction in emissions from ODS substitutes aligns with Vermont's Hydrofluorocarbons Rule, which mandates a phase down of the use of HFCs to meet the goal of a 40% reduction from the 2013 level of use by 2030.[22] This level of reduction also aligns with the Short-Lived Climate Pollutant reduction

[22] State of Vermont Agency of Natural Resources. December 15, 2020. *Chapter 38: Rules Regarding Phase-Down of the Use of Hydrofluorocarbons.* https://dec.vermont.gov/sites/dec/files/aqc/laws-regs/documents/Vermont_HFC_Rule_Adopted_CLEAN.pdf

strategy from California, which requires a reduction of HFCs of 40% by 2030.[23] Additionally, the recently announced federal HFC Allocation Rule directs the U.S. Environmental Protection Agency to phase down HFC production and consumption by 85% over the next 15 years.[24] These two policies can drive ODS substitute emissions reductions by 2030. Efficiency Vermont's refrigerant management initiative, as discussed in the 2025 non-energy section, can also help to achieve these emissions reductions (including reducing leaks, replacing high GWP refrigerants with low GWP refrigerants, and other benefits). Long-term refrigerant management strategies are discussed in the *2050 Greenhouse Gas Emissions Reductions* section.

Emissions reductions from agriculture includes a 30% reduction in emissions from manure management by 2030. This could come from increased adoption and availability of manure management technology like waste digesters or from programs that help farmers to adopt these measures. Longer-term strategies for emissions reductions from agriculture are discussed in the *2050 Greenhouse Gas Emissions Reductions* section.

## Electric

**Electricity Growth by 2030**

In the mitigation scenario, during the five years from 2025 to 2030, electricity consumption is projected to grow more rapidly than during the five years from 2020 to 2025, increasing from 6.4 TWhs in 2025 to 7.9 TWhs in 2030. As Figure 24 shows, while there is ongoing strategic electrification occurring in the residential sector, and a slight pickup in the commercial sector, the area of greatest increase is within the transportation sector, as manufacturing ramps up, EVs come down in price, technology improves, and charging stations become more ubiquitous—all of which result in increased customer demand and market penetration.

[23] California Air Resources Board. March 2017. *Short-Lived Climate Pollutant Reduction Strategy*. https://ww2.arb.ca.gov/sites/default/files/2020-07/final_SLCP_strategy.pdf

[24] U.S. Environmental Protection Agency. Last updated November 8, 2021. "Final Rule - Phasedown of Hydrofluorocarbons: Establishing the Allowance Allocation and Trading Program under the AIM Act." https://www.epa.gov/climate-hfcs-reduction/final-rule-phasedown-hydrofluorocarbons-establishing-allowance-allocation

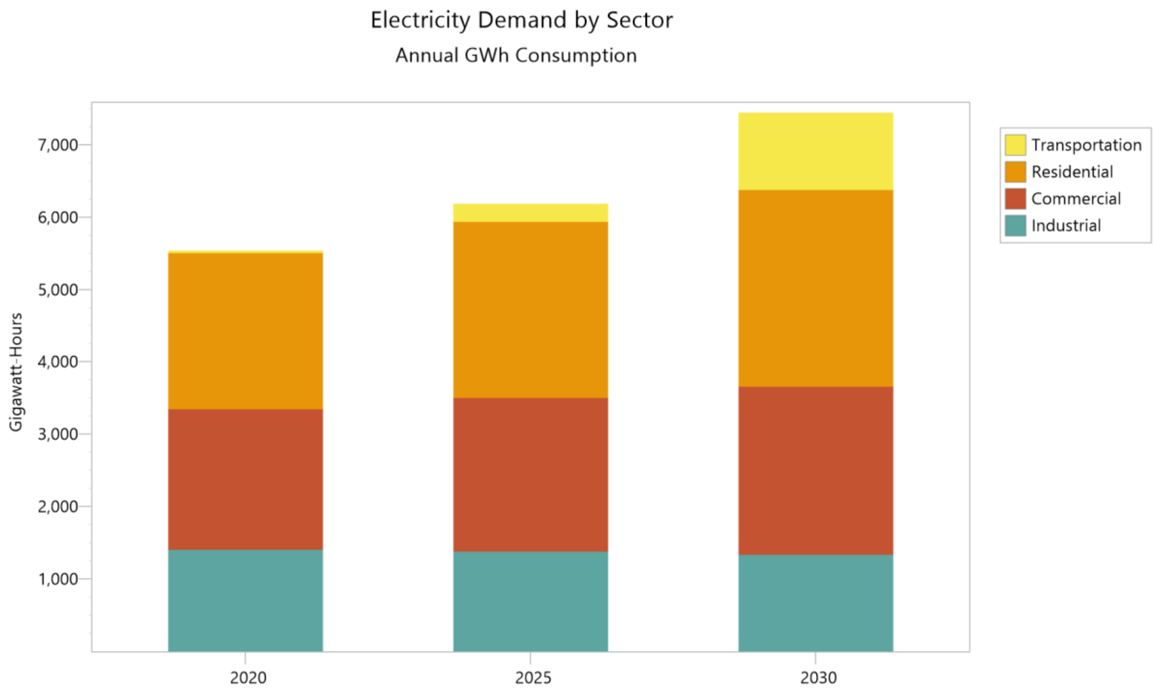


**Figure 24. Mitigation Scenario Electricity Demand (GWh) by Sector, 2020 through 2030**

Peak demand continues to increase, as shown in Table 7, with the mitigation scenario resulting in 1.76 GWs compared to baseline of 1.25 GWs. This is expected as electric demand increases, but it is important to note that a limited amount of flexible demand management is incorporated into the mitigation scenario. The flatline of peak in the baseline scenario (from 1.22 GWs in 2025 to 1.25 GWs in 2030) illustrates that, absent strategic electrification, little growth would be occurring. This sheds light on the degree to which Vermont's efforts in efficiency and demand management are important complements to strategic electrification and increasing investment in renewable generation.

**Table 7. Peak Electric Demand (MW) Mitigation Scenario and Baseline**

| Scenario | 2020 | 2025 | 2030 |
|---|---|---|---|
| Baseline Scenario | 1,193 | 1,208 | 1,240 |
| Mitigation Scenario | 1,230 | 1,374 | 1,653 |

In the mitigation scenario, by 2030 total generation of 9,100 GWh is higher than demand. This reflects the requirement to meet electricity demand in all time periods, and the increasing share of solar and wind. The mitigation scenario reflects adherence to the RES and other Vermont policies, with current contracts expiring according to current agreements and using current technology costs. The generating mix in each time period reflects lowest projected price electricity to meet demand. As shown in Figure 25, the greatest shifts from 2025 to 2030 are increases in regional onshore and offshore wind (1,000 GWhs) and an increase of 300 GWhs in regional combined cycle gas, which is used to meet system needs in times of low renewable outputs.

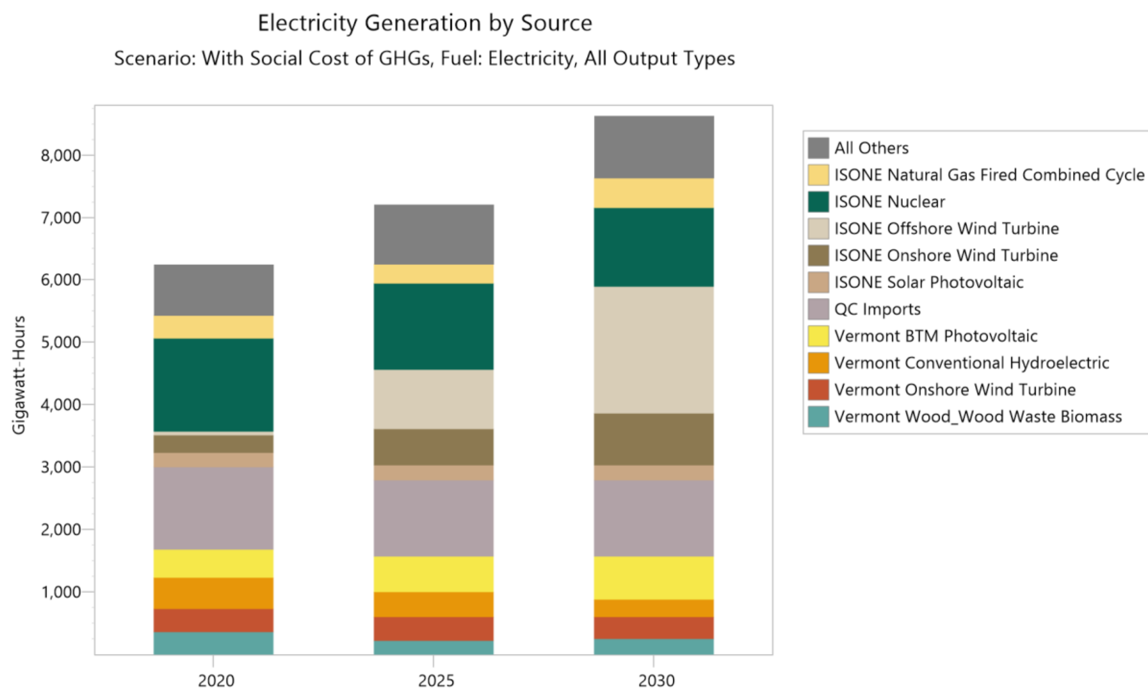


**Figure 25. Annual Electric Generation (GWh) by Source in Mitigation Scenario**

Figure 24 and Figure 25 illustrate how the mitigation scenario includes excess generation to meet peak, highlighting the opportunity for more sophisticated load management and coordination. The opportunity for utilities to save on generation, distribution, and transmission costs through ongoing exploration and implementation of flexible load management and non-wires alternatives increases as the pace of electrification and renewable generation accelerates. Box 9 outlines the role of flexible and coordination demand management in reducing overall electric system needs.

**Box 9. The Role of Flexible and Coordinated Load Management (known as Demand Management)**

The concept and practice of demand management in the electricity sector has been in use for several decades. Historically, it has typically involved electric utilities calling upon large industrial electricity users (such as semiconductor manufacturers) to reduce electricity consumption when electricity prices reach a certain price or when reliability is of concern. Some Vermont homeowners may be familiar with utility programs offering a financial incentive to allow the utility to lower the temperature setting on an electric hot water heater during certain peak demand times. Generally, however, the concept of demand management is unfamiliar for people who have only paid residential electricity bills.

The original concept of demand response, or changing the “electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time” or providing “incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized,” is now expanding into a far broader concept of flexible and coordinated load management involving more technologies (EVs, combined heat and power units, electric water heaters, heat pumps, battery storage) and additional end users (industry, small and large commercial and residential customers). Looking ahead, options such as bidirectional charging from EVs can offer a new range of potential for coordinated load management. Having a large fleet of EVs that can effectively function as on-demand battery storage during peak events could be a game changer for flexible load management and cost-effective growth in average (versus peak) load.

The concept of flexible and coordinated load management is also far more dynamic than historical demand response programs, which focused solely on reducing electricity at a certain time. Imagine an orchestra conductor calling upon different instruments at different times, for different lengths of time and different reasons. Some Vermont utilities, often working with third-party aggregators, now have this role; they identify when solar and wind is producing and therefore when surplus electricity may be available for storage, then pull from that reserve when demand increases. Programs such as pilot rate design offerings that direct end users as to the best time to charge EVs are already showing the potential that flexible and coordinated load management can provide in aligning supply with demand. Vermont Electric Power Company's most recent *Long Range Transmission Plan* also highlights how flexible and coordinated load management can contain future needs and costs for transmission upgrades.

Sources: Aghaei, Jamshid, and Mohammad-Iman Alizadeh. February 2013. "Demand Response in Smart Electricity Grids Equipped with Renewable Energy Sources: A Review". *Renewable and Sustainable Energy Reviews*, Vol. 18, 64–72.
https://www.sciencedirect.com/science/article/abs/pii/S1364032112005205
Vermont Electric Power Company. n.d. *2021 Vermont Long Range Transmission Plan.*
https://www.velco.com/assets/documents/2021%20VLRTP%20to%20PUC_FINAL.pdf

**Electricity Sector Key Insights for 2030**

The same key principles discussed in the 2025 *Electric* section above hold for the 2030 period, with the caveat that by 2030, the work of investigating and reviewing various options must shift to implementing and deploying those options while continuing to investigate and provide pilot initiatives. By 2030, as compared to 2025, the approach to ensuring that the power sector can handle the increased demand must be iterative, reflecting a "plan-do-check-act" methodology. Ongoing research must continue as technology advances and markets shift (such as when the costs for various technologies decrease), but actions must also be implemented (such as increased demand management activities), then revised as the results from these activities are observed. There are several overarching key activities that must take place:

- Ensure that strategic electrification is accessible to all through education, incentives, rental policies, and the development of financing products that allow for longer loan terms that fully capture the value in shifting to more efficient, electrified technologies.
- Carefully investigate how best to prepare for future significant load growth as the electrification of other sectors occurs (such as by researching and piloting favorable electric rates to incentivize activities aligned with the chosen policy).
- Assess a 100% RES, evaluating the costs and benefits of the location (in state versus regional), type (wind, solar, batteries, hydro, biomass, biofuels), and size.

- Continue to deploy and analyze the results of demand management tools and techniques.
- Continue to review current and future generation contracts and projects.
- Continue to proactively identify potential future grid upgrades and non-transmission alternatives.

## *2050 Greenhouse Gas Emissions Reductions*

By 2050 GHG emissions in the mitigation scenario are more than 81% lower than they were 2018, decreasing from 8.2 MMTCO2e to 1.54 $MMTCO_2e$ (see Figure 26). Meeting the GWSA requirement for reductions of gross emissions requires reductions from every sector and a steep pace of change, particularly in the early years up to 2030.

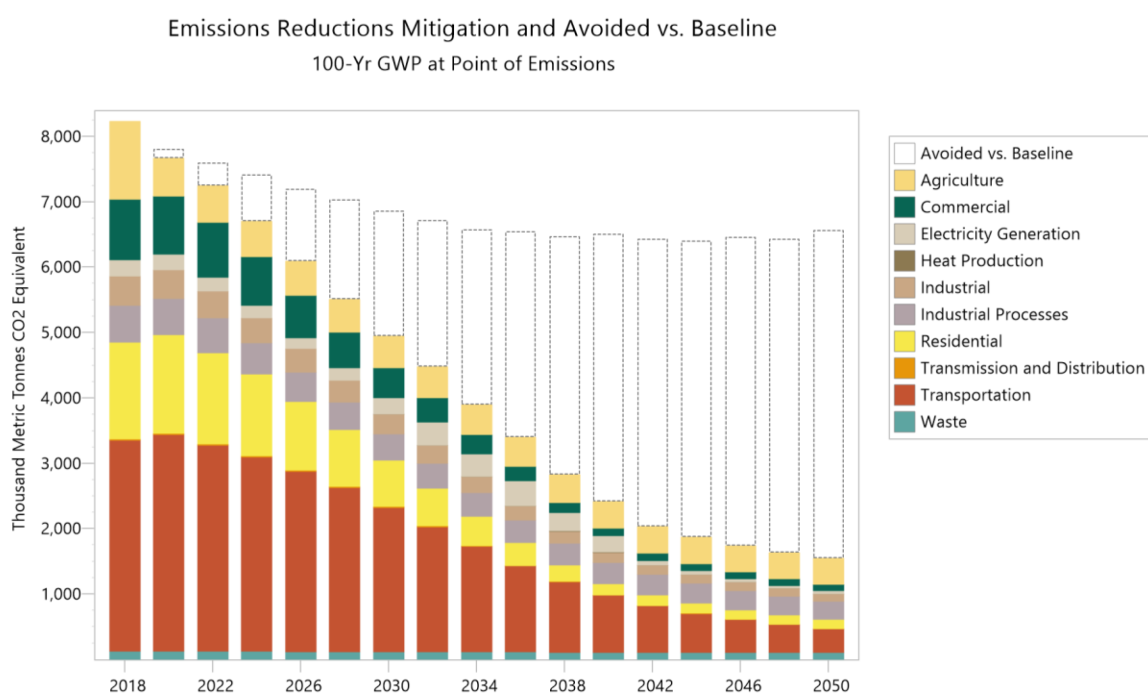


**Figure 26. Mitigation Scenario Emissions and Avoided versus Baseline**

The GWSA requirements for 2050 include Vermont not only reducing gross emissions by the amount shown in Figure 26, but also that the state has net-zero total emissions, indicating that a minimum of 1.7 MMTCO2e of sequestration be maintained. Sequestration and achievement of the net-zero requirement is discussed further in the 2050 *Non-Energy* section below.

## Transportation

By 2050, transportation sector GHG emissions are modeled to decline by 88% in the mitigation scenario relative to today. This reduction is primarily achieved through the proliferation of EVs, increases in vehicle efficiency, and the use of cleaner fuels. The application of biofuels and reductions in VMT also contribute to the reduction, but to a lesser extent. By 2050, there are about 643,500 light-, medium-, and heavy-duty EVs on the road in Vermont in the mitigation scenario, up from 125,700 in 2030. EVs will need to make up approximately 89% of the total vehicle stock (as shown in Figure 27) and be responsible for about 93% of VMT. In the mitigation scenario, light-duty ICEV sales phase out by 2035, when 100% of new vehicle sales are electric.

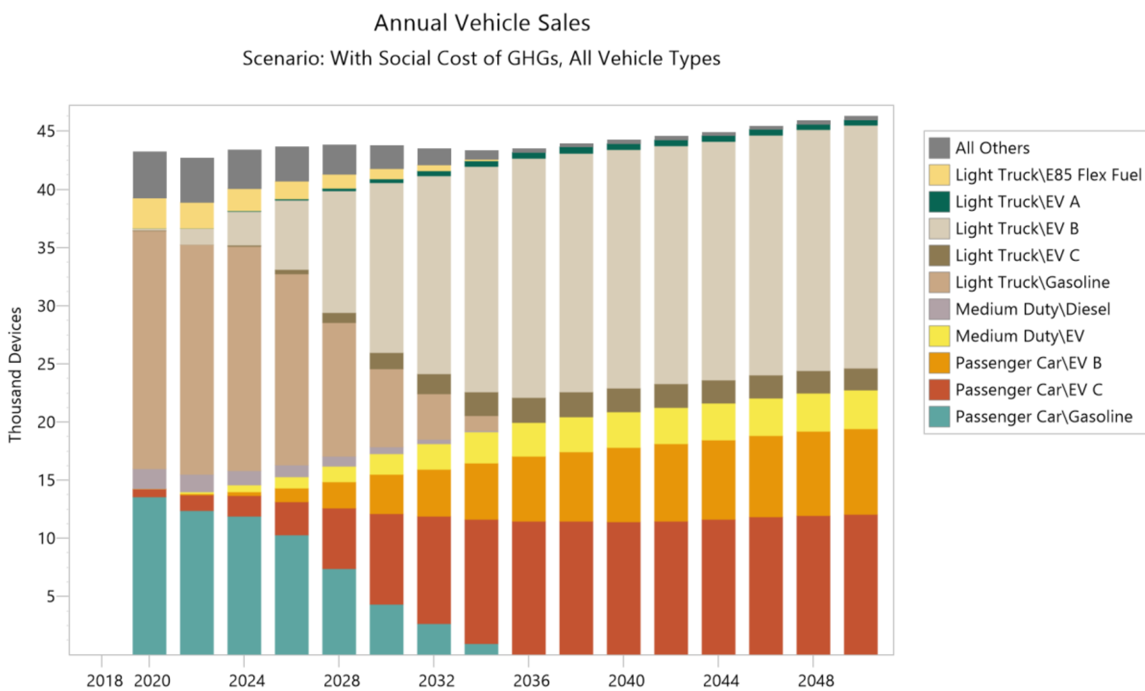


**Figure 27. Annual Vehicle Sales by Vehicle Type, Mitigation Scenario**

By 2050, there will need to be about 62,000 medium- and heavy-duty EVs on the road, making up 82% of the entire medium- and heavy-duty vehicle stock. This increase from 2030 is largely due to falling costs in this vehicle class. For example, in 2050, the upfront cost of a medium-duty battery EV is projected to be 6% less expensive than its diesel counterpart. This is compared to a 164% premium in 2021. As shown in Figure 28, the upfront cost premium of a medium-duty battery EVs is expected to decrease sharply from 2021 to 2030, then gradually decrease through 2050.

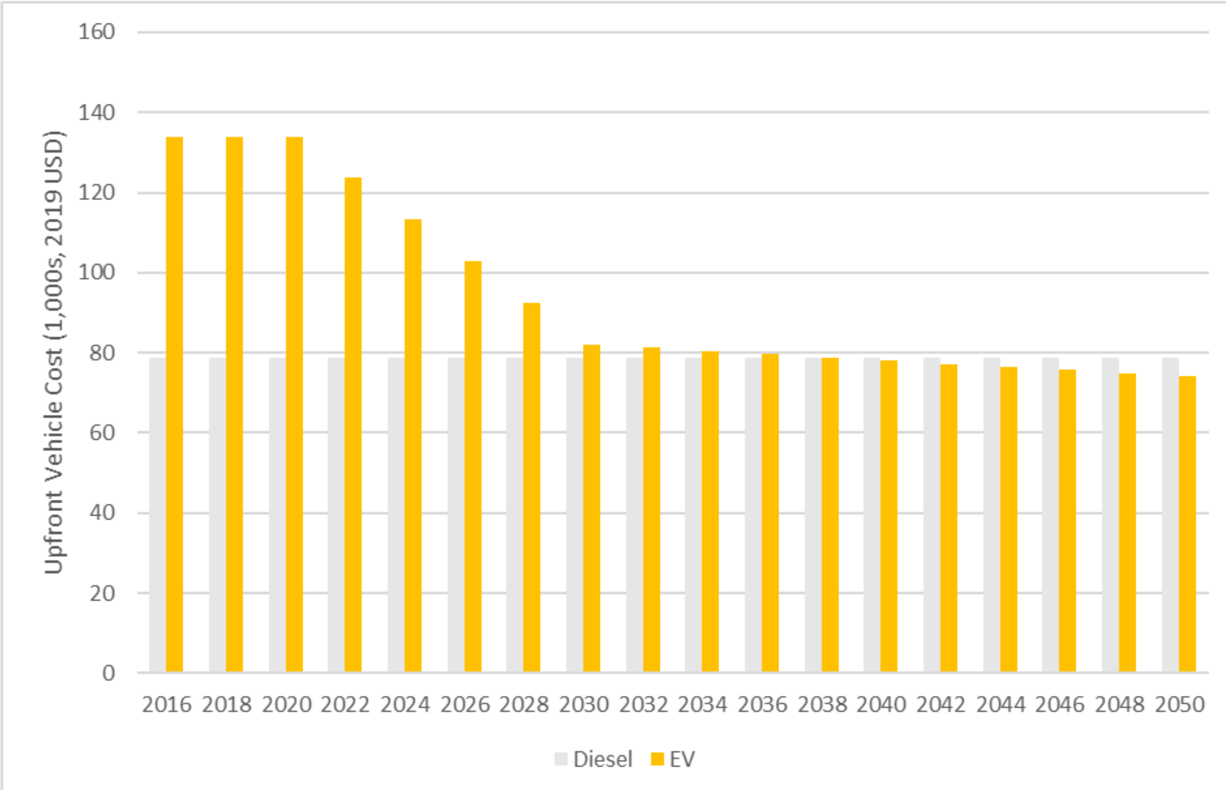


**Figure 28. Upfront Vehicle Cost Assumption in LEAP for Medium-Duty Vehicle Segment**

Reducing VMT in Vermont is another important component of the transportation sector's GHG emissions reduction strategy- in the mitigation scenario. As shown in Figure 29, the mitigation scenario includes initiatives and investments that steadily decrease VMTs in comparison to the baseline, resulting in an 8% reduction in VMT in the mitigation scenario compared to the baseline scenario by 2050.

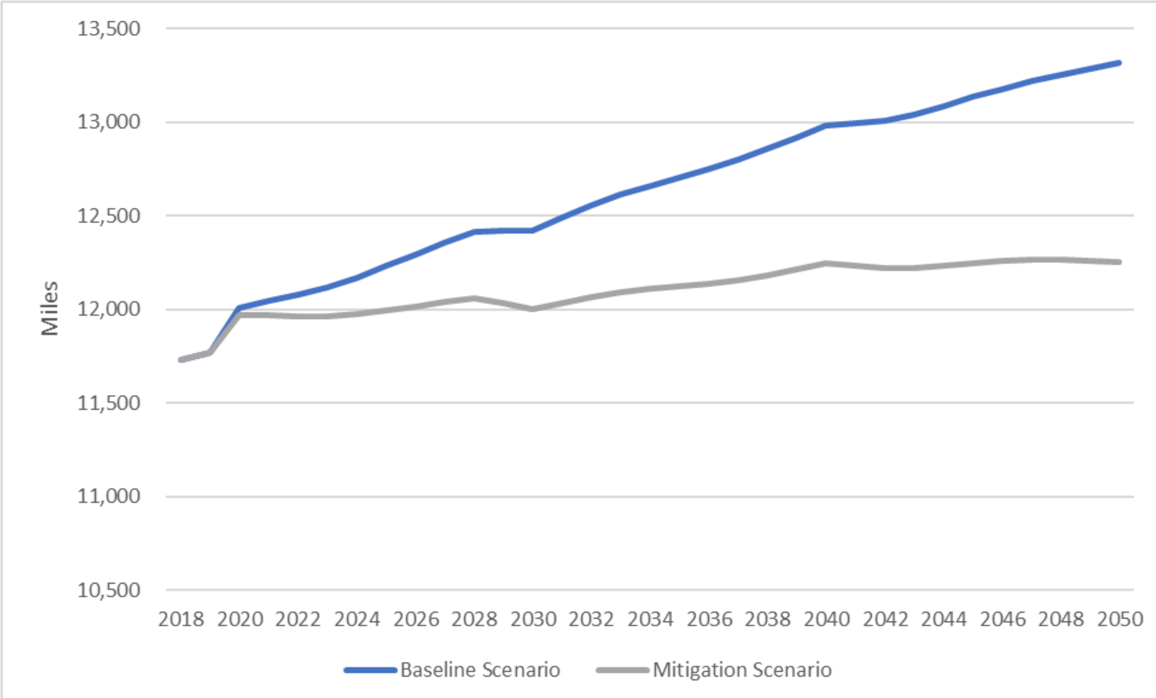


**Figure 29. Vehicle Miles Traveled per Capita in Baseline and Mitigation Scenarios**

To achieve this level of reduction, VMT policies in Vermont must reduce the need to travel, shift to more VMT-efficient modes of travel, and/or reduce trip lengths. Teleworking and other policies that use technology to replace physical travel are examples of strategies that reduce the need to travel. Better transit services and higher parking costs are examples of strategies designed to shift the mode of travel to more VMT-efficient modes. Mixed-use development and other land development policies typical of Smart Growth are examples of strategies designed to shorten trip lengths. The most effective VMT management policies address all three aspects of VMT: mode of travel, trip length, and forgone trips.

Equity considerations must be embedded in all VMT reduction policies to achieve the aims stated by the CSM Subcommittee. The income raised from strategies such as higher parking costs or VMT-based fees can be used to address equity impacts and other agency goals. A wisely implemented and balanced Smart Growth strategy can avoid gentrification and should be able to promote social equity and public health at the same times as it reduces VMT per capita. Monitoring of the design, implementation, and operation of the Complete Streets should ensure a balanced and equitable result that avoids or otherwise compensates for potential gentrification effects.

### Transportation Sector Key Insights for 2050

The CAP mitigation scenario implies dramatic changes in the transportation sector compared to today. To achieve the reductions in the scenario, on-road vehicles will need to be fueled with nearly 100% electricity or hydrogen. Public and workplace charging stations will need to be widely available. Non-road vehicles like lawn mowers, leaf blowers, forklifts, and boats will need to be electric. The availability of transit, including urban and intercity buses, passenger rail, and micro transit, will need to be roughly double today. Active transportation will need to flourish as urban densities increase and travel demand management programs take hold.

With these changes, the cost of transportation for households and businesses is expected to decline. These savings can be reinvested into other priorities such as leisure, consumer goods, and personal savings, potentially bolstering other parts of the economy. That said, it is anticipated that some businesses could be negatively impacted, such as gas station owners and vehicle maintenance workers.

Yet, several key uncertainties remain that could impact this description of 2050, such as the penetration of shared and autonomous vehicles and the level of managed charging. Recent research finds that a scenario in which all light-duty vehicles in the U.S. were shared, autonomous, electric, and had a centrally managed charging provider would require only 9% of today's vehicle population and only 0.2 chargers per vehicle (compared to close to 1.0 today). Further evaluation of these impacts is warranted.

## Buildings

By 2050, the buildings sector is modeled in the mitigation scenario to be thoroughly transformed and modernized, as buildings will need to have more efficient thermal shells (through a combination of new construction techniques and weatherization upgrades), and heating loads will need to largely be met through highly efficient heat pumps. Flexible load management and coordinated and connected loads will need to be prevalent, and biofuels will need to displace conventional fossil fuels. The pace of change has slowed some in comparison to early years of the plan but, as shown in Figure 30, there is roughly a doubling of the number of heat pumps, heat pump water heaters, and home weatherization retrofits by 2050 relative to 2030. Wood heating and biofuels (including distributed renewable gas and biodiesel) are projected to serve roughly one-fifth of the residential final energy demand by 2050.

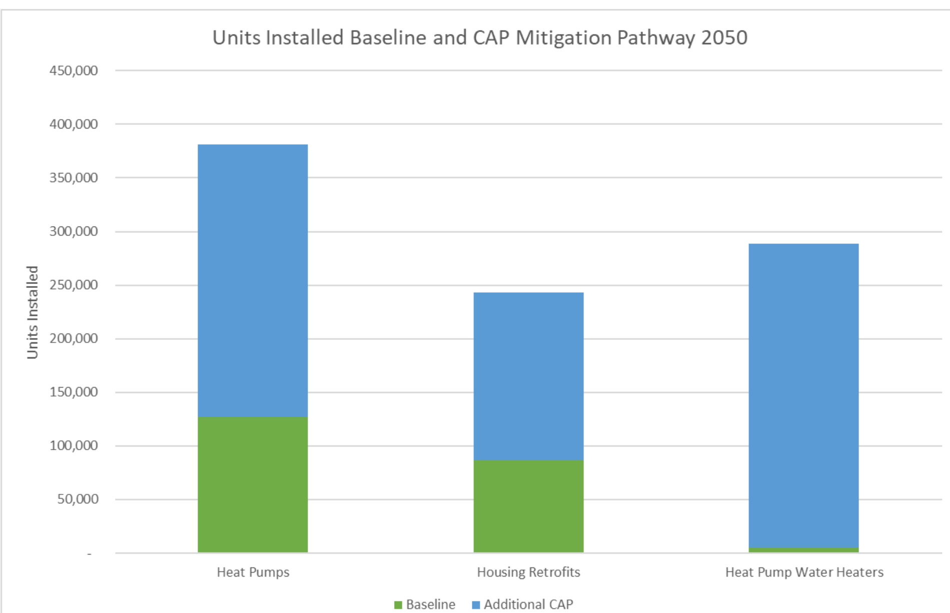


**Figure 30. Residential Building Measures Installed by 2050**

By 2050 heat pumps remain the most important strategy for emission reductions in the residential sector, contributing 40% of total emission reductions. Biodiesel is by far the second most important strategy, contributing about 30% of the reductions, with a mix of other strategies also making non-trivial contributions.

The mix of strategies deployed in the mitigation scenario to meet the 2050 GWSA requirements is more speculative than estimates for 2025 and 2030 because it is difficult to predict how technology will evolve and how the costs of different strategies will change over time—for example, there have been significant advances in cold-climate heat pump technology over the past five to 10 years. If those advances continue, and if costs decline as economies of scale are realized, new lower cost manufacturers enter the market, contractors become more familiar with the technology, and other advances take place, heat pumps could provide even more emissions reductions.

The mitigation scenario also includes significant emissions reductions for commercial buildings, and these are also primarily related to the adoption of heat pumps for space heating. Reduced emissions for cooking, through biofuels or electrification, are also illustrated in Figure 31.

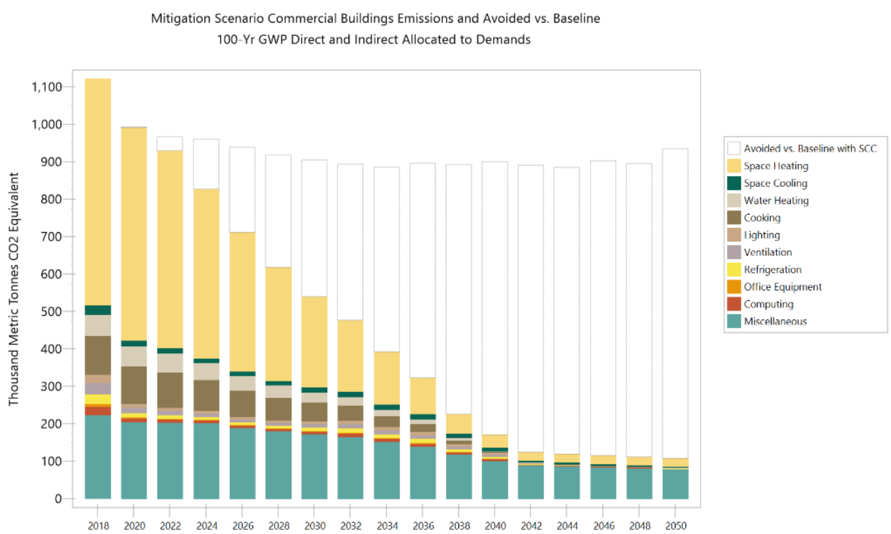


**Figure 31. Mitigation Scenario Commercial Buildings Emissions and Avoided versus Baseline**

Emissions from industrial buildings are also significantly reduced by 2050 in the mitigation scenario as illustrated in Figure 32.

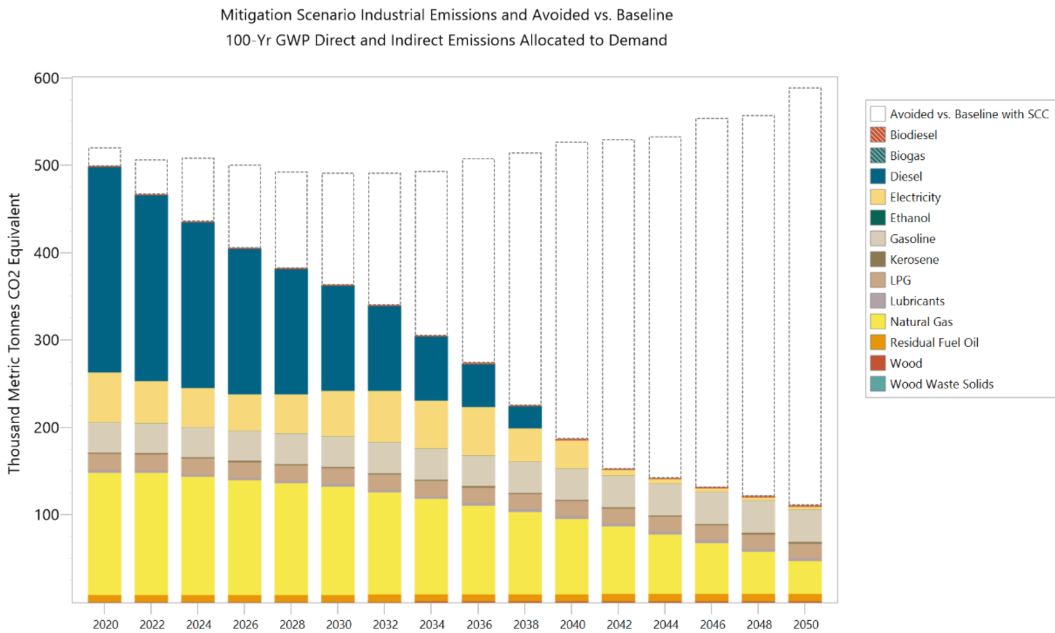


**Figure 32. Mitigation Scenario Industrial Buildings Emissions and Avoided versus Baseline**

In contrast to the residential and commercial sectors, where there is a sharp decline in final energy demand due to highly efficient heat pumps replacing combustion equipment, the reduced emissions from industrial buildings in the mitigation scenario are driven more by an increasing share of renewable biodiesel and biogas in industrial applications, reflected by the expanding orange and red hatched elements of Figure 33.

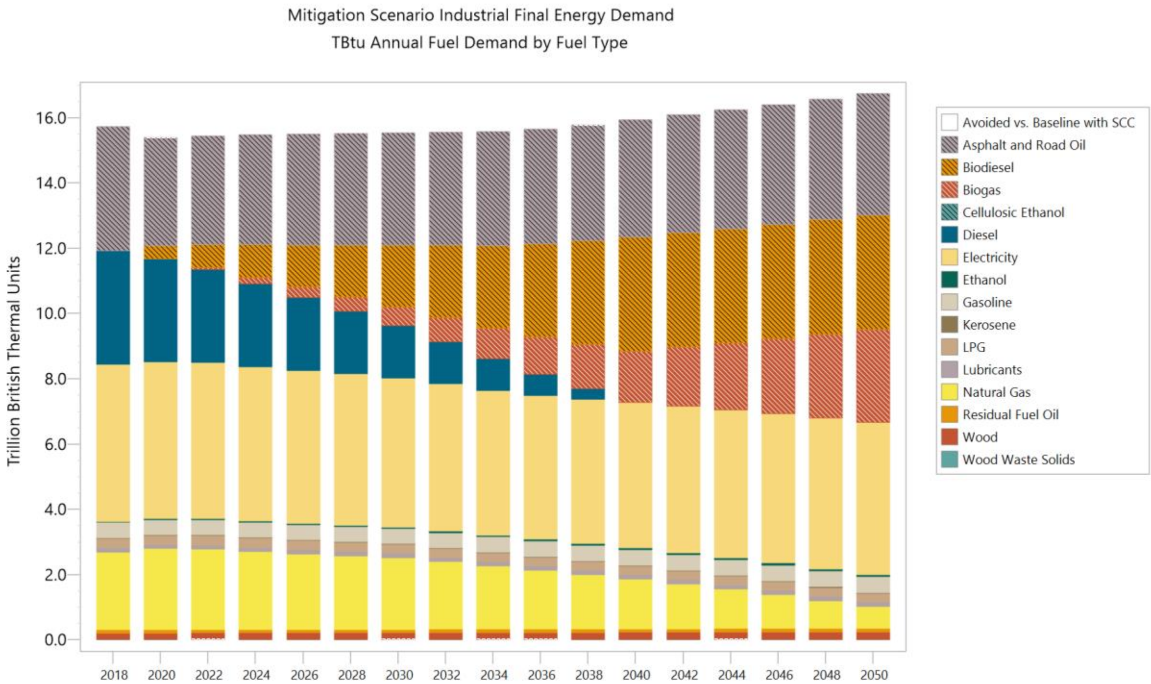


**Figure 33. Mitigation Scenario Industrial Buildings Final Energy Demand by Fuel**

**Building Sector Key Insights for 2050**

While less certain than the 2025 and 2030 scenarios, in 2050 the building sector will at least need to be thoroughly transformed and modernized. Most Vermont buildings will need to be insulated, air sealed, and reliant primarily on either electricity or biofuels to heat, cool, and provide hot water and cooking at a rate of about twice the activity in 2030. Industry will still use some fossil fuel but will need to be well on its way to being electrified or using biofuels. Electric loads will need to be flexible yet well controlled and managed to balance the electric grid system and the buildings it serves. Significant technological advances relative to today's technology should help provide greater savings at lower costs and with more options. Yet, macro societal changes such as population and demographics will likely impact planning and approaches to meeting the goals, requiring flexibility, and ensuring a focus on what lies ahead.

## Non-Energy

**Greenhouse Gas Emissions Reductions from Non-Energy Sector in 2050**

By 2050, GHG emissions from the non-energy sector in the mitigation scenario are modeled to be reduced to 776.0 TMTCO2e, or 38% of 2020 emission levels and 23% of 2030 emission levels. This is a reduction of 477.4 TMTCO2e between 2020 and 2050 and of 229.0 TMTCO2e between 2030 and 2050.

Figure 34 illustrates overall emissions from 2020, 2030, and 2050 by branch of the non-energy sector. While emissions from the waste sector remain relatively steady over the planning horizon, there are substantial reductions from industrial processes and agriculture. The categories with the most significant emissions reductions between 2020 and 2050 are ODS substitutes, enteric fermentation, manure management, and agricultural soils.

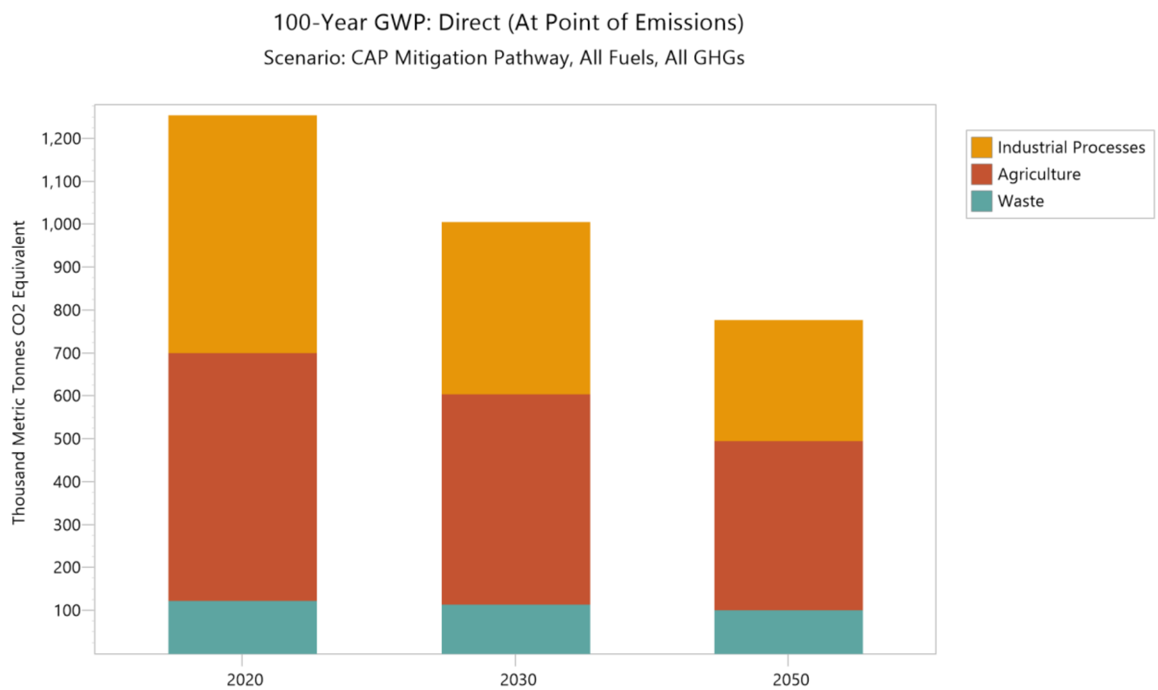


**Figure 34. Non-Energy Sector Emissions in 2020, 2030, and 2050**

In the mitigation scenario, the largest non-energy emissions reductions are from ODS substitutes, which decline by 78% of 2020 levels by 2050. There are several strategies recommended by the CSM Subcommittee that could reduce emissions from ODS substitutes, each involving the expansion of a statewide refrigerant management program. Long-term strategies within a refrigerant management program include reducing the leakage of HFCs from refrigeration systems, reducing the end-of-life emissions of HFCs from refrigeration, and reducing the use of HFCs in refrigerant systems.

By 2050, semiconductor manufacturing emissions have been reduced in the model by 8% from their 2020 levels. However, these reductions are all obtained by 2030, and the mitigation scenario does not include any further reductions in the 2030 to 2050 time period. There is therefore an opportunity to further explore future opportunities to reduce these emissions through efficiencies and the use of alternatives to high GWP fluorinated gases in the manufacturing process.

By 2050 agriculture non-energy emissions are modeled to be reduced by 32% of 2020 levels, to 394.6 TMTCO2e. These reductions continue to come from enhanced practices in feed management to reduce enteric fermentation emissions, manure management, and cropping and tillage to increase sequestration from agricultural soils. Adopting these actions should coincide with increased education, outreach, research, and technical and financial assistance programs for Vermont farmers.

Emissions from enteric fermentation, which represent the biggest source of agricultural emissions, is anticipated to be reduced through a climate feed management program. This could include feed amendments, for example seaweed or biochar, or improvements to feed quality.[25] Methane reduction from introducing seaweed into diets is an example of feed management that is cited in scientific literature,[26] though more research is needed into the scalability and costs for Vermont farmers, as well as the impacts of producing seaweed.[27]

Emissions reductions from agricultural soils, which is the source of second-largest emissions reductions, is anticipated to come from an increase in soil organic matter sequestration from altered soil management practices. A 0.1% increase in soil organic matter per year on corn and hay fields can help Vermont meet its climate change goals (Patch 2021). Examples of practices that could increase soil sequestration include reducing tillage and increasing vegetative cover, like no-till and cover crop practices. Grazing practices that increase vegetative cover and forage quality, such as rotational grazing, would also increase agricultural soil carbon sequestration.

Emissions reductions from manure management, which represent a smaller segment of agricultural emissions than enteric fermentation and soils, is anticipated to come from methane reduction using waste digesters (Patch 2021). There could also be farmer-to-farmer education about improved soil and manure management.

These strategies for agricultural emissions reductions are emerging areas of opportunity. More research is needed to understand emissions from agriculture, including the level of current emissions, the scope and pace of emissions reductions that are possible, and the costs for these practices to reduce agriculture non-energy emissions.

The focus of reductions within the non-energy sector is not on waste, which emits less GHG emissions than industrial processes and agriculture. Waste in the mitigation scenario is reduced from 123.2 TMTCO2e in 2020 to 101.2 TMTCO2e in 2050. While there could be advances in capturing emissions from wastewater, for example, it would represent a small portion of overall emissions from the non-energy sector.

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25 Patch, Ryan. June 24, 2021. "GWSA Vermont Climate Council Ag & Ecosystem Subcommittee Subtask Group 5C: Recommendations." Vermont Climate Council Ag & Ecosystems Subcommittee Meeting. https://aoa.vermont.gov/sites/aoa/files/Boards/VCC/GWSA%20VCC%20Ag%20and%20Ecosystem%20Subcommittee%20Subtask%20Group%205C%20Recommendations%206-24-21.pdf

26 Roque, Breanna M. et al. March 17, 2021. "Red Seaweed (*Asparagopsis Taxiformis*) Supplementation Reduces Enteric Methane by over 80 Percent in Beef Steers." *PLoS ONE* 16(3): e0247820. https://doi.org/10.1371/journal.pone.0247820

27 Abbott, D, Wade et al. December 18, 2020. "Seaweed and Seaweed Bioactives for Mitigation of Enteric Methane: Challenges and Opportunities." *Animals* 10(12): 2432. https://doi.org/10.3390/ani10122432

## Land Use, Land Use Change, and Forestry

Land use, land use change, and forestry (LULUCF) is an important contributing factor to meeting the GWSA's 2050 net zero requirement. Carbon sequestration, or the uptake of carbon from the atmosphere, and storage from this sector act as emissions sinks. The mitigation scenario includes LULUCF sequestration from lands, ecosystems, and forests at a declining rate, represented by the yellow segment below the x-axis in Figure 35.

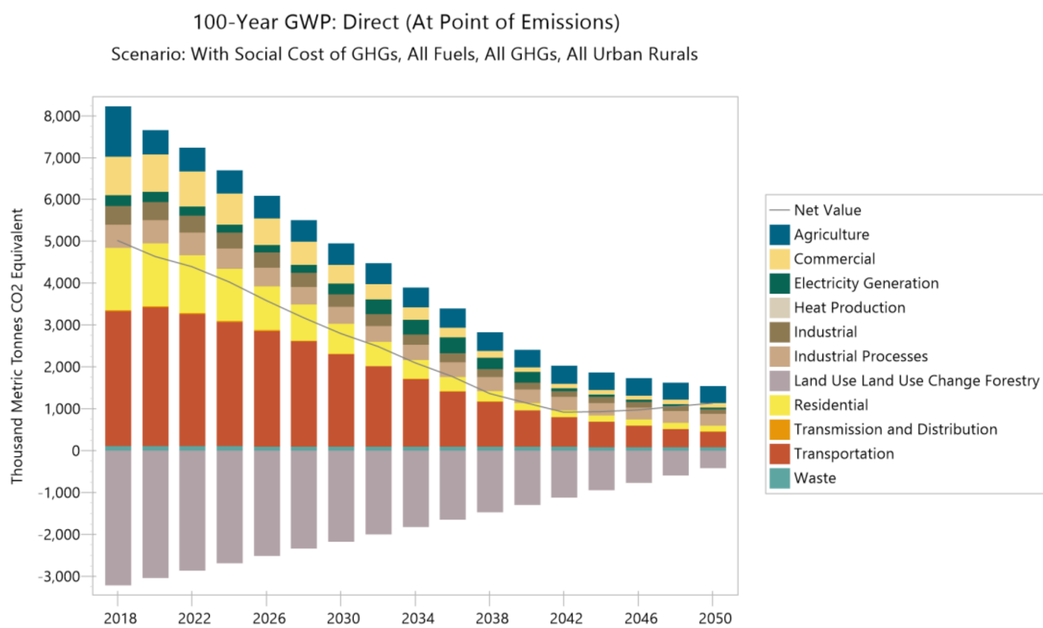


**Figure 35. Mitigation Scenario Gross and Net Emissions by Sector**

The sequestration estimate from LULUCF in the mitigation scenario is based on the *Carbon Budget Report* completed by the University of Vermont members of the Cadmus Team under Task 2 of its Technical Support Assignment for the Vermont Climate Council, including the initial level of sequestration of -3.2 MMTCO2e in 2018.[28] The linear decline in future sequestration is based on historical trends and research indicating that the overall rate of sequestration from LULUCF is likely declining.

Page 58 of that same *Carbon Budget Report* states that within the forests sector of LULUCF, "…forests that have remained forests are sequestering carbon at a slower rate than they did in the past. At the same time, there has been both an increase in emissions from the conversion of forests to other uses

[28] Galford, Gillian, Dr. Heather Darby, Frederick Hall, and Dr. Alexandra Kosiba. September 2021. *A Carbon Budget for Vermont: Task 2 in Support of the Development of Vermont's Climate Action Plan*. p. 7. https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/Carbon%20Budget%20for%20Vermont%20Sept%202021.pdf

and a decrease in additional sequestration from land in other uses being converted back to forest. These trends cause a net increase in land use emissions over time."

As indicated by the "Total" line in Figure 35, if the rate of carbon sequestration declines at a steady rate, Vermont will not meet the requirement of net zero emissions by 2050. The mitigation scenario results indicate that maintaining sequestration at or -1.8 MMTCO2e, which is approximately the level of sequestration in 2035 in the figure, is necessary to meet the net zero 2050 requirement.

More research is needed to inform estimates of the current level of carbon sequestration from LULUCF, as well as the rate of decline of carbon sequestration between now and 2050.

Due to a lack of available data on carbon sequestration from LULUCF, the levels are the same in the baseline and mitigation scenarios of the LEAP model. This represents an opportunity to incorporate improved LULUCF practices into the climate mitigation scenario to continue to sequester and store carbon, which may allow Vermont to reach the state's emissions reductions targets.

**Non-Energy Key Insights for 2050**

There are four key insights for the non-energy sector by 2050:

- The largest non-energy emissions reductions by 2050 are modeled to be from ODS substitutes. A statewide refrigerant management program could reduce emissions from ODS substitutes.
- Industrial process emissions from semiconductor manufacturing are not decreased after 2030, requiring further attention to the future opportunities to reduce these emissions.
- Emissions from agriculture are significantly reduced by 2050. Reductions can come from enhanced practices in feed management to reduce enteric fermentation emissions, manure management practices like waste digestors, and cropping and tillage to increase sequestration from agricultural soils.
- The mitigation and baseline scenarios both include a steady decline in sequestration, resulting in net emissions being above zero by 2050. Research, funding, and initiatives to address the potential for natural and working lands to maintain or increase levels sequestration will be central to meeting the 2050 net zero target.

## Electric

**Electricity Requirements by 2050**

In the 2050 mitigation scenario, more than half of Vermont's total final energy demand is met by electricity. As illustrated in Figure 36, this compares to electricity's roughly 15% share of total energy demand today and the 20% share projected in the baseline.

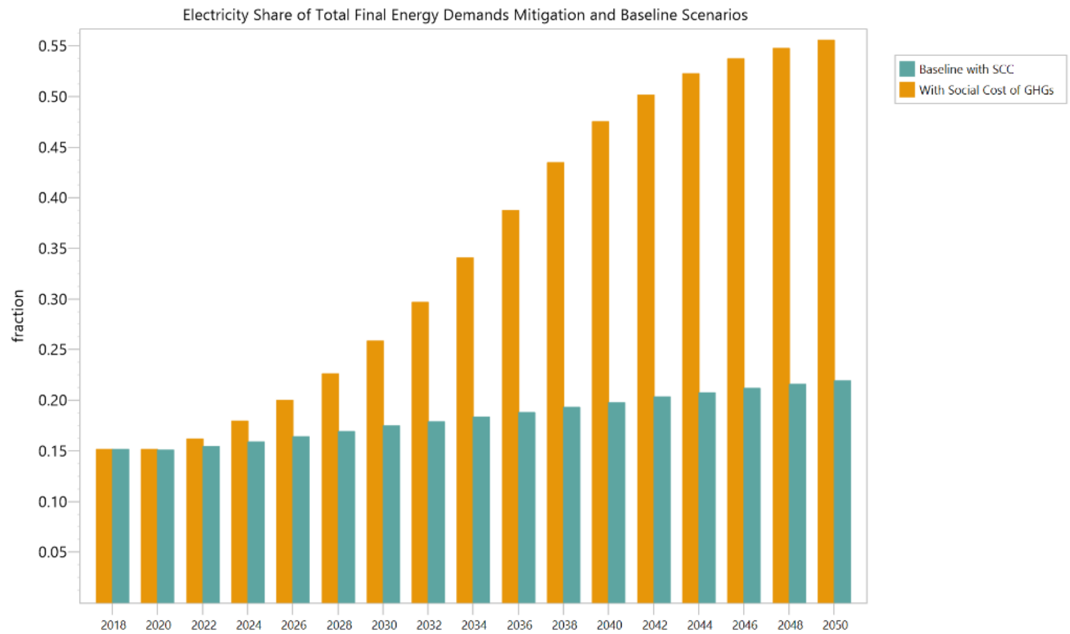


**Figure 36. Electricity as Share of Total Energy Demand Mitigation and Baseline Scenarios**

In addition, by 2050, not only has the share of total energy demand met by electricity increased, but the share of renewable generation in the mitigation scenario is increased to reflect an expansion of the renewable energy standard to 100% by 2050, as illustrated in Figure 37.

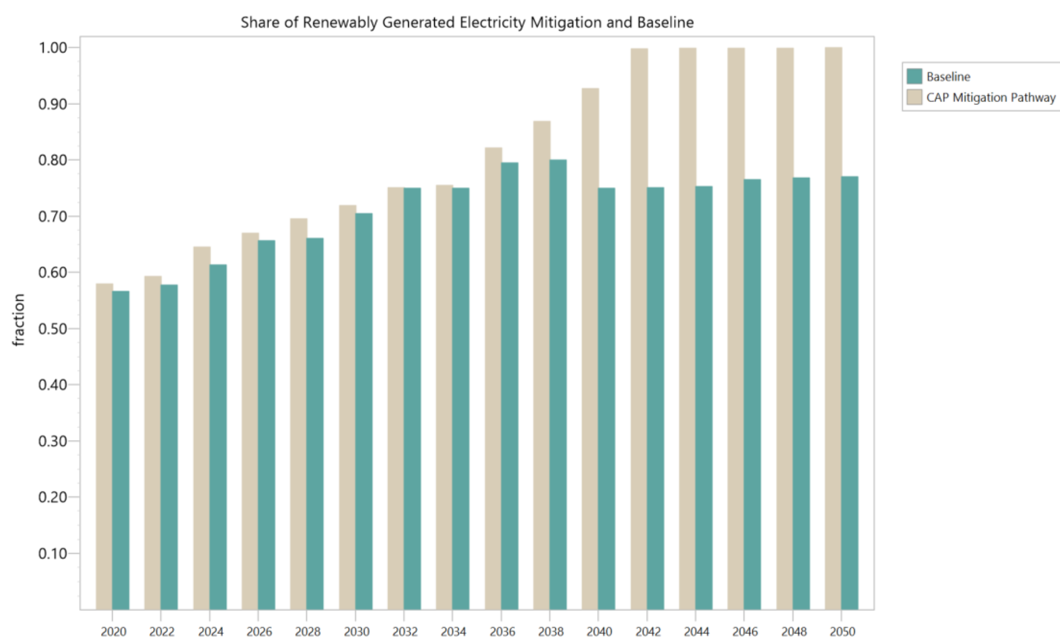


**Figure 37. Share of Annual Electric Generation from Renewables Baseline and Mitigation Scenarios**

Between 2030 and 2050, the mitigation scenario electricity demand increases from 7.9 TWhs to 12.1 TWhs (the baseline scenario increases from 5.8 TWhs in 2030 to 6.9 TWhs in 2050). The transportation sector requires the largest increase of 4.4 TWhs, followed by the residential sector at 3.6 TWhs. The commercial sector also increases from 2.4 TWhs in 2030 to 2.7 TWhs in 2050, but this growth is not as significant as growth in the transportation and residential sectors. The industrial sector increases slightly from 1.34 TWhs in 2030 to 1.37 TWhs in 2050 (shown in Figure 38).

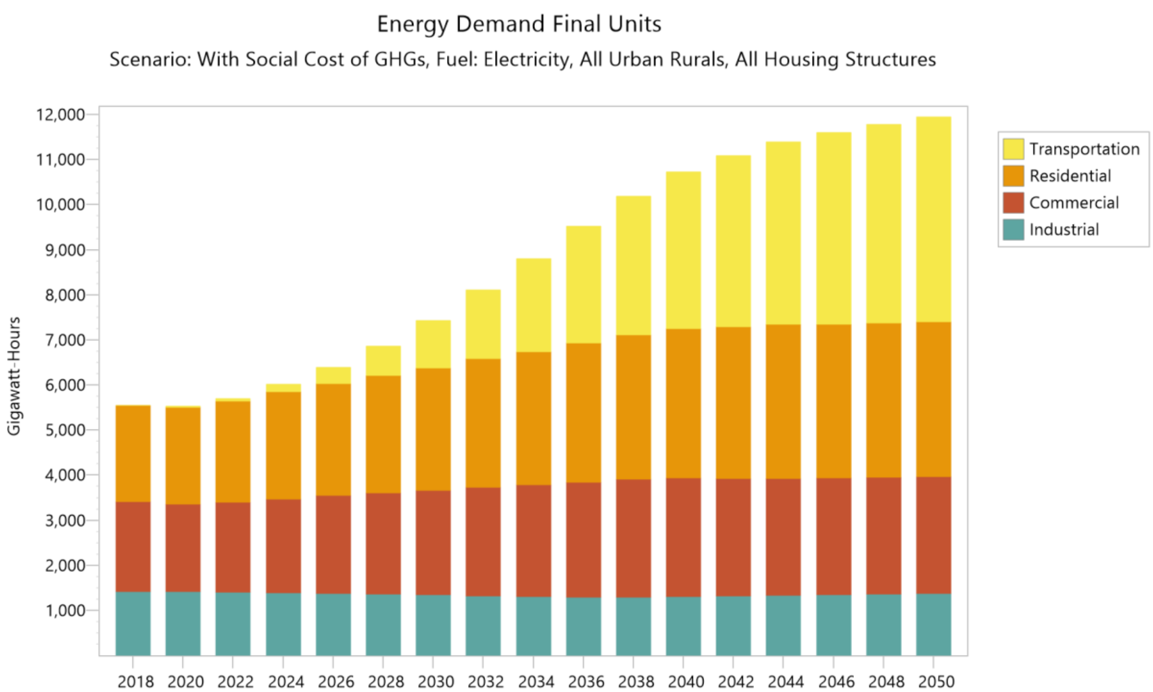


**Figure 38. Mitigation Scenario Electricity Demand (GWh) by Sector**

Peak demand in the mitigation scenario rises from 1.8 GWs in 2030 to 2.7 GWs in 2050, while the baseline scenario shows an increase from 1.3 GWs in 2030 to 1.5 GWs in 2050 (Figure 39).

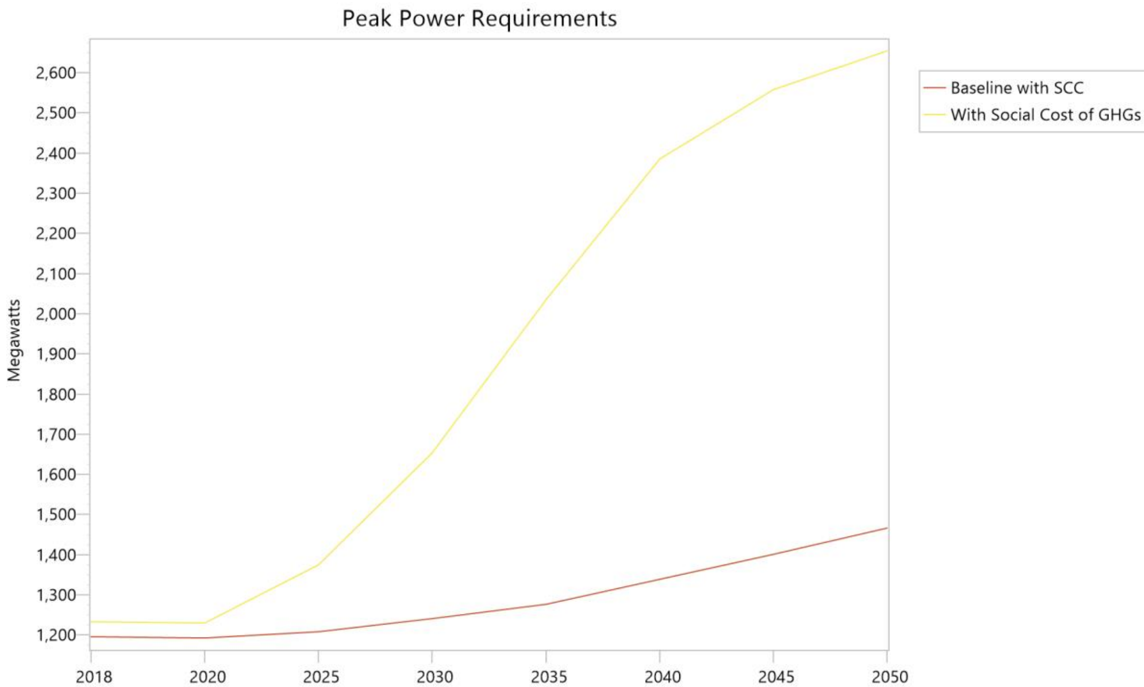


**Figure 39. Peak Power Requirements (MW) in Mitigation and Baseline Scenarios**

As discussed in the 2025 and 2030 sections on electric sector requirements, the mitigation scenario results in a significantly higher level of total generation than what is required to meet end use demand. This reflects renewable generating capacity required to meet demands in all time periods and the zero operating fuel costs for renewable generating capacity to run once installed. Figure 40 illustrates the electricity sector module balance for the mitigation scenario, with Vermont's electricity demand represented by the orange bars below the x-axis and the total from generating resources illustrated by the yellow bars above the axis. The red bars, which increase particularly in the latter years, illustrate surplus power that may be exported, curtailed, or used for further strategic electrification.

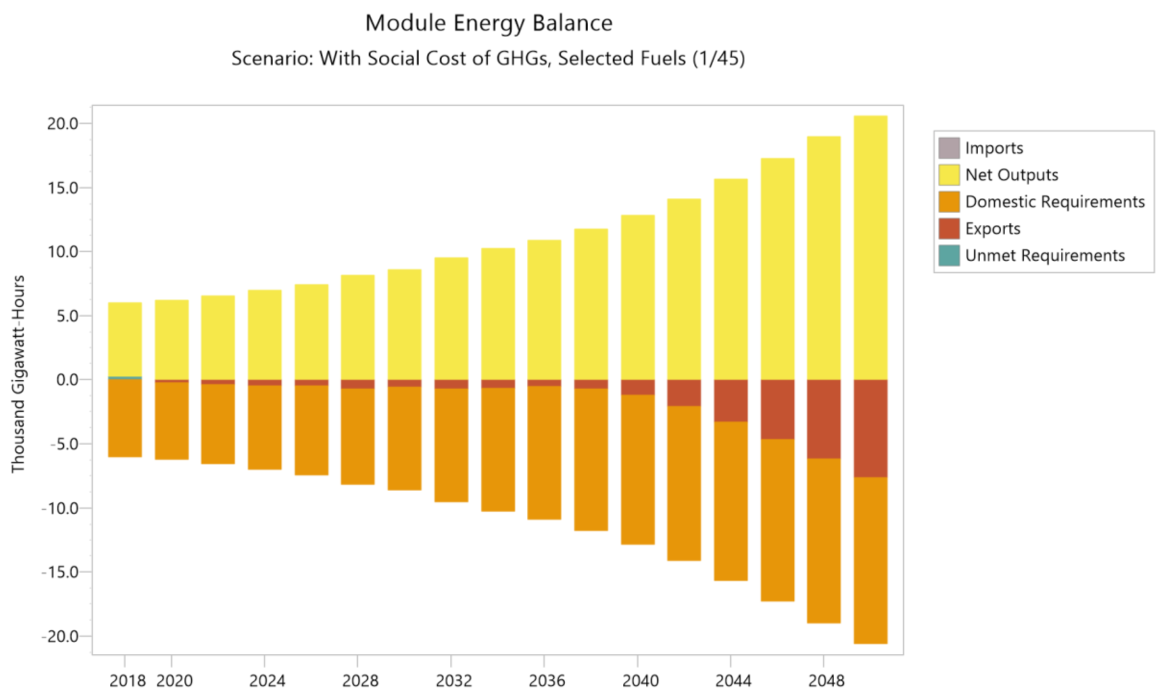


**Figure 40. Mitigation Scenario Electricity Sector Module Balance**

It is highly likely that some portion of the surplus generation can be reduced by coordinated load management or storage. Alternatively, it could be productively used to support hydrogen-to-gas projects for industrial sector needs. The LEAP modeling conducted for the CAP is not meant to substitute for more detailed electricity sector planning and modeling, which are necessary to better understand options for future electricity sector planning and investment. These include, at a minimum, the degree to which demand management is deployed, as well as the location, size, type, and cost of different resources.

Nevertheless, the power sector results from the mitigation scenario clearly indicate the magnitude of the electricity sector's contributions to meeting the GWSA requirements, and provide Vermont policy makers, regulators, and utilities with important directional guidance.

### Electricity Sector Key Insights for 2050

There are several key insights from the electricity sector mitigation scenario by 2050:

- Vermont's energy economy is expected to be highly dependent on electricity. Further, by 2050, Vermont's grid will be 100% renewably powered. A reliable and robust infrastructure to meet power needs is critical and will be a significant asset to the state.
- Ongoing assessment regarding accessibility to adequate infrastructure and equitable electrification activities are needed to ensure that the shift to clean energy is equitable and that no Vermonter is left behind. It is likely that achieving full access at all times may be challenging.

Therefore, ongoing program design will likely be needed with regular evaluation and program modifications.

- The grid must be dynamic, robust, and flexible, harnessing varying opportunities for coordinated load management across multiple sites and multiple end uses to reduce overall system costs. In keeping with the past 30 years, research and innovation, as well as testing pilot programs, will be critical to ensure that new technological advances are selected and applied appropriately.
- Storage (battery and other) will need to help reduce system costs and improve resilience and reliability.
- As technology advances, new opportunities for strategic electrification of industrial loads may be developed and implemented, including the use of renewable electricity to create hydrogen or renewable gas and other potential opportunities such as direct air capture sequestration that are not yet well developed.

## Economic Results

This section presents economic results comparing the mitigation scenario to the baseline. The economic results based on the LEAP modeling include the net present value of direct additional costs and savings for meeting the requirements, and the profile of the annual costs and savings over time. Additional structural economic impacts (including the direct, indirect, and induced spending effects and the related changes in overall economic activity and jobs) have also been estimated using the IMPLAN economic modeling tool.

### *Economic Comparison of Mitigation Scenario to Baseline*

The mitigation scenario results in cumulative emissions reductions of 85 MMTCO2e by 2050 in comparison to the baseline. Figure 41 Figure 41 illustrates the discounted net present value of attaining these reductions is $6.4 billion (in 2019 dollars, at a 2% discount rate). These results include valuation of the avoided social, economic, and environmental damages from GHG emissions, based on the *Social Cost of Carbon* report[29] and recommendations from the Project Team, and as adopted by the Science and Data Subcommittee. In Figure 41, these savings and the savings from avoided fuel consumption appear as positive values above the horizontal axis, while additional costs and investments required by the CAP to meet the GWSA requirements appear below the horizontal axis.

[29] Energy Futures Group, Inc. August 18, 2021. *Social Cost of Carbon and Cost of Carbon Model Review: Analyses and Recommendations to Support Vermont's Climate Council and Climate Action Plan.* https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/SCC%20and%20Cost%20of%20Carbon%208-31%20DH%20revised.pdf

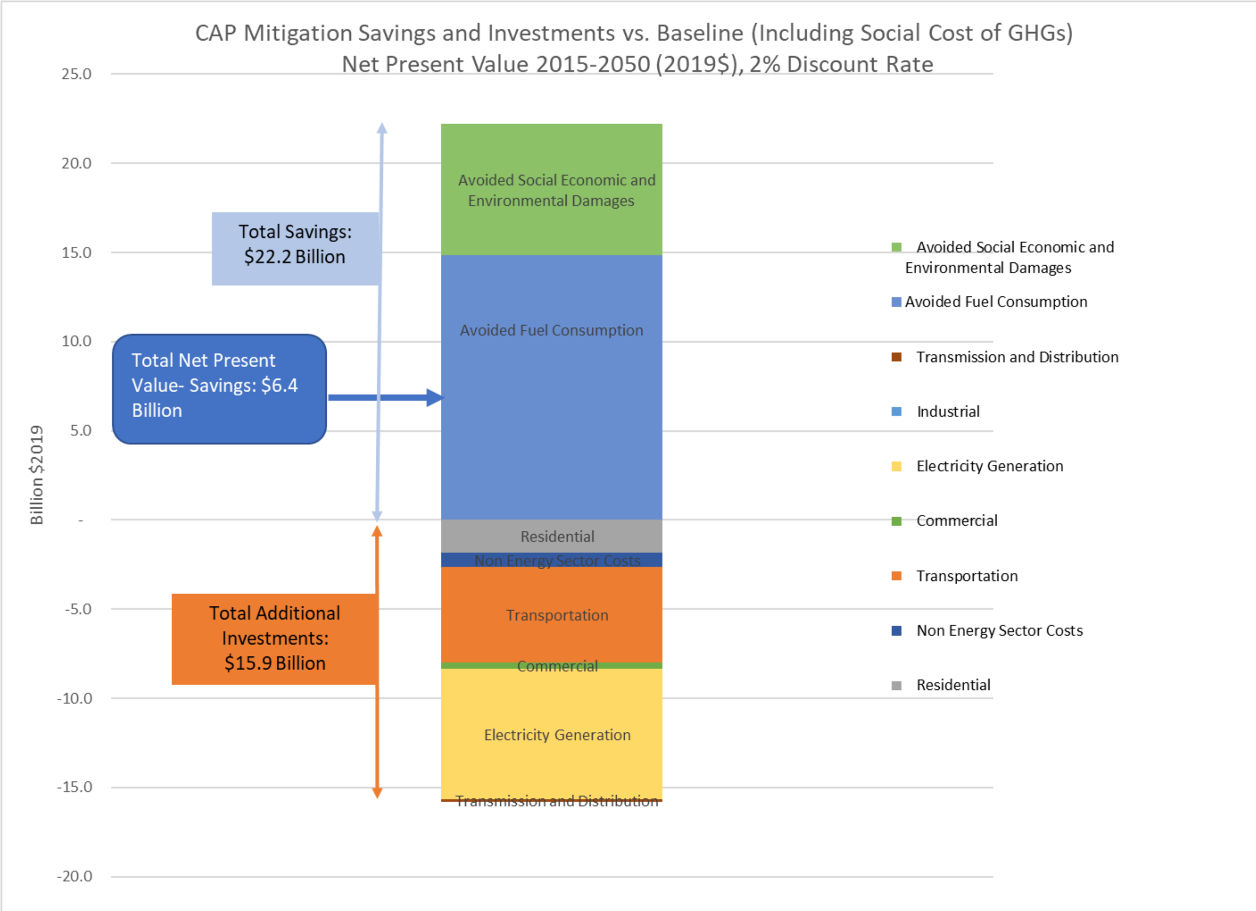


**Figure 41. Mitigation Scenario Net Present Value Compared to Baseline - $6.4 Billion of Net Benefits through 2050.**

The results indicate the present value of the total additional investments through 2050 to be $15.9 billion. This includes $7.3 billion of investments in electric generation and an additional $0.2 billion for transmission and distribution upgrades—investments that are required to meet the growing electric demands created by the transition to EVs and to heat pumps for building space and water heating. Offshore wind, onshore wind, and solar make up the largest areas of new electric investments. While the LEAP model includes optimization calculations that consider estimated capital, fixed and variable operating costs, as well as diurnal and seasonal variations in output, these results are simply directional. They do not eliminate the need for and value of more detailed planning, by the utilities, and other parties such as VELCO and ISO-NE, for further optimization of investments in the electric sector.

Increased investments in transportation include additional costs (compared to a conventional vehicle) for EVs in the near term (that is, over time in the model, the initial costs of battery EVs reach parity with internal combustion engines), charging infrastructure and initiatives to reduce VMT. The present value of the increased investments and spending for the transportation sector is $5.4 billion, indicative of major changes in this sector, which is Vermont's largest historic and current source of GHG emissions.

The present value of additional investments in the building sector are $2.1 billion. These investments occur mostly in the residential sector and include the combined investments of switching to heat pumps and weatherizing buildings. The former offsets or completely replaces the use of fossil fuels for space and water heating, and the latter reduces the amount of increased electric generating capacity required while making homes more comfortable and affordable.

The present value costs for avoided non-energy emissions from the agricultural and industrial sectors are $0.8 billion. The estimated costs include initiatives to reduce direct emissions of methane and nitrous oxide from agricultural practices, and to reduce the emissions of high GWP fluorinated gases used as refrigerants and in semiconductor manufacturing.

The present value of the combined additional costs and investments across all sectors is $15.9 billion, represented by the orange flag marker in Figure 41 above. The total savings from avoided fuel costs (present value of $14.8 billion) and avoided social, economic, and environmental damages from reduced emissions (present value of $7.4 billion) total $22.1 billion, illustrated by the blue "Total Savings" flag in Figure 41. The total savings more than offset the present value of the total investments, and thus the net present value of the mitigation compared to the baseline is $6.4 billion of savings, illustrated by the dark blue flag to the left of the column.

Economic results and impacts equaling billions of dollars can understandably be viewed as substantial. However, these are the present value of the additional costs and expenditures for the mitigation scenario compared to the baseline over three decades. Subject to weather and price volatility for fossil fuels, Vermont historically spends over $3 billion each year on energy, meaning the required investments for meeting the mitigation scenario represent a relatively small percentage increase (roughly 1%) of the total energy expenditures Vermont would allocate anyways.

These results also indicate that while the pace of change to meet the requirements may seem daunting, the overall scale of changes in spending is not out of sync with historical spending patterns. The economic comparison of the mitigation scenario to the baseline presented above considers the net present value of increased investments and savings over three decades, discounted back to 2019. Figure 42 below details the annual additional costs and savings (in 2019 dollars) Figure 42. This figure further illustrates how meeting Vermont's GWSA requirements is expected to create positive net economic impacts over time.

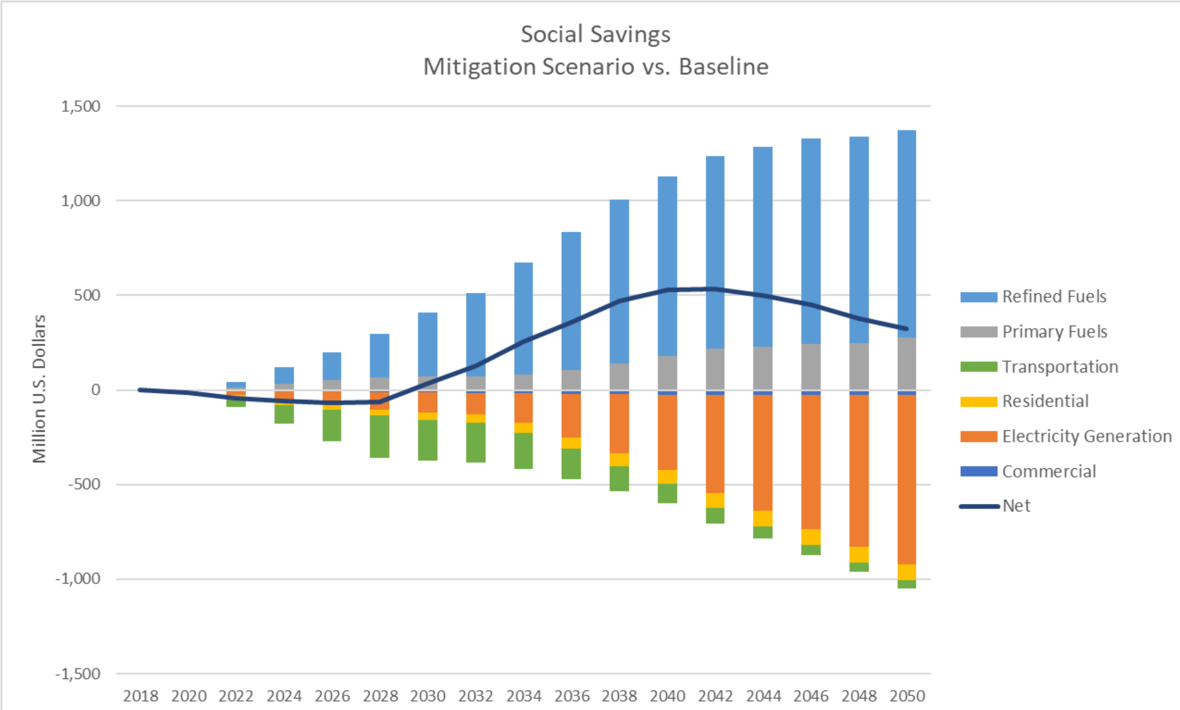


**Figure 42. Mitigation Scenario Annual Savings and Costs Compared to Baseline**
Increased Investments and Costs through 2030 Lead to Significant Savings thereafter.
The mitigation scenario avoids both refined and primary fuels (based on renewable and non-renewable resources) but the majority of avoided consumption is refined fuels consisting of imports of gasoline and other refined petroleum products.

Figure 42 illustrates that during the first decade, increased costs and investments in transportation, residential and commercial buildings, and electric generation are partially, but not completely, offset by fossil fuel savings. Thus, the "Net Value" line indicates that annual net investments range from $35 million to $235 million higher than baseline through 2030. After that, the annual savings (including fossil fuels and avoided economic damages from avoided emissions) outweigh annual additional costs and investments. This is represented by the net value line crossing below the horizonal axis value of zero after 2030. In the later years, additional investments in electricity generation become a larger share of the additional costs as renewable capacity is increased to meet the needs of an increasingly electrified energy system.

The two sets of economic results presented in Figure 41 and Figure 42 above are complementary, with the first indicating the cumulative net present value of the changes in spending and investments, while the second provides greater detail on the profile of the additional costs and savings over time. In both cases, the mitigation scenario compares favorably and provides net economic benefits in comparison to the baseline.

Another way to view the economic impacts is presented in Figure 43, which illustrates the annual differences in costs and savings by cost category. This shows the relative scale of savings from avoided fossil fuel consumption (dark blue bar, labeled “Fuel Secondary Production”) in comparison to the avoided economic damages from avoided emissions (brown bar, labeled “Environmental Externalities”).

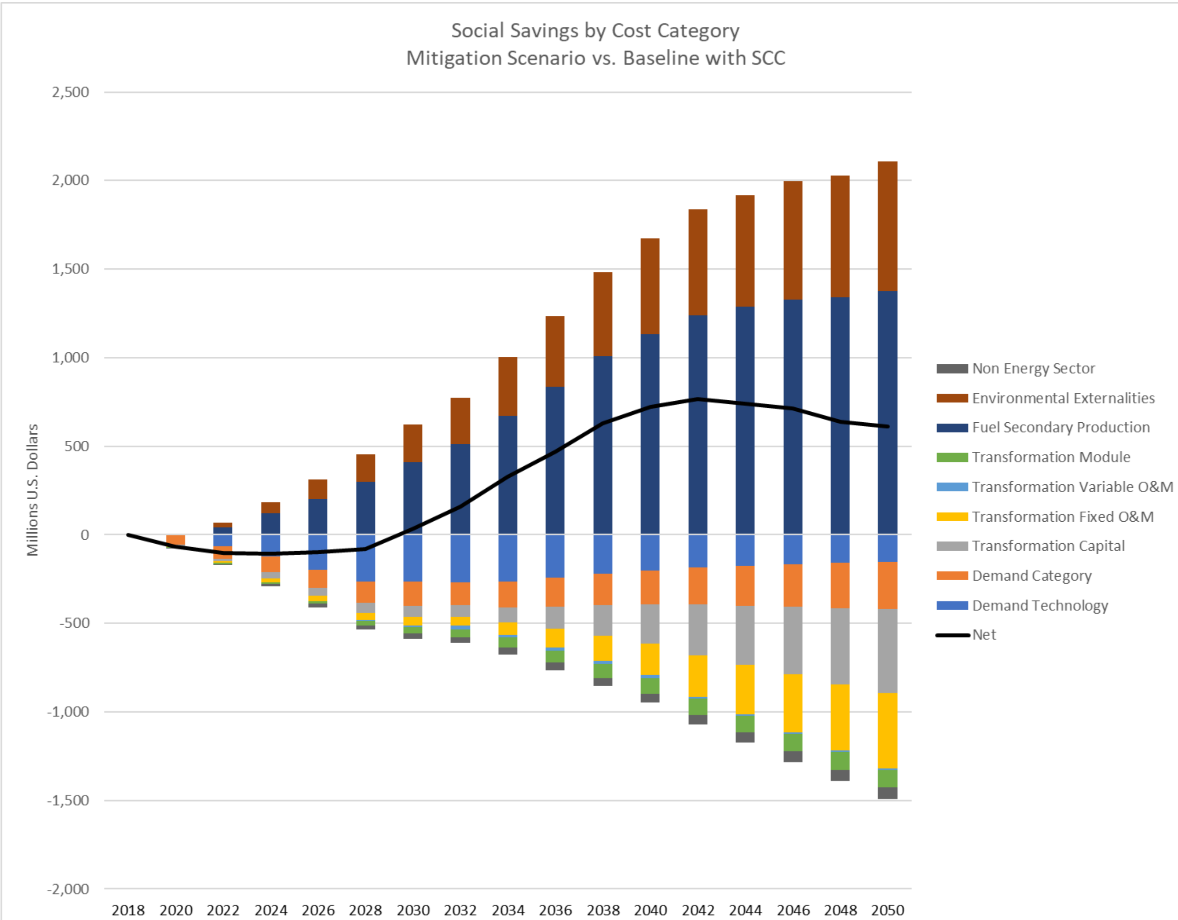


**Figure 43. Mitigation Scenario Annual Costs and Savings Compared to Baseline**
Early Investments in Transportation and Buildings (Demand) Followed by Later Investments in Electricity (Transformation) are Offset by Fossil Fuel Savings and Avoided Economic Damages from GHG Emissions.

## *Statewide Economic Impacts*

The results comparing the mitigation scenario to the baseline, presented in the preceding section, are based on changes in direct spending, both in state and out of state. To gain additional insight to the impacts of meeting the GWSA requirements, our team also considered how changes from the mitigation scenario ripple through the statewide economy. For example, there are upfront costs to weatherizing a home or purchasing an EV, and some of those costs occur out of state (such as EV manufacturing) while other costs (such as weatherizing a building) create economic activity in Vermont. Reduced fossil fuel consumption means fewer dollars are flowing out of state (since Vermont imports all its fossil fuels). Over time, the savings to Vermonters from avoided expenditures on fossil fuels due to more efficient equipment and buildings can be re-spent by households and businesses. A portion of that re-spending will remain in the state, creating further economic activity.

Cadmus used IMPLAN software to model impacts of the mitigation scenario and its opportunity costs along four key indicators: employment, labor income, value-add, and output.[30] Net economic impacts are positive in the near term (2020 through 2030), in the future (2031 through 2050) and in the overall mitigation timeline (2020 through 2050), as shown in Table 8. At the bottom of the table are summary statistics for the entire Vermont economy in 2019, for context. Compared to the size of Vermont's economy in a single year, net impacts from the mitigation scenario are relatively small (<1% annually) considering they are spread over decades.

**Table 8. Economic Impacts to Vermont from Mitigation Scenario Investments and Opportunity Costs**

| Investment Time Period | Employment (job-years) | Labor Income (billions) | Value Added (billions) | Output (billions) |
|---|---|---|---|---|
| 2020-2030 (11 years) | 18,500 | $0.8 | $0.9 | $2.2 |
| 2031-2050 (20 years) | 91,400 | $3.9 | $4.7 | $10.1 |
| **2020-2050 (31 years)** | **109,600** | **$4.7** | **$5.6** | **$12.3** |
| VT Economy Overall 2019 | 440,000 | $34 | $34 | $67 |

Cadmus conducted the economic analysis in two parts and summed the results to obtain the values in Table 8.

(1) Mitigation Scenario Spending and Savings: Includes changes in demand across various industries and commodities to comply with the GWSA, such as increased building weatherization and decreased fossil fuels.

(2) Opportunity costs are the net costs of the mitigation scenario (spending minus savings) spread over the residential and commercial sectors of Vermont. IMPLAN cannot model opportunity costs for the commercial sector, so this analysis focused on household impacts, assuming 70% of the net costs are allocated to the residential sector.

The IMPLAN methodology details and definitions are presented in *Appendix A*. Results from each component are discussed next.

## Mitigation Scenario Spending and Savings

Table 9 shows impacts from near-term mitigation activities (2020 through 2030) and the overall mitigation scenario 2020 through 2050. Statewide impacts are positive overall along all indicators, showing increased employment, income, and value-added or wealth generated in the state. Near-term impacts are approximately 22% of the total, indicating that economic impacts will ramp up in the later part of the timeline (between 2031 and 2050).

[30] See *Appendix A* for official definitions.

**Table 9. Summary Results for Mitigation Scenario**

| Investment Period | Employment (Job-Years) | Labor Income (billions) | Value Added (billions) | Output (billions) |
|---|---|---|---|---|
| 2020-2030 | 24,000 | $1.1 | $1.4 | $3.1 |
| 2031-2050 | 91,000 | $3.8 | $4.7 | $10.1 |
| **2020-2050** | **115,000** | **$4.9** | **$6.1** | **$13.1** |

Employment impacts are concentrated to a few industries directly relating to mitigation scenario investments, as shown in Figure 44. On the horizontal axis are the full range of IMPLAN industries (each of which is assigned a code, see *Appendix A* for more detail) and the vertical axis the employment impact from the 2020 through 2050 mitigation scenario.

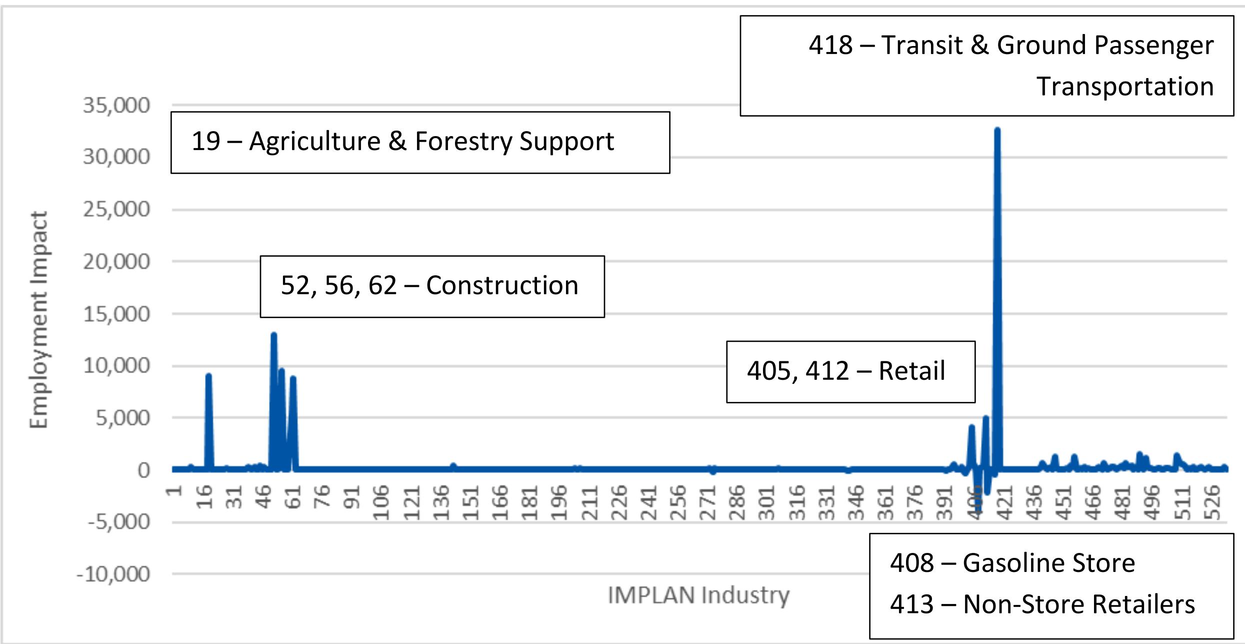


**Figure 44. Employment Impacts by Industry (2020-2050 Investments)**

Most industries are not significantly affected, however there are several spikes of note in the figure. The first spike corresponds to agriculture and forestry support services, which is a result of non-energy-sector investments in agriculture processes. The next trio of spikes are categorized as construction and maintenance/repair of buildings and roadways. IMPLAN industries 402 through 413 are various types of retail, and, in aggregate, retail employment increases. Industries 405 and 412 are building material and miscellaneous store retailers and they gain the most employment of all retail industries. Gasoline stores and non-store retailers (firewood dealers, direct selling) experience a decrease in employment. The largest industry impact by far is in transit and ground passenger transportation (industry 418). This arises from the significant investments in public transit to reduce VMTs. A table of employment impacts by most affected industries is provided in *Appendix A*.

## Residential Sector Opportunity Cost

Transitioning to a clean energy economy will require upfront investments to achieve long-term benefits. These investments and savings opportunities will impact how Vermonters spend household income in the near-, medium-, and long-term. This section describes the expected economic impacts from changes to household income in aggregate. Net costs are greatest in the near term. In the mid- to long-term these impacts are negative, which represents net *savings* to Vermonters, as shown in Table 10.

**Table 10. Net Costs of Mitigation Scenario by Time Period**

| Time Period | Mitigation Scenario Net Costs (millions) |
|---|---|
| 2020-2030 | $1,593 |
| 2031-2050 | $(450) |
| **Total** | **$1,142** |

Based on feedback from the CSM Subcommittee, Cadmus assumed that 70% of the net costs of the mitigation scenario would be spread across Vermont households. Net costs of the mitigation scenario amount to $1.14 billion, so this translates into an aggregate decrease of $799 million in household income.

IMPLAN requires allocating costs along nine household income groups (such as less than $15,000, from $150,000 to $200,000, and greater than $200,000). Because policy development is underway, Cadmus examined whether allocation along different schemes would result in differing outcomes, with the goal of identifying approaches to minimize negative economic impacts. The two cost allocations we examined were (1) proportional to the number of households in each income group and (2) proportional to air transportation demand. Given the CAP's stated dedication to equity, the Cadmus/EFG team chose to include the air travel scheme as a proxy, as it places more of the opportunity cost on higher-income households. It should be noted that these allocations are merely illustrative of how economic impacts could occur based on different policymaking priorities and is not predictive of how the impacts will occur, given all the uncertainties around how final CAP policies will be designed and adopted. The allocation schemes can be found in Figure 45 and values can be found in *Appendix A*.

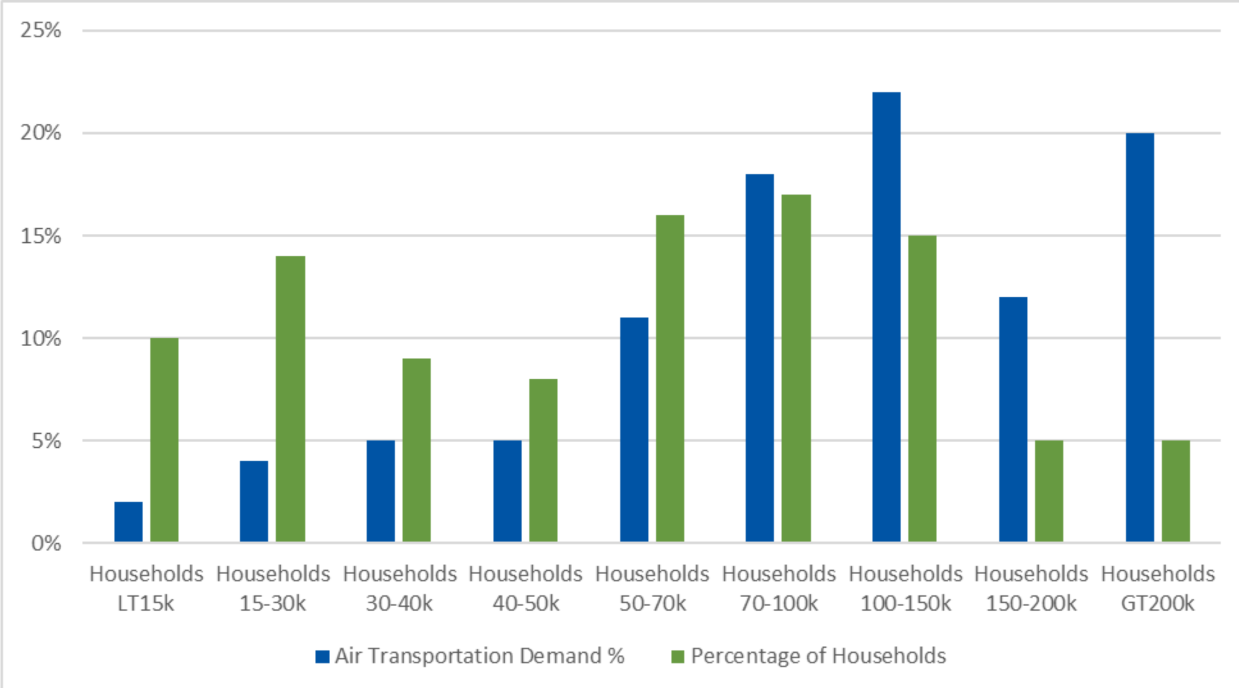


**Figure 45. Residential Opportunity Cost Allocation Schemes**

As shown in Figure 46, the impacts of opportunity costs are negative over both the near term (2020 through 2030) and for the overall mitigation period of 2020 through 2050. The allocation scheme makes a bigger difference in the near term than the overall period. This is expected, as the net costs are higher in the near term ($1.59 billion) than the overall mitigation scenario ($1.14 billion). In the near term, there is a difference of 2,100 jobs between the two allocation schemes.

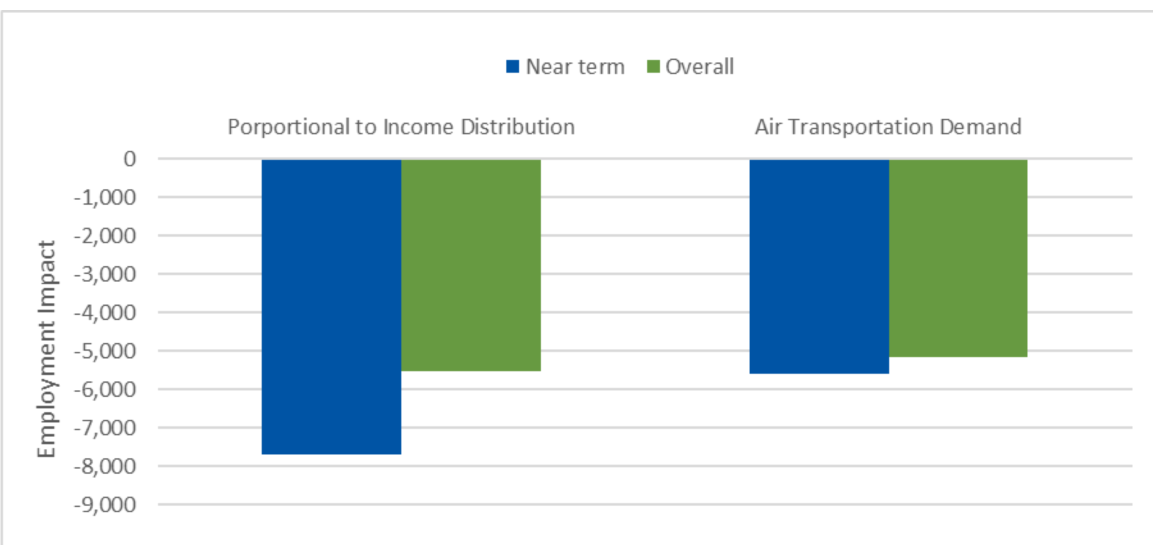


**Figure 46. Economic Impacts of Opportunity Costs to Residential Sector**

The order of magnitude of impacts from the opportunity costs (approximately 5,000 jobs) is relatively small compared to those gained from the mitigation scenario spending (approximately 115,000 jobs). Adding the opportunity cost impacts to the mitigation scenario impacts still results in overall positive impacts. Note that Table 8 includes the air transportation demand opportunity cost.

Reducing expenditures on fossil fuel imports while increasing investment in activities such as heating system upgrades, weatherization, transportation infrastructure and local renewable energy production generates positive economy-wide impacts relative to the non-compliant baseline. It also creates the need for more local jobs that ramp up over time. The IMPLAN analysis is based on a static structure for relationships between sectors of the economy, and impacts may be even greater if Vermont were to further develop industries that are part of the mitigation scenario supply chain, such as EVs and electric vehicle supply equipment (EVSE).

### *Sensitivity Analyses*

Sensitivity analyses help to further the understanding of how the economic results presented above change when subject to varying assumptions. Based on feedback and recommendations from the subcommittees, three sets of varying assumptions are used to compare the baseline and mitigation scenarios under alternative assumptions.

Public stakeholders and members of the Science and Data Subcommittee encouraged an analysis assuming a higher level of emissions from electricity imports from Hydro Quebec to reflect emissions from flooding for hydro reservoirs, the direct release of methane, and a loss of sequestration from forest that is inundated. Quebec imports (which is mostly hydro, but also includes wind) account for roughly 20% of the generation mix in 2020, declining to 16% in 2025, 13% in 2030, and 6% in 2050. The impact of including higher estimated GHG emissions for Hydro Quebec generation is relatively modest, resulting in a total increase of 275 TMTCO2e from 80 million tonnes of CO2e by 2050 in the mitigation scenario, to 80.3 million tonnes under the sensitivity scenario. Figure 47 illustrates the minor difference in comparative cumulative emissions from the mitigation scenario (light red line) and the sensitivity case with higher Hydro Quebec emissions (light blue line). These results suggest that even if higher emissions values are applied for Hydro Quebec imports, it will not have a large impact on Vermont’s ability to meet the GWSA requirements.

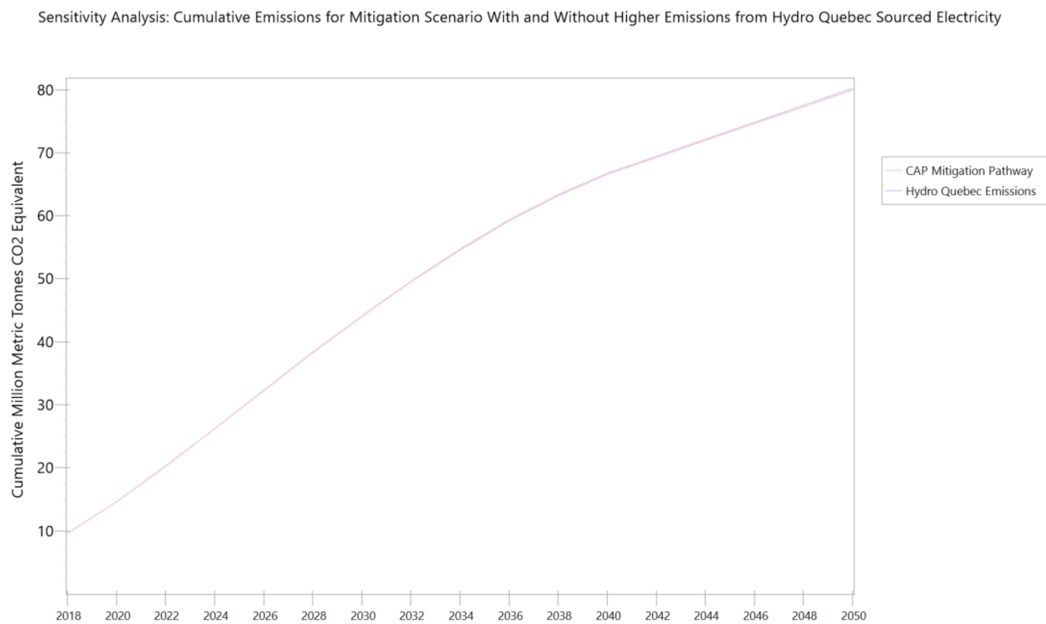


**Figure 47. Comparison of Cumulative Emissions from Mitigation Scenario with and without an Assumption of Higher Emission Levels from Hydro Quebec–Sourced Electricity**

Another sensitivity requested by public stakeholders and members of the Science and Data Subcommittee was to include emissions of biogenic carbon dioxide (CO2) emissions in the pathway results. The Project Team's *Task 1 Report on the Greenhouse Gas Inventory*[31] and methodologies discusses how Vermont's current inventory reports on biogenic CO2 emissions separately and, consistent with guidelines from the U.S. Environmental Protection Agency and the Intergovernmental Panel on Climate Change, Vermont's inventory and the GWSA targets are based on gross emissions levels that do not include biogenic emissions.

The emissions and energy accounting framework in LEAP enables reporting on both biogenic and non-biogenic CO2 emissions, with the latter being used throughout this report. Biogenic emissions are 14% higher in the mitigation scenario than the baseline scenario in 2030. This increases total emissions in 2030 by between 1.8 MMTCO2e and 2.0 MMTCO2e. By 2050, biogenic emissions in the mitigation scenario are less than the baseline by 4% and would add 1.6 MMTCO2e to the 2050 level of emissions. Including biogenic emissions in the mitigation pathways analysis and determining whether Vermont meets the GWSA requirements would require modifying the emissions inventory and the requirement target levels to include the biogenic emissions.

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[31] Energy Futures Group, Inc. August 10, 2021. *Greenhouse Gas Inventory Review: Vermont's Current Methods, Comparison with Accepted Practices, and Recommendations*. https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/GHG%20Inventory%20Report%208-10-2021.pdf

The final sensitivity recommended by the Project Team is to examine results based on a higher level of population growth. The LEAP model includes a high population scenario, which has a greater population growth rate than the mitigation scenario. Both scenarios start at the same population level in 2018, but due to the higher population growth rate, the high population scenario has about 62,530 more people living in Vermont in 2050.

The high population scenario results in higher emissions than the mitigation scenario. Unsurprisingly, much of the increase in emissions comes from the demand sector, particularly from transportation and residential. In 2030, the high population scenario results in additional emissions of 65.9 TMTCO2e, an increase of about 1.3% above mitigation scenario emissions in 2030. In 2050, the high population scenario results in an additional 56.5 TMTCO2e, an increase of about 3.3% over emissions in the mitigation scenario.

## Policy Implications

The CSM Subcommittee has been thoughtful and deliberate in their development of a set of policies they anticipate will be necessary to comply with the requirements of the GWSA, including achieving the necessary GHG reduction targets cost-effectively and equitably. The mitigation scenario is intended to align the initial LEAP modeling conducted by SEI with the recommendations of the CSM Subcommittee. Examples of policies consistent with recommendations from the CSM Subcommittee and that support attaining the GWSA targets in the mitigation scenario are presented in Table 11.

**Table 11. Examples of Policies Supporting Vermont Meeting GWSA Emission Requirements**

| Policy | Sector | Description |
|---|---|---|
| Transportation Climate Initiative | Transportation | A regional collaboration of Northeast and Mid-Atlantic states aimed at lowering CO2 emissions from gasoline and on-road diesel fuel. TCI is capped and reduces total CO2 through an auctioning process that generates proceeds for investment in CO2 reduction strategies. |
| EV incentives | Transportation | Vermont currently offers incentives up to $4,000 per vehicle for purchasing or leasing a new EV on a first-come, first-served basis. Income-qualifying residents are also eligible for funds covering 25% of the costs to purchase a fuel-efficient vehicle up to $5,000. |
| Deployment of EV charging infrastructure to support additional EVs | Transportation | EV supply equipment projects are eligible for low-interest financing through the State Infrastructure Bank. Loans of $100,000 with an interest rate of 1% are available for publicly accessible charging station projects. |
| California Advanced Clean Cars II | Transportation | Requirement on light-duty automakers to deliver an increasing share of EVs to Vermont starting with model year 2026 and reaching 100% of new light-duty vehicles by model year 2035. |
| California Advanced Clean Trucks | Transportation | Requirement on truck manufacturers to deliver an increasing share of medium- and heavy-duty EVs to Vermont, reaching as high as 75% by 2035 for certain vehicle types. |
| Workplace transportation demand management | Transportation | Employer telework and travel demand management measures encourage commuters to use more VMT-efficient means of commuting. Travel demand management measures include ride-sharing programs, subsidized transit passes, bike lockers, showers, marketing of travel demand management measures to employees, and subsidized vanpools. |
| Transit expansion | Transportation | Expanding transit service encourages mode shifting from personal vehicles. |
| Bike, walk, and micro-mobility expansion | Transportation | Complete Streets policies aim to design and operate city streets to better serve all road users, including pedestrians, bicyclists, and transit passengers, who are often underserved by traditional street designs. |
| Smart Growth | Transportation | Smart Growth policies encourage reduced trip lengths and shifts to VMT-efficient modes of travel. Such policies include funding, prioritization, streamlined permitting, and tax breaks, among other mechanisms, to incentivize transit-oriented development, higher-density and mixed-use development, infill or brownfield development, improved transit, and active transportation (bike and pedestrian) infrastructure, and neighborhoods with a range of housing and transportation options. |

| Policy | Sector | Description |
|---|---|---|
| Vehicle Efficiency Price Adjustment | Transportation | Feebate or "true cost pricing" for new vehicle purchases, by class, at the time of registration. Fuel-inefficient vehicles pay a fee while EVs and fuel-efficient vehicles receive a rebate. |
| Clean Heat Standard | Buildings | The CHS is an increasingly stringent annual performance standard that would require Vermont Gas and wholesale suppliers of fuel oil, propane, and other fossil fuels to continuously increase the amount of "clean heat" being used by homes and businesses, thereby reducing the amount of fossil fuels burned ("dirty heat") and the resulting amount of GHGs emitted. In this context, "heat" refers not just to how buildings are heated in winter, but also to how water is heated, how clothes are dried, how cooking is performed, how industrial processes are fueled, and how other energy end uses that currently rely on fossil fuels are met. A range of strategies can be used to generate the "clean heat" credits that would be necessary to demonstrate annual compliance with the CHS, such as weatherization; efficiency measures; electrification with heat pumps, heat pump water heaters, induction cooktops, and other technologies; renewable biomethane, biodiesel, hydrogen, district heating, solar thermal, and other fuels; and advanced wood heating systems. |
| Weatherization at scale | Buildings | Weatherizing Vermont homes not only saves energy and makes homes safer, healthier, and more comfortable, but by insulating and air-sealing it also reduces buildings' energy loads and prepares them for installing heat pumps and biomass heating systems. The Weatherization at Scale initiative would significantly ramp up efforts to insulate and air seal thousands of homes each year through the establishment of sustained funding from the allocation of state and federal resources, increased financial incentives, implementing an innovative on-bill repayment program through utility and financial partners, a carve out for credits for weatherization from the CHS, and significant workforce development initiatives. The Weatherization at Scale initiative has established a goal of treating an additional 90,000 low- and moderate-income Vermont homes over 10 years. |
| Rental Property Efficiency Standard | Buildings | Under a rental property efficiency standard, multifamily buildings (three units or more) that have tenants would be required to meet minimum efficiency requirements for insulation levels, air tightness, and heating system efficiency, and/or to meet a performance standard for space heating efficiency. It is assumed that such a standard would be passed into law in the early 2020s with implementation occurring over about a decade. Technical assistance and financial incentives would be provided to assist landowners in meeting the standard. This policy would work in tandem with the Weatherization at Scale initiative, with most of the multifamily units improved serving low- and moderate-income households and therefore also counting toward the Weatherization at Scale goals but ensuring that multifamily rental properties are addressed. |

| Policy | Sector | Description |
|---|---|---|
| Zero Energy Ready Building Energy Code and Compliance | Buildings | New homes and commercial buildings that are built properly from the start to achieve zero energy standards will not need to receive expensive weatherization services in the future. Vermont has established some of the most aggressive new construction standards in the country for residential and commercial buildings by proposing a net zero ready energy code by 2030. While the energy code has been making significant steps toward this goal, newly constructed buildings have not always kept pace, especially in the residential sector. If Vermont is going to achieve its 2030 zero energy new construction goals, a significant effort must be undertaken to enforce compliance with the Residential and Commercial Building Energy Standards by naming an authority having jurisdiction, putting in place a code enforcement system, and training builders, contractors, and those in the building trades in building science and zero energy construction practices. |
| Refrigerant management | Non-Energy | Refrigerant management is a major way for Vermont to reduce HFC emissions from ODS substitutes. Efficiency Vermont, for example, has launched a refrigerant management initiative, focused on reducing refrigerant emissions. This includes reducing leaks in existing systems containing refrigerants, replacing, or installing new systems or equipment with low GWP equipment, and swapping out high GWP refrigerants with low GWP refrigerants where possible. Refrigerant management in Vermont is a long-term effort and emissions reductions from these efforts are reflected through 2050. |
| Agricultural policies | Non-Energy | Agricultural policies can include incentives and other forms of assistance to promote reduced emissions from enteric fermentation, agricultural soils, and manure management. These can include increased research, demonstration, and incentives to promote the adoption of alternative feed practices, soil practices like no-till and cover crop, and waste digestors. |
| Process manufacturing | Non-Energy | Policies to promote or require industries that have significant non-energy emissions, including semiconductor manufacturing, to report and develop comprehensive reduction plans incorporating both energy and non-energy emissions. |
| Electrification for all | Electricity | To ensure that all Vermonters are able to participate in this transition, programs and policies will be needed to address various barriers including ability to pay for retrofits and upgrades (e.g. developing targeted incentive programs and financing products), identifying and addressing through program design various technical barriers (e.g. need for updated panels, addressing other building issues such as mold, vermiculite), and developing alternative program design opportunities to ensure lower-income and multi-family, condominium residents are able to access specific technologies (e.g. EVSE, community solar). |
| Renewable Energy Standard 100% | Electricity | Strategically assessing how Vermont’s RES should be modified and expanded to accurately direct the market to select the preferred mix of renewables and Tier III opportunities. For example, size, type, and location of renewable technologies in coordination with Tier III opportunities such as strategic electrification, storage, efficiency, with (perhaps) new activities to be added to Tier III, such as demand management. |

| Policy | Sector | Description |
|---|---|---|
| Flexible and coordinated load management | Electricity | Ongoing research, experimentation, and piloting of various flexible and coordinated load management activities will be critically necessary to ensure the power sector build out is as cost-effective and strategic as possible. New regulations, incentives and programs may be needed to leverage optimal approaches. |
| Rate design | Electricity | Redesigning rates to assist and allow for greater flexible and coordinated load management will be needed. These are already available through some utilities, particularly for EV charging. Additional support to smaller utilities will likely be needed, as will partnerships with third party aggregators to lessen work required of the end user. |

By designing the mitigation scenario in LEAP to reflect the pathways, strategies, and actions recommended by the CSM Subcommittee for the CAP, our analysis highlights that, taken together, these interventions can achieve the 2025, 2030, and 2050 targets and are cost-effective in achieving Vermont's numerous GWSA requirements. The scenario modeling conducted with LEAP provides important information for decision-makers as they further refine and begin to implement these policies, including the level of penetration and pace of adoption necessary in the near and long term. It is important to note that because of the system dynamics of decarbonization, many of these policies are interrelated and should be pursued together.

## Conclusion

This *Vermont Pathways Analysis Report*, prepared by the Project Team, provides technical and analytic support for the VCC and its subcommittees and working groups as they develop a CAP to reduce GHGs by 26% below 2005 levels by 2025, 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050. In addition, the GWSA requires that by 2050 Vermont has net zero emissions with total sequestration meeting or exceeding emissions of GHGs. Throughout this report, supported by detailed scenario modeling using the LEAP tool, we have identified the scale and pace of changes required to meet these levels of emissions reductions. While these changes are possible, they will not be easy. The changes will require significant and immediate action in every sector, followed by sustained attention and revisions to programs, initiatives, services, funding, and public messaging. Meeting the requirements of the GWSA can create net economic benefits as Vermont spends less on fossil fuel imports and invests more to improve the performance of and reduce emissions from buildings, transportation systems, agriculture, industrial processes, and the electricity system. Much of the necessary changes build on Vermont's historical commitments and leadership in developing clean energy solutions. Most critical for Vermont and the global community, however, is to face the reality that planning can no longer displace or delay the need for action, and the decades ahead will be a time of deep and transformative change.

# Appendix A. IMPLAN Analysis Methodology

Direct spending produces ripple effects across an economy, affecting supply chains and household spending. For instance, offering EV incentives will increase EV demand, which will affect not only automotive manufacturing but also automotive dealerships and transportation of durable goods. These changes in demand will affect the compensation of workers in these industries, who will then re-spend funds. As the money cycles through the economy, the amounts decrease over time through leakage, or spending on imports or other services from out of Vermont.

The purpose of the macroeconomic impact analysis is to quantify the broader Statewide effects of the mitigation scenario relative to the baseline. Cadmus used IMPLAN software based on Vermont's economy in 2019 (the latest year data are available) to analyze outputs from LEAP.

At its core, IMPLAN is based on an input-output matrix that captures how various parts of the economy are connected. It describes what industries buy and sell to each other and to households and the government. By inputting a direct change to one industry, the software can estimate impacts on connected industries.

IMPLAN produces the following indicators:

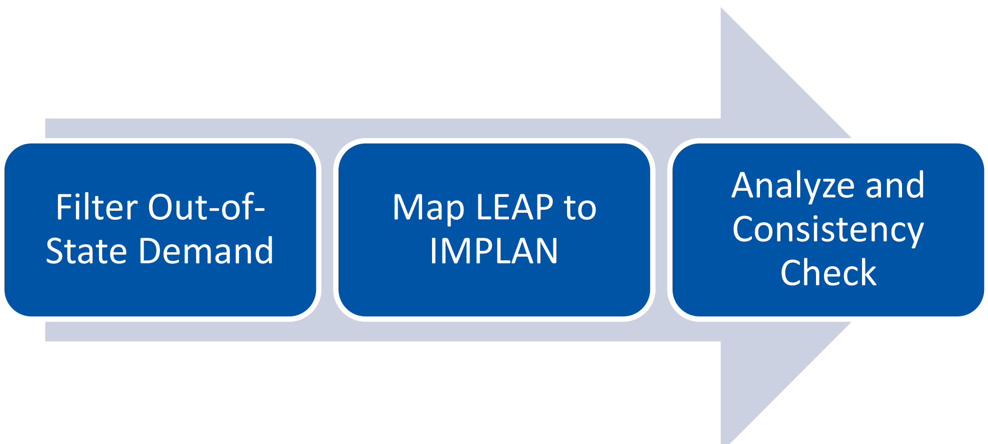
- Employment – a full or part time job lasting one year, consistent with the definition used by the US Bureau of Economic Analysis and Bureau of Labor Statistics. As person can have more than one job, this is not a count of employed persons.
- Labor income – The combination of employee compensation (wages, salaries, benefits, payroll taxes) and proprietor income (e.g., self-employed individuals).
- Output – The total annual production of each industry or commodity (e.g., total revenues adjusted for inventory changes). Example: A baker sells $10,000 worth of cake products. The output is $10,000.
- Value-add – Output minus the intermediate inputs. In other words, it is the increase in value that an industry contributes. Example: A baker sells $10,000 worth of cakes. The baker pays $3,000 in shop costs and $4,000 for ingredients. The value-add is $10,000 minus $7,000 in costs (intermediate inputs), or $3,000.

Since IMPLAN is based on 2019 data, the model is most accurate for changes in the near term. Economies evolve over time so an analysis for demand changes in 2050 will inherently be less accurate than one for 2030. In this study, the team looked at changes occurring from 2020-2050. Other limitations of the model include use of linear industry relationships, which may not hold true for marginal changes. For example, if an industry has an average employment of 10 per million in output, this would be over all production in one year. Adding an additional (marginal) million in output may not actually require 10 additional jobs, but the IMPLAN software would estimate the impact to be 10 direct jobs. As such, an IMPLAN analysis is intended to be order-of-magnitude in nature.

## *Modeling Process – Mitigation Scenario*

Cadmus started with results generated by SEI from LEAP.[32] The process is summarized in Figure A-1. First Cadmus filtered out demand for any out-of-state spending. Since our IMPLAN model is for the state of Vermont, we are not able to model changes out of the study region. The second step was identifying the appropriate IMPLAN codes to use for each of the LEAP mitigation costs. In this step, any imports (such as fossil fuels) were removed from the analysis since the impacts would accrue out of the region. We kept supply chain (local) impacts that support those imports. Supply chain impacts include transportation and retail and wholesale operations. Finally, Cadmus modeled the remaining cost categories in IMPLAN and analyzed the results, checking to ensure that the largest impacts could be traced back to the inputs.

**Figure A-1. Process of Translating LEAP Outputs to IMPLAN Inputs**




Starting and final input amounts by sector are shown in Table A-1. The value that ultimately went into IMPLAN is greater than the original amount because the fuels sector increased significantly (most of the decreased demand is in imported fossil fuels).

[32] LEAP v 2.03 Outputs, values provided in MM $2019 with 2% discount rate

**Table A-1. Comparison of LEAP Output and IMPLAN Inputs**

| Sector | Description | LEAP Output (Millions 2019$) | IMPLAN Inputs (Millions 2019$) |
|---|---|---|---|
| Residential | Maintenance and equipment | 1,840 | 1,311 |
| Commercial | Maintenance and equipment | 348 | 348 |
| Road Transport | Vehicles and charging | 2,744 | 659 |
| VMT | Road improvements and public transit | 2,642 | 2,642 |
| Non-Energy | Agriculture support services, refrigeration | 779 | 495 |
| Delivered Heat | Construction and power boiler | 154 | 154 |
| Electricity | Construction of power structures, generation, natural gas, batteries and solar | 1,489 – in state<br>6,033 – out of state | 1,483 |
| Fuels | Fossil fuels, biogas, biodiesel, ethanol, imported electricity, wood pellets, cord wood, wood waste solids | -14,048 non-wood fuels<br>-839 wood-based fuels | -4,041 |
| **Total** | | **1,142** | **3,052** |

The final IMPLAN inputs are provided in Table A-2 by industry or commodity code.

**Table A-2. Final IMPLAN Inputs**

| IMPLAN Code | Description | Amount (2019$MM) |
|---|---|---|
| 418 | Transit and ground passenger transportation | 1,321 |
| 62 | Maintenance and repair construction of highways, streets, bridges, and tunnels | 1,321 |
| 56 | Construction of other new nonresidential structures | 1,254 |
| 3039 | Electricity | 1,177 |
| 3052 | Newly constructed power and communication structures | 1,175 |
| 61 | Maintenance and repair construction of residential structures | 779 |
| 3412 | Retail services - Miscellaneous store retailers | 390 |
| 19 | Support activities for agriculture and forestry | 250 |
| 60 | Maintenance and repair construction of nonresidential structures | 244 |
| 3307 | Semiconductors and related devices | 113 |
| 143 | All other miscellaneous wood product manufacturing | 90 |
| 45 | Electric power generation - Biomass | 86 |
| 275 | Air conditioning, refrigeration, and warm air heating equipment manufacturing | 78 |
| 272 | Other commercial service industry machinery manufacturing | 69 |
| 241 | Power boiler and heat exchanger manufacturing | 61 |
| 222 | Other aluminum rolling, drawing, and extruding | 61 |
| 3395 | Wholesale services - Machinery, equipment, and supplies | 56 |
| 52 | Construction of new power and communication structures | 39 |
| 42 | Electric power generation - Solar | 37 |
| 55 | Construction of new commercial structures, including farm structures | 31 |
| 3405 | Retail services - Building material and garden equipment and supplies stores | 22 |
| 3404 | Retail services - Electronics and appliance stores | 22 |
| 3415 | Rail transportation services | 11 |
| 3394 | Wholesale services - Household appliances and electrical and electronic goods | 7 |
| 333 | Storage battery manufacturing | 6 |
| 39 | Electric power generation - Hydroelectric | 6 |
| 479 | Waste management and remediation services | 2 |

| IMPLAN Code | Description | Amount (2019$MM) |
|---|---|---|
| 48 | Natural gas distribution | 2 |
| 3396 | Wholesale services - Other durable goods merchant wholesalers | 0 |
| 3400 | Wholesale services - Other nondurable goods merchant wholesalers | (12) |
| 274 | Heating equipment (except warm air furnaces) manufacturing | (43) |
| 3342 | Heavy-duty trucks | (79) |
| 3401 | Wholesale services - Wholesale electronic markets and agents and brokers | (105) |
| 3417 | Truck transportation services | (134) |
| 3392 | Wholesale services - Motor vehicle and motor vehicle parts and supplies | (175) |
| 3402 | Retail services - Motor vehicle and parts dealers | (310) |
| 413 | Retail - Non-store retailers | (981) |
| 3399 | Wholesale services - Petroleum and petroleum products | (1,843) |
| 3408 | Retail services - Gasoline stores | (1,975) |
| **Total** | | **$3,052** |

## *Opportunity Cost*

While increased spending typically translates to greater economic activity, any expenditure could have been spent on other activities that produce alternative economic effects. To model opportunity costs, Cadmus allocated 70% of net mitigation scenario costs to changes in household income, with the other 30% of costs assumed to fall in the nonresidential sectors.[33]

As was shown in Table A-2, the net cost of the mitigation scenario is $1.1 billion. Taking 70% of this amount yields $799 million in opportunity costs that we will model as being spread over Vermont households. Cadmus modeled two allocation schemes, shown in Table A-3, which outlines the percentage for each income group and the effective amount modeled. The first scheme is proportional to the household population distribution by income group, meaning everyone pays a similar level for decarbonization. The second scheme is based on air transportation demand, which we obtained from the underlying IMPLAN household demand data. The results show that wealthier households have relatively greater demand for air transportation.

[33] IMPLAN cannot be used to model nonresidential sector opportunity costs, so those were not included.

**Table A-3. Opportunity Cost Allocations**

| Description | Air Transportation Demand | Air Transport Amount ($MM) | Proportional to Population | Proportional to Population Amount ($MM) |
|---|---|---|---|---|
| Households LT15k | 2% | -16 | 10% | -80 |
| Households 15-30k | 4% | -32 | 14% | -112 |
| Households 30-40k | 5% | -40 | 9% | -72 |
| Households 40-50k | 5% | -40 | 8% | -64 |
| Households 50-70k | 11% | -88 | 16% | -128 |
| Households 70-100k | 18% | -144 | 17% | -136 |
| Households 100-150k | 22% | -176 | 15% | -120 |
| Households 150-200k | 12% | -96 | 5% | -40 |
| Households GT200k | 20% | -160 | 5% | -40 |

## *Employment Impacts by Industry*

Table A-4 shows the impacts for industries with employment changes greater than 2,000.

**Table A-4. Employment Impacts by Industry (Absolute Value Greater than 2,000)**

| IMPLAN Code | Description | Employment Impact |
|---|---|---|
| 418 | Transit and ground passenger transportation | 32,600 |
| 52 | Construction of new power and communication structures | 12,900 |
| 56 | Construction of other new nonresidential structures | 9,500 |
| 19 | Support activities for agriculture and forestry | 9,000 |
| 62 | Maintenance and repair construction of highways, streets, bridges, and tunnels | 8,800 |
| 61 | Maintenance and repair construction of residential structures | 5,500 |
| 412 | Retail - Miscellaneous store retailers | 5,000 |
| 405 | Retail - Building material and garden equipment and supplies stores | 4,200 |
| 413 | Retail - Non-store retailers | -2,100 |
| 408 | Retail - Gasoline stores | -4,000 |

# Appendix B. Additional Resources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