

WHITEPAPER

The EAN Emissions Reductions Pathways Model

August 2021

Prepared by



ENERGY ACTION NETWORK

The EAN Emissions Reduction Pathways Model Whitepaper

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Executive Summary

The EAN Emissions Reduction Pathways Model (the Model) has been developed by EAN to present pathway scenarios that would be necessary for Vermont to meet its statutory greenhouse gas (GHG) reduction requirements for the years 2025 and 2030, as set out by the Global Warming Solutions Act. The Model primarily focuses on emission reductions related to energy use, which makes up roughly three-quarters of total emissions.¹ EAN's attempt to model pathways is based on current best practices and technological options. The Model is not a prediction of what will happen in the future, it is meant to illustrate the scale and pace of transformation that will be necessary to hit the Global Warming Solutions Act's requirements.

The model depicts 20 separate reduction measures which are grouped into six overall pathways split between the Transportation and Thermal sectors. The Transportation pathways are: Electrification, Transportation Mode Changes, and Efficiency & Low-Carbon Fuels. The Thermal pathways are: Electrification, Weatherization & Efficiency, and Wood & Biofuels. Vermont's electric generation and power purchases are already very low carbon so pathways for the Electric sector were not characterized in the Model. However, all new capacity additions were assumed to be low carbon, with the entire sector approaching net zero emissions by 2035.

There are four key takeaways from the Model:

1) Meeting our emissions reduction requirements for 2025 and 2030 is possible:

We have the technology and know-how using presently available measures.

2) Equipment choices matter greatly:

Although GHG emissions from the energy sectors are primarily driven by fossil fuel use, fossil fuel use is primarily driven by equipment choices. Therefore, changing out fossil fuel-based

¹ Vermont Agency of Natural Resources, Vermont Greenhouse Gas Inventory and Forecast (1990-2017), 2021.

vehicles and heating systems (and other appliances and pieces of equipment) in favor of zero or low-carbon emitting alternatives is key to unlocking both near and long-term emissions reductions. The timing of equipment change out will often occur before the end of its useful lifecycle. This gets fossil fuel equipment out of use quicker, and low-carbon equipment in use faster.

3) Clean vehicles and clean heating systems will need to be installed at a *geometric rate rather than a linear rate*:

This is both because of the "lock-in" effect of equipment purchase choices having an impact on emissions for decades and also because Vermont's emissions reduction requirements are not linear. For instance, we will need greater energy sector emissions reductions by 2030 than 2025 (0.96 Million Metric Tons CO₂e vs 2.63 Million Metric Tons CO₂e). Many of these markets also need time to build up in order to reach the level needed to achieve significant emissions reductions.

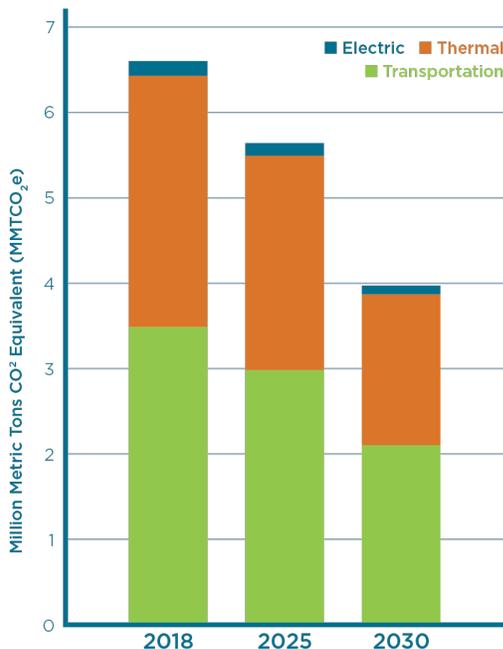
4) Each measure will have different impacts over differing time periods:

For example, the Model shows transportation efficiency improvements playing a big role in meeting the 2025 reduction targets, but its impact declines over time. On the other hand, electrification of transportation plays a bigger role in meeting 2030 targets than it does in meeting 2025 targets, so its impact increases over time. Additionally, some measures that have not been widely implemented yet will have to scale significantly and rapidly in order to meet 2030 targets, including transportation electrification and RNG in the thermal sector.

Introduction

The EAN Emissions Reduction Pathways Model has been developed to present pathway scenarios for Vermont to meet its statutory GHG reduction requirements for the years 2025 and 2030. These requirements are laid out in the Global Warming Solutions Act (GWSA), which also states that these pathways shall “provide for greenhouse gas emission reductions that reflect the relative contribution of each source or category of source emissions.” The two figures below show the targets for each milestone year, and provides an illustrative view of how each sector will need to proportionally adjust over time.² In terms of nominal reductions, in million metric tons CO₂ equivalent (MMTCO₂e), the largest reductions would need to occur in the Transportation and Thermal sectors.

Energy emissions goals by milestone year



Source: EAN Emissions Reduction Pathways Model, 2021.

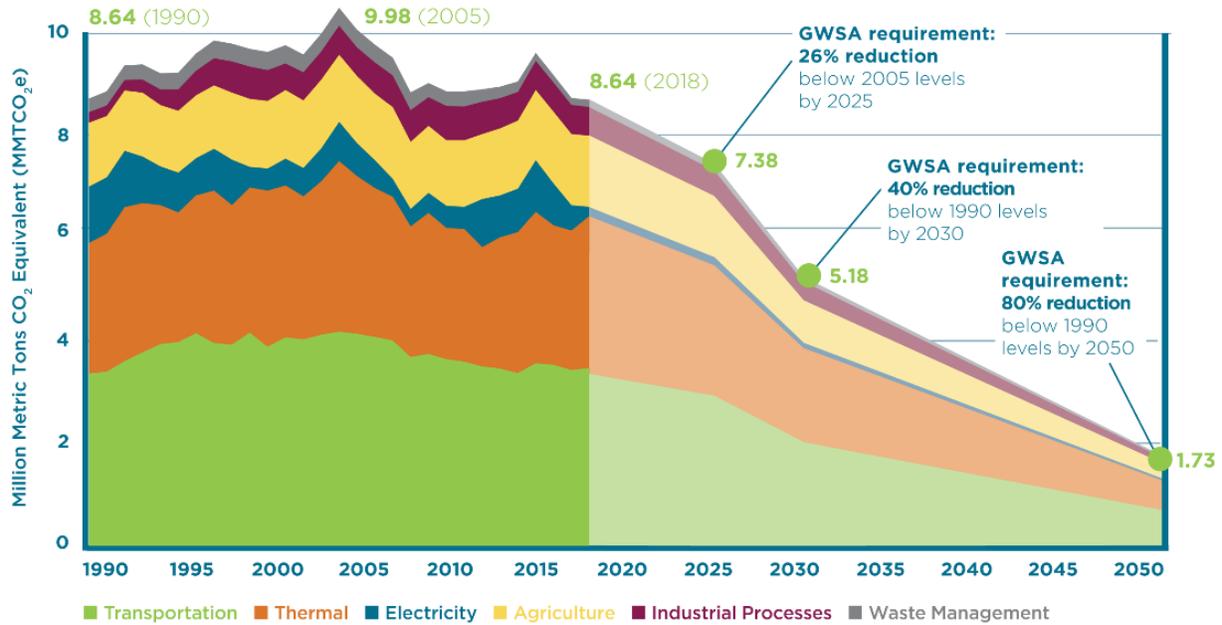
The model focuses on GHG emission reductions related to energy use, which makes up roughly 76% of total emissions, as of 2018.³ EAN’s attempt to model pathways is based on current best practices and options. These are known, proven, and available emission reduction measures, for which there exist peer-reviewed literature and/or measured characteristics. The Model only examines currently-identified feasible measures and technologies: more prospective pathways or measures may play a role in meeting out-year targets, especially for 2050, but we did not include pathways or measures where we were not confident of their readiness to be

deployed and scaled in Vermont over the next 5-10 years (green hydrogen, for instance).

² Please note that the figure on this page only shows energy sectors, whereas the figure on the following page shows all sectors.

³ Vermont Agency of Natural Resources, Vermont Greenhouse Gas Inventory and Forecast (1990-2017), 2021.

Vermont's historical GHG emissions and future requirements



Source: Vermont Agency of Natural Resources, Vermont GHG Emissions Inventory and Forecast (1990-2017), 2021.

Also important to note is that Measures have varying impacts, in terms of emission reductions. As such, this analysis focuses more on those Measures for which there is evidence to suggest that they will likely have a greater impact. This Model represents EAN's best attempt to characterize the impact of the Pathways, given energy use and emission data presently available. Many of the included assumptions were based on the latest technical characterizations that have been used in state policy.

Additionally, although this model can and should serve as a reference for policymakers, it is a sectoral pathways model and not a policy pathways proposal. The Model is not a prediction of what will happen in the future. We will likely need to create policy and regulatory frameworks that do not yet exist in order to achieve the scale and pace of transformation that we model. Also, as markets, technologies, and behaviors evolve, we expect that targets for some Measures will be surpassed, while others may not be met. The ultimate goal of the Model is to present illustrative Pathways of the scale and pace of change that will likely be necessary to meet the energy-related emissions reduction requirements of the GWSA.

This Model also does not address what the most cost-effective emissions or equitable reduction pathways would be. Additional economic, demographic, environmental, and health related analysis—especially about cost effectiveness and equity—will be necessary complements to this model to inform sound policy, regulatory, and program design.

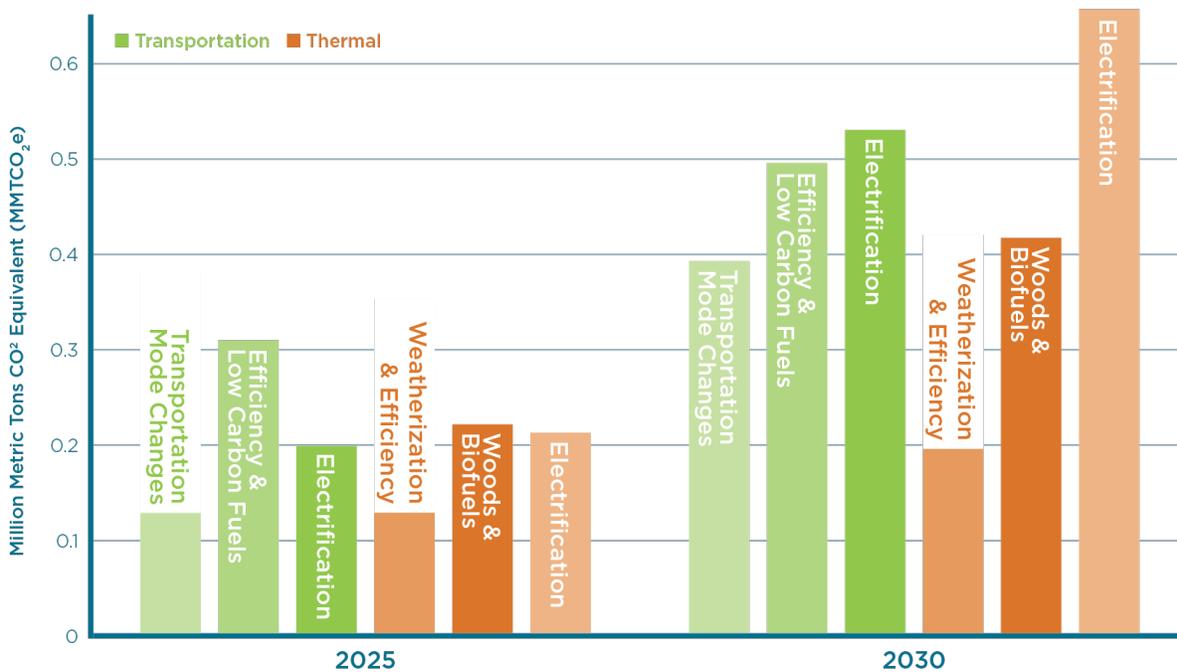
This Model has undergone multiple iterations and continual improvements from November 2020 to June 2021. Initial feedback and review were provided by many partners from organizations ranging from the Vermont Agency of Natural Resources (ANR), the Vermont Department of Public Service (PSD), the Vermont Agency of Commerce and Community Development (ACCD), Energy Futures Group (EFG), and the Regulatory Assistance Project (RAP).⁴

⁴ We would like to thank, in particular, the following individuals: Collin Smythe, TJ Poor, Claire McIlvennie, Philip Picotte, Ken Jones, Richard Faesy, Chris Neme, Bill Regan, and Richard Cowart, among others.

Key Findings

The Model is designed around the goal of meeting both the 2025 and 2030 GWSA emissions reduction requirements. EAN’s definition of meeting the targets is being within 0.1 MMTCO₂e of the targets (10% above or below the targets). Rather than trying to model to meet the exact target amount, it is a directional model that speaks to the necessary rate and scale of change within a margin of error.

Emissions reductions by pathways



Source: EAN Emissions Reduction Pathways Model, 2021.

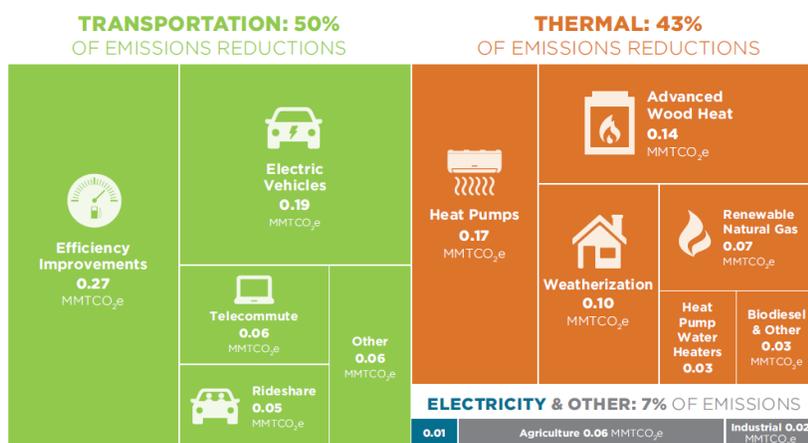
The model depicts 20 separate reduction Measures, which are grouped into six overall Pathways, as shown in the above graph. These Pathways and Measures are split between the Transportation and Thermal sectors. Both sectors are made up of three broad pathways. The Transportation Pathways are: Electrification, Transportation Mode Changes, and Efficiency & Low-Carbon Fuels. The Thermal Pathways are: Electrification, Weatherization & Efficiency, and Wood & Biofuels. The graphics below show the relative significance of the highest-impact

measures across the Transportation and Thermal sectors.⁵ Although these are not the only technology and method options possible, they are the ones that were identified as having the greatest opportunity for GHG reductions, and thus received the greatest focus for this analysis.

Based on the selected assumptions and inputs, the Model’s output shows that the Electrification Pathways, for both Thermal and Transportation, will play the most significant

Modeled emission reductions for 2025

Total reductions of 1.26 MMTCO₂e to meet Vermont’s statutory emissions reduction requirements

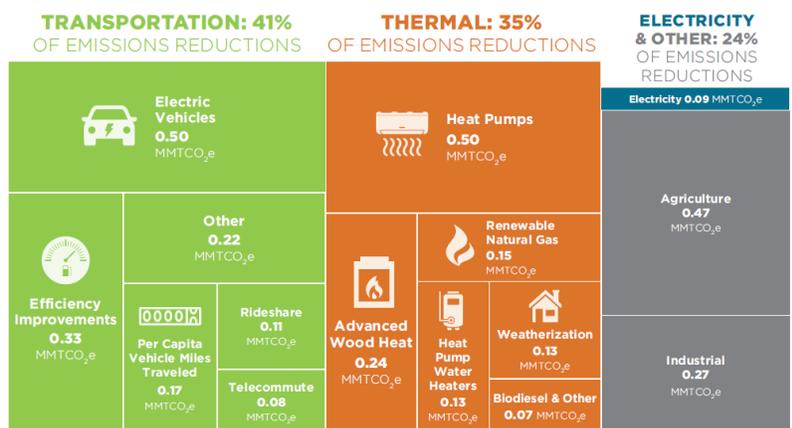


role in reductions during the time period leading up to 2030, as seen in the graphic above.

Together, the Thermal and Transportation Electrification Pathways make up approximately 34% of total energy emissions reductions in 2025, which increases to 44% in 2030.⁶ The relative significance

Modeled emission reductions for 2030

Total reductions of 3.46 MMTCO₂e to meet Vermont’s statutory emissions reduction requirements



of electrification shows the need to create strong policy frameworks that will support the necessary electric technology uptake across all sectors.

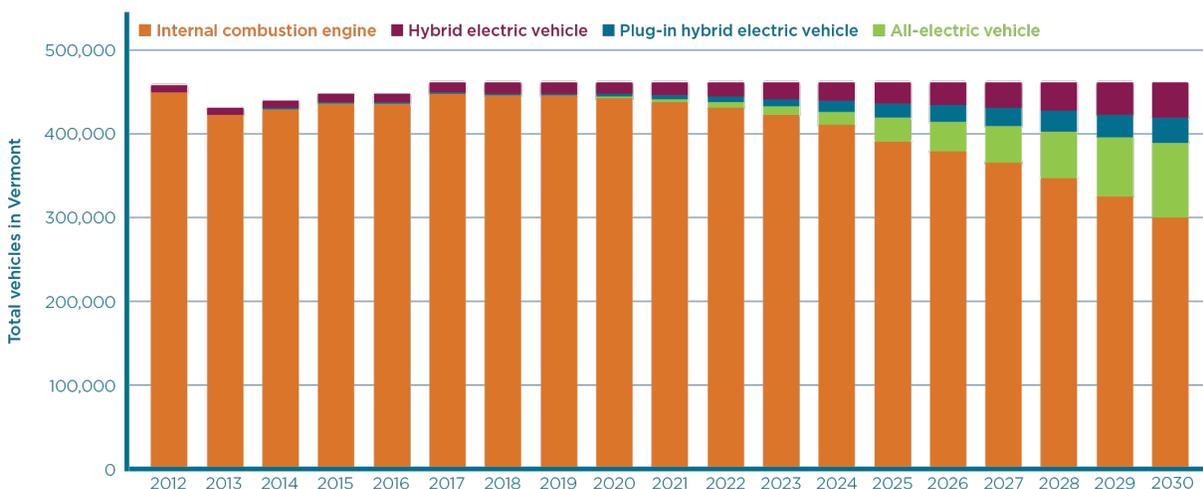
Source for both graphs: EAN Emissions Reduction Pathways Model, 2021

⁵ While the graphics include Agriculture and Industrial Processes, these are not actually included in the Model. They are meant to serve illustrative purposes.

⁶ By 2050, the Model shows that Electrification will be responsible for around 60% of total energy emissions reductions.

In 2025, the Model shows that the Transportation Efficiency & Low Carbon Fuels Pathway will result in the greatest energy emissions reductions. This is primarily due to efficiency increases in the fossil-fuel based vehicle fleet. However, due to the changing vehicle fleet composition, over time less focus will be on making the fossil-fuel based fleet more efficient, and more focus will be on electrifying the fleet as a whole. The most significant pathway ramp-up rate, in terms of scale, involves Transportation Electrification, which encompasses light and heavy-duty electric vehicles and buses. Electric Vehicles in the light-duty fleet (LVF) is the Measure that sees the greatest reductions, across both 2025 and 2030. These are vehicles that would replace internal combustion engine vehicles. The chart below shows the changing LVF composition through 2030 that the Model shows would be necessary to meet the Transportation emissions targets.⁷

Light vehicle fleet composition



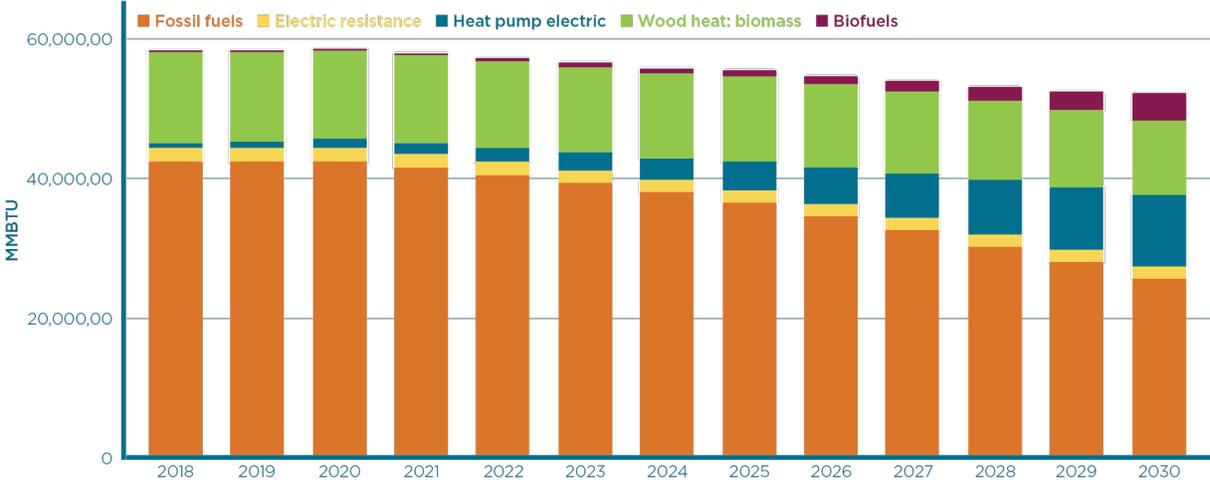
Source: EAN Emissions Reductions Pathways Model, 2021; Vtrans, Transportation Energy Profile, 2019.

Close behind the Transportation Electrification Pathway, in terms of change of pace, is the Thermal Wood & Biofuels Pathway, which has a smaller emissions impact but has the greatest ramp rate through 2030. This rapid change of pace is mostly due to the Renewable Natural Gas

⁷ Historic data for the chart comes from the 2019 Vermont Transportation Energy Profile. Future projections come from the 2021 EAN Emissions Reduction Pathways Model.

(RNG) Measure. The graphic on the following page shows the changing thermal heat load composition. Although biofuels (which includes RNG) still make up a small portion of the heat load breakdown, it increases dramatically over the 12-year period that is shown. The graphic also highlights the ramp rate that is expected to occur in heat pumps, although it is less than that for biofuels.

Thermal heat load composition



Source: VT Thermal Fuels and GHG Milestones Projections to 2050 (May 2021 version)

Although each Pathway has varying degrees of impacts, in order to meet the required emissions reductions, *all* of the Pathways and Measures would be needed at the scale and pace as shown in the Model. If Vermont falls short on any of the pathways, other pathways and/or measures will be needed to make up the difference. It is also important to note that the required emissions reductions for 2030 are almost three times greater than 2025, which further highlights the changing ramp-up rates over time.

Vermont’s electric generation and power purchases are already very low carbon and account for only 2% of the state’s emissions.⁸ So although the Electricity sector plays an important role in the decarbonization of Vermont’s energy use, because of the significant work that has

⁸ Vermont Agency of Natural Resources, Vermont Greenhouse Gas Inventory and Forecast (1990-2017), 2021.

already been done in promoting renewables and acquiring low-carbon sources of electricity, the Model does not include any specific Electricity sector Pathways.⁹ It does, however, assume that all new capacity additions will be low carbon, with the entire sector approaching net zero emissions by 2035. This assumption aligns directionally with the required compliance with the Renewable Energy Standard (RES).

⁹ The Model also assumes that the future requirements of the Renewable Energy Standard will be met.

Methodology

There are a few broad points that are important to keep in mind regarding the methodology of the Model before jumping into more in-depth details. The Model uses 2018 as its baseline and starting point year. This year was selected because some of the Measures do not have more recent status updates or unit counts, and it was necessary for all of the Measures to begin at the same starting point. From 2018, the Model projects emissions reductions and associated input changes on an annual basis. Although this paper focuses on the time period through 2030, the Model has been built to detail emissions to 2050. The period after 2030 was not included in this paper due to the uncertainty of technology change and market behavior that we cannot currently predict.

The Model focuses on energy sectors, with most of the attention on the Thermal and Transportation sectors. As stated above, energy emissions make up the vast majority of emissions in Vermont. Moreover, the Thermal and Transportation sectors make up 96% of energy-related emissions.^{10,11} Also stated above, due to the significant work that has already been done in promoting renewables and acquiring low-carbon sources of electricity, future changes to the Electricity sector do not play a large role in the Model.

In setting the 2025 and 2030 emissions reduction goals, each sector's reduction amount is equal to at least the proportion of overall energy emissions it is responsible for. For the Transportation sector this would be 53%, and for Thermal 43%.^{12,13} The 2025 and 2030 targets for each sector, shown here, are based on this breakdown.



Source: EAN Emissions Reduction Pathways Model, 2021.

¹⁰ Together they make up roughly 74% of overall emissions.

¹¹ Vermont Agency of Natural Resources, Vermont Greenhouse Gas Inventory and Forecast (1990-2017), 2021.

¹² Transportation is responsible for 40% of overall emissions, and Thermal for 34%.

¹³ Vermont Agency of Natural Resources, Vermont Greenhouse Gas Inventory and Forecast (1990-2017), 2021.

The Model is broken down into 20 separate reduction Measures which, based on the model inputs, emerged as having the greatest reduction potential, as well as those that current evidence suggests are most likely to gain traction over the time period leading up to 2030. These measures were chosen based on current best practices and options. The Model only examines currently-identified feasible methodologies and technologies.

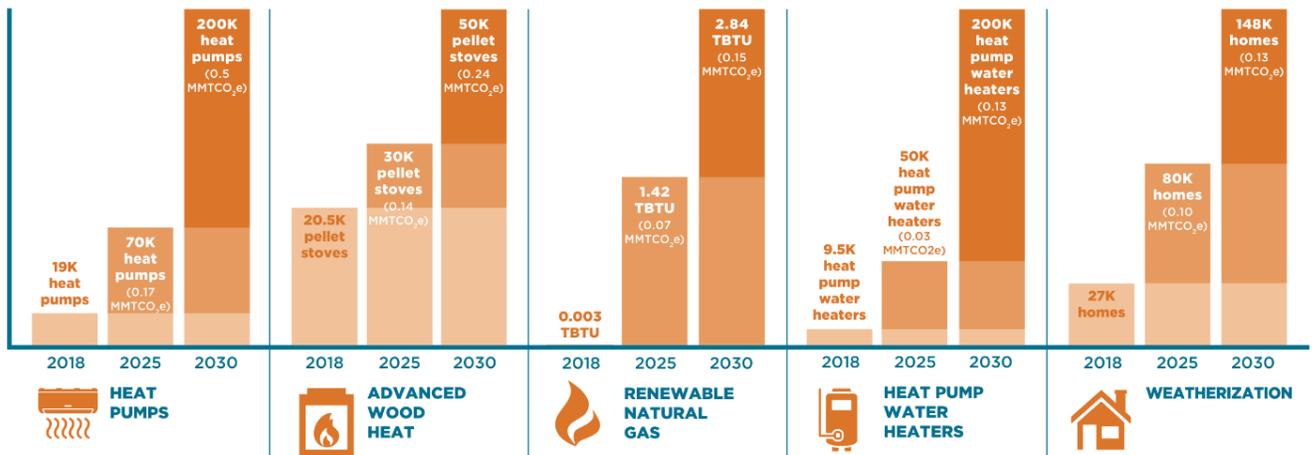
The Model uses assumptions from peer-reviewed literature, or those that have published measured characteristics. As much as possible, Vermont-specific assumptions were used to get the most accurate representation of likely impacts. Assumptions will be discussed at length in the following section.

The Model tries to correct for interactive effects amongst measures as much as possible. This is done to avoid misstating emissions reduction impacts from the various measures. For example, in the Thermal sector, while the Weatherization Pathway initially has a large reduction impact due to the immediate effect of reducing fossil fuel emissions, over time as fossil fuel equipment is replaced with more efficient electric options, the GHG impact of building weatherization falls and needs to be reflected in the Model. This Pathway also includes a component related to equipment efficiency which will lower the heating and cooling load over time. Without taking these changes into account, the Model would risk overcounting the emissions reductions from Weatherization & Efficiency.

Main Assumptions

The backbone of the analysis for the Model are the energy and emission assumptions that were used. As noted previously, the assumptions reflect current best practices and options, and only those with peer-reviewed literature and measured characteristics were used. As much as possible, Vermont-specific assumptions were used to reflect the most accurate and likely impacts in the state. This is important as Vermont has very specific characteristics that cannot be accurately represented by national-level assumptions. Each technology measure also used assumptions regarding annual rates of change that were applied in order to meet specific targets and market penetration assumptions. Assumptions regarding emissions factors as well as the five highest-impact measures will be discussed below. The highest-impact measures, along with their unit count growth and associated emissions reductions, are shown in the below graphic.¹⁴

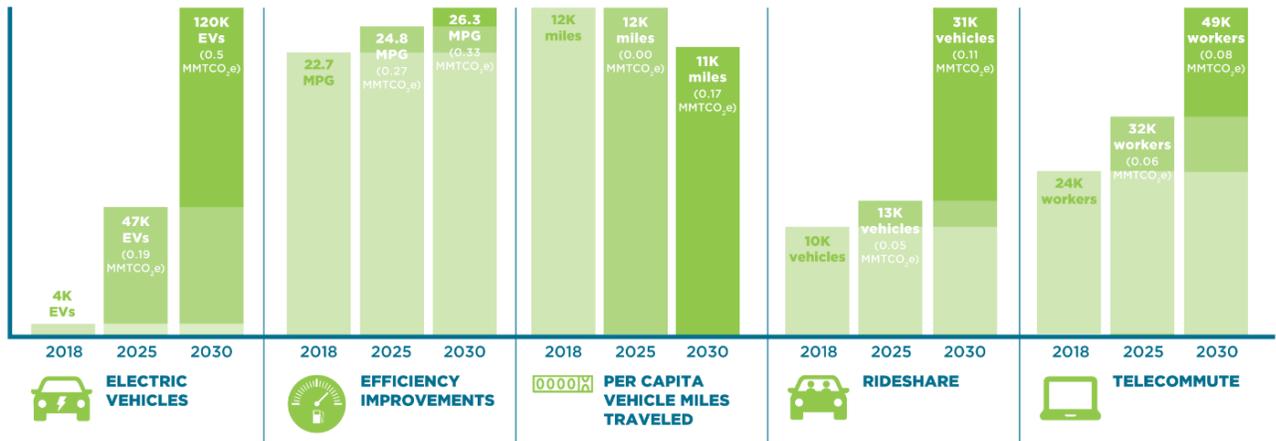
Highest impact thermal measures in EAN Pathways Model



Source: EAN Emissions Reduction Pathways Model, 2021. Note: graph shows cumulative unit counts and is scaled based on unit count growth, not GHG reduction.

¹⁴ This graphic shows the necessary scale and pace of adoption, by measure. It is not scaled for GHG reductions – for a more in-depth view of that, see the graphic on page 6.

Highest impact transportation measures in EAN Pathways Model



Source: EAN Emissions Reduction Pathways Model, 2021. Note: graph shows cumulative unit counts and is scaled based on unit count growth, not GHG reduction.

One of the most important assumption categories is that of Emissions Factors. These are of great significance as every single Pathway and Measure’s impact depends on its emissions factors. The majority of the emissions factors used came from either the Environmental Protection Agency (EPA) or the Energy Information Administration (EIA). These sources were chosen due to their rigorous methodologies and widespread usage. The only deviations are the emissions factors for Electricity and Wood. Both of their emission factors are derived by EAN from the Vermont Agency of Natural Resource’s 2018 GHG inventory to align with current state GHG accounting methodology.

The electricity emission factor deviates most from the assumptions published by EPA and EIA. This is because Vermont has the least carbon intensive electricity portfolio in the U.S., so using regional or national level data would not be accurate. Comparing it to the regional level, the ISO-New England electric emission factor is greater than Vermont’s by a factor of 10.^{15,16}

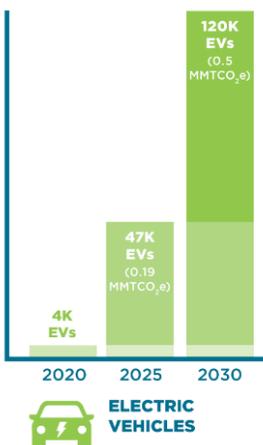
¹⁵ The electric emission factor for ISO-NE is 310 kg CO₂e/ MWh, while the one for Vermont is only 28 kg CO₂e / MWh.

¹⁶ ISO-New England oversees the operation of New England’s bulk electric power system and transmission lines. It serves Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

The wood emission factor also deviates from the EPA and EIA factors and is based on the Agency of Natural Resource’s GHG methodology for wood emissions. Their methodology assumes Vermont’s wood procurement is done on a “sustainable harvest” basis, and thus net CO₂ emissions are zero on a hundred-year global warming potential cycle. ANR does count methane emissions from biomass combustion and includes a factor for the fossil fuel used in harvesting and transport of biomass fuel. The model uses a CO₂e factor of 5.44 kg CO₂e/ MMBTU compared to the EPA assumption of 95 kg CO₂e/ MMBTU for wood.

There are also some important caveats to note regarding the emissions factors for biofuels. ANR currently does not characterize biofuels at all in its GHG inventory or methodology. As such, future updates to the inventory could have implications on the Model’s assumptions and accompanying results. The Model uses EPA and CA lifecycle emission estimates for biofuels, but the Model’s assumptions could change if future Vermont GHG Emissions Inventories account for biofuel emissions on a different basis. This would impact the emissions factors for RNG, biofuel oil, ethanol, and biodiesel. For each of these, we do not know whether the emissions factors (and consequently, the emissions reductions) will increase or decrease in future ANR emissions accounting. Using the Model’s current biofuel methodology, it is able to meet (and actually has a surplus for) the 2025 and 2030 emissions reductions targets.

Electric Vehicles:



Electric vehicles (EVs) are one of the largest-impact measures in the Model. As shown in the included graphic, the Model shows 47,000 EVs by 2025 and 120,000 EVs by 2030.¹⁷ Vermont currently has around 4,000 EVs, which shows the rapid transformation needed by this measure. Meeting these targets would mean about one out of every four new personal vehicles purchased in Vermont over the next five years would need to be electric and then at least one out of every two vehicles

¹⁷ These vehicle counts are inclusive of both all-electric vehicles and plug-in hybrids.

between 2026-2030. These unit count projections were not chosen arbitrarily. They follow the 2025 goals laid out in the State’s Comprehensive Energy Plan and the electric vehicle forecasts in the VELCO 2021 long range plan.¹⁸ The Model’s 2025 unit count follows the “high” 2025 scenario in the plan, while the 2030 unit count falls between the “medium” and “high” 2030 scenarios.¹⁹ The VELCO forecast and EAN’s projections also follow guidance on projected supply of EVs available from Drive Electric VT on what is regarded as feasible in terms of market supply and uptake.

The 2016 Comprehensive Energy Plan (CEP) calls for 10% of registered vehicles in Vermont to be electric by 2025. Currently the Model shows 10% by 2025 and 26% by 2030.²⁰ The Model also includes assumptions related to the breakdown of the electric vehicle fleet between all-electric vehicles (AEVs) and plug-in hybrids (PHEVs). According to the most recent registration data, 34% of EVs in Vermont are AEV, and 66% PHEV. However, the proportion of AEVs relative to PHEVs has been increasing over the past few years.²¹ Forecasting the continuation of this trend toward AEVs, the Model projects the EV proportion breakdown to change over time to be 40% PHEV by 2025, and 25% PHEV by 2030.²² The decrease in proportion of PHEVs within the EV fleet will result in greater emissions reductions, as AEVs have a smaller carbon footprint than PHEVs.²³

In addition to the above-discussed assumptions, assumptions related to the characterization of the Vermont vehicle fleet come from the 2019 Vermont Agency of Transportation (VTrans) Transportation Energy Profile (TEP). The TEP informed assumptions related to fleet size and characterization. The 2019 Tier III TAG Planning Tool (TAG), which measures the fossil fuel

¹⁸ These forecasts were developed by Itron

¹⁹ The Itron “High” 2025 scenario is 41,969 vehicles. The Itron “Medium” 2030 scenario is 71,624 vehicles, and the “High” 2030 scenario is 190,125 vehicles.

²⁰ Although this Whitepaper only discusses modeling results through 2030, the Model itself projects out through 2050. By 2050, the Model predicts that 90% of the light-duty fleet will be electric.

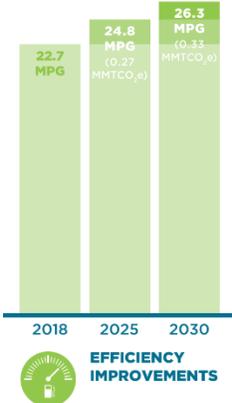
²¹ Itron, 2020 Long-Term System Load Forecast Year, 2020.

²² By 2050 the Model forecasts that only 15% of EVs will be PHEV.

²³ PHEVs run on gas roughly 45% of the time so they have a larger impact than AEVs.

reduction impacts of Tier III utility programs, was used as the benchmark for more technical aspects relating to the efficiency of electric vehicles and their potential emission reductions.

Fleet Efficiency Increases



Efficiency increases within both the light vehicle fleet (LVF) using internal combustion engines (ICE), as well as the ICE heavy duty fleet (HDF) are Measures that also result in significant energy emissions reductions. The Model shows an increase in overall efficiency for the ICE LVF from 22.7 mpg in 2018, to 26.3 mpg in 2030. Similarly, the ICE HDF efficiency increases from 6.5 mpg in 2018, to 7.7 mpg in 2030. The LVF efficiency assumptions follow those set out by VTrans in the 2019 TEP, which shows an annual increase of 0.3 mpg. The HDF efficiency increase assumption, set at 0.03

mpg per year, was made by EAN, based on historic trends and the current stalemate concerning implementation of the 2016 Phase 2 Heavy Duty Efficiency Standards.²⁴

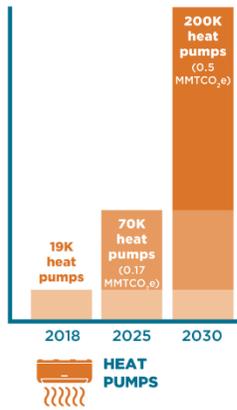
Unlike for other Measures, there are no specific CEP goals related to vehicle efficiency. However, there are indirect goals that will be impacted by it. The CEP has an overall goal of reducing total transportation energy use by 20% from 2015 levels by 2025. Increasing fleet efficiency will have a significant impact on total transportation energy use. Taking into account all of the Transportation Pathways, the Model shows an overall 36% reduction in transportation energy use from 2010 levels by 2030. In 2030, Efficiency Improvements account for 25% of total modeled Transportation reductions, which shows the relative importance of this Measure.

It is also important to note that the Model assumes that the ICE fleet decreases over time (as EVs begin to be a significant portion of the overall fleet). Because of this, LVF ICE efficiency reductions peak in 2032, and HDF ICE efficiency reductions peak in 2037.

²⁴ This covers heavy duty vehicles from 2018-2027

Heat Pumps:

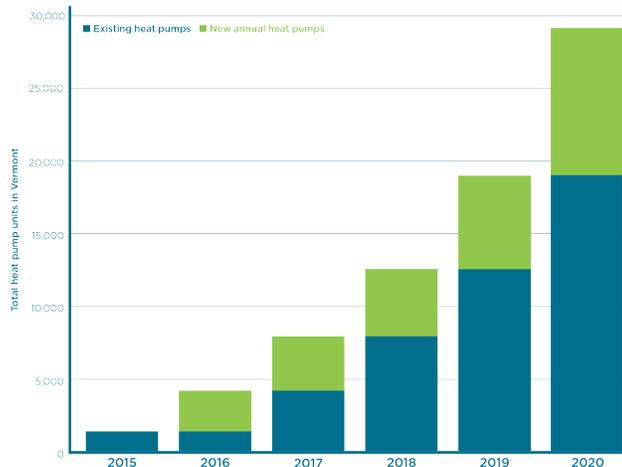
Air-source heat pumps (heat pumps) are another one of the largest-impact measures shown in the Model. The Model shows a cumulative 70,000 heat pumps installed by 2025, and 200,000 heat pumps by 2030. Similar to EVs, the heat pump projections fall roughly in line with those set out in the VELCO 2021 long range plan “high forecast scenario”.



These projections also meet (and exceed) the CEP, which set the goal of installing 35,000 heat pumps by 2025. The Model shows a doubling of this number, which reflects the necessary uptake for the Thermal sector to meet its proportional sectoral emissions reduction target. The unit count

in the Model also follows other projections in the industry, given recent geometric growth in heat pump installation rates. The chart below shows the rate of heat pump installations in Vermont from 2015 – 2020. In recent years there has been an increasing rate in adoption of heat pumps, which is expected to continue in coming years.

Heat pumps installed in Vermont



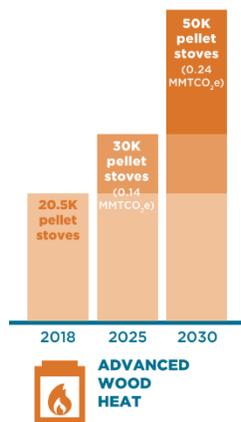
Source: EAN Community Progress Maps

Technical assumptions for heat pumps are largely drawn from the 2019 TAG. From this, the Model uses assumptions related to electric consumption, annual heating load, and load displacement. Assumptions regarding current heat pump unit counts were provided by Efficiency Vermont. The Model specifically analyzes ductless models, all of which displace a

proportion of a building’s total heating and cooling load, and thus are partial electrification measures.²⁵ Centrally-ducted systems are also important as they could offset the entire thermal load and make use of already-existing heating distribution systems that some homes in Vermont have. However, this measure was not included as ducted heat pumps are lower efficiency than ductless systems and they have not yet gained much market share in the state.

Advanced Wood Heat

Advanced wood heat (AWH) is the most significant Thermal Measure in 2025. Although Electrification surpasses it in terms of reductions in 2030, AWH still plays an important role in



2030 as well. The Model forecasts 30,000 efficient pellet stoves and other advanced wood heat systems (including automated pellet or chip boilers and furnaces) by 2025, which increases to 50,000 units in 2030. The 2030 Advanced Wood Heat Roadmap by Renewable Energy Vermont and the Biomass Energy Resource Center (BERC) served as the starting point for these targets. However, the 2025 and 2030 projections do deviate from those in the Roadmap. Due to the slow market uptake in recent years of AWH, EAN made the decision to scale back the market penetration of this measure.

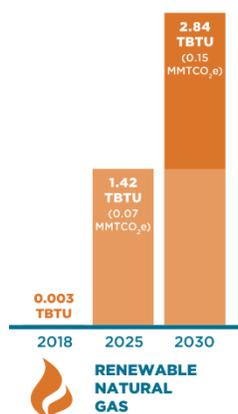
The CEP has a goal of wood making up 35% of building heat by 2030. The Model shows wood to be around 26% of the Thermal heat load by 2030. As stated above, EAN took a more conservative approach regarding wood heat penetration given recent trends and current market conditions.

The two most significant sources for wood heat impact assumptions are the 2016 Advanced Wood Heat Baseline Report (AWH) by BERC and the 2019 TAG. The AWH Report helped inform

²⁵ The Model assumes that single zone heat pumps displace roughly 34% of the heating and cooling load, and multi zone heat pumps displace roughly 76%.

metrics such as unit counts, replacement characteristics, and consumption information. Although the AWH Report is somewhat dated now, it is the most comprehensive report on the subject that is specific to Vermont. The 2019 TAG informed metrics concerning household heat savings and fossil fuel offsets.

Renewable Natural Gas



Renewable Natural Gas (RNG) is the third-highest impact pathway for the Thermal sector (behind heat pumps and advanced wood heat). The Model predicts that Vermont will have 1.42 TBTU (trillion btu) of RNG in 2025, and 2.84 TBTU in 2030. These figures roughly align to 10% of natural gas being RNG by 2025, and 20% by 2030.²⁶ This will entail a fast ramp rate, as the baseline year (2018) starts at only 0.02%.²⁷ However, these percentage milestone targets align with published commitments from Vermont Gas Systems' (VGS) Comprehensive Energy Plan.

Although not directly related to RNG specifically, there are CEP goals that relate to these RNG targets. The most significant example is the goal of increasing the share of renewable energy used in buildings to 30% of all primary building energy consumption. The Model shows the Thermal sector reaching 34% renewability in buildings by 2025. While this is mostly due to wood heat, RNG does play a significant role in contributing towards this milestone.

The most significant source for RNG-related assumptions came from VGS. Although no specific reports were used to inform the Model, VGS was able to provide data for inputs related to current consumption levels, as well as future projections. The Model currently assumes that RNG has a net zero GHG impact. However, if ANR's GHG methodology begins to characterize

²⁶ Although beyond the scope of this Whitepaper, the Model allows for the possibility that in 2050 80% of natural gas consumption will be RNG and/or hydrogen.

²⁷ This is based on VGS annual data showing 2650 MMBtu of RNG consumption in 2018.

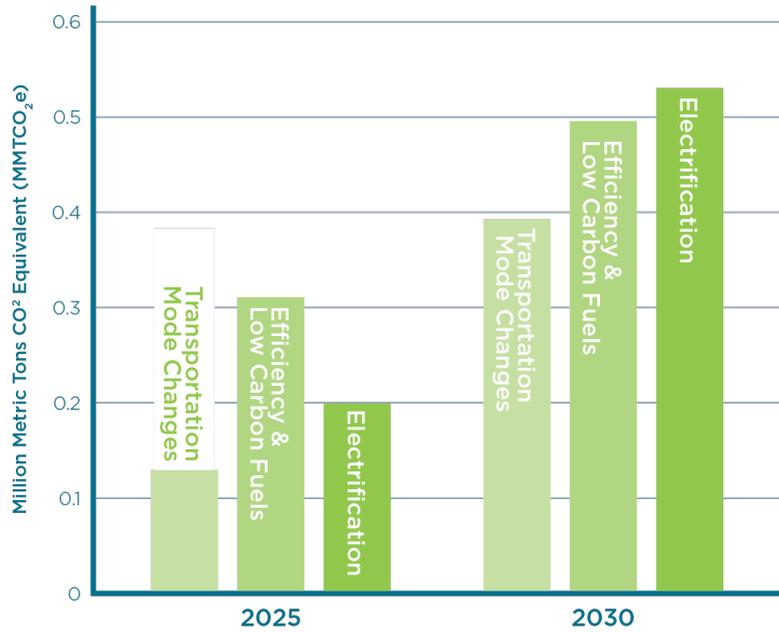
RNG emissions factors,²⁸ this change in assumptions would have an unknown impact on this measure's emission reductions impacts.

²⁸ ANR currently does not characterize RNG in its GHG inventory methodology

Appendices

Appendix: Transportation Deep Dive

Transportation pathway reductions



Source: EAN Emissions Reduction Pathways Model, 2021.

The Transportation sector is made up of three overall pathways: Electrification, Transportation Mode Changes, and Efficiency and Low Carbon Fuels. As noted previously, while the Efficiency & Low Carbon Fuels Pathway initially sees the greatest emissions reductions, in the longer term, Electrification will result in the largest emissions reductions. This is because more and more of the fleet is expected to become electric.

Electrification Pathway:

This pathway includes all identified technology options to switch from an ICE vehicle to an EV. Its relative impact is small in 2025, but it becomes much more significant by 2030. This is due to the pace of market uptake that the Model assumes the industry will see.

Included measures:

- *Electric Vehicles*: This includes both PHEVs and AEVs. The Model indicates that in order for Vermont to meet its GWSA requirements, 47,000 EVs are needed by 2025 and 120,000 EVs by 2030. By 2050, 90% of the LVF fleet would have to be EV.
- *HDF Electrification*: This looks at Vermont's heavy-duty fleet. The Model assumes that 30% of new HDF sales will be electric by 2030, and 100% of new sales will be electric by 2050. These assumptions come from the Memorandum of Understanding (MOU) signed by 15 Northeast states related to electric medium- and heavy-duty vehicles.²⁹
- *Bus Electrification*: This includes both public transit buses as well as school buses. The same assumption for goals were used for both bus types: 10% of the fleet would be electric by 2030, and 90% by 2050. Due to the small fleet size in the state, this is the lowest-impact measure in Transportation Electrification.

Transportation Mode Change Pathway:

This pathway includes all options related to rider behavior and method. Although this is an important pathway, it does not see the same impact on emissions reductions from 2025 to 2030 as the Electrification or Efficiency/ Low-Carbon Fuels Pathways show. Due to the voluntary nature of the measures, the rural nature of Vermont, and the dependence on long-term land-use strategies to help reduce VMT, there are limits to the potential for some of these measures in the next 5-10 years. Also important to note is that many of these measures will call for significant infrastructure changes, which are not addressed by the Model.

Included measures:

- *Carpool/ Rideshare*: This measure includes both carpooling (seat capacity of 3), and vanpooling (seat capacity of 6) used for commuting purposes only. The vast majority of vehicles modeled (97%) are cars, which comes from data about carpool registrations.

²⁹ Northeast States for Coordinated Air Use Management, 15 States and the District of Columbia Join Forces to Accelerate Bus and Truck Electrification, 2020.

The modeling assumption for this goal is that 30% of commuters will be participating in Rideshare by 2030, and 50% of commuters in 2050.

- *Public Transportation:* This measure includes individual riders using public transportation for commuting purposes only. It does not take into account general ridership. The modeling assumption for this measure is for 2% of commuters to use public transportation by 2030, and 5% by 2050.³⁰ These targets may seem relatively low compared to those in other measures, but due to the rural nature of the state and the limited availability of public transportation, EAN felt that this was a reasonable goal.
- *Bike/ Walk Commuters:* This measure includes all individuals who either walk or bike, for commuting purposes only. The Model assumes that 10% of commuters will travel by this method by 2030, and 13% of commuters by 2050. Similar to the Public Transportation measure, there is limited growth to this measure due to the rural nature of Vermont as well as the significant infrastructure upgrades needed for this to be more feasible for the general population.
- *Telecommute:* This measure accounts for the emissions reductions from those workers who work from home and don't produce emissions traveling to and from work. This measure has some amount of uncertainty as the long-term impact of post-pandemic telecommuting trends is yet to be known. However, the Model assumes that 10% of workers will telecommute between 2025 and 2030. This increases to 15% after 2030. It also includes a Pandemic period (2020-2022) that assumes 25% of workers are telecommuting.
- *Rail Transit:* This measure accounts for all ridership on trains in Vermont (it is not restricted to commuters). Many of the assumptions related to ridership come directly from Amtrak. The Model assumes an annual 3% increase in ridership through 2030, which drops to an annual 1% increase from 2030 to 2050. Given the historic change in ridership (and taking into account the impact of the pandemic), EAN assumes that rail will have a minimal impact. Because of this, the Model does not place a heavy emphasis on it.

³⁰ The baseline year (2018) starts with just 0.86% of commuters using public transportation.

- *VMT Reductions*: This measures the emission reductions that would be accrued from reducing the average statewide annual vehicle miles traveled (VMT) from the current amount of 12,497 miles to 11,000 by 2030. The last few years have seen increases in VMT so any reduction in miles is not modeled to begin until 2025. This VMT is applied to the entire LVF, which includes all ICE, EV, and HEVs. It is also important to note that this only includes non-commute related travel.

Efficiency and Low-Carbon Fuels Pathway:

This pathway relates to the use of biofuels in Vermont’s vehicle fleet (both LVF and HDF). It also includes High Efficiency Vehicles (HEVs) and increasing efficiency in the general ICE fleet. This is the most impactful Pathway in 2025, which shows the importance of creating a more efficient fleet and transitioning towards biofuels in ICE vehicles. After 2028, this Pathway becomes overshadowed by the Transportation Electrification Pathway as more and more of the LVF is expected to be electric by that point.

Included measures:

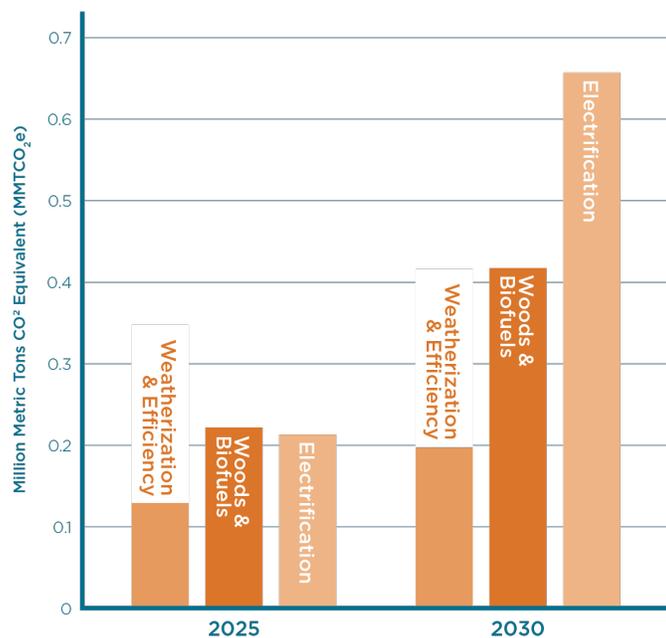
- *Biofuels (LVF and HDF)*: This measure represents the use of biofuels in the ICE fleet for both LVF and HDF. The Model breaks out the impact of LVF and HDF separately, but they are both looking at the same thing. HDF biofuels see higher emissions reductions throughout the period of the model. This is mostly due to the slower pace of adoption of electrification for HDF. The LVF sees a much higher rate of EV adoption, which places less significance on the remaining ICE in the fleet. There could be changes in emissions savings if the emissions factor of biodiesel is updated in ANR’s GHG methodology to a value different than the one the Model uses.
- *Hybrids*: This measure examines the impact of HEVs within the LVF. The Model assumes that 5% of the fleet will be HEV by 2025, and 9% of the fleet by 2030.³¹ In terms of fleet size, this equates to 24,000 HEVs in 2025 and around 43,000 in 2030.

³¹ After 2030, the share of HEVs drop to be 6% by 2050. This reflects the growing significance of EVs that the Model predicts will occur after 2030.

- *ICE Efficiency Increases (LVF and HDF):* This measure tracks the efficiency increases within the LVF and HDF ICE vehicles. The Model shows an increase in overall efficiency for ICE LVF from 22.7 mpg in 2018, to 26.3 mpg in 2030. Similarly, the ICE HDF efficiency increases from 6.5 mpg in 2018, to 7.7 mpg in 2030.
- *Rail/ Aviation Biofuels:* The use of biofuels in rail and aviation within Vermont are modeled together. Both instances assume a 70% reduction in emissions by 2050 to reflect the growing use of biofuels. The reductions don't begin until 2030, so for the purposes of this Whitepaper,³² this measure has no impact.

Appendix: Thermal Deep Dive

Thermal pathway reductions



Source: EAN Emissions Reduction Pathways Model, 2021.

Similar to the Transportation sector, the Thermal sector is comprised of 3 Pathways: Electrification, Weatherization and Efficiency, and Wood/ Biofuels. Also similar to Transportation, Electrification has the greatest long-term impact.

³² This Whitepaper focuses on the time period through 2030.

Electrification Pathway:

This pathway includes electric technology types that are able to replace less-efficient heating options. Similar to the Transportation sector, the Model shows the need for large growth in Electrification between 2025 and 2030. This pathway has the most impact for the Thermal Sector, and is the second-most significant pathway overall, after Transportation Electrification.

Included measures:

- *Cold Climate Heat Pumps:* This includes the growing use of heat pumps in the residential and commercial building stock. It is broken down between single zone and multi zone unit types, which each have their own respective assumptions. The Model assumes that 60% of heat pumps are single zone through 2025, which drops to 40% after 2025. This impacts emissions reductions as multi zone heat pumps result in larger emissions savings. The Model uses the assumption that there will be 70,000 heat pumps by 2025, and 200,000 by 2030.³³ The Model specifically analyzes ductless models, all of which displace a proportion of the heating and cooling load, and thus are partial electrification measures.
- *Ground Source Heat Pumps:* This measure specifically tracks ground source heat pumps (GSHPs). The Model forecasts 1,000 GSHPs by 2025, and 5,000 by 2030. Despite the high emissions savings associated with GSHPs, due to currently high installation costs and logistical challenges, the Model assumes a limited uptake of new GSHPs. If hardware and installation costs are brought down in the future, then GSHPs may play a more significant role.
- *Heat Pump Water Heaters:* This measure tracks the emissions reductions associated with replacing fossil fuel water heating with heat pump water heaters. The Model assumes there will be 50,000 heat pump water heaters by 2025, and 200,000 by 2030. The rate of adoption slows considerably after 2030 due to the limited size of Vermont's

³³ These numbers are inclusive of both single zone and multi zone unit types.

housing stock – at that point the majority of residential buildings would have heat pump water heaters installed.³⁴

Weatherization & Efficiency:

This Pathway represents the buildings that have undergone comprehensive weatherization and/or equipment efficiency upgrades. The GHG reduction impact from weatherization declines over time as the mix of fuels becomes less carbon intensive. It also includes a component related to equipment efficiency which will lower the heating and cooling load over time. This is an important pathway as the effectiveness of many of the Thermal measures (such as those discussed in the Electrification pathway) hinge on comprehensive weatherization of Vermont's building stock. Although the GHG impact of this Pathway decreases over time, there are other co-benefits related to it that have great value, such as enabling fuel switching once lower heating loads are achieved, improvements in user comfort, lowering the cost to the grid of electrification, and lowering the cost to fossil fuel customers of increased reliance on biofuels.

Included measures:

- *Weatherization*: This measure tracks the impacts of comprehensive weatherization on the Vermont building stock. For the Residential sector, the Model assumes that a cumulative 80,000 units will be weatherized by 2025, and 148,000 by 2030.³⁵ It also assumes that there will be a 25% reduction in the thermal load by 2050. Over 75% of Vermont homes were built before 1990, and 60% before 1980, which means there are many opportunities for improved weatherization.
- *Commercial*: For the Commercial sector, the Model assumes a 15% reduction in the thermal heating and cooling loads by 2050.
- *Industrial Processes*: For the Industrial sector, the Model assumes a 10% reduction in the thermal process loads by 2050.

³⁴ The Model assumes the number of residential households in Vermont to be around 260,000

³⁵ It is further assumed that 100% of the housing stock will be weatherized by 2050.

Wood and Biofuels Pathway:

This Pathway includes the options to use Advanced Wood Heat (AWH), Biofuels, and RNG to heat homes and buildings. AWH has been studied for both residential and commercial applications. AWH initially contributes the most towards emissions reductions for this pathway, but by 2030 the Model forecasts that VGS' goal of 20% RNG in its pipelines will have the largest impact.

Included measures:

- *Advanced Wood Heat – Residential and Commercial:* This measure includes pellet stoves as well as larger automated chip and pellet boilers or furnaces. On the residential side, the Model forecasts a cumulative 30,000 units by 2025, which increases to 50,000 units in 2030. On the commercial side, the Model forecasts 2,000 pellet/ woodchip systems by 2025, and 4,000 by 2030.
- *Renewable Natural Gas:* The RNG measure tracks the impact of replacing natural gas consumption with RNG. The Model forecasts that 10% of gas consumption will be by RNG by 2025, and 20% by 2030. There could be a change in emissions savings if EAN's assumed emission factor of RNG is not what is used in ANR's GHG methodology update.
- *Biofuels:* This measure studies the impact of replacing the use of fuel oil with biofuels in homes. The Model uses the assumption that 5% of oil use will be biodiesel by 2025, and 20% by 2030.

Industrial Process Energy:

Industrial process energy accounts for around 12% of the thermal sector fuel use and 15% of the sector's GHG emissions. Although efficiency improvements are expected and new electric technologies can lower industrial energy use and GHG emissions over time, because EAN lacked studies that characterize such pathways, specific process energy efficiency improvements were not included in the Model, but assumed to result in a 10% load reduction by 2050.

Appendix: Future Updates

There are a number of updates that EAN hopes to incorporate into future versions of the Model for it to be as robust as possible:

- Incorporate long-term population and housing stock growth into the projections.
Currently there are no assumptions about population changes over time
- Include a more nuanced view of EV types. Currently the Model only distinguishes between all-electric vehicles and plug in hybrids but this could be broken down to a more granular level
- Think further about interactive effects to avoid misstating any of the Measures' impacts.
This applies to cases such as,
 - The interaction of wood heat, heat pumps, and biodiesel in the Thermal sector
 - The interactions of biofuels with EVs
- Add in a simple cost-effectiveness analysis or financial modeling component

Pathway measures: Unit count and percentage change

	Pathway	Measures	Baseline Unit Count (2018)	2025 Unit Count	2025 Percent Increase	2030 Unit Count	2030 Percent Increase
THERMAL	Electrification	Cold Climate Heat Pumps	13,770	70,000	408%	200,000	1352%
	Electrification	Ground Source Heat Pumps	198	1,063	437%	5,023	2437%
	Electrification	Heat Pump Water Heater	9,510	50,000	426%	200,000	2003%
	Weatherization & Efficiency	Residential	27,186	80,000	9%	148,102	16%
	Wood and Biofuels	Advanced Wood Heat - Commercial	231	1,586	587%	3,205	1287%
	Wood and Biofuels	Advanced Wood Heat - Residential	20,490	30,000	46%	50,000	144%
	Wood and Biofuels	RNG	2,650	1,417,038	53373%	2,839,221	107040%
	Wood and Biofuels	Biofuels	280,424	280,424	9%	1,020,640	16%
	Weatherization & Efficiency	Commercial	15,767,000	15,223,364	-3%	14,846,567	-6%
	Weatherization & Efficiency	Industrial Process	6,788,000	6,632,741	-2%	6,524,021	-4%
TRANSPORTATION	Transportation Mode Changes	Bike / Walk	22,055	30,305	37%	33,000	50%
	Transportation Mode Changes	Carpool	10,052	12,518	25%	30,558	204%
	Transportation Mode Changes	Public Transportation	2,800	4,516	61%	6,353	127%
	Transportation Mode Changes	Rail Transit	94,249	115,914	23%	134,377	43%
	Transportation Mode Changes	Telecommute	24,206	32,434	34%	48,651	101%
	Efficiency and Low Carbon Fuels	HDF Biofuel	6,970,965	9,529,154	37%	12,574,529	112%
	Efficiency and Low Carbon Fuels	LVF Biofuel	21,970,533	18,369,819	-16%	13,892,470	-25%
	Efficiency and Low Carbon Fuels	Hybrids	12,027	24,000	100%	42,536	254%
	Electrification	Electric Bus	-	48	4676%	213	21219%
	Electrification	Electric HDF	1	86	8465%	1,095	109402%
	Transportation Mode Changes	VMT Reductions	12,497	12,497		11,000	
	Efficiency and Low Carbon Fuels	HDF Efficiency	7	7		8	
	Efficiency and Low Carbon Fuels	ICE Efficiency	23	25		26	
	Electrification	EVs	2,985	46,000	1441%	120,000	3920%

Source: EAN Emissions Reduction Pathways Model, 2021.