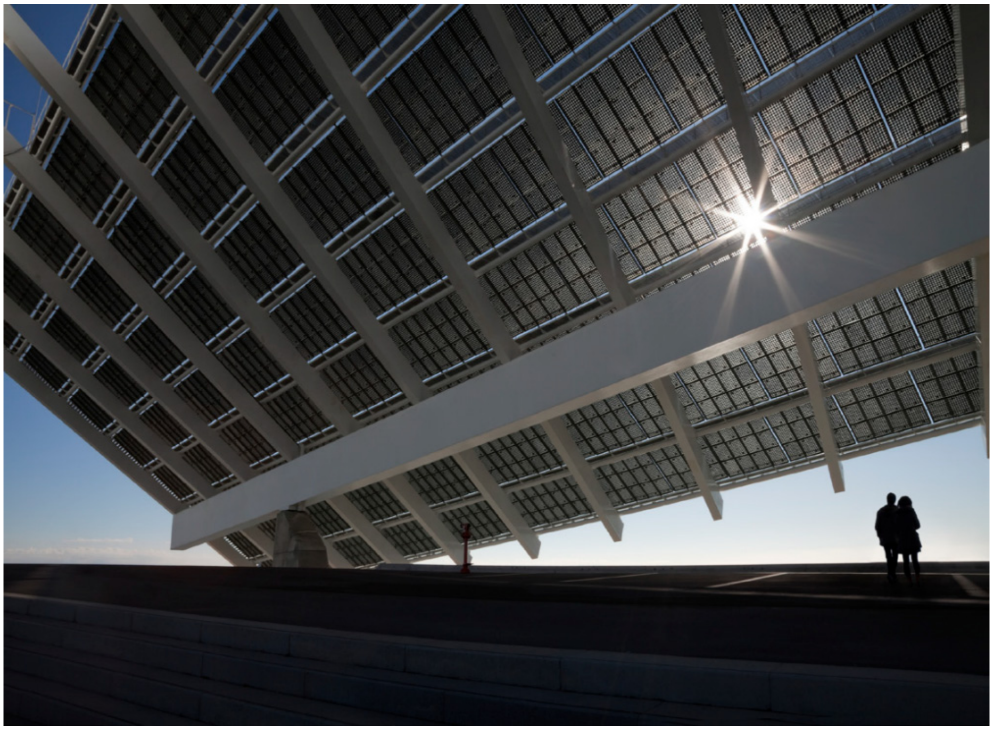
Vermont Solar Market Pathways



Volume 4

Methods and Detail Tables

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Introduction

This volume details the methodology used in the Vermont Solar Market Pathways Report. The primary analysis was conducted using the Long Range Energy Alternatives Planning (LEAP) system, developed by the Stockholm Environment Institute.[1] The LEAP analyses focused on modeling a future with 20% electricity from solar by 2025, with a focus on long term planning and the achievement of the Vermont's legislated renewable energy and emissions goals. The level of detail achieved in the model differed between sectors and was based on best available data at the granularity needed to address the identified focus areas.

In addition to informing the Vermont Solar Market Pathways goal of outlining a pathway to obtaining 20% electricity from solar power by 2025, the modeling effort detailed in this section provided an analytical background for the energy planning efforts of Vermont's Regional Planning Commissions (RPCs). In the 2016 legislative session, the Vermont legislature passed Act 174, which established a new set of regional energy planning standards, which if met allow those plans to carry greater weight in Vermont's siting process for energy generation[2]. The standards require RPCs to create plans which map a path to reaching the state's goals of 90% renewable energy by 2050 and do the following:

- Estimate current energy use across transportation, heating, and electric sectors
- Establish 2025, 2035, and 2050 targets for thermal and electric efficiency improvements, and the use of renewable energy for transportation, heating and electricity
- Evaluate the amount of thermal-sector conservation, efficiency, and conversion to alternative heating fuels needed to achieve the targets
- Evaluate transportation changes and land use strategies needed to achieve the targets
- Evaluate electric-sector conservation and efficiency needed to achieve the targets[3]

The Vermont statewide energy model created for the Vermont Solar Market Pathways project provided the foundational modeling of the Vermont energy demand for 2015, 2025, 2035, and 2050. The demand was regionally allocated using demographic data and residential home energy data from the American Community Survey and the U.S. Census. The modeling results helped regions understand the level of efficiency and fuel switching needed in various end uses to meet the state's ambitious goals. The end-use specific data also gave the regions some latitude to create region-specific plans that reflect their energy priorities. For example, where the statewide modeling and projections predict a need for widespread switching from fuel oil to heat pumps and, to a lesser extent, modern wood heating, a region may choose to focus instead on switching more homes to modern wood heating and fewer homes to heat pumps. The results also made clear the imperative for meeting and exceeding the states aggressive weatherization

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[1] [1] Heaps, C.G., *Long-Range Energy Alternatives Planning (LEAP) System*, version 2015.0.24 (Somerville, MA, USA: Stockholm Environment Institute, 2016).

[2] Vermont Department of Public Service, "Act 174 Recommendations and Determination Standards," Accessed 11/10/2016, http://publicservice.vermont.gov/content/act-174-recommendations-and-determination-standards

[3] Guidelines for Satisfying the Analysis and Targets Section of the Department of Public Service's Determination Standards, Department of Public Service, November 9, 2016.

targets and a significant shift from gasoline and diesel powered transportation to electric and biodiesel vehicles to meet state targets.

Act 174 requires the RPCs to generate maps of each region that identify potential areas for the development of renewable energy resources and area that are not suitable for renewable energy resources or other development. The modeling produced through the Vermont Solar Market Pathways project helps planners at the town and regional level understand how much energy and conservation are needed to meet these goals. The Team sent renewable energy capacity numbers from the $90x2050_{VEIC}$ model to regions that participated in the energy planning pilot. This allowed them to benefit from the work the Team and stakeholders did creating and refining the supply model, but could be perceived as telling the regions what mix of solar, wind, and other generation options they had to host. After the pilot, regions were not given any supply information so that they would create their own generation mix. These regions still benefited from estimates from this project of energy use by fuel and sector and the amount efficiency could be expected to contribute.

Approach

Historic information was primarily drawn from the Public Service Department's Utility Facts 2013[4] and the US Energy Information Administration. Projections came from stakeholder inputs, the utilities' Committed Supply,[5] and the Total Energy Study (TES)[6] Framework for Analysis of Climate-Energy-Technology Systems (FACETS) data. The Reference scenario was predominantly aligned with the TES Business as Usual (BAU) scenario. The VEIC 90% x 2050 scenario was based on a blend of the Total Renewable Energy and Efficiency Standard (TREES) Local High and Low Bio scenarios. Workbooks that provided assumptions and data for the BAU scenario in the FACETS data was provided by the Vermont Department of Public Service (DPS). The workbook containing transportation-specific data will hereafter be referred to as TES Transportation Data. The workbook detailing consumption from the other sectors will be referred to as TES General Data. There were slight deviations from the FACETS data, which are discussed in further detail below.

The following sections provide detailed information on model inputs for each demand sector and the electricity supply. For demand, each section details methodology and inputs by scenario (Historic, Reference and $90 \text{ x } 2050_{VEIC}$). All other scenarios not mentioned here (the high solar scenarios: SDP, Low Net Metering, Delayed Deployment) have the same demand as the $90 \text{ x } 2050_{VEIC}$ scenario.

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[4] Vermont Public Service Department, *Utility Facts 2013*, http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/Utility_Facts/Utility%20Facts%202013.pdf.

[5] Vermont Public Service Department provided the data behind the graph on the bottom half of page E.7 in *Utility Facts 2013.* It is compiled from utility Integrated Resource Plans

[6] Vermont Public Service Department, *Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals.* December 8, 2014. http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/TES/TES%20FINAL%20Report%2020141208.pdf.

Residential

The TES provides total fuels used by sector. We used a combination of industry data and professional judgement to determine demand inputs at a sufficiently fine level of detail to allow for analysis at many levels, including end use (heating, water heating, appliances, etc.), device (wood stove, furnace, heat pump) or home-type (single family, multi-family, seasonal, mobile). Assumptions for each are detailed below. Costs were assigned to the residential portfolio based on Efficiency Vermont's 2013 Demand Resources Plan (DRP), which budgets costs and savings for Vermont's electrical efficiency, thermal efficiency, and process fuels efficiency. Costs for the reference scenario came from "Scenario 2," and costs for the 90 x 2050_{VEIC} and SDP scenarios came from "Scenario 3." Third party costs were estimated in the DRP to be about 67% of Efficiency Vermont costs, so DRP cost estimates for Efficiency Vermont were multiplied by 1.67 to estimate the total incremental cost of efficiency.[7] Costs were allocated per housing type based on the percent of total residential energy consumed by each type. All other assumptions for residential demand are at a per-home level. In each scenario, the energy consumption is built on an assumption of the number of households of each type (single family, multi-family, mobile home, and seasonal home) in Vermont.

Historical Data

In the historic data, number of households by type is derived from the American Community Survey.

Space Heating

The team determined per home consumption (energy intensity) by fuel type and home type. EIA data on Vermont home heating provided the percent share of homes using each type of fuel. 2009 Residential energy consumption survey (RECS) data provided information on heating fuels used by mobile homes. Current heat pumps consumption estimates were found in a 2013 report prepared for Green Mountain Power by Steve LeTendre entitled *Hyper Efficient Devices: Assessing the Fuel Displacement Potential in Vermont of Plug-In Vehicles and Heat Pump Technology*.

Additional information came from the following data sources:

- 2010 Housing Needs Assessment[8]
- EIA Vermont State Energy Profile[9]

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[7] Vermont Energy Investment Company, "Recommended Electric Energy Efficiency Scenario for Vermont's 20-Year Demand Resources Plan Comparative Analysis and Findings," April 16, 2014 http://psb.vermont.gov/sites/psb/files/projects/EEU/drp2013/1.%20VEIC%20DRP%20Scenario%20Recommendation.pdf.

[8] Vermont Housing and Finance Agency, "2010 Vermont Housing Needs Assessment," December 2009, http://accd.vermont.gov/sites/accd/files/Documents/strongcommunities/housing/complete%20final%20report.pdf.

[9] U.S. Energy Information Administration, "Vermont Energy Consumption Estimates, 2004," https://www.eia.gov/state/print.cfm?sid=VT

- 2007-2008 VT Residential Fuel Assessment[10]
- EIA Adjusted Distillate Fuel Oil and Kerosene Sales by End Use[11]

The analyst team made the following assumptions for each home type:

- Multi-family units use 60% of the heating fuel used by single-family homes, on average, due to assumed reduced size of multi-family units compared to single-family units. Additionally, where natural gas is available, the team assumed a slightly higher percentage of multi-family homes use natural gas as compared to single-family homes, given the high number of multi-family units located in the Burlington area, which is served by the natural gas pipeline. The team also assumed that few multi-family homes rely on cordwood as a primary heating source.
- Unoccupied/Seasonal Units: On average, seasonal or unoccupied homes were expected to use 10% of the heating fuel used by single-family homes. For cordwood, we expected unoccupied or seasonal homes to use 5% of heating fuel, assuming any seasonal or unoccupied home dependent on cordwood are small in number and may typically be homes unoccupied for most of the winter months (deer camps, summer camps, etc.)
- Mobile homes—The 2009 Residential Energy Consumption Survey (RECS)[12] provided mobile home energy consumption data by fuel.

Space Cooling

The 2007-2008 Vermont Residential Fuel Assessment informed estimates of current and historic residential air conditioning. Efficiency Vermont products experts provided estimates for the use of heat pumps as air conditioners, as the relatively new technology was not reflected in the study.

Lighting

Lighting for single-family homes in the historic years was projected by Efficiency Vermont lighting experts to consume an average of 2300 kWh per home per year. Lighting in multifamily, mobile, and seasonal homes was expected to consume 70%, 50%, and 10% of the energy used for lighting by single-family homes, respectively.

Water Heating

Current and historic estimates of water heating consumption by fuel and home type were derived from the Efficiency Vermont Technical Reference Manual.[13]

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[10] Frederick P. Vermont Residential Fuel Assessment: for the 2007-2008 heating season. Vermont Department of Forest, Parks and Recreation. 2011.

[11] U.S. Energy Information Administration, "Adjusted Distillate Fuel Oil and Kerosene Sales by End Use," December 2015, https://www.eia.gov/dnav/pet/pet_cons_821usea_dcu_nus_a.htm.

[12] U.S. Energy Information Administration, "Residential Energy Consumption Survey," 2009, https://www.eia.gov/consumption/residential/data/2009.

[13] Efficiency Vermont, "Technical Reference User Manual (TRM): Measure Savings Algorithms and Cost Assumptions, No. 2014-87," March 2015,

Appliances and Other Household Energy Use

EnergyStar appliance estimates and the Efficiency Vermont Electric Usage Chart[14] provided estimates for appliance and other extraneous household energy uses.

Using the sources and assumptions listed above, the team created a model that aligned with the residential fuel consumption values in the TES.

Reference Scenario: 2050

In both the Reference and 90 x 2050_{VEIC} scenarios, the state population is assumed to grow at 0.35% per year.[15] People per house are assumed to decrease from 2.4 in 2010 to 2.17 in 2050.

Space Heating

The Reference scenario heating demand projections were developed in line with the TES Reference scenario. This included the following: assumed an increase in the number of homes using natural gas, increase in the number of homes using heat pumps as a primary heating source (up to 37% in some home types), an increase in the share of homes heated with wood pellets, and a drastic decline in homes heating with heating oil. Heating system efficiency and shell efficiency were modeled together and, together, were estimated to increase 5-10% depending on the fuel type. However, heat pumps were expected to continue to increase in efficiency (becoming 45% more efficient, when combined with shell upgrades, by 2050). Future projections of heat pump efficiency were provided by Efficiency Vermont Efficient Products and Heat Pump program experts. For heat pump use in mobile homes, heat pumps were not widely deployed in mobile homes in 2009 and did not appear in the RECS data. Therefore, the team applied the ratio of oil consumed in single-family homes and mobile homes to estimate mobile home heat pump energy consumption based on single-family heat pump consumption.

The Reference scenario also reflects some trends increasing home sizes.

Space Cooling

Space cooling for room air conditioning and central air conditioning was expected to remain constant in the Reference scenario. Heat pump cooling efficiency was expected to improve by 40% by 2050. Penetration of cooling was expected to increase to 85% by 2050, based on widespread deployment of heat pump technology, an aging population, warmer summers, and an increase in available, inexpensive technology.

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http://psb.vermont.gov/sites/psb/files/docketsandprojects/electric/majorpendingproceedings/TRM%20User%20Manual%20No.%202015-87C.pdf.

[14] Efficiency Vermont, "Electric Usage Chart Tool," https://www.efficiencyvermont.com/tips-tools/tools/electric-usage-chart-tool.

[15] Jones, Ken, and Lilly Schwarz, *Vermont Population Projections-2010-2030*, August, 2013. http://dail.vermont.gov/dail-publications/publications-general-reports/vt-population-projections-2010-2030.

Lighting

Residential lighting efficiency predictions were estimated by Efficiency Vermont products experts to be 1.7% annual efficiency increase in the Reference scenario for all home types.

Water Heating

The Reference scenario water heating demand estimates mirrored the heating estimates: an increase in homes using natural gas to mirror that of the increase in heating, a significant decline in homes heating water with electric resistance, oil, and propane, and an increase in homes heating water with wood pellets, solar thermal, and heat pump water heaters. The efficiency of all water heaters except solar thermal was expected to increase slightly from 2010-2050.

Appliances and Other Household Energy Use:

The efficiency of household appliances was expected to increase from 2010-2050, however, energy consumed by other plug loads such as personal electronics is expected to increase and, in the Reference scenario, outweigh any efficiency gains.

90 x 50$_{\text{VEIC}}$ Scenario: 2050

Space Heating

For the 90 x 2050$_{\text{VEIC}}$ scenario, scenario heating demand projections were developed in line with the TES TREES Local scenarios, a hybrid of the high and low biofuel cost scenarios. This included the following: assumed increase in the number of homes using heat pumps as a primary heating source (up to 70% in some home types), an increase in home heated with wood pellets, a drastic decline in homes heating with heating oil and propane, and moderate decline in home heating with natural gas. Heating system efficiency and shell efficiency were modeled together and were estimated to increase 10%-20% depending on the fuel type. However, heat pumps are expected to continue to rapidly increase in efficiency (becoming 50% more efficient, when combined with shell upgrades by 2050). We also reflect some trends increasing home sizes.

Space Cooling

In the 90 x 2050$_{\text{VEIC}}$ scenario, the number of homes with heat pump cooling was expected to increase at the same rate as homes with heat pump heating. The efficiency of all heat pump technologies was expected to increase some, with heat pump cooling showing a nearly 50% increase in efficiency.

Lighting

Residential lighting efficiency predictions were estimated by Efficiency Vermont products experts to be 3.5% annual efficiency increase in all non-Reference scenarios.

Water Heating

Like the Reference scenario, the 90 x 2050$_{\text{VEIC}}$ scenario water heating demand estimates mirrored the heating estimates: an increase in homes using natural gas to mirror that of the increase in heating, a significant decline in homes heating water with electric resistance, oil, and propane, and an increase in homes heating water with wood pellets, solar thermal, and heat pump water heaters. Unlike the Reference scenario, efficiency of all water heaters except solar thermal was expected to increase more than 20% from 2010-2050.

Appliances and Other Household Energy Use

Like in the Reference scenario, the efficiency of household appliances was expected to increase from 2010-2050, however, energy consumed by other plug loads such as personal electronics is expected to increase and, in the Reference scenario, outweigh any efficiency gains. Plug load growth in the 90 x 2050_{VEIC} scenario is less than that in the Reference scenario.

Commercial

Costs were assigned to the commercial portfolio based on Efficiency Vermont's 2013 Demand Resources Plan (DRP), which budgets costs and savings for Vermont's electrical efficiency, thermal efficiency, and process fuels efficiency. The DRP estimates commercial and industrial costs together. This analysis assumed commercial costs accounted for 90% of total C&I costs. Costs for the reference scenario came from "Scenario 2." and costs for the 90 x 2050_{VEIC} and SDP scenarios came from "Scenario 3." Third party costs were estimated in the DRP to be about 67% of Efficiency Vermont costs, so DRP cost estimates for Efficiency Vermont were multiplied by 1.67 to estimate the total incremental cost of efficiency.[16] Demand estimates were calculated as follows.

Historical Data

Historic data drew upon the TES FACETs data and available EIA data. Commercial energy use estimates are entered in to the model as energy consumed per square foot of commercial space, on average.

Reference Scenario: 2050

Projected change in the energy demand from the commercial sector was based on commercial sector data in the TES. This was calculated using TES FACETs data. The FACETs model uses estimates from the Annual Energy Outlook[17] and the Commercial Buildings Energy Consumption Survey[18] to estimate changes in commercial square footage and fuel consumption per square foot. Commercial building square footage is expected to grow almost 17% from 2010 to 2050. However, the model anticipates increasing efficiency to reduce total consumption despite a growth in commercial square footage.

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[16] Vermont Energy Investment Company, "Recommended Electric Energy Efficiency Scenario for Vermont's 20-Year Demand Resources Plan Comparative Analysis and Findings," April 16, 2014 http://psb.vermont.gov/sites/psb/files/projects/EEU/drp2013/1.%20VEIC%20DRP%20Scenario%20Recommendation.pdf.

[17] U.S. Energy Information Administration, "Annual Energy Review 2010", 2010.

[18] U.S. Energy Information Administration, "Commercial Buildings Energy Consumption Survey," 2003. https://www.eia.gov/consumption/commercial/data/2003/.

90 x 50_{VEIC} Scenario: 2050

Commercial energy use estimates are entered in to the model as energy consumed per square foot of commercial space, on average. This was calculated using data from the TES, with an adjustment to the natural gas and electric consumption. The TES was conducted in 2012 and did not reflect the 2015 cancellation of Phase II of Vermont Gas's pipeline expansion, the revenue from which was slated to fund an expansion of the gas pipeline to southern Vermont, which is now on hold. The team reflected this change in the commercial demand projections with a slight decrease in anticipated commercial natural gas consumption and a slight increase in anticipated electricity consumption.[19] Total energy consumption amounts aligned with the TES even after the adjustment for natural gas.

Industrial

Industrial use for each scenario was entered directly from the results of the TES data, except for natural gas and electricity. As noted above, the TES was conducted before the cancellation of Vermont Gas's pipeline expansion. The LEAP model reflects this change with a significant reduction in natural gas use and a corresponding increase in electrification. Costs were assigned to the industrial portfolio based on Efficiency Vermont's 2013 Demand Resources Plan (DRP), which budgets costs and savings for Vermont's electrical efficiency, thermal efficiency, and process fuels efficiency. The DRP estimates commercial and industrial costs together. This analysis assumed industrial costs accounted for 10% of total C&I costs. Costs for the reference scenario came from "Scenario 2," and costs for 90 x 2050VEIC and SDP scenarios came from "Scenario 3." Third party costs were estimated in the DRP to be about 67% of Efficiency Vermont costs, so DRP cost estimates for Efficiency Vermont were multiplied by 1.67 to estimate the total incremental cost of efficiency.[20]

Historical Data

Historic industrial energy consumption was primarily based on the TES FACETs Data. However, detailed electricity consumption and natural gas consumption was available from the 2013 Utility Facts data and the EIA. These data sources reported similar numbers and were used instead of the TES data for historic electricity and natural gas.

Reference Scenario: 2050

Industrial use for each scenario was entered directly from the results of the TES data, except for natural gas and electricity. As noted above, the TES was conducted before the cancellation of Vermont Gas's pipeline expansion. The LEAP model reflects this change with a significant reduction in natural gas use and a corresponding increase in electrification. However, the ratio

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[19] Dobbs, Taylor, "Vermont Gas Cancels Second Phase of Pipeline," *Vermont Public Radio,* Feb 10, 2015, http://digital.vpr.net/post/vermont-gas-cancels-second-phase-pipeline#stream/0.

[20] Vermont Energy Investment Company, "Recommended Electric Energy Efficiency Scenario for Vermont's 20-Year Demand Resources Plan Comparative Analysis and Findings," April 16, 2014 http://psb.vermont.gov/sites/psb/files/projects/EEU/drp2013/1.%20VEIC%20DRP%20Scenario%20Recommendation.pdf.

of consumption of each fuel between the Reference and 90 x 2050$_{VEIC}$ scenarios remains the same in 2050.

90 x 50$_{VEIC}$ Scenario: 2050

Like in the Reference scenario, industrial use in the 90 x 2050$_{VEIC}$ and SDP scenarios was entered directly from the results of the TES data, except for natural gas and electricity. As noted above, the TES was conducted before the cancellation of Vermont Gas's pipeline expansion. The LEAP model reflects this change with a significant reduction in natural gas use and a corresponding increase in electrification. However, the ratio of consumption of each fuel between the Reference and 90 x 2050$_{VEIC}$ scenarios remains the same in 2050.

Transportation

The transportation branch focused on aligning with values outlined in the Total Energy Study (TES) Framework for Analysis of Climate-Energy-Technology Systems (FACETS) data in the transportation sector in the Business as Usual (BAU) scenario. The 90 x 2050$_{VEIC}$ scenario was predominantly aligned with a hybrid blend of the Total Renewable Energy and Efficiency Standard (TREES) Local High and Low Bio scenarios in the transportation sector of FACETS data. There were slight deviations from the FACETS data, which are discussed in further detail below.

An underlying workbook that provided assumptions and data for the BAU scenario in the FACETS data was provided by the Vermont Department of Public Service (DPS). This workbook will be henceforth referred to as TES Transportation Data. Upon reviewing the total tBtu values in 2015 in both data sources, it was discovered there are significant differences in each fuel sector. Therefore, the utilization of values from either or both TES FACETS data or TES Transportation Data may need additional refinement and discussion.

The incremental costs of electric vehicles, and associated reduction in maintenance costs, were based on information from the American Automobile Association and from Drive Electric Vermont.[21] Light duty electric vehicles were expect to meet price parity with combustion vehicles by 2020,[22] and the model reflects that estimate. Other costs associated in transforming the transportation sector were captured in fuel costs as discussed below.

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[21] American Automobile Association, "Your Driving Costs, 2016 Edition," 2016, http://exchange.aaa.com/wp-content/uploads/2016/04/2016-YDC-Brochure.pdf.

[22] Nykvist, B., and Nilsson, M., "Rapidly falling costs of battery packs for electric vehicles," *Nature Climate Change",* vol 5, April 2015, www.nature.com/natureclimatechange.

Historical Data

Light Duty Vehicles

Light Duty Vehicle (LDV) efficiency is based on a number of assumptions: Gasoline and ethanol efficiency were derived from the Vermont Transportation Energy Profile.[23] Diesel LDV efficiency was obtained from TES Transportation Data. Biodiesel LDV efficiency was assumed to be 10% less efficient than LDV diesel efficiency.[24] Electric vehicle (EV) efficiency was derived from an Excel worksheet from Drive Electric Vermont. The worksheet calculated EV efficiency using the number of registered EVs in Vermont, EV efficiency associated with each model type, percentage driven in electric mode by model type (if a plugin hybrid vehicle), and the Vermont average annual vehicle miles traveled.

Miles per LDV was calculated using the following assumptions: data from the Vermont Agency of Transportation provided values for statewide vehicles per capita and annual miles traveled.[25] The vehicles per capita value in the Transportation Energy Profile was used to error check the results from the LEAP model. Heavy duty vehicle (HDV) miles per capita, which is discussed below, was multiplied by the Vermont population assumptions outlined above and was subtracted out of annual miles traveled to create an estimate of LDV miles per capita. The total number of LDVs in Vermont was sourced TES Transportation Data. The calculated LDV miles per capita was multiplied by the population of Vermont and divided by the number of LDVs to calculate miles per LDV.

The number of vehicles for each fuel type in the LDV sector were compared against the total calculated number of LDVs to create percentages of each fuel type that were entered into LEAP. In addition, the number of vehicles in the LDV sector was compared against the total number of LDVs and HDVs to create percentages for these two sectors, which were also entered into LEAP. The number of ethanol and gasoline vehicles were calculated using the Goal Seek function in Microsoft Excel to match 2015 BAU values in the FACETS data. The Goal Seek function relied on efficiency and miles per vehicle values discussed above as well as fuel energy content properties (e.g. Btu/gallon and Btu/kwh) derived from LEAP and from the Alternative Fuels Data Center.[26]

A similar Goal Seek method was used to calculate the number of biodiesel and diesel vehicles: However, diesel and biodiesel are used in other transportation fuel sectors, and so a method was derived to properly proportion the total energy values between these sectors. The 2015

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[23] Jonathan Dowds et al., "Vermont Transportation Energy Profile," October 2015, http://vtrans.vermont.gov/sites/aot/files/planning/documents/planning/Vermont%20Transportation%20Energy%20Profile%202015.pdf.
[24] U.S. Environmental Protection Agency: Office of Transportation & Air Quality, "Biodiesel," *Www.fueleconomy.gov*, accessed August 19, 2016, https://www.fueleconomy.gov/feg/biodiesel.shtml.
[25] Jonathan Dowds et al., "Vermont Transportation Energy Profile."
[26] Alternative Fuels Data Center (AFDC), "Fuel Properties Comparison" (Alternative Fuels Data Center (AFDC), October 29, 2014), http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf.

BAU FACETS values for biodiesel and diesel were portioned into the LDV sector using the calculations and assumptions below.

To calculate the number of diesel vehicles, the 2015 BAU energy values from FACETS data for biodiesel were assigned exclusively to the HDV (discussed below) and LDV sectors (e.g. not the rail sector). The section containing total fuel consumption by vehicle type in the TES Transportation Data workbook was used to create a diesel energy ratio of LDVs to the sum of HDVs and LDVs.[27] This created an estimate of the split of vehicles capable of using biodiesel and diesel between the HDV and LDV sectors. This ratio was multiplied by the 2015 BAU FACETS biodiesel value. Lastly, this calculated value was used with the “Goal Seek” function to estimate the number of biodiesel vehicles.

To calculate biodiesel vehicles, the 2015 BAU diesel values from FACETS data were assigned to HDV, LDV and rail sectors. The LDV/HDV diesel ratio illustrated above was multiplied by the difference of the FACETS diesel value in 2015 minus the calculated amount of diesel in the rail sector, which is discussed below. Lastly, this calculated energy value was used with the “Goal Seek” function to estimate the number of diesel vehicles.

The number of EVs were sourced directly from Drive Electric Vermont, which, as discussed above, provided a worksheet of actual EV registrations by make and model. This worksheet was used to calculate an estimate of the number of electric vehicles using the percentage driven in electric mode by vehicle type to devalue the count of plug-in hybrid vehicles

Heavy Duty Vehicles

Similar to the LDV vehicle efficiency methods above, HDV efficiency values contained a variety of assumptions from different sources. A weighted average of HDV diesel efficiency was calculated using registration and fuel economy values from the Transportation Energy Data Book.[28] The vehicle efficiency values for diesel and compressed natural gas (CNG) were all assumed to be equal.[29] Diesel efficiency was reduced by 10% to represent biodiesel efficiency.[30] Propane efficiency was calculated using a weighted average from the Energy Information Administration Annual Energy Outlook table for Freight Transportation Energy Use.[31]

The total number of HDVs in Historic Data was calculated using the difference between the total number of HDVs and LDVs in 2010 in the Vermont Transportation Energy Profile and the

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[27] Stacy C. Davis, Susan W. Diegel, and Robert G. Boundy, “Transportation Energy Data Book: Edition 34” (Oak Ridge National Laboratory, August 2015), http://cta.ornl.gov/data/tedb34/Edition34_Full_Doc.pdf.
[28] Ibid.
[29] “Natural Gas Fuel Basics,” *Alternative Fuels Data Center*, accessed August 19, 2016, http://www.afdc.energy.gov/fuels/natural_gas_basics.html.
[30] U.S. Environmental Protection Agency: Office of Transportation & Air Quality, “Biodiesel.”
[31] US Energy Information Administration (EIA), “Freight Transportation Energy Use, Reference Case,” *Annual Energy Outlook 2015*, 2015, http://www.eia.gov/forecasts/aeo/data/browser/#/?id=58-AEO2015&region=0-0&cases=ref2015&start=2012&end=2040&f=A&linechart=ref2015-d021915a.6-58-AEO2015&sourcekey=0.

total number of LDVs from TES Transportation Data.[32] HDV miles per capita was calculated using the ratio of total HDV miles traveled from the 2012 Transportation Energy Data Book and the 2012 American Community Survey U.S. population estimate.[33,34] The total number of HDVs and HDV miles per capita were combined with the population assumptions outlined above to calculate miles per HDV.

The number of vehicles in each HDV fuel sector was calculated using the "Goal Seek" function in Excel to match final energy units in each respective fuel sector in the TES FACETS data. More specifically, the FACETS 2015 BAU energy values for compressed natural gas and liquid propane gas were assigned only to the HDV sector. The 2015 BAU FACETS values for biodiesel and diesel were portioned into the HDV sector using similar calculations as mentioned in the LDV section above: the diesel ratio used in the LDV method above was flipped to instead represent the ratio of HDVs to LDVs.

Rail

The rail sector of the transportation branch consists of two types: freight and passenger. Currently in Vermont, freight and passenger rail use diesel fuel.[35,36] The energy intensity (Btu/short ton-mile) of freight rail was obtained from the U.S Department of Transportation Bureau of Transportation Statistics.[37] Both Btu/short ton-mile and Btu/car mile have shown downward trends over past years, and so the most recent (2013) energy intensity value was chosen for Historic Data. The energy intensity of passenger rail (Btu/passenger mile) was also obtained from the U.S Department of Transportation Bureau of Transportation Statistics.[38] Passenger levels have experienced high volatility in recent years, and Btu/passenger mile was the only available data in terms of passenger rail efficiency. To smooth out the volatility of passenger levels, a 10-year efficiency average (Btu/passenger mile) was used for diesel passenger rail. Freight ton-miles were sourced from TES Transportation Data. Passenger miles were calculated using two sets of information. First, distance between Vermont Amtrak stations and the appropriate Vermont border location were estimated using Google Map data. Second,

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[32] Jonathan Dowds et al., "Vermont Transportation Energy Profile."

[33] "Transportation Energy Data Book: Edition 33" (Oak Ridge National Laboratory, n.d.), accessed August 18, 2016.

[34] U. S. Census Bureau, "Total Population, Universe: Total Population, 2012 American Community Survey 1-Year Estimates," *American Fact Finder*, 2012, http://factfinder.census.gov/bkmk/table/1.0/en/ACS/12_1YR/B01003/0100000US.

[35] US Energy Information Administration (EIA), "Freight Transportation Energy Use, Reference Case."

[36] Vermont Agency of Transportation Operations Division - Rail Section, "Passenger Rail Equipment Options for the Amtrak Vermonter and Ethan Allen Express: A Report to the Vermont Legislature," January 2010, http://www.leg.state.vt.us/reports/2010ExternalReports/253921.pdf.

[37] U.S. Department of Transportation: Office of the Assistant Secretary for Research and Technology Bureau of Transportation Statistics, "Table 4-25: Energy Intensity of Class I Railroad Freight Service," accessed August 26, 2016, http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_25.html.

[38] U.S. Department of Transportation: Office of the Assistant Secretary for Research and Technology Bureau of Transportation Statistics, "Table 4-26: Energy Intensity of Amtrak Services," accessed August 26, 2016, http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_26.html.

2013 passenger data was obtained from the National Association of Railroad Passengers.[39] Combined, these two components created total Vermont passenger miles.

Air

The air sector of the transportation branch was entered into LEAP as a "Technology with Total Energy." This allowed the analyst team to enter the appropriate FACETS data values directly into LEAP. The air sector is expected to continue using Jet Fuel in both the BAU and TREES LOCAL scenarios. Therefore, only a high-level value was necessary for entry into LEAP using the scenario alignment methods discussed above.

Reference Scenario: 2050

The projections to 2050 were tailored utilizing similar methods above with customization based on available data, which are discussed below.

Light Duty Vehicles

Ethanol and gasoline LDV efficiency was sourced from TES Transportation Data. To reach this value, a weighted average efficiency of LDVs was calculated using efficiency and the number of vehicles in each category (e.g. internal combustion engine (ICE) Cars, ICE Trucks, Hybrid Electric Cars, Hybrid Electric Light Trucks, Plug-in Electric Vehicle (PHEV) Cars, and PHEV Light Trucks).

LDV diesel efficiency was also sourced from TES Transportation Data. A similar weighted average efficiency was calculated using the 2050 values of number of vehicles and average efficiencies for diesel cars and light trucks. LDV biodiesel efficiency in 2050 was assumed to remain 10% below that of typical diesel fuel.[40]

LDV electric vehicle efficiency was assumed to increase at a rate of .6%. This was a calculated weighted average of 100-mile electric vehicles, 200-mile electric vehicles, plug-in 10 gasoline hybrid and plug-in 40 gasoline hybrid vehicles from the Energy Information Administration Annual Energy Outlook.[41]

LDV miles per vehicle was sourced from TES Transportation Data for the year 2050. The number of LDVs was derived using the same methodology as discussed in the Historic Data section above, utilizing FACETS data. As the FACETS data and the TES Transportation Data greatly differed on the total energy value for electricity in the transportation sector, which is discussed above, the smaller, more feasible value (in terms of the resulting number of EVs)

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[39] National Association of Railroad Passengers, "Fact Sheet: Amtrak in Vermont," 2016, https://www.narprail.org/site/assets/files/1038/states_2015.pdf.

[40] U.S. Environmental Protection Agency: Office of Transportation & Air Quality, "Biodiesel."

[41] U.S. Energy Information Administration, "Light-Duty Vehicle Miles per Gallon by Technology Type," *Annual Energy Outlook 2015*, 2015, https://www.eia.gov/forecasts/aeo/data/browser/#/?id=50-AEO2016&cases=ref2016~ref_no_cpp&sourcekey=0.

from the TES Transportation Data was used. The FACETS diesel and biodiesel values were split into LDV and HDV sectors using the same methodology as in Historic Data above.

Heavy Duty Vehicles

Diesel HDV efficiency was assumed to increase at a rate of 0.59%. This is a weighted average of light, medium and heavy freight diesel vehicles.[42] Similar to above, biodiesel was assumed to be 10% less efficient than diesel vehicles.[43] Compressed natural gas was assumed to be equal in terms of efficiency, consistent with the Historic Data methodology above. A weighted average efficiency growth rate was calculated using the same methodology and source as diesel HDV above. Miles per vehicle was assumed to remain constant. The methodology in Historic Data was used for both splitting the FACETS values and calculating the total number of vehicles.

Rail

Freight short ton-miles were derived from TES Transportation Data. Passenger and freight rail were assumed to remain powered by diesel, with a small percentage of biodiesel being added to the total freight energy mix. This biodiesel/diesel ratio was derived from TES Transportation Data. The energy intensity of passenger and freight rail was assumed to remain constant, in line with assumptions used in TES Transportation Data. Passenger miles, however, were assumed to grow at a compound rate of 1.7% per year.[44]

The diesel energy intensity discussed in the rail section within Historic Data above was converted to gallons per short ton-mile using fuel property assumptions listed above. Similar to above, biodiesel was assumed to have 10% less efficiency than diesel.[45] The value for gallons per short ton-mile was then converted to Btu per short ton-mile using biodiesel fuel properties assumptions listed above and was entered into LEAP.

Air

The air sector utilized the same methodology as discussed above in Historic Data.

90 x 50$_{\text{VEIC}}$ Scenario: 2050

Light Duty Vehicles

Efficiency values, miles per vehicle and the number of diesel and biodiesel LDVs and HDVs were derived using the same method discussed above for the Reference scenario.

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[42] US Energy Information Administration (EIA), "Freight Transportation Energy Use, Reference Case."
[43] U.S. Environmental Protection Agency: Office of Transportation & Air Quality, "Biodiesel."
[44] Joseph Barr, AICP et al., "Vermont State Rail Plan: Regional Passenger Rail Forecasts," January 28, 2015, http://vtrans.vermont.gov/sites/aot/files/rail/Tech%20Memo%204.pdf.
[45] U.S. Environmental Protection Agency: Office of Transportation & Air Quality, "Biodiesel."

Projections for number of electric vehicles were sourced from the EV section of the **Volume 2 Net Metering and Focus Area Briefs**. Otherwise, the number of vehicles were calculated using similar methods as illustrated in the LDV section of Historic Data, utilizing FACETS data.

FACETS data were altered slightly to de-emphasize the utilization of ethanol in the statewide mix. The DPS has indicated a shift in focus away from ethanol, due to the high energy cost to make the fuel and the lack of local fuel resources.[46] Therefore, this analysis used a calculated a replacement value for ethanol FACETS data comprising 15% of the total fuel blend of ethanol and gasoline. In Historic Data it is close to 11% of the gasoline and ethanol mix.

Similar to the Reference scenario, LDV miles per capita in 2050 was sourced from TES Transportation Data.

Heavy Duty Vehicles

It was assumed HDVs will switch entirely from diesel to biodiesel or renewable diesel by 2050. Recent advances with biofuel back this assumption. Cities such as Oakland and San Francisco are integrating a relatively new product called renewable diesel into their municipal fleets that does not gel in colder temperatures and has a much lower overall emissions factor.[47] Historically, gelling in cold temperatures has been prohibitive of higher percentages of plant-based diesel replacement products.

Although there has been some progress toward electrifying HDVs, the 90 x 2050_{VEIC} scenario does not include electric HDVs. This could be a potential area of improvement to the model as options for electric HDVs emerge and potentially transform the existing market. The California Air Resources Board indicated a very limited number of electric HDVs are in use within the state.[48] Anecdotally, Tesla communicated it is working on developing an electric semi-tractor that will reduce the costs of freight transport.[49] In an analysis of electrification options for fleet vehicles, the Electrification Coalition outlines three scenarios with barriers, incentives and potential timelines for EV integration into all fleet vehicle classes through 2020 and beyond. The timeline in all three scenarios offers a positive outlook for the integration of EVs in all vehicle classes.[50] Lastly, the economic and health benefits of electric buses and other HDVs could accelerate the adoption of this potentially widespread technology option.[51]

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[46] Vermont Energy Investment Corporation, "Solar Market Pathways Stakeholder Meeting #7 Meeting Notes."

[47] Oregon Department of Transportation and U.S. Department of Transportation Federal Highway Administration, "Primer on Renewable Diesel," accessed August 29, 2016, http://altfueltoolkit.org/wp-content/uploads/2004/05/Renewable-Diesel-Fact-Sheet.pdf.

[48] California Environmental Protection Agency Air Resources Board, "Draft Technology Assessment: Medium- and Heavy-Duty Battery Electric Trucks and Buses," October 2015, https://www.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf.

[49] Elon Musk, "Master Plan, Part Deux," *Tesla*, July 20, 2016, https://www.tesla.com/blog/master-plan-part-deux.

[50] Electrification Coalition, "Fleet Electrification Roadmap," November 2010, http://www.rmi.org/Content/Files/Fleet%20Electrification%20Roadmap.pdf.

[51] Noel, Lance and McCormack, Regina, "A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus," *Applied Energy* 126 (2014): 246–55.

Rail

Similar assumptions were used for freight ton-miles as those outlined above in the Reference scenario. A compound growth rate of 3% was used, consistent with the historical growth rates of rail passenger miles in Vermont.[52] Passenger rail is assumed to completely transform to electric locomotion. Freight rail is assumed to transform to biodiesel. Energy intensity assumptions for these sectors are identical to the Reference scenario above with the addition of electric passenger rail. Similar to the method above, to smooth out the volatility of passenger levels, a simple 10-year efficiency average (Btu/passenger mile) was used for electric passenger rail.[53]

Air

The air sector utilized the same methodology as discussed above in Historic Data.

Supply

The **electricity supply** is based on the TES,[54] the utilities' Committed Supply,[55] and other sources as needed to meet the 90 x 2050 goal and the demand projected in the model. Other than generators outside Vermont that are in the Committed Supply, electricity supply is assumed to be within Vermont. Hydro Quebec and Seabrook nuclear are the most significant source of out of state supply.

Table 7 gives the generating capacity for each sources over time, while **Table 1** focuses on new in-state capacity added to meet the goals. It shows the capacity added in the model between 2015 and 2050 for the 90 x 2050_{VEIC} and SDP scenarios.

Table 1. New Capacity Added 2015-2050

New capacity by 2050 (MW)			Source	
Scenario	**90 x 2050 VEIC**	**SDP**	**90 x 2050 VEIC**	**SDP**
New in-state hydro	93		Barg, 2007[7]	
Solar	1,611	2,026	TES	Brings PV to 34% of generation
Wind	550		Brings wind to 30% of generation	

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[52] Joseph Barr, AICP et al., "Vermont State Rail Plan: Regional Passenger Rail Forecasts."

[53] U.S. Department of Transportation: Office of the Assistant Secretary for Research and Technology Bureau of Transportation Statistics, "Table 4-26: Energy Intensity of Amtrak Services."

[54] Vermont Public Service Department, *Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals.* December 8, 2014. http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/TES/TES%20FINAL%20Report%2020141208.pdf.

[55] Vermont Public Service Department provided the data behind the graph on the bottom half of page E.7 in *Utility Facts 2013.* It is compiled from utility Integrated Resource Plans

Table 2 shows the capacity factor and source for hourly data for each renewable energy type. The hourly data was used to determine generation from each resource and to identify the timing, frequency, duration, and magnitude of mismatch between supply and demand in **Volume 1: 4.1 Bulk Power System Integration.** These results informed discussions of load management, regional trading, curtailment, and energy storage. The exact balancing of the high solar scenario is an area of ongoing analysis and the numbers may change depending on the ability to shift demand to match renewable generation. If load management and storage is insufficient, more renewable generation with the needed output shape, or capacity expected to be curtailed at times will be added.

Table 2. Capacity Factor and Hourly Profile

Capacity factor		Generation profile source	Precision
Demand	n/a	2013 VT load from ISO-NE[56] scaled up to the model's 2025 GWh	Hourly
In-state hydro	48%	Calculated from existing committed GWh of supply and installed MW capacity	Annual
New in-state hydro	52%	USGS 2007-2015 flow of White River at West Hartford 15-minute data from 2013, which was chosen as a year with near average flow and little missing data	15-minute
Hydro-Quebec	70%	GMP's contract: 7am – 11pm, 7 days a week	Hourly
Solar	13.7%	NREL 2013 National Solar Radiation Data Base, 30° tilt, no tracking	30-minute
Wind	38%	NREL Eastern Wind Dataset[57] 10-minute data for 17 simulated sites in Vermont, 2004-2006, 2005 was chosen because output was between the other two	10-minute
Biomass[58]	90% (max)	Dispatched if the other renewables are not meeting demand	Calculated from others

Costs for energy in the model are broken in to four categories: capacity costs, fixed overhead and maintenance (O&M) costs ($/MW), variable O&M costs ($/MWh), resource costs (e.g. $/ton of wood chips), and transmission and distribution (T&D) costs.

Capital costs for solar were estimated starting with data from the CESA Vermont Solar Cost Study[59] and reducing it according to a trend that begins with the historic data and flattens out

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[56] ISO-New England, Zonal Information, *SMD Hourly Data.* http://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/zone-info

[57] NREL, 2012, *Eastern Wind Dataset,* http://www.nrel.gov/electricity/transmission/eastern_wind_methodology.html

[58] Biomass fired electric plants such as McNeil and Ryegate operate like fossil fuel plants in that their fuel can be stored for use when electricity is needed. The 90% capacity factor reflects the ability to run nearly constantly, but the actual runtime in this case depends on the ability of other renewable energy to meet demand.

[59] Seddon, L.W., "Vermont Solar Cost Study: A report on Photovoltaic System Cost and Performance Differences Based on Design and Siting Factors," Clean Energy States Alliance, February 29, http://cesa.org/resource-library/resource/vermont-solar-cost-study-a-report-on-photovoltaic-system-cost-and-performance-differences-based-on-design-and-siting-factors.

as the capacity weighted average approaches $1/W in 2050. The Federal Investment Tax Credit reduces the cost of all solar through 2021 and for non-residential solar through 2025 after ramping down. Capital costs for in-state non-solar electric generation were estimated using data from OpenEI.[60]

The National Renewable Energy Lab (NREL) provided estimates of fixed O&M costs for solar.[61] OpenEI provided fixed cost estimates for other fuels.

Unless otherwise noted, current fuel/resource cost estimates come from the Vermont Fuel Price Report[62] and the projected rates of change in fuel prices are from EIA's Annual Energy Outlook[63] and the Alternative Fuels Data Center.[64] Natural gas cost estimates are provided by the 2014 EIA Natural Gas Price and Expenditure Estimates.[65] Bulk wood pellet resource cost estimates were provided by the Biomass Energy Research Center. Nuclear resource cost estimates came from Green Mountain Power's Seabrook contract.[66] Hydrogen fuel costs estimates came from NREL.[67]

Transmission and distribution estimates varied between the reference scenario and the 90 x 2050_{VEIC} scenarios to reflect grid upgrade costs to accommodate the higher share of more variable wind and solar generation.[68]

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[60] OpenEI, "Transparent Cost Database," accessed March 21, 2016, http://en.openei.org/apps/TCDB/transparent_cost_database.

[61] NREL, "Distributed Generation Energy Technology Operations and Maintenance Costs," 2013, http://www.nrel.gov/analysis/tech_cost_om_dg.html.

[62] Vermont Department of Public Service, "Vermont Fuel Price Report", December 2015, http://publicservice.vermont.gov/publications-resources/publications/fuel_report.

[63] U.S. Energy Information Administration, "Annual Energy Outlook 2015," https://www.eia.gov/outlooks/aeo/pdf/0383(2015).pdf.

[64] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Clean Cities Alternative Fuel Price Report," January 2016, http://www.afdc.energy.gov/uploads/publication/alternative_fuel_price_report_jan_2016.pdf.

[65] U.S. Energy Information Administration, "Natural Gas Price and Expenditure Estimates," 2014, https://www.eia.gov/state/seds/data.cfm?incfile=sep_fuel/html/fuel_pr_ng.html.

[66] Green Mountain Power, "Green Mountain Power Strikes Long-Term, Low Cost Power Deal With NextEra Energy Resources," May 24, 2011, http://news.greenmountainpower.com/press-releases/green-mountain-power-strikes-long-term-low-cost-p-nyse-nee-0760048.

[67] Ramsen, T. "Pathway Projected Cost, Lifecycle Energy Use and Emissions of Emerging Hydrogen Technologies," National Renewable Energy Laboratory, June 9, 2015, https://www.hydrogen.energy.gov/pdfs/review15/sa036_ramsden_2015_o.pdf.

[68] Ludlow, P., T. Vitolo and J. Daniel, "A Solved Problem: Existing measures provide low-cost wind and solar integration," *Synapse Energy Economics,* August, 2015, http://www.synapse-energy.com/sites/default/files/A-Solved-Problem-15-088.pdf.

Detailed Tables

The following tables aggregate and summarize the energy demand and supply for the Solar Development Pathways (SDP) scenario as calculated by LEAP based on the inputs as detailed above. Spreadsheets containing all detailed inputs are available upon request. Table 3 and Table 4 provide the data graphically depicted in **Figures 1** and **2** of **Volume 1**.

Table 3. Total energy demand by sector and year (Million MMBtu), SDP Scenario

Sector	2010	2015	2020	2025	2030	2035	2040	2045	2050
Residential	36.7	36.0	34.1	32.2	30.0	27.9	26.0	23.9	21.5
Commercial	17.8	18.1	17.7	17.1	16.4	15.6	15.0	14.3	13.6
Industrial	16.4	16.2	15.7	15.3	14.8	14.4	13.9	13.4	13.0
Transportation	45.6	44.0	40.8	37.4	31.4	27.3	23.8	20.8	18.2
Total	116.5	114.3	108.3	100.2	92.6	85.2	78.7	72.5	66.3

Table 4. Total energy demand by fuel and year (Million MMBtu), SDP Scenario

Fuels	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	18.9	19.4	20.0	20.9	22.8	24.2	25.6	27.0	28.2
Natural gas	13.4	12.9	11.6	10.2	8.3	6.6	5.0	3.4	1.8
Gasoline	29.6	28.2	25.5	22.6	16.0	11.5	7.5	4.1	0.9
Jet kerosene	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4
Kerosene	1.0	1.0	0.8	0.7	0.6	0.4	0.3	0.1	-
Diesel	10.4	9.8	8.3	6.9	5.5	4.2	2.8	1.5	0.1
Residual fuel oil	2.3	2.3	2.3	2.2	2.2	2.1	2.1	2.0	2.0
LPG	8.9	8.7	7.9	7.1	6.2	5.4	4.6	3.8	2.9
Oil	14.5	13.8	11.9	10.0	8.1	6.2	4.3	2.2	0.0
Ethanol	4.0	3.8	3.3	2.5	1.9	1.4	0.9	0.5	0.2
Solar Thermal	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2
Coal	1.2	1.1	0.9	0.8	0.6	0.5	0.3	0.2	-
CNG	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Biodiesel	0.1	0.8	2.6	4.3	6.1	7.8	9.6	11.5	13.4
Wood chips	3.0	3.2	3.7	4.2	4.7	5.2	5.7	6.3	6.8
Wood pellets	0.6	0.8	1.1	1.4	1.7	1.9	2.1	2.2	2.3
Cord wood	7.1	7.0	6.8	6.6	6.4	6.2	6.2	6.1	6.0
Total	116.5	114.3	108.3	100.2	92.6	85.2	78.7	72.5	66.3

Table 5. Electric demand by sector and year (GWh), SDP Scenario

Sector	2010	2015	2020	2025	2030	2035	2040	2045	2050
Residential	2095	2143	2230	2334	2504	2617	2724	2810	2875
Commercial	2020	2084	2102	2106	2096	2086	2087	2098	2096
Industrial	1405	1432	1499	1567	1634	1701	1769	1836	1903
Transportation	2	7	18	103	437	686	925	1155	1376
Total	5522	5666	5849	6239	6671	7090	7504	7898	8251

Table 6. Generation by source by year (GWh), SDP Scenario

Fuels	2010	2015	2020	2025	2030	2035	2040	2045	2050
In state hydro	548	891	938	938	938	938	938	938	938
New in state hydro	0	5	36	78	172	248	268	286	297
HQ and NYPA hydro	1865	1703	1218	1203	1214	1214	1214	1214	1214
New hydro import	0	0	0	0	0	0	0	0	0
Farm methane	0	50	67	92	92	92	92	92	92
Landfill methane	102	108	125	92	92	58	58	58	58
Wind	180	646	682	682	682	682	682	682	682
New wind	0	42	308	503	693	1181	1298	1404	1474
Wood	465	591	591	591	591	591	591	591	591
Natural gas ISO market	754	437	414	199	103	206	168	125	83
Nuclear	0	914	705	609	528	0	0	0	0
Vermont Yankee nuclear	2167	0	0	0	0	0	0	0	0
Oil	51	0	0	0	0	0	0	0	0
Residential PV	7	67	145	222	282	341	400	459	519
Commercial PV	5	44	96	147	186	226	265	304	343
Parking canopy PV	0	9	32	54	67	80	94	107	120
Community net metered PV	0	51	179	306	377	448	518	589	660
Utility scale PV	6	110	318	526	657	788	920	1051	1183
Total	6150	5669	5852	6112	6674	7903	7507	7902	8254

Table 7. Available electricity generation capacity by year (MW)

Fuels	2010	2015	2020	2025	2030	2035	2040	2045	2050
In state hydro	212	212	223	223	223	223	223	223	223
New in state hydro	0	2	10	25	60	68	77	85	93
HQ and NYPA hydro	311	284	200	198	198	198	198	198	198
New hydro import	0	0	0	0	0	0	0	0	0
Farm methane	1	6	8	11	11	11	11	11	11
Landfill methane	13	13	15	11	11	7	7	7	7
Wind	119	194	205	205	205	205	205	205	205
New wind	0	19	113	206	300	400	450	500	550
Wood	75	75	75	75	75	75	75	75	75
Natural gas ISO market	800	800	800	800	800	800	800	800	800
Nuclear	210	119	90	78	67	0	0	0	0
Vermont Yankee nuclear	620	0	0	0	0	0	0	0	0
Oil	25	21	20	20	20	20	20	20	20
Residential PV	7	54	117	180	228	276	324	372	420
Commercial PV	5	36	78	120	152	184	216	248	280
Parking canopy PV	0	8	26	45	56	67	78	89	100
Community net metered PV	0	43	149	255	314	373	432	491	550
Utility scale PV	5	84	242	400	500	600	700	800	900
Total	2403	1968	2370	2852	3220	3507	3816	4124	4432

Table 8. Fuel costs

Fuels	Starting Price	% change to 2025
Hydro	-	
Farm methane	-	-
Landfill methane	-	-
Wind	-	-
Wood Chips (electricity generation)	$34/ton	1.81%
Wood Chips (thermal)	$55/ton	2.02%
Wood Pellets	$275/ton	No change
Cord Wood	$227/cord	No change
Coal	$2.31/MMBTU	7.67%
Natural gas ISO market	$35.07/MWH	No change
Natural Gas (thermal)	$0.0123/cubic feet	22.21%
Nuclear	$.0466/kWh	No change
Vermont Yankee nuclear	$.0052/kwh	N/A
Oil	$3.73/Gal	28.74%
Jet Kerosene	$15.41/MMBTU	44.59%
Solar	-	-
Biodiesel	$2.49/Gal	No change
CNG	$2.45/Gallon of Gasoline equivalent	No change
Diesel	$3.36/gallon	28.74%
Gasoline	$2.85/gallon	27.51%
Kerosene	$3.09/gallon	28.74%
Residual Fuel Oil	$10.45/MMBTU	33.89%
LPG	$2.54/gallon	11.68%
#2 Fuel Oil	$2.84/gallon	28.74%

Table 9. Capacity cost $ per Megawatt of production capacity

Fuels	2015	2020	2025	2030	2035	2040	2045	2050
In state hydro	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
New in state hydro	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
HQ and NYPA hydro	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
New hydro import	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Farm methane	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55
Landfill methane	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55
Wind	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
New wind	1.97	1.90	1.83	1.76	1.73	1.70	1.67	1.64
Wood (for electricity)	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55
Nuclear	4.93	4.5	4.2	4.13	4.78	4.13	4.13	4.13
Residential PV	2.53	2.02	2.27	1.97	1.77	1.60	1.52	1.44
Commercial PV	1.68	1.34	1.36	1.31	1.17	1.03	1.01	.96
Parking canopy PV	2.11	1.68	1.70	1.64	1.47	1.33	1.26	1.20
Community net metered PV	1.56	1.24	1.25	1.21	1.09	0.98	0.93	0.80
Utility scale PV	1.34	1.07	1.08	1.04	0.93	0.84	0.80	0.76

Table 10. Transmission and distribution costs by scenario

Scenarios	Transmission and Distribution Cost		
	2010	2025	2050
Reference	5.5	6.6	5.5
90 x 50VEIC	5.5	6.0	7.0
Solar Development Pathways	5.5	6.5	7.0

Table 11. Overhead and maintenance costs by generation type

Fuels	**Fixed O&M ($000/MW)**		**Variable O&M ($/MWH)**	
	2015	**2025**	**2015**	**2025**
In state hydro	20	20	6	6
New in state hydro	20	20	6	6
HQ and NYPA hydro	20	20	6	6
New hydro import	20	20	6	6
Farm methane	100	100	4	4
Landfill methane	100	100	4	4
Wind	31	31	8.46	8.46
New wind	30.7	27.3	8.46	7.44
Wood	100	100	4	4
Natural gas ISO market	20	20	-	-
Nuclear	109	109	.62	.62
Vermont Yankee nuclear	109	109	.62	.62
Residential PV	20	20	-	-
Commercial PV	20	20	-	-
Parking canopy PV	20	20	-	-
Community net metered PV	20	20	-	-
Utility scale PV	20	20	-	-

Table 12. Economic Results: Cumulative Costs & Benefits, 2010-2025 and 2010-2050, Relative to Reference Scenario. Discounted at 3.0% to year 2015. Million 2015 U.S. Dollar

	2010-2025				**2010-2050**			
	90 x 2050 VEIC	**Solar Development Pathways**	**Delayed Deployment**	**Lower Net Metering**	**90 x 2050 VEIC**	**Solar Development Pathways**	**Delayed Deployment**	**Lower Net Metering**
Demand	**851**	**851**	**851**	**851**	**924**	**924**	**924**	**924**
Residential	416	416	416	416	403	403	403	403
Commercial	261	261	261	261	654	654	654	654
Industrial	58	58	58	58	145	145	145	145
Transportation	115	115	115	115	-278	-278	-278	-278
Transformation	**306**	**498**	**319**	**488**	**1,873**	**2,544**	**1,853**	**2,326**
Transmission and Distribution	-3	13	13	13	102	142	142	142
Electricity Generation	308	485	306	475	1,771	2,402	1,711	2,184
Resources	**-1,080**	**-1,140**	**-1,078**	**-1,148**	**-11,270**	**-11,439**	**-11,249**	**-11,429**
Production	83	83	83	83	380	380	380	380
Imports	-1,162	-1,222	-1,160	-1,231	-11,650	-11,819	-11,629	-11,809
Exports	-	-	-	-	-	-	-	-
Unmet Requirements	-	-	-	-	-	-	-	-
Environmental Externalities	-	-	-	-	-	-	-	-
Non Energy Sector Costs	-	-	-	-	-	-	-	-
Net Present Value	**77**	**209**	**91**	**190**	**-8,473**	**-7,971**	**-8,472**	**-8,179**
GHG Savings (Mill Tonnes CO2e)	7	7	7	7	83	83	83	83
Cost of Avoiding GHGs (U.S. Dollar/Tonne CO2e)	11	29	13	27	-102	-96	-102	-98

Table 13. Emissions table-- 100-Year Global Warming Potential (GWP): Direct (At Point) Emissions, Solar Development Pathways Scenario for All Fuels, All GHGs (Thousand Metric Tonnes CO_2 Equivalent

Branches	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Avoided vs. Reference	0	211	795	1556	2278	3083	3790	4494	5195
Total Demand	**6139**	**5889**	**5270**	**4467**	**3696**	**2926**	**2207**	**1509**	**818**
Residential	1683	1602	1414	1228	1014	814	622	419	204
Commercial	714	710	648	579	504	427	350	272	189
Industrial	668	644	585	526	467	408	348	289	230
Transportation	3075	2933	2623	2134	1712	1277	886	528	194
Transformation	**957**	**867**	**789**	**668**	**536**	**456**	**356**	**254**	**150**
Transmission and Distribution	789	762	684	600	487	386	294	200	105
Electricity Generation	168	105	105	69	49	70	62	54	45
Total	7096	6756	6059	5135	4232	3382	2563	1763	968