# ENERGY POLICY OPTIONS FOR VERMONT

## Technologies and Policies to Achieve Vermont's Greenhouse Gas and Renewable Energy Goals

PREPARED BY
**DUNSKY ENERGY CONSULTING**
with the collaboration of Sustainable Energy Economics, KanORS-EMR Consultants, Grasteu Associates Inc., and Forward Thinking Consultants LLC

PREPARED FOR
**VERMONT PUBLIC SERVICE DEPARTMENT**

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Dunsky Energy Consulting remains solely responsible for any errors or omissions in this report.

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# EXECUTIVE SUMMARY

## INTRODUCTION

Responding to the publication of the 2011 Comprehensive Energy Plan, which called for a Total Energy Study (TES), the Vermont Legislature passed Act 170 of 2012 (modified by Act 89 of 2013), requiring the Vermont Public Service Department (PSD) to conduct this study. The purpose of the TES is to identify the most promising policy and technology pathways to reach Vermont's renewable energy and greenhouse gas (GHG) reduction goals. The TES is a multi-phased process that began in January 2013 and has involved decision-makers, experts and the general public. The TES results will inform the next iteration of Vermont's Comprehensive Energy Plan, due to be released in late 2015.

## THE TOTAL ENERGY STUDY: POLICY AND TECHNOLOGY MODELING

This report describes the energy modeling phase of the TES. It begins by describing the process by which the PSD, in close collaboration with the Dunsky Energy Consulting team, defined an array of twenty future technology and policy scenarios, and subsequently selected three scenarios for comprehensive analysis. Quantitative analysis was conducted using the Framework for Analysis of Climate-Energy-Technology Systems (FACETS) energy system optimization model. FACETS was used to construct a Business as Usual (BAU) scenario, projecting Vermont's energy production and consumption (and associated emissions) in the absence of additional climate and energy policies. It was then used to simulate how the energy system would evolve using different policy mechanisms designed to help achieve the State's long-term goals.

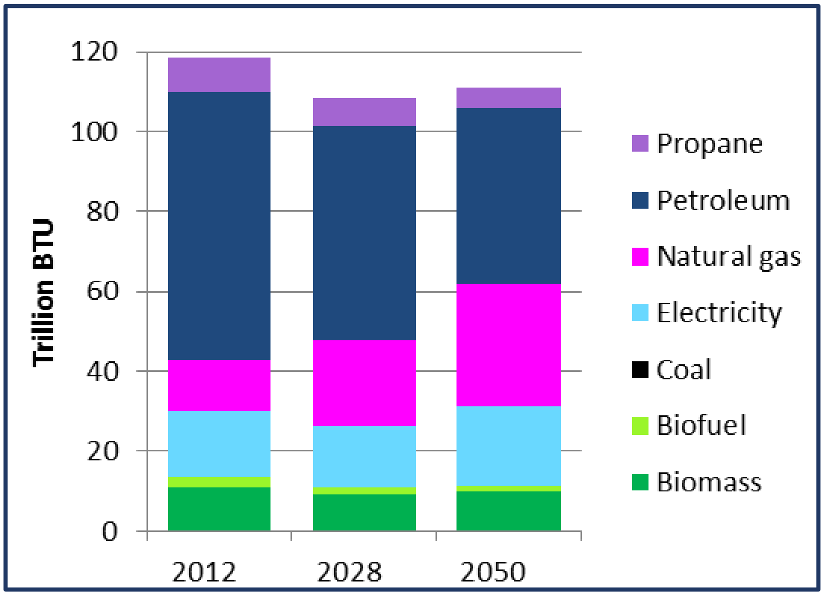
These models allow us to understand how each policy approach would impact the adoption of a broad array of technologies and practices – including heating and cooling equipment, vehicle types and usage, fuel types, and other energy-consuming technologies – across all sectors of the State's economy. The analysis accounts for Vermont's reasonably-available resources, as well as available technologies to meet consumers' needs.[1] This report discusses how these scenarios were built, the modeling results, and the conclusions that can be drawn from them.

[1] We note that transportation modal switching and land use policies (e.g. smart growth) were not modeled; due to data limitations, analysis of the industrial sector – a very small portion of the state's energy use – was also limited.

## BUSINESS-AS-USUAL (BAU)

The first step in the modeling process is to construct a Business as usual (BAU) scenario that represents the evolution of the current Vermont energy system, assuming no new policies directed at renewable energy or GHG emissions reductions. As shown in Fig. ES-1 below, the total amount of energy consumed annually in Vermont is projected to decrease slightly from 2012 to 2050, due to greater efficiency of home heating, lighting, and other devices, as well as the new federal light-duty vehicle CAFE standards, which require nearly a doubling of new vehicle efficiencies over the coming decades.

**Fig. ES-1: Vermont Energy Consumption 2012-2050 – Business As Usual (BAU) Scenario**




Along with this decrease in total energy consumption, Vermont's energy-related greenhouse gas emissions are projected to decrease by about 10% between 2012 and 2050.

Despite this slight reduction in energy usage and carbon emissions, achieving Vermont's long-term goals – a 75% reduction in GHG emissions and 90% renewable energy content – will require far more aggressive changes to the State's energy systems.

## POLICY OPTIONS FOR MEETING VERMONT'S STATEWIDE GOALS

Vermont has established policy goals of reducing emissions of greenhouse gases from 1990 levels by 50% by 2028, and by 75% by 2050, in addition to obtaining 90% of all energy from renewable resources by that same year.[2,3] The Dunsky Team's analysis shows that these goals are technically achievable under each of the three potential policy approaches we modelled:

1. **Carbon Tax Shift:** a revenue-neutral tax[4] on greenhouse gases emitted from energy resources across all sectors, to be offset by a corresponding tax reduction in other areas of the economy (e.g. reductions in income, sales and use, corporate, and/or other taxes)

2. **TREES Basic:** The Total Renewable and Energy Efficiency Standard (TREES) applies a schedule, provided by the PSD, of mandatory shares of total energy consumption derived from either renewable energy or improved energy efficiency. Under this schedule, non-renewable energy ramps down linearly from current levels to 10% of Vermont's total energy needs by 2050. Energy distributors are required to demonstrate compliance with the standard, either by directly sourcing an escalating percentage of their supply from renewables or efficiency, or by purchasing renewable or efficiency "credits" from entities with amounts in excess of the standard.

3. **TREES Local:** The TREES Local policy begins with the TREES Basic described above, but further requires an increasing share of the renewable energy requirement to be sourced in-state.

As the reader can see, each of these policy options represents a different degree of flexibility – or inversely, of constraint – on how market actors can achieve the overall goals.

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[2] 10 V.S.A. § 578(a)

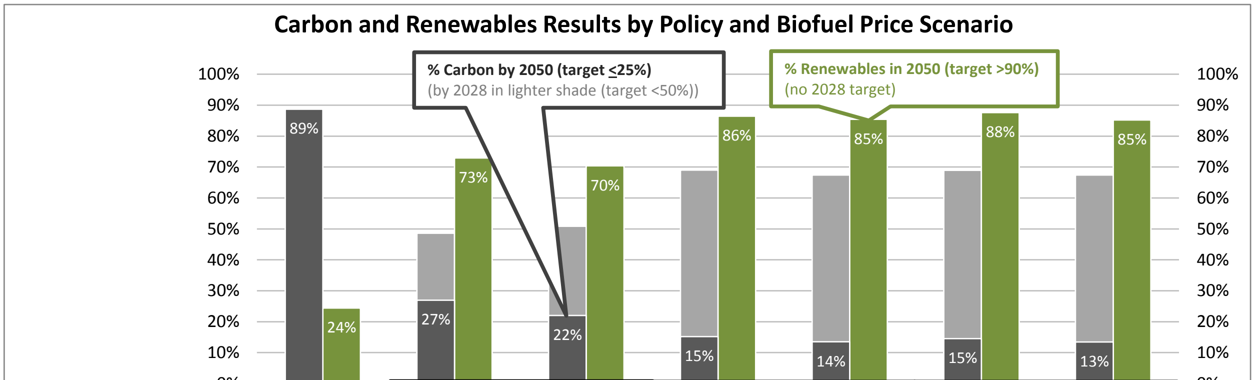
[3] State of Vermont, *2011 Comprehensive Energy Plan*.

[4] From Vermont Public Service Department, *Total Energy Study: Report to the Vermont General Assembly on Progress Toward a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals.* December 2013. "Creation of an economy-wide carbon tax in the context of tax reform, maintaining at or near revenue neutrality for the State. In this option, other taxes are cut by an amount equal to or close to the amount of revenue raised by the carbon tax. This carbon tax has the effect of sending a price signal much closer to the societal cost of emissions incurred, addressing the market failure of the mismatch between prices and costs."

## RESULTS

Fig. ES-2, below, presents an overview of the anticipated impacts of each policy option ("TaxSHIFT" "TREES Basic", and "TREES Local"), for two scenarios regarding future biofuels prices ("LoBio$" and "HiBio$").

**Fig. ES-2: Policy Options and Projected Results**




| | BAU | TaxSHIFT (LoBio$) | TaxSHIFT (HiBio$) | TREES Basic (LoBio$) | TREES Basic (HiBio) | TREES Local (LoBio$) | TREES Local (HiBio$) |
|---|---|---|---|---|---|---|---|
| 2028 CO2 Emissions | 87% | 49% | 51% | 69% | 67% | 69% | 67% |
| 2050 Renewable content | 24% | 73% | 70% | 86% | 85% | 88% | 85% |
| 2050 CO2 Emissions | 89% | 27% | 22% | 15% | 14% | 15% | 13% |

The ability of the energy system to change is highly dependent upon the assumed evolution of liquid biofuel prices in the future. For this reason, we conducted a sensitivity analysis around two such price scenarios. As explained further in this report, the reader should note that in order to account for these sensitivities, we adjusted the level of the carbon tax under the TaxSHIFT policy according to the assumed price of biofuels. As such, the level of carbon tax increases far more rapidly under the "HiBio$" scenario than under the "LoBio$" one, in order to meet the State's carbon reduction goals.

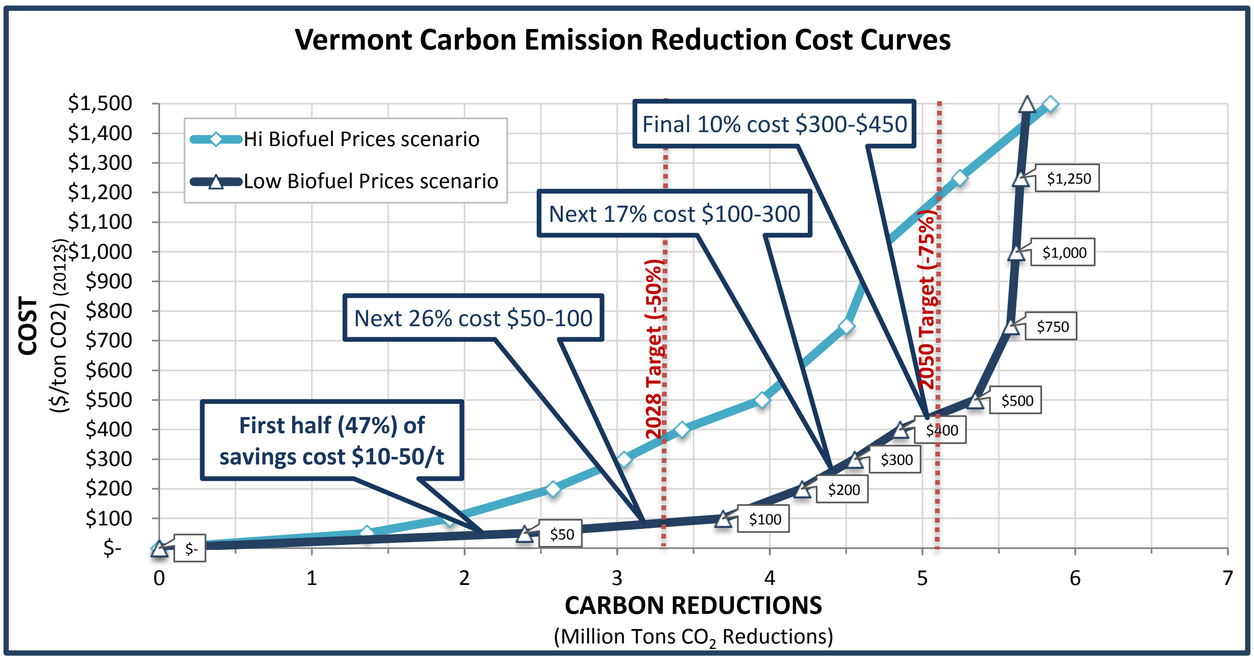
**The Dunsky Team's analysis finds that achieving the goal of a 75% reduction in Vermont's greenhouse gas emissions by 2050 is achievable under all three policy options, and at a moderate cost.** That said, each option evokes a trade-off regarding the other targets. For example, a Carbon Tax Shift also achieves the mid-term GHG target of 50% by 2028, but falls short of the 2050 renewable energy target. Inversely, both TREES policies achieve the long-term GHG target *and renewable energy* targets, but fall short of the mid-term (2028) GHG reductions target.

## DISCUSSION OF COSTS

Results show that achieving these significant targets comes at a moderate cost: depending on the policy option as well as assumptions regarding future biofuel prices, achieving the targets will add between 2.2% and 5.5% to the direct cost of meeting Vermonters' energy needs. While assumptions around liquid biofuels prices are responsible for the bulk of the cost range, the choice of policy approach also plays a role, with a carbon tax being generally more economically efficient than either TREES standard.

Figure ES-3, below, provides a "cost curve" of emissions reductions. As the reader will see, assuming low biofuel costs, nearly half of the long-run goal can be achieved at costs of between \$10 and \$50 per ton of $CO_2$e. The marginal cost of emissions reductions increases thereafter, rising to approximately \$450 for the final ton needed to achieve the 2050 target. Given how much of the target is available at relatively low cost, the *average* cost of savings over the full 38-year period is limited to approx. \$40 per ton of $CO_2$.

**Fig. ES-3: Cost Curves for Carbon Emissions Reductions in Vermont**




***Under the low biofuel price scenario, the first 3.7 MT, i.e. nearly three-quarters of the 2050 emissions reduction target, and all of the 2028 target, can be achieved at a cost of between \$10 and \$100 per ton.***

Vermont currently imports most of the energy consumed in the state. An unassessed benefit of achieving the statewide goals will likely be to shift a significant share of the energy production and associated economic activity from imports to Vermont-based sources.[5] While The Dunsky team's analysis was limited to Vermont's energy system, accounting for the macroeconomic impacts of each option should be a consideration in choosing among policy options. We understand that the PSD will be using the results presented herein to assess their likely impact on key macroeconomic indices, such as employment and Gross State Product, as part of the broader Total Energy Study report package.

Finally, another benefit of these policies is a potential improvement in air quality, given a likely reduction in air emissions associated with the electrification of vehicles and buildings, and/or from a shift to cleaner-burning fuels and technologies. These improvements, and associated health and economic benefits, were not modelled as part of this report.

## CONCLUSION

While each policy option – in addition to sensitivities around liquid biofuel prices – will generate different energy mixes, all cases revolve around three "pillars" upon which Vermont's energy transformation will be built:

1. *Efficiency*: increased energy efficiency and conservation, beyond current projections.
2. *Fuel Switching*: accelerated adoption of liquid biofuels and electricity in vehicles, and of woody biomass and electricity in buildings; and
3. *Clean Power*: growth in renewable power generation to support electrification.

**The Dunsky Team's analysis suggests that the transformation needed to achieve Vermont's greenhouse gas emissions reduction and renewable energy goals are ambitious but, to a significant extent, achievable.** The Carbon Tax Shift approach could be expected to hit the State's 2028 *and* 2050 GHG reduction targets, albeit falling short of the renewable energy goals. Meanwhile, the TREES policies would achieve Vermont's long-term GHG *and* renewable energy goals (significantly exceeding the former), while falling short of the 2028 GHG target.

**Furthermore, the cost of achieving these goals appears moderate.** Under the low biofuel price scenario, the cost of meeting the state's energy needs increases by a modest 2.2% to 3.3%. Under the high biofuel price scenario, costs increase by 4.5% to 5.5%. Under all cases, the added cost is lower than the assumed cost of inaction. Finally, this analysis does not account for other benefits to the state, including those associated with improved commercial balances from increased in-state economic

[5] Depending on the policies chosen, the share of in-state supply can be expected to supply up to 60% of all domestic consumption by the end of the period (under the TREES-Local option).

activity, as well as from potentially improved air quality and associated health and infrastructure benefits.

In choosing the preferred policy approach, policymakers may need to choose between the tradeoffs identified previously, namely which targets to prioritize (long-term renewable energy vs. mid-term carbon goals), and the extent to which the presumed macroeconomic benefits of increased in-state sourcing are worth the additional cost of the TREES policy options. Other considerations – around administrative burden, risks, cost, compliance, and even political feasibility – may be equally as important.

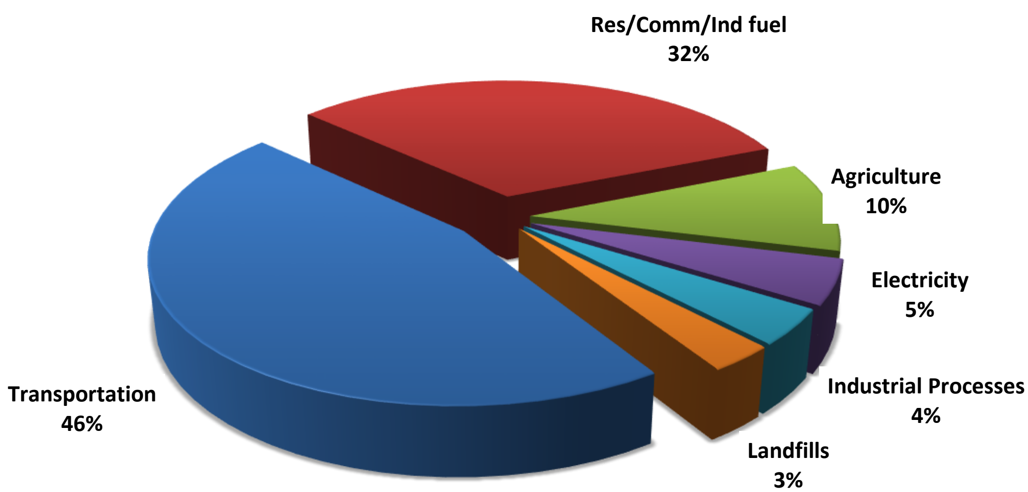
Regardless of which approach is pursued, achieving the goals will clearly require a bold – and sustained – policy commitment. While we provide recommendations regarding next steps to be undertaken, most critically is the need for a more detailed feasibility assessment of the two primary options: a tax shift from other areas of the economy toward carbon, or a renewable energy standard that applies to all fuels and sectors, including transportation.

# INTRODUCTION

## VERMONT'S CHALLENGE

Energy use accounts for 83% of Vermont's current greenhouse gas emissions. In fact, nearly half (46%) of Vermont's 2012 emissions came from energy used for transportation, and another third (32%) from fuels used to heat homes and businesses. By contrast, electricity generation is responsible for only 5% of emissions. Figure 1 below provides the full breakdown of greenhouse gas emissions by sector.

**Figure 1: Vermont's 2012 Greenhouse Gas (GHG) Emissions Sources[6]**




In response to the Comprehensive Energy Plan, in 2012 the Vermont State Legislature adopted Act 170 which, as later modified by Act 89 of 2013, requires the Public Service Department (PSD) to conduct a Total Energy Study of policies and funding mechanisms designed to achieve the state's greenhouse gas and renewable energy goals in an integrated and comprehensive manner.

Specifically, the Total Energy Study (TES) is designed to chart technically effective and economically feasible paths to an energy system that meets Vermont's energy goals:

- 50% reduction in greenhouse gas emissions (from 1990 levels) by 2028

[6] Vermont Agency of Natural Resources, http://www.anr.state.vt.us/anr/climatechange/Vermont_Emissions.html

- 75% reductions in greenhouse gas emissions (from 1990 levels) by 2050, and
- 90% of all energy sourced from renewable resources by 2050.

Reducing Vermont's greenhouse gas emissions will require changes in the consumption patterns of multiple fuels across multiple sectors and end-uses. This new energy economy must also be capable of satisfying Vermonters' needs across the transportation, industrial, commercial and residential sectors for heating, lighting, mobility, and other services.

Some of the changes that will be needed for this transition have already begun, driven by technological innovation, market economics, and the existing policy environment. Energy efficiency is a proven, cost-effective energy resource for Vermont. The costs of some forms of renewable energy have fallen dramatically in recent years. These factors, combined with structural changes[7] to Vermont's economy, resulted in statewide greenhouse gas emissions in 2011 which were no higher than they were in 1990[8]. However, achieving a 75% reduction in greenhouse gases will require major changes to Vermont's current patterns of energy production, distribution, and usage. In terms of the 90% renewable energy goal, renewables currently (2012) supply only about 20 percent of Vermont's total energy consumption. Clearly, significant new policies are needed to drive Vermont's clean energy transition fast enough, and far enough, to meet the statewide goals.

## SCOPE OF WORK

To assist in completing the TES, the Vermont Public Service Department (PSD) contracted the Dunsky Team to perform comprehensive modeling of alternate energy future policy scenarios for Vermont. This work is intended to help the Vermont Legislature, other policy makers, and the public chart a path to achieving Vermont's ambitious greenhouse gas mitigation and renewable energy goals.

The Dunsky team was tasked with defining, in close collaboration with the PSD, an array of twenty future technology and policy scenarios, and subsequently with modelling three of them using the Framework for Analysis of Climate-Energy-Technology Systems (FACETS[9]) optimization model. This report describes the process leading to the analysis, and then presents the results of the FACETS model – including the ability of each scenario to achieve Vermont's greenhouse gas and renewable energy goals. Finally, we discuss conclusions that can be drawn from model results. Please note that this study

[7] For example, according to the US Energy Information Administration thousands of short tons of coal were still burned annually as fuel in Vermont until the end of the 20th century. This illustrates that it can take a long period of time for obsolete technologies to completely disappear from Vermont's energy economy. http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/total/use_tot_VTa.html&sid=VT

[8] Vermont Greenhouse Gas Emissions Inventory Update 1990-2011; 12/2013; VT Agency of Natural Resources

[9] More information on the FACETS model is available at http://facets-model.com/.

considers only greenhouse gas emissions associated only with energy production, transportation, and consumption.

The long-term modeling of Vermont's energy economy described in this report was designed to present Vermonters with a state-of-the-art tool for evaluating different sustainable energy futures for the state, with a view to informing Vermont's policy choices going forward. It is intended to inform the next Vermont Comprehensive Energy Planning process.

## PURPOSES OF THIS REPORT

The PSD is required by Act 170 of 2012, modified by Act 89 of 2013, to conduct a Total Energy Study of policies and funding mechanisms designed to achieve the state's greenhouse gas and renewable energy goals in an integrated and comprehensive manner. The TES has been a multi-phased process with Phase 1 beginning in January 2013 with the preparation of the "Policy Options for Achieving Vermont's Renewable Energy and Carbon Targets" Report"[10] and the solicitation of input from stakeholders via written comments, public hearings, and a series of focus groups through the balance of the year. The Dunsky Team's role began with Phase 2 of the TES and involved the assessment of the technology and policy scenarios identified in Phase 1, including in-depth modeling of three of those policy scenarios. This document describes the policy scenarios assessment process and presents the results of the energy modeling.

## DIALOG WITH THE PSD, STAKEHOLDERS, AND CLIMATE CABINET

During the project, the Dunsky Team worked closely with the PSD to ensure cohesion with the State's objectives, and to ensure access to, and application of, the most current Vermont-specific energy data. PSD staff have been consistently available and engaged with each step of our work.

The TES is also designed to gather input from the public and interested stakeholders. As part of Phase 1, in August and September of 2013, the PSD held eleven stakeholder meetings on different topics related to the TES. In December of 2013 the PSD also solicited public input on a Legislative Report and provided the Dunsky Team with a summary of the comments received.

In February 2014, the PSD held a consultative session with the Governor's Climate Cabinet at which the Dunsky team was invited to review consideration of key issues as well as present initial assessment of

[10] Policy Options for Achieving Vermont's Renewable Energy and Carbon Targets (Prepared for the Vermont Department of Public Service), RAP, 2013, available at http://publicservice.vermont.gov/sites/psd/files/Pubs_Plans_Reports/TES/Total_Energy_Study_RFI_and_Framing_Report.pdf

the array of technology and policy options available to Vermont, and to discuss which policy scenarios would be modelled using the comprehensive FACETS tool. Following this session, the PSD provided the Dunsky team with direction regarding the specifics of the three policy scenarios retained for modelling.

## HOW TO READ THIS REPORT

If Vermont takes no additional action to reach its statewide greenhouse gas and renewable energy goals, and economic growth follows historic trends, energy consumption per capita, total energy consumption, and total carbon dioxide emissions will all decrease from 2014 to 2050[11]. The energy intensity of the Vermont (and the national) economy, in terms of pounds of $CO_2$ per unit of economic output, has been gradually dropping for decades. With the turn of the 21st century, Vermont's absolute energy consumption appears to have turned a corner and now exhibits a negative growth rate — thanks in part to innovative state policies like the Energy Efficiency Utilities.

By itself, the projected decrease in emissions under a "business as usual" scenario[12] will not be nearly enough to meet Vermont's statewide goals by 2050. The new emissions projection needed to achieve Vermont's goals demands a new perspective on approaches to mitigating greenhouse gas emissions. Instead of trying to turn back the tide of rising energy use and emissions, the charge for policy makers is to figure out how to accelerate existing trends (a much more attractive and achievable prospect).

This report is rooted in a complex modelling exercise designed to assess how Vermont's energy system would evolve in reaction to various policy options. As with any effort to look forward in time, it should be considered as a source of directional, rather than descriptive information about potential energy futures for Vermont. We suggest that the reader focus on the relative, rather than the absolute, estimates of the differences between the policy scenarios discussed.

[11] Annual Energy Outlook 2014 with projections to 2040, EIA, 4/2014

[12] A so called "Business as Usual Scenario (BAU)" or "baseline" estimates future greenhouse gas emissions if Vermont adopts no new policies aimed at reducing those emissions.

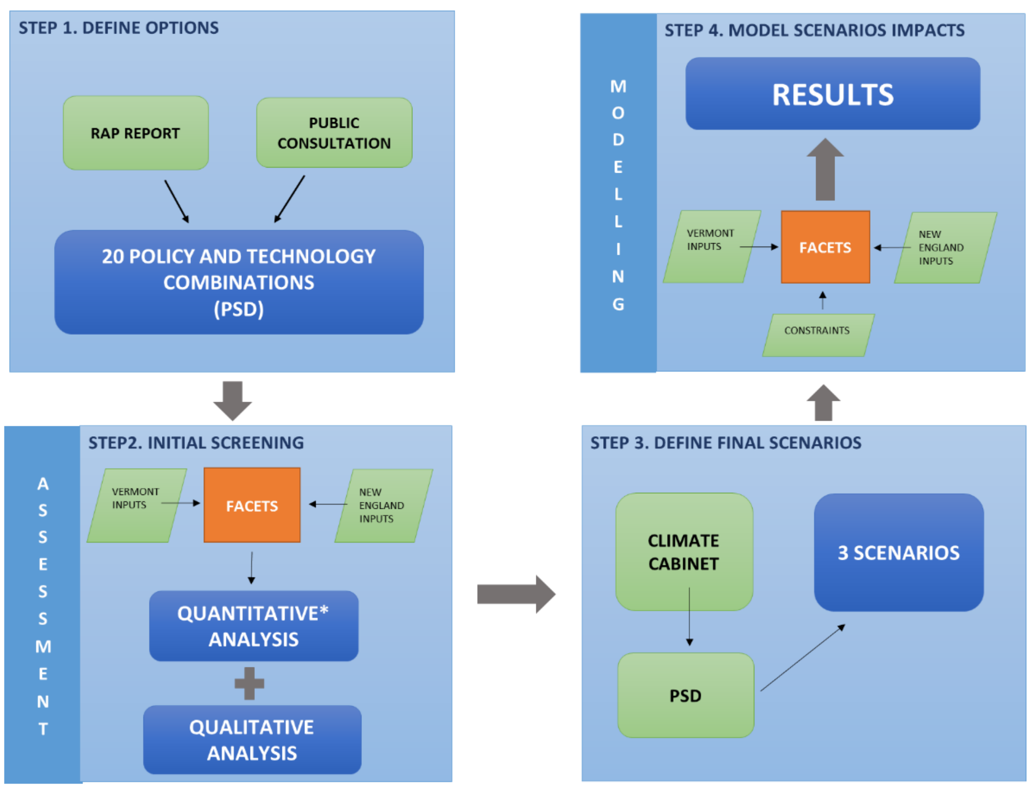
# METHODOLOGY

The Dunsky Team set out to assist the PSD in narrowing the analytical focus from a broad range of potential future policy and technology pathways (called policy options in this report) to a limited number of most attractive options, and then to submit those to comprehensive analysis using the FACETS model. This report describes the process of narrowing the focus of the TES from twenty to three policy options, and discusses the results of the FACETS modelling of those final three.

We adopted a four-step process as illustrated in Figure 2:

1. Define the array of options
2. Conduct an initial assessment to screen options
3. Define a smaller set of three policy options for comprehensive energy and economic modelling
4. Conduct comprehensive modelling and describe the energy, greenhouse gas, and economic results associated with each policy scenario.

**Figure 2: Summary TES Modeling Process**




**Preliminary FACETS model runs*

Below we expand on the process undertaken for each of the four key steps.

## MODELING VERMONT'S ENERGY ECONOMY IN THE FACETS MODEL

Reducing Vermont's GHG emissions will require changes in the consumption patterns of multiple fuels across multiple sectors and end-uses. To understand how this can best be achieved, sophisticated computer models like FACETS can be critical tools in addressing complex systems, and can help to answer questions such as:

- What are the best ways of achieving emissions reduction targets given the fuels and technologies currently available or potentially available in the future?
- Which fuels will need to be used more and which less, in order to achieve the targets?
- What penetration of established and innovative technologies into specific sectors of the economy will be necessary to reduce emissions to a desired target?
- How will measures undertaken in one sector impact the choices and costs available in other sectors?
- How much will it cost to effect these changes?
- What are the key risks Vermont faces in meetings its goals and managing the costs of energy system changes?

***The Vermont FACETS Model***

- *Supports optimization, not just simulation*
- *Allows for complex interactive effects*
- *Represents the entire energy economy of Vermont*
- *Is built on an extensive array of data, including significant Vermont-specific data*
- *Covers energy resources, technologies, and demand for useful energy services*
- *Contains over 20,000 combinations of technologies and commodities (e.g. light diesel consumption in heavy trucks)*
- *Includes 11,000 existing power plants, and hundreds of options for new plant types*
- *Allows several dozen options to meet each end use demand, including space heaters, lightbulbs, cars and trucks, among others*

The FACETS computer model is designed to answer questions like these on a system-wide basis. FACETS goes beyond merely simulating potential future options, and allows users to account for complex interactive effects and optimize for lowest total energy system cost. These capabilities serve the objectives of the TES project by allowing identification of the most cost-effective technology and policy combinations to meet energy service needs.

FACETS is based on the TIMES (The Integrated MARKAL-EFOM System) model generator.[13] A TIMES model represents the entire energy system of a country or region as a network, including all forms of energy extraction, transformation, distribution, end-uses, and trade. Each stage in the network has many different specific technologies available, each characterized by economic and technological parameters. The model also tracks greenhouse gas and criteria air pollutant emissions.

The model calculates through the network to find the least-cost options[14] for meeting all demands for useful energy services (e.g. vehicle-miles of transportation, BTUs of space heat, and so on). These end use service demands are exogenously specified in a business-as-usual scenario, driven by projections of population and economic activity. In policy options, where additional model constraints and/or taxes may be imposed to model new policies, energy service demands are elastic to their own prices, allowing for partial equilibrium adjustment to changes in the prices of each individual service. For example, people will drive more (or less) if the price of vehicle travel goes down (up) relative to baseline projections.

The model solves to minimize the net costs of the entire energy system, including investment costs, operation and maintenance costs, and the costs of resources and imported fuels, minus the incomes of exported fuels and the residual value of technologies at the end of the model horizon, in addition to any welfare losses due to endogenous demand reductions. Model outputs at each point in time include future investments in and activities of all technologies, including all fuel consumption and emissions, and the marginal prices of all fuels. Figure 3 summarizes the key model inputs and outputs. Additional information about FACETS can be found in Appendix A.

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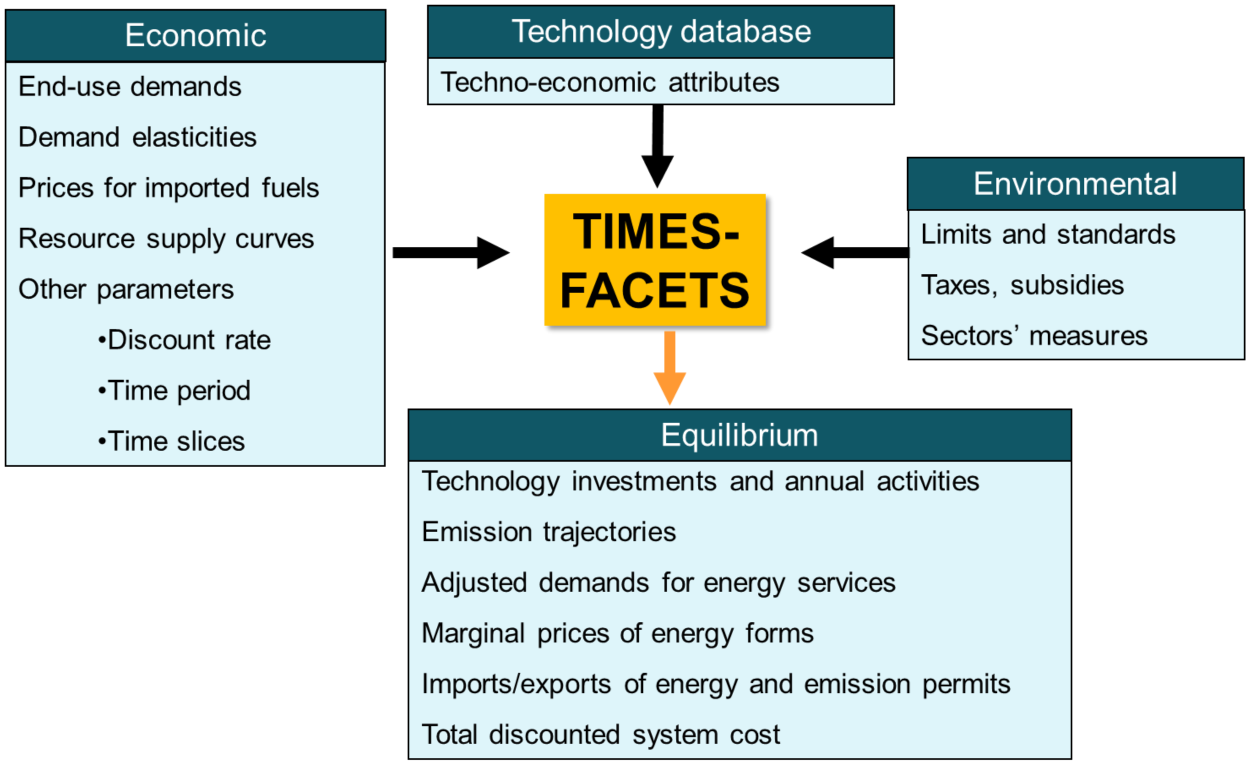
[13] Within the Energy Technology Systems Analysis Program of the International Energy Agency, MARKAL and TIMES models are currently used by more than 80 institutions in nearly 70 countries for various purposes including economic analysis of climate and energy policies.

[14] Technically, this corresponds to an assumption that *energy markets are under perfect competition*. A single optimization simulates market equilibrium by searching for the maximal net total producer plus consumer surplus or, equivalently, minimizing the net total cost of the energy system.

**Figure 3: Vermont FACETS Inputs and Outputs**




FACETS was originally developed as model of the entire energy economy of the United States, with demand disaggregation at the nine region census levels, and electricity production regionalized to the major US grids. For the TES project, the Dunsky Team extracted Vermont from its New England demand and electricity regions, using Vermont-specific population, energy consumption, and electricity capacity. For others, where aspects of Vermont's energy economy differed significantly from New England's, we augmented the FACETS database with other Vermont-specific data. The model was then run with Vermont embedded in the larger New England region, which in turn is embedded in the national energy system. Thus trade in electricity and other fuels takes place across state and regional borders.

The power of optimization energy computer models is the ability to keep track of a very large number of variables and their interactions over time, and thereby model complex systems like state or national energy systems. It is the Dunsky Team's intention that the Vermont's FACETS analysis provide useful insights into the complex interactions between energy, greenhouse gas emissions, and public policy in Vermont, and serve as a common reference for the next stage of Vermont's political engagement on meeting the State's renewable energy and greenhouse gas goals.

## STEP 1: DEFINE OPTIONS

Prior to commencement of the Dunsky Team's work, the PSD retained the Regulatory Assistance Project (RAP) to outline options for the state to consider. The RAP Framing Report, published in June of 2013, provided a broad overview of available technologies and policies and was designed to facilitate discussions with stakeholders about the potential means to reach Vermont's greenhouse gas reduction and renewable energy goals.

In August and September of 2013, the PSD held eleven stakeholder meetings on different topics related to the TES. Based on the RAP report, the stakeholder sessions, and subsequent discussions with the Dunsky Team, the PSD defined twenty combinations of policy approaches and technology pathways that might contribute to meeting the statewide goals.

## STEP 2: INITIAL SCREENING

The second phase of the TES process involved assessing the twenty policy and technology combinations with the objective of choosing three for full-scale computer modelling. This initial screening required a mix of both qualitative and quantitative analyses.

- **Quantitative:** To generate quantitative data to help inform the qualitative assessment process, the Dunsky Team conducted preliminary runs of the FACETS model, first developing a Business as usual baseline scenario, and then applying Vermont's 2028 and 2050 greenhouse gas reductions goals as additional constraints[15]. FACETS then determined the least-cost pathway to the targets by investing in efficiency, switching fuels, and adopting new technologies as needed to achieve the targets. A set of parametric carbon tax runs were also used to develop a cost curve for carbon emissions reductions, showing how much reduction could be achieved at different cost levels under varying assumptions. These simplified first runs did not attempt to model an actual policy approach. However, the results helped to pinpoint the lowest cost greenhouse gas emissions reductions available in Vermont's energy economy. They also identified the significant impact that the price and availability of liquid biofuels—which are assumed to be imported to Vermont from the rest of the country—will have on the cost and achievability of meeting Vermont's emissions goals. The risk posed by biofuels price and availability was then treated a primary sensitivity variable for the remainder of the study.

- **Qualitative:** The Dunsky Team and PSD staff used their combined professional experience, including in-depth knowledge of options, costs, and risks, to qualitatively assess each scenario based on the following criteria: Contribution to the greenhouse gas and renewable energy

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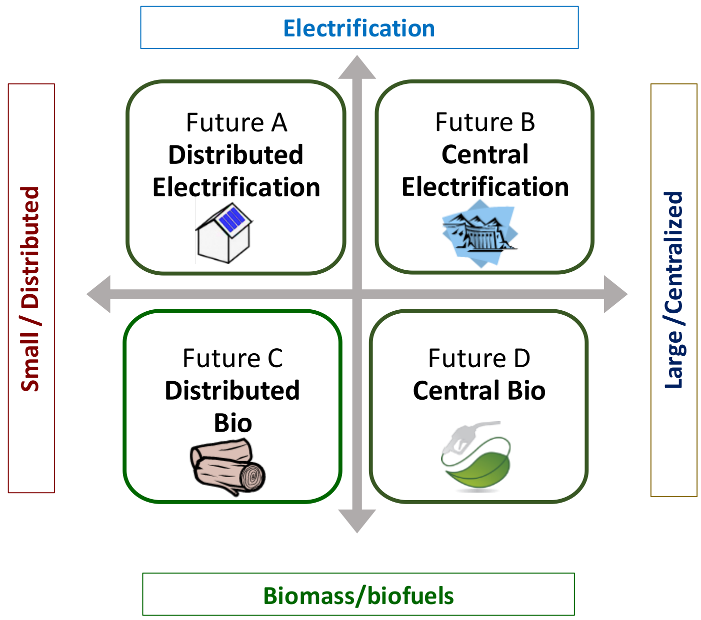
[15] Developing appropriate technical constraints for FACETS was an important part of the model development process. Economic and policy constraints were added in the final three policy scenarios.

targets; Cost minimization; Pacing (time required to implement); Maximizing in-state economic activity; and Risk. Note that the first two criteria benefited from the preliminary quantitative analysis described previously.

**Figure 4: Technology Emphasis Matrix**




The initial screening illustrated a number of interesting aspects of Vermont's energy economy. First, energy efficiency and energy conservation will continue to play a central role beyond current projections. Biofuels and woody biomass already have shares of Vermont's energy economy and are poised for growth. Biomass (solid fuels) tends to be local and relatively small scale while biofuels (liquids, primarily ethanol) are almost entirely imported in the form of ethanol mixed into gasoline. Vermont's electricity supply is centralized and relatively low-carbon. There appears to be a sufficient supply opportunity to power the electrification of light-duty transportation (automobiles). In the transportation and space heating sectors, electricity, biofuels and woody biomass will compete to replace the liquid fossil fuels consumed in those sectors today. Fuel switching within each sector is highly dependent upon relative fuel commodity price, and the cost and availability of efficient new technologies that use the new fuel resources (such as cold climate heat pumps and pellet-fired residential boilers).

These insights led to a technology emphasis matrix, shown in Figure 4. The matrix has four quadrants defined by the four distinct directions which Vermont could follow in the future. The actual path Vermont takes will probably involve some elements of each quadrant. Nonetheless, these divisions are useful for considering policy approaches, each of which can put more or less emphasis on a technology direction. The four technology futures and some pros and cons are described below:

- ***Distributed Electrification –*** In this future, low-carbon electricity replaces fossil fuels in areas like light-duty transportation and home heating (biomass). More electricity is generated from local, in-state power sources, like solar PV. Distributed generation has a greater overall impact on emissions in the long-term due to the avoidance of transmission losses and an overall low risk profile, since risk is distributed across multiple options. However, Vermont's electricity system is currently centralized and it would take time and investment to put the necessary distributed electrification infrastructure in place.

- ***Central Electrification –*** Low carbon electricity replaces fossil fuels for transportation and heating/cooling, but the power is provided by the current, centralized electric utility model from utility-scale renewable energy projects. Considering in-state resource limits, major imports from Québec and other areas in the Northeast can be expected. On the other hand, the existing utility infrastructure allows electrification to start quickly and could be promoted under different policy approaches with manageable risks.

- ***Distributed Bio –*** Biofuels replace gasoline and diesel as motor fuels, and woody biomass replaces heating oil, in particular in the residential and institutional sectors. After an initial period of importing out-of-state know-how and expertise, a relatively speedy saturation of use of in-state capabilities can be anticipated, as well as an increasing in-state economic activity. Low carbon fuels can be manufactured in Vermont, with mostly in-state or New England production and distribution. Pellets are a form of woody biomass that would play a relatively large role in space heating. We note greater uncertainty for the bio-energy than for the electrification futures due to uncertainties about the price and availability of liquid biofuels. The ability of local sources to meet the demand for transport biofuels is also a significant source of uncertainty, since local production of biofuels is expected to remain very limited.

- ***Central Bio*** – A strong policy approach favouring biomass and biofuels, large-scale biomass for heat and power, and/or biofuels for transportation. Potential liquid biofuel availability concerns are mitigated by allowing most of the supply to be imported from out-of-state, particularly for transportation but also for a portion of space heating. As we noted for Distributed-Bio future, there is greater uncertainty for the bio-energy than for the electrification futures, due to uncertainties about price and availability of biofuels and the low efficiency of centralized biomass electric generation[16].

These technology futures proved useful to the team in considering policy options, since different policies will lead to different mixes of technology adoption.

## STEP 3: DEFINE POLICY OPTIONS

### *FIVE INITIAL POLICY SETS*

In the third step of the process, the Dunsky Team proceeded to examine five distinct policy approaches to enabling the deployment of low carbon technologies. These approaches consisted of bundles of

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[16] The modeling confirmed that centralized biomass electric generation is uneconomic, except in very constrained cases, because of its relatively low efficiency.

policies and regulations that may appear in one or more policy approaches.[17] Vermont's energy future may involve components of some or all of them. It is worth noting that the PSD recognises the paramount role of energy efficiency, but rather than design a specific "Enhanced Efficiency" policy scenario, it is assumed that policies promoting energy efficiency would be an essential part of all the policy options.

The policy approaches initially considered were:

- ***A Total Renewable Energy and Efficiency Standard (TREES) –*** This would require Vermont's energy distributors to acquire a steadily increasing portion of their energy sales from renewable energy sources, or to offset sales by corresponding improvements in customer energy efficiency. To benefit from the lowest-cost options, clean energy providers could generate tradable "TREES Certificates", which could then be traded among distributors. TREES is fundamentally an expanded version of renewable portfolio standards, which have a long track record across the U.S., but which have been primarily associated with electric power generation. *The inclusion of a TREES scenario was required by the Total Energy Study enabling legislation*.[18]

- ***A Carbon Tax Shift –*** This places a tax on each ton of greenhouse gas emissions at a sufficient magnitude to drive substitution for low-carbon fuels and technologies. The tax would apply to all energy-related activities across Vermont. A corresponding series of tax *reductions*, not specified in this analysis, would ensure that the carbon tax shift remains "revenue neutral", and that total state tax collections do not change.

- ***Renewable Targets with Carbon Revenue –*** This would involve setting voluntary clean energy targets by sector, backed up by mandatory requirements in the event that voluntary targets are not met. In addition, a very modest carbon tax (significantly smaller than under *Carbon Tax Shift*) would generate revenues to fund new energy efficiency programs and other mechanisms to support the transition to clean energy.

- ***The Sector Specific Approach –*** This approach implies custom policies tailored to particular aspects of critical sectors such as transportation, space heating, and electricity generation.

- ***A NE Regional Focus –*** Finally, this approach acknowledges that Vermont is already part of a regional energy network and works with neighboring New England states (and Canadian provinces) to aggregate more market power and invest in clean energy infrastructure.

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[17] A comprehensive discussion of the five policy sets considered in this analysis is included in the PSD's TES Legislative Report. Refer to Appendix C of this report for a summary table comparing the scenarios proposed for evaluation.

[18] Act 170 of 2012, modified by Act 89 of 2013

Based on an initial assessment of the strengths and weaknesses of each of these policy approaches, the Dunsky Team and the PSD held a consultative session with the Governor's Climate Cabinet and their staff on February 25, 2014. This meeting provided both critical feedback from a broad perspective, and informed the PSD's choice of the final three policy approaches to submit to comprehensive modelling with FACETS.

### *FINAL THREE OPTIONS FOR MODELING*

The quantitative and qualitative assessment of the twenty initial options yielded the choice of the final three – a carbon tax shift and two TREES options – for a number of reasons. In particular, they were found to be attractive in terms of expected cost and effectiveness in meeting state goals; they are fully implementable by the State of Vermont; and they allow for a useful contrast of objectives (cost minimization, renewable energy, and economic development) and associated impacts.

We note that the three approaches selected for modelling are largely "technology agnostic" (not linked to or favoring the development of specific technologies), and face different risks in terms of meeting emissions goals and expected costs. Tax policies are likely to achieve emissions reductions at lowest cost, since they allow the market to choose winners and losers among the broadest range of solutions. Meantime, a Total Renewable Energy and Efficiency Standard (TREES) also allows for market-driven cost-optimization (thanks to its inclusion of certificate trading), but within the somewhat more restricted realm of renewable energy and energy efficiency solutions. Finally, a TREES-Local policy adds further restrictions to certain solutions (namely, out-of-state renewables), in exchange for increased certainty of in-state economic benefits.

For example, if biofuels prices are low, a carbon tax may translate into reduced oil consumption for transportation (replaced with biofuels), but fossil fuels may still be used in other sectors. TREES policies, on the other end, will likely reduce the use of nuclear and fossil fuels and incentivize efficiency and earlier development of technologies like solar PV.

#### *1. REVENUE-NEUTRAL CARBON TAX SHIFT*

This revenue neutral tax is applied to all fuels and follows a Pigouvian redistribution of tax burden from "goods" like income to a "bad" (carbon emissions). Beginning at $10/ton of $CO_2$ equivalent in 2015, it grows linearly over time to a maximum value in 2050. The specific trajectory needed to meet Vermont's 2028 and 2050 goals depends heavily on the assumed price for imported biofuels. A parametric set of runs with tax levels starting at $10/ton in 2015 and ramping by different degrees was used to identify the levels needed to reach Vermont's emissions goals. The Results section below reports on the two trajectories needed to achieve the targets if biofuels prices are low (ramp up from $10/ton to a maximum of $450/ton by 2050), or high ($10 up to $1,250/ton by 2050). Full graphical results for all the parametric runs are shown in Appendix E.

The Carbon Tax Shift scenario does not focus on a specific fuel or technology, is agnostic regarding whether energy is imported or domestically produced, and does not differentiate whether the energy comes from renewable or non-renewable sources, nor whether its production is geographically centralized or distributed. Notably, it does not directly incentivize renewable energy.

### 2. TREES BASIC

The TREES options apply a schedule, provided by the PSD, of mandatory shares of total energy needs to be derived from either renewable energy, or improved energy efficiency (beyond already-anticipated *baseline* improvements). Under this schedule, renewable energy ramps up linearly from current levels of approximately 20%, to 90% of Vermont's projected needs by 2050[19].

### 3. TREES LOCAL

The TREES Local policy option imposes the same TREES standard for inclining renewable energy use as above, and then introduces an additional constraint: the use of in-state renewable energy sources. This bias is modeled as a maximum share of total energy needs met by out-of-state resources, declining from the current level of approximately 80%, to only 40% by 2050. This results in a threefold increase in the share of the state's total energy needs that would be sourced in-state.[20]

In practice, this policy could be implemented in the form of greater credits for in-state renewables and energy efficiency, lower credits for out-of-state renewables, or some combination thereof. Please note that energy efficiency beyond BAU trends and federal policies is considered an in-state resource for these purposes.

Table 1 below shows the out-of-state shares for the TREES-Basic and TREES-Local options. Note that the TREES-Basic achieves a higher in-state share under high biofuels prices than under low biofuels prices, because of the greatly reduced biofuels imports when prices are high.

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[19] For purposes of calculating Vermont's total energy needs in each model year, a modified Business as usual scenario was constructed including national energy efficiency policies, such as Corporate Average Fuel Economy standards, but which backs out additional state efficiency programs that are expected to reduce consumption in the Business as usual scenario. See more discussion in the Energy Efficiency section below.

[20] Following PSD's direction, the maximum out-of-state share for the TREES-Local policy was set at 40% in 2050. Using the shares from the TREES-Basic runs for a guideline, the constraint was set to create an achievable, but modestly more ambitious, target than achieved by TREES alone, ramping to 60% in 2042 on the way to reaching 40% in 2050.

**Table 1: Share of Renewable Energy Imported under TREES-Basic and TREES-Local**

| | | 2020 | 2028 | 2034 | 2042 | 2050 |
|---|---|---|---|---|---|---|
| BUSINESS-AS-USUAL | | 81% | 82% | 82% | 82% | 82% |
| TREES POLICY OPTION *(and Biofuel Price Scenario)* | | | | | | |
| TREES Basic | *Low Bio $* | 75% | 68% | 59% | 44% | 40% |
| | *High Bio $* | 78% | 77% | 75% | 63% | 48% |
| TREES Local | *Low Bio $* | 75% | 68% | 58% | 44% | 40% |
| | *High Bio $* | 78% | 77% | 70% | 60% | 40% |

By applying this constraint, the TREES Local scenario further restricts the options available to meet the State's goals, but ensures that by the end of the period, the majority of energy consumed in Vermont is also produced in-state.

## STEP 4: MODEL POLICY SCENARIO IMPACTS

To prepare the Vermont FACETS model for scenario analysis, the Dunsky Team worked in close cooperation with the PSD to build a Business as Usual (BAU) base case to simulate Vermont's current energy economy. We calibrated the model by applying appropriate supply constraints, and adjusting demand until FACETS consistently produced the current energy consumption for the Vermont market.

As indicated above, a large amount of the energy that Vermonters currently use is imported from outside of the state. Energy prices and availability are determined by regional, national, and international markets. To fully reflect the actual flows of energy into the state, the BAU scenario was built on a database that includes relevant Vermont, New England regional, and US energy system resources, including import/export options with Canada. The key issues and assumptions are discussed in the following sections, and are summarized in Table 2.

# MODEL ASSUMPTIONS

## OVERVIEW OF KEY CONSTRAINTS AND ASSUMPTIONS

Model calibration involved setting exogenous limits on the availability of resources and penetration of some fuels and technologies to reflect realistic non-economic barriers, technical or otherwise, in the Vermont market. The PSD provided a maximum development schedule for wind and small-scale (non-utility) solar electricity based on current trends and an assessment of regulatory and siting issues. The PSD and the Dunsky team developed estimated limits on the future penetration of woody biomass as a home heating fuel and limitations on the ability of some homes to switch away from delivered liquid fuel. Vermont Gas Systems provided projections on the future expansion of the natural gas distribution system. Table 2 below summarises key model assumptions.

Vermont's statewide goals include both greenhouse gas reduction and renewable energy share targets. While the two are linked, our analysis assumes that achieving the greenhouse gas reductions has primary importance, and the policy approaches were designed to meet those goals.

**Table 2: Key Energy Resource Assumptions**

| ENERGY SOURCE | CONSTRAINTS AND KEY ASSUMPTIONS[21] |
|---|---|
| **Natural Gas** | **Technical Constraints:** none (price driven)<br>(Carbon emissions are based on the carbon content of the fuel only.) |
| **Biofuels (liquid)** | **Technical Constraints:** none (price driven)<br><br>**Carbon content**: As provided by the PSD using an *energy return on ton of fossil carbon invested* approach. Carbon contents for liquid biofuels:<br>• Biodiesel 100%: 13.2 kg/MMBTU, (perhaps falling over time to 9.1 kg/MMBTU<br>• Ethanol 100%: corn ethanol 56 kg/MMBTU shifting over time to cellulosic at something like 8 kg/MMBTU<br><br>**Price scenarios**: As provided by the PSD<br>• The "low" biofuels price case is based on current market price premiums for corn ethanol and biodiesel includes a $0.31 retail price premium for E100 and a $0.47 retail price premium for E100 (to be applied proportionately to fuel blend mixes – e.g. E85 would be 85% of $0.31. Values based on EBISnewsletter-sample.pdf) corresponding to a 9% premium over the prevailing price for gasoline for ethanol and a 12% premium for biodiesel. This case corresponds to an assumption that the US biofuels industry can scale up current production at these premiums such that |

[21] Carbon intensities for renewable fuels were provided by PSD.

Vermont can import unlimited quantities of biofuel, with acceptable carbon intensities, at these prices without impacting the broader US market.

- The "high" case includes the first 10 million gallons at a 50% price premium (based on a low estimate of the amount of local biodiesel that could be produced), with the remainder at a 250% price premium – designed to be high enough to effectively price biofuels out of the running. This case corresponds to an assumption that no mature US biofuels industry develops, and low-carbon biofuels remain a niche commodity. Although this case was designed to price biofuels out of the running, they continue to penetrate substantially where the model lacks other options to reduce carbon emissions, particularly for medium and heavy-duty vehicle travel.

**Biomass (solid)**

**Technical Constraints:**

- Cordwood: max 25% penetration of cord wood for residential space heating.
- Pellets and Chips: none

**Supplies:**

Woody biomass supplies for cordwood and chips were based on data from the *2010 Basic Update of the Vermont Wood Supply Study*[22], drawing on supplies available within Vermont and surrounding counties. A resource supply curve was developed in conjunction with PSD, guided by data from the Oak Ridge National Lab *Billion Ton Update*[23].

Pellets are assumed to be available as unlimited import from out-of-state sources, at a price two-thirds that of home heating oil, consistent with recent *Vermont Fuel Price Report* data.

**Carbon content:** As provided by the PSD using an *energy return on ton of fossil carbon invested* approach. Carbon contents for solid biomass:

- Pellets: 6.4 kg/MMBTU
- Cord Wood: 1.8 kg/MMBTU
- Chips: 2.8 kg/MMBTU

**Wind and Solar**

**Technical constraints:** See table below; values chosen to reflect reasonably-anticipated constraints (e.g. siting).

| Year | Max Non-Utility Solar PV Capacity (MW) | Max Utility Solar PV Capacity (MW) | Max Wind Power Capacity (MW) |
|---|---|---|---|
| 2010 | 42 | | |
| 2015 | 84 | | |

[22] Biomass Energy Resource Center, *2010 Basic Update of the Vermont Wood Supply Study*, 2010.

[23] U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN.

| | | | | |
|---|---|---|---|---|
| | 2020 | 105 | | 150 |
| | 2025 | 140 | | |
| | 2030 | 176 | | |
| | 2035 | 214 | | |
| | 2040 | 253 | | 350 |
| | 2045 | 294 | | |
| | 2050 | 300 | 1000 | 400 |
| **Hydro imports** | **Technical constraints:** none.<br>**Others:** Imports from Hydro Quebec are considered zero carbon and renewable, as defined by statewide goals. | | | |
| **Nuclear** | **Technical constraints:** none (imports from NE pool available).<br>**Others:** Nuclear is assigned a fossil equivalent of 10,500 BTU/KWh for purposes of exclusion from the statewide renewable energy goals. It is assumed to be zero carbon. | | | |
| **Farm methane** | **Technical constraints:** The current 4 MW of existing production increases to 11 MW over 15 years and then stays constant.<br>**Others:** Farm methane is assumed to be zero carbon. | | | |
| **Oil/Propane** | **Technical constraints:** 5% each *minimum* shares for oil and propane heated homes in 2050, to account for portion that cannot or will not switch to another source. | | | |

Among the many assumptions that feed into the model, the treatment of energy efficiency, liquid biofuels and woody biomass, transportation electrification, and the way in which the model accounts for future innovations are worthy of special attention. We briefly discuss each of these below.

### *SPOTLIGHT ON ENERGY EFFICIENCY*

Entering into this project, stakeholder opinion strongly suggested that energy efficiency was readily available and most often the least expensive resource in Vermont, and should play a primary role in meeting statewide goals. Subsequent quantitative analysis confirmed this (see Model Calibration Scenarios below). Therefore rather than design a specific "Enhanced Efficiency" policy scenario for modelling, the PSD asked the Dunsky Team to assume that policies promoting energy efficiency would be an essential part of all three final options.

In the BAU scenario, the efficiency of energy use increases over time, due to improvements in available technologies, as well as U.S. national policies such as appliance efficiency standards and automobile CAFE standards, are part of the baseline demand projection. However, all three of the final options modeled for this project allow for and make use of additional energy efficiency, beyond what we see today in Vermont and the BAU case.

While it is useful in policy terms to conceptualize energy efficiency as a "resource" like fossil fuels or wind power - that can and should be considered to meet demands alongside other resources - modeling energy efficiency in a systems model like FACETS requires it to be thought of in a different way. FACETS does not explicitly consider energy efficiency programs, except in cases where specific constraints on the rate of energy use are imposed (e.g. federal CAFE standards). Rather, for each energy end use, FACETS considers specific energy technologies, with different efficiency levels, to satisfy demand for energy services at the lowest-cost. For example, FACETS includes over a hundred different furnaces, boilers, and other devices to meet home heating demand, which use a variety of fuels, are gauged at up to five levels of efficiency, and are available at different upfront capital costs. FACETS also offers seven levels of building shell efficiency improvement. In selecting the cost-optimal technologies to satisfy demand, FACETS considers the investment costs of technologies, their fixed and variable operating and maintenance costs, and the fuel prices, generated within the model. For example, if the price of heating oil increases, FACETS considers the cost of switching to a pellet-fired boiler, against the cost of adding attic insulation and the cost (and availability) of switching to natural gas. The substitution of electric motor drive for internal combustion engines for automobiles is one example of technology shift that can generate large energy and cost savings due to improved efficiency.

FACETS also allows demand to change as consumers respond to energy price increases. In the residential sector, for example, the model might reflect the likelihood of increasing numbers of households choosing to use clotheslines in the summertime rather than electric clothes driers, as prices increase. As a result, energy consumption reductions are achieved not only through the penetration of more energy efficient technologies, but alsot through price-induced changes in consumption behavior.

Thus in FACETS, efficiency does not appear as a resource that can be added up and accounted for similarly to other resources, but rather shows up as energy that is not consumed when the model makes more efficient choices. Modeling a policy like the TREES Basic, which requires efficiency and renewables to supply a growing portion of Vermont's energy needs, requires creating a counter-factual case without additional efficiency programs to serve as a baseline from which policy-induced efficiency will reduce consumption. For this purpose, a modified Business as usual scenario was created that added consumption expected to be avoided by Vermont programs including current Efficiency Vermont, Vermont Gas System, and Burlington Electric energy efficiency programs – based on US EPA's estimate of embedded program efficiency in AEO 2013[24] – back into the energy consumption baseline. This baseline then served as the basis for calculating the maximum amount of fossil and nuclear energy that could be consumed each year in the TREES options, as well as the maximum out-of-state resource consumption in the TREES-Local options.

[24] http://www.epa.gov/statelocalclimate/state/statepolicies.html

In Vermont, the greatest efficiency impacts in the model results appear where the energy service demand is greatest, that is in light-duty vehicle choice (e.g. more efficient vehicles, electric vehicles) and in space heating equipment choices (e.g. pellet boilers, heat pumps).

In all scenarios that meet the statewide greenhouse gas reduction and renewable energy goals, energy efficiency increases significantly over current levels because it is often cheaper than adding renewable energy to the system.

### *SPOTLIGHT ON BIOFUELS AND BIOMASS*

For the purposes of this report, renewable fuels derived from plant matter are referred to as *biofuels* when in a liquid state, and *biomass* when in a solid state. (Methane gas harvested from anaerobic microbial digestion of organic matter[25] is also categorized as biomass, but is available in relatively small amounts). Biofuels consist primarily of biodiesel and ethanol. Ethanol is commonly blended with the gasoline used in light-duty vehicles. Biodiesel can be used as a transportation fuel or as a substitute for #2 heating fuel oil. In the US, most biofuels are produced through large-scale industrial agriculture from crops like corn and soybeans. The potential for local production in Vermont is limited and our analysis assumes that most biofuels would be imported.

Solid biomass includes cord wood, wood chips, and wood pellets[26]. Cord wood is a common heating fuel in Vermont, used in wood stoves and wood fired boilers, primarily in residential applications. According to US census data[27], at 15.4% Vermont has the highest percentage of households that use wood as a primary heating fuel of any U.S. state.

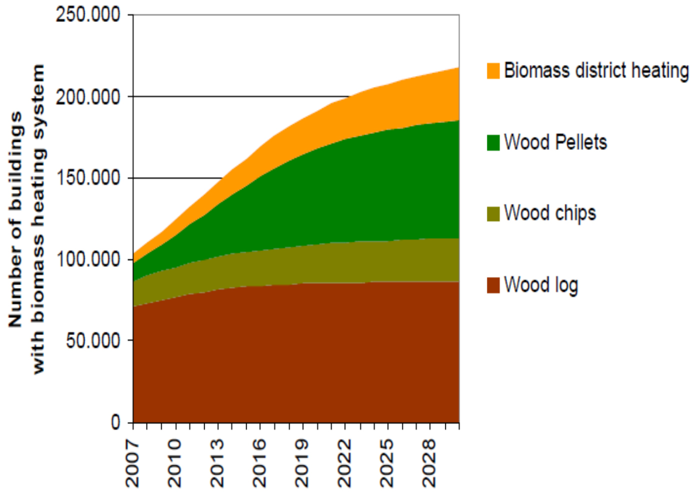
Wood chips are a by-product of logging and sawmills. Wood chips are burned in two Vermont power plants to generate electricity and Vermont has over 45 schools that heat with wood chips. Some school wood chip boilers have been in continuous operation for over 25 years.

[25] Examples include the methane harvesting at some Vermont wastewater treatment facilities and Green Mountain Power's "Cow Power" manure to methane program.

[26] Grass-based biomass was not considered in this study.

[27] Wood Heating House Percentage State Rank based on U.S. Census American Community Survey 2008-2012. EIA also indicates that, from 2005 to 2012, the number of households in Vermont that burn wood as their main source of heat has increased by more than 100 percent, available at: http://www.eia.gov/todayinenergy/detail.cfm?id=15431

**Figure 5: Upper Austria Biomass Heating Systems**




Pellets are a refined fuel made from wood chips and sawdust compressed to a consistent size and shape. Pellets take up considerably less space per Btu than wood chips and are easy to move mechanically, to store, and to burn. Pellet burning stoves, furnaces and boilers offer automated operation similar to oil or natural gas-fired equipment. There are also an increasing number of pellet boilers in use in commercial applications. Pellets have already begun to demonstrate an ability to make woody biomass space heating feasible and attractive to Vermonters who cannot, or prefer not, to heat with cord wood.

The state of Upper Austria shares some similarities with Vermont, and currently obtains a third of building space heating energy from woody biomass. Further, it expects to reach a 50% share by 2030, on a total of about 450,000 buildings (see Figure 5)[28,29].

Almost all cord wood used in Vermont comes from Vermont forests, as do most of the approximately 60,000 tons of wood chips used to heat Vermont schools and other buildings each year. About two thirds of the roughly 600,000 tons of woodchips burned annually at two Vermont power plants comes from surrounding states. There is currently one pellet production plant in Vermont with several more proposed. Currently, much of the pellet fuel that is consumed in Vermont comes from out of state.

Both biofuels and biomass are low carbon, but not carbon free in terms of net greenhouse gas emissions. See Table 2 above for assumptions regarding the carbon content of these fuels. We note that much as the evolution in the price of biofuels is uncertain, so too is its future carbon content. In that respect, the reader may view the price sensitivities used in this exercise as proxies for carbon content sensitivities (for example, a high biofuels price scenario could equally reflect a lower-priced, but higher-

[28] Christine, Gerhard Del & Christiane Egger, *Target setting for RES-H/C in Upper Austria*. Öhlinger. February, 2010.

[29] European residential biomass combustion technology tends to be more efficient and cleaner burning than equivalent U.S. equipment. Northeast States for Coordinated Air Use Management (NESCAUM) has reported that the adoption of more stringent emission limits on solid wood fueled-units in Europe expanded the residential market for wood heating by increasing the ability to install units in more populous settings. NESCAUM has suggested that the U.S. could see similar results if comparable standards were adopted by EPA. EPA's proposed Phase 2 emissions standards for residential wood heating devices should help spur technology improvement.

carbon content scenario). We caution though that this analogy extends only to consideration of carbon emissions, not to assumptions around renewable energy.

### *SPOTLIGHT ON ELECTRICITY GENERATION*

Vermont is part of the New England electricity grid, which generates and distributes relatively low-carbon electricity. With an electric portfolio containing significant renewable and nuclear resources, electricty consumption in Vermont contributes to only 5% of the state's total greenhouse gas emissions (see Figure 1). This makes switching transportation and building heating demand to rely on electricity rather than fossil fuels an intriguing greenhouse gas emission reduction strategy.

As explained above in the "FACETS Model" section, FACETS takes all costs associated with electricity generation as model inputs, minimizes the costs of meeting all end use service demands, whether using electricity or some other fuel, and provides the marginal prices of electricity as a model output.

For each energy service, such as personal vehicle transportation, FACETS makes decisions based on the marginal costs of each technological option, including capital, operating, and fuel costs. In the real Vermont marketplace, some fuels may be priced close to their marginal costs, while others, such as electricity, are priced in different ways. Regulation, market structures, and energy utility tariff designs may distribute the costs of electrification as a greenhouse gas reduction strategy across society in different ways. These will have significant impacts on the rate of adoption of new electro-technologies (like electric cars or cold-climate heat pumps).

### *SPOTLIGHT ON INNOVATION*

FACETS assumes that, over time, market share will shift to the technologies that offer the energy services Vermonters need at the lowest prices. For example, electrically-powered, ductless air-source heat pumps compete with oil-fired residential furnaces to provide heating for Vermont homes in FACETS, just as they do in the actual market.

FACETS projects the future of Vermont's energy economy by drawing from a large existing database of energy-related technologies. Some of these technologies have limited availability and are not cost-effective today, but may become cost-effective in the long term under conditions that increase the price of high carbon fuels. The Dunsky team included newer technologies only when it was possible to develop reasonable assumptions regarding their likely costs and efficiencies, drawing from expert sources and professional judgement.

What FACETS—and all other energy models—cannot do is project surprises, such as breakthrough innovations, or a rapid change in fuel prices due to geopolitical events or new resource discoveries. For example, a breakthrough in electricity storage technologies, in particular for vehicles, could dramatically change the economics of fuel switching opportunities. The results presented here represent the least cost way of achieving Vermont's goals using a reasonable set of projections for future cost and performance of existing or currently anticipated technologies.

# RESULTS

## OPTIONS OVERVIEW

As discussed above, the Vermont FACETS model was used to simulate Vermont's energy future under a number of policy options, including most notably:

1. **Business As Usual (BAU):** the evolution of Vermont's current energy system in the absence of any specific new statewide policies
2. **Preliminary Optimization and Parametric Tax runs:** preliminary model runs, used to inform the initial qualitative screening.[30]
3. **Carbon Tax Shift:** a revenue-neutral tax shift, reducing tax on "goods" (e.g. income, employment) and increasing tax on a "bad" (greenhouse gas emissions).
4. **TREES Basic:** a requirement that energy suppliers source a growing percent of their energy from renewable resources; allows for market trading among vendors and buyers.
5. **TREES Local:** a modified version of TREES Basic that requires a share of the eligible renewable energy to be derived from in-state projects or resources.

In the following section we present the key results of each of these modelling scenarios. Readers will note that as we proceeded, it became evident that the results were very sensitive to the price/availability of biofuels. For this reason, we decided to run high and low biofuels price cases for the Preliminary Optimization scenario as well as for each of the three final policy options. This change further required that we also run the Carbon Tax Shift scenario at two different tax levels in order to meet the emissions goals under the two biofuels price cases.

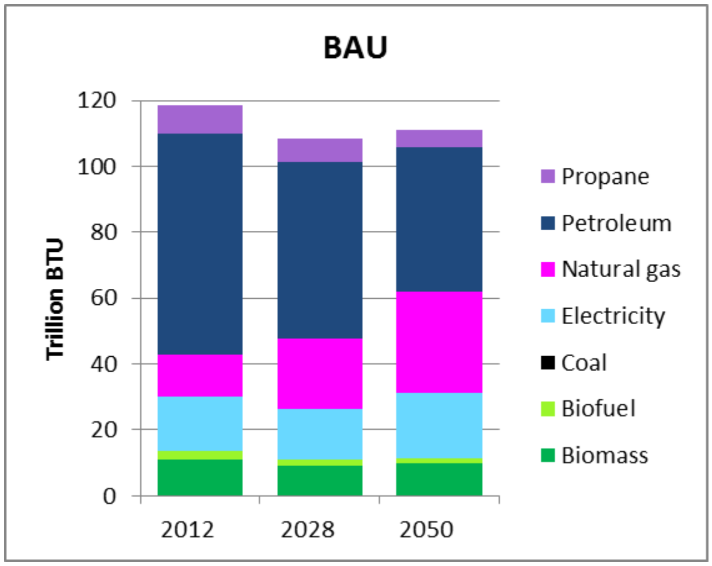
[30] The optimization run asks what would occur if $CO_2$ were reduced by 50% by 2028 and 75% by 2050 in the lowest cost manner (with no other specific policy direction or other constraints). The tax runs allowed the construction of a cost supply curve showing how the availability of emission reduction opportunities at different prices.

## MODEL CALIBRATION

The Dunsky team worked in close cooperation with the PSD to calibrate the model by building the Business as Usual (BAU) base case to simulate Vermont's current energy economy. We provided Vermont energy supply costs and resource constraints as inputs, and then adjusted the model until it consistently produced the current energy consumption for the Vermont market. For this purpose, the Dunsky team drew from data provided by Vermont Gas Systems on current and projected natural gas consumption, from the Biomass Energy Resource Center on the availability and pricing of woody biomass fuels, and from the PSD and other state agencies on a wide range of other parameters.

Most importantly, as shown in Figure 6, the total amount of energy consumed annually in Vermont is projected to decrease slightly from 2012 to 2050. Flat or negative growth in electricity consumption is now evident in several parts of the U.S.[31] Fuel oil sales per household for residential space heating in Vermont have been declining for decades and the legislature has recently had to confront the impact of declining gasoline sales on gasoline tax revenues. There are multiple reasons for these trends, but underlying them has been a steady increase in energy productivity and the slow decoupling of economic growth from growth in energy consumption.

**Figure 6: VT Energy Consumption - Business as Usual**




Home heating, lighting, and other devices have steadily become more efficient, and new light-duty vehicle CAFE standards, which require nearly a doubling of new vehicle efficiencies over the coming decades, are a major contributor to the declining energy consumption in the BAU. It is also worth noting that Vermont's population stability – the number of Vermonters is projected to remain constant between 2014 and 2050 – also influences to the trajectory for energy demand. As the productivity of energy use increases, energy consumption per capita declines. Because Vermont's population remains constant, total energy consumption declines as well.

Under the BAU scenario greenhouse gas emissions slowly decrease, but only by a total of approximately 10% by 2050, as shown in Figure 7 below.

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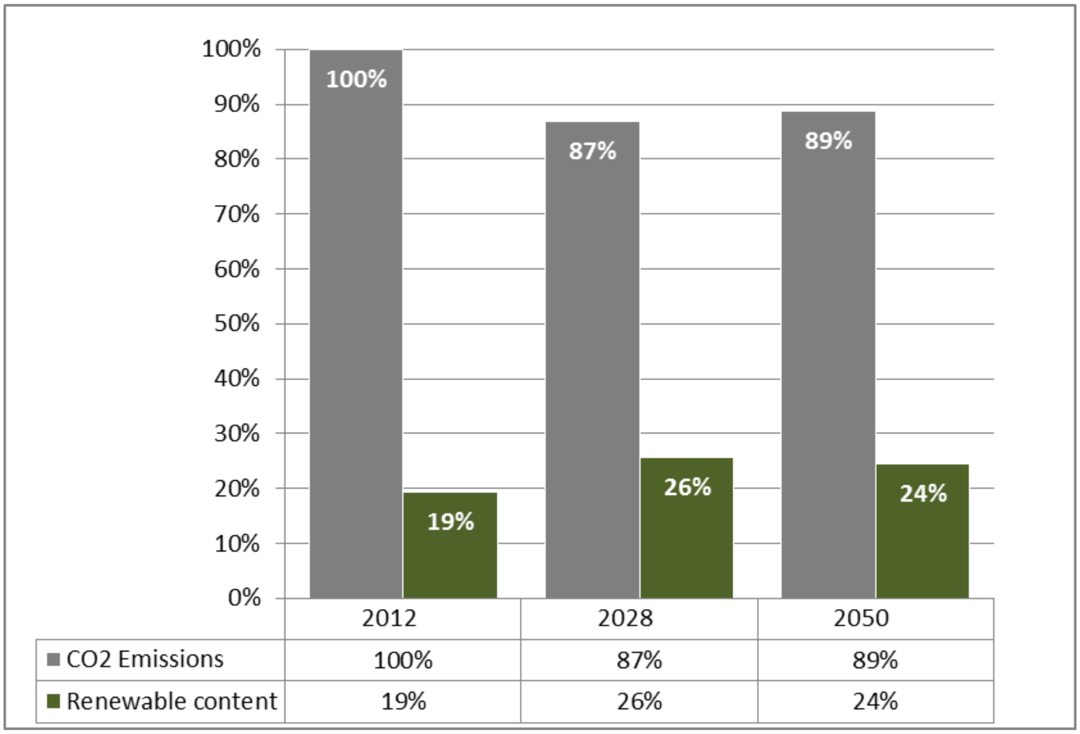
[31] Why Is Electricity Use No Longer Growing? American Council for Energy Efficiency Economy (ACEEE), 2014. Nadel, Steve; Rachel Young

**Figure 7: Emissions & Renewables: Business-As-Usual**



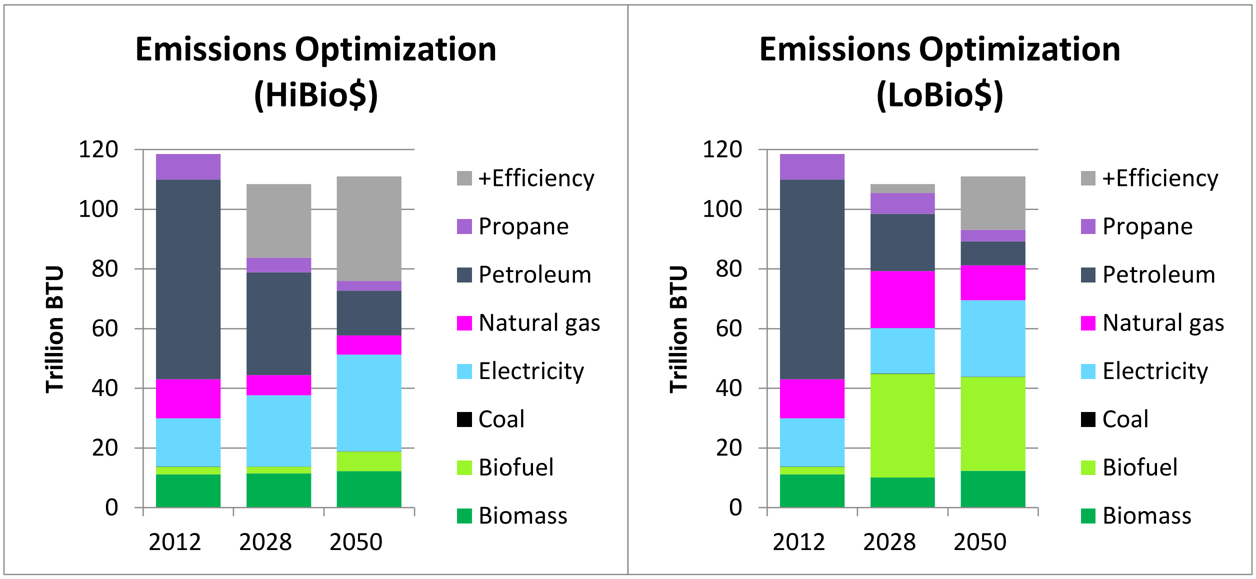

In this world, the total share of renewable energy in Vermont's fuel mix does not increase significantly. Without significant new policies, Vermont's energy system falls dramatically short of both its dual carbon emissions goals (achieving 13% and 11% reductions by 2028 and 2050, respectively, in lieu of the 50% and 75% reduction targets), and its renewable content goal (achieving 24% in lieu of the 90% target by 2050).

## PRELIMINARY OPTIMIZATION AND TAX RUNS

For the Preliminary Optimization runs, the Dunsky Team instructed FACETS to reduce Vermont's greenhouse gas emissions by 50% by 2028 and 75% by 2050 relative to 1990 levels. All policies and constraints applied exactly matched the BAU case. Under this scenario, FACETS calculated the lowest cost path to reach Vermont's greenhouse gas emissions goals by switching from higher-carbon to lower-carbon fuels, substituting more efficient technologies for less efficient ones, importing additional low carbon electricity, and in some cases reducing demands in response to higher prices. Given the impact of uncertainty regarding the future of biofuel prices, the Dunsky Team chose to run the model using two biofuel price scenarios: the "low" case assumes a 9% premium over the prevailing price for gasoline for ethanol and a 12% premium for biodiesel, which is roughly the current price premium for the biofuels currently blended into gasoline and diesel. The "high" price biofuels case assumes a 50% premium for the first 10 million gallons and the remainder of supply available at 250% premium.

By comparing the BAU and Preliminary Optimization scenarios, the Vermont FACETS model added a useful quantitative dimension to the process of choosing the three final Vermont energy future options for comprehensive modeling.

**Figure 8: VT Energy Consumption – Preliminary Optimization, Two Biofuels Price Levels**




As shown in Figure 8, in 2028 and 2050, both biofuels price cases of the Preliminary Optimization scenario utilize more energy efficiency than the BAU scenario does. As described above in the "Spotlight on Energy Efficiency" sub-section, FACETS selects more energy efficient technologies when doing so costs less than switching to lower carbon fuels or renewable technologies. As long as efficiency is the relatively least expensive resource, more of it is purchased. Moreover, both scenarios above involve a significant expansion of electricity for transportation (e.g. electric vehicles) and/or space heating (e.g. heat pumps). In both cases, the electric technologies are also more energy efficient than the fossil fuel powered technologies they replace, resulting in both a switch from fossil fuels to lower-carbon electricity *and* an increase in absolute energy efficiency.

The role of efficiency is considerably more pronounced, particularly early on, in the high biofuels price case, suggesting that efficiency provides an important opportunity to insulate Vermont against the risks posed by uncertainty around biofuels price and availability.

The differences between the two biofuels price cases are profound in their implications for technology and infrastructure. If biofuels are cheap and available, they dominate the market for transportation and the infrastructure to transport, sell, and use motor fuels with increasingly high percentages of biofuels must be installed. If biofuels are expensive and scarce, there is more electricity in light-duty transportation, requiring battery charging infrastructure for electric vehicles.

Figure 9 and 10 below illustrate how, under an economically-optimal model constrained to achieve the emission reduction goals, different biofuel price scenarios impact the ability to simultaneously achieve the state's 90% renewable energy target by 2050.

**Figure 9: Emissions & Renewables: Preliminary Optimization Scenario (Low Biofuels Price)**

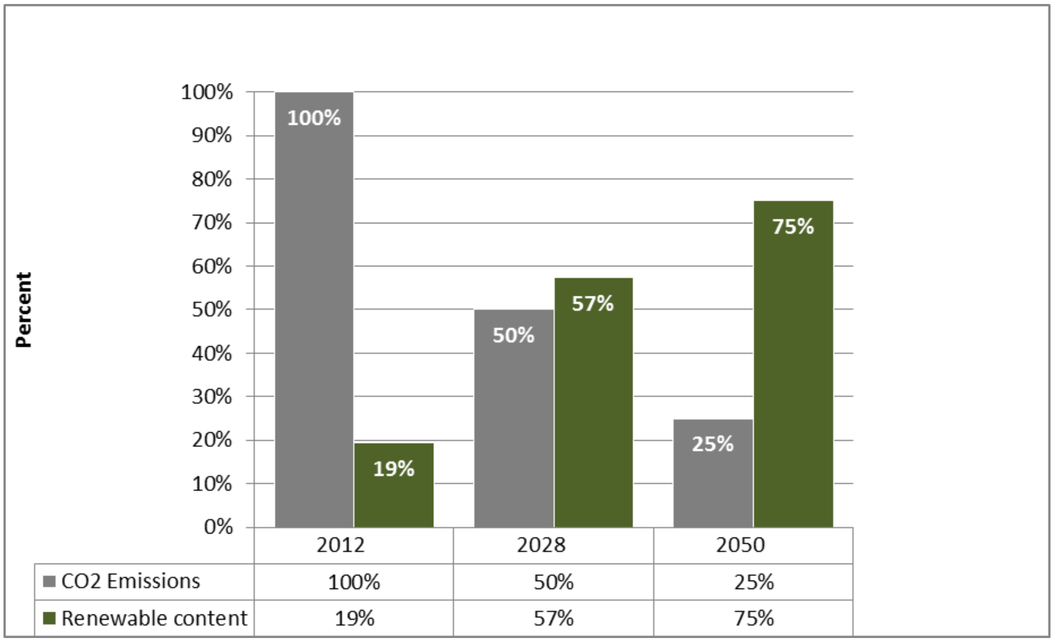
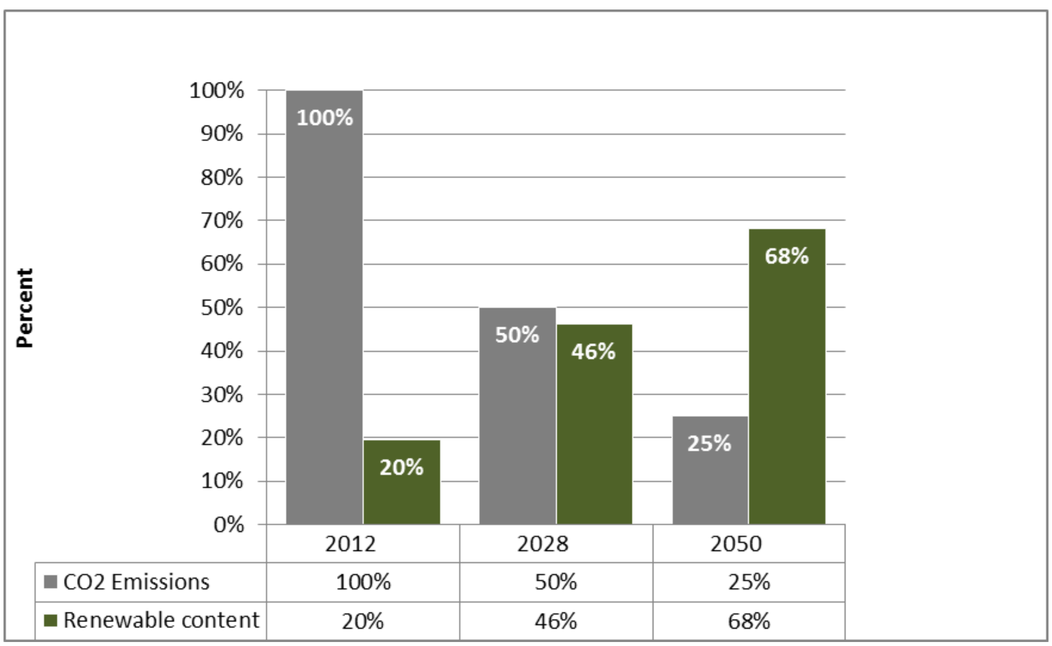
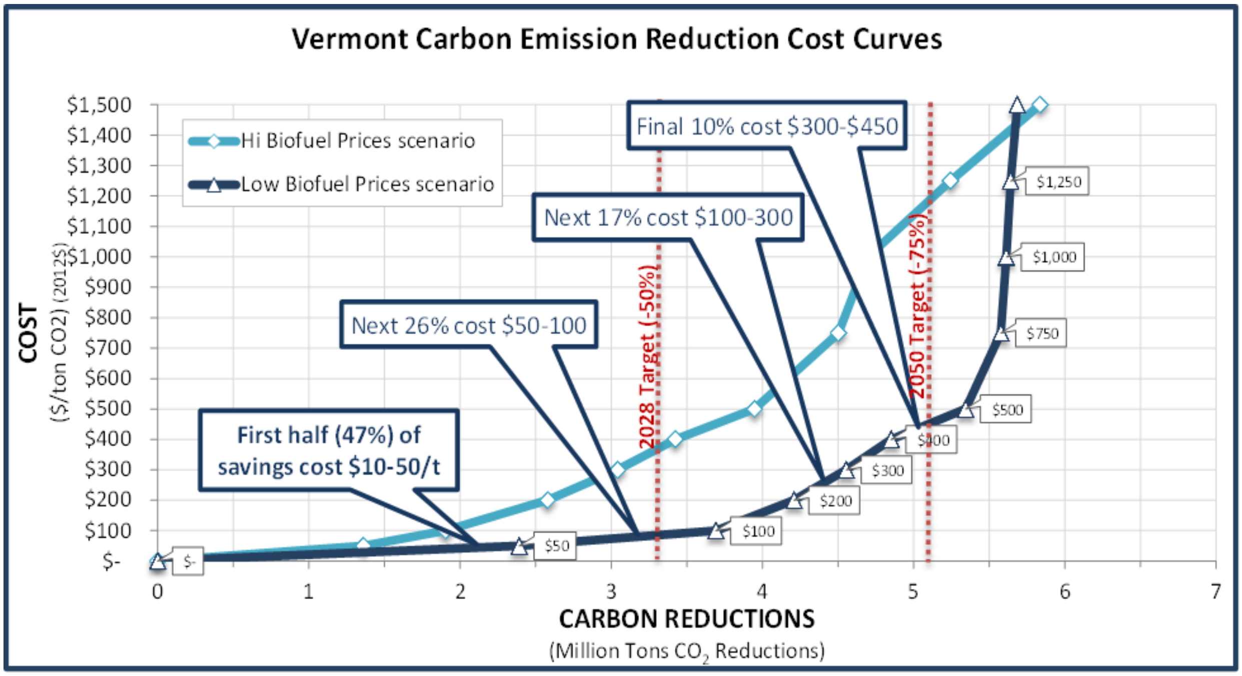



**Figure 10: Emissions & Renewables: Preliminary Optimization Scenario (High Biofuels Price)**



During this preliminary analysis phase, a set of parametric carbon tax runs were also used to develop a cost curve for carbon emissions reductions, showing how much reduction could be achieved at different cost levels. Figure 11 below shows the resulting curves in 2050, under both the high and low biofuels price assumptions, and dramatically illustrates the cost impacts for Vermont of this key uncertainty.

### Figure 11: Vermont Carbon Emission Reduction Cost Curve




***Under the low biofuel price scenario, the first 3.7 MT, i.e. nearly three-quarters of the 2050 emissions reduction target, and all of the 2028 target, can be achieved at a cost of between $10 and $100 per ton.***

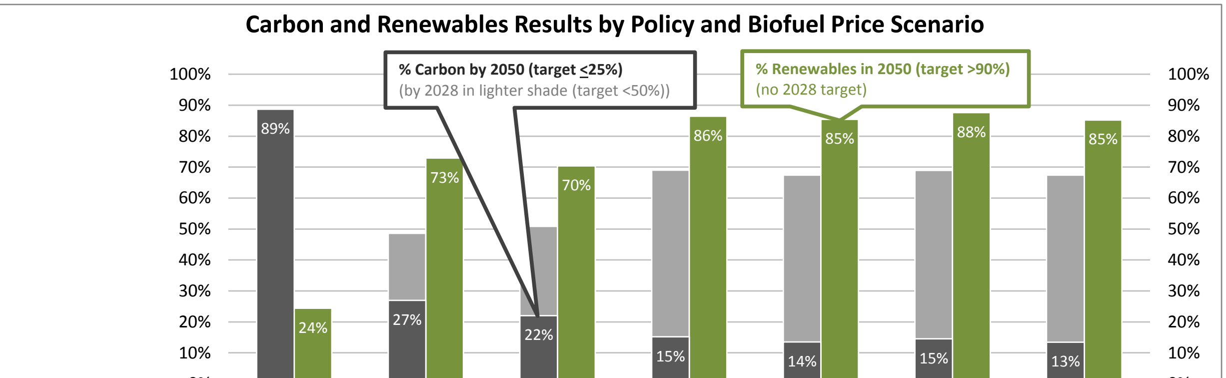
As we can see, when biofuels are readily and cheaply available to be swapped in for current petroleum uses, significant emissions reductions are available at very low cost, and all the reductions needed to achieve the 2050 target are available for less than $500 per ton. When biofuels are very expensive, substantial reductions are still available at low cost, but the cost curve rises much more steeply, and a very high tax rate is required to get all the way to the 2050 target. These curves were used to select the tax rates needed to model the tax policies in the next phase of the project.

## POLICY OPTIONS: OVERVIEW OF RESULTS

All three of Vermont's goals – emissions reductions of 50% and 75% by 2028 and 2050, respectively, and renewable energy content of 90% by 2050 – are intrinsically linked. Nonetheless, in designing policy options, priority was given to the long-run greenhouse gas emissions reductions.

**Accordingly, the Dunsky Team's analysis finds that achieving the goal of a 75% reduction in Vermont's greenhouse gas emissions by 2050 is achievable under all three policy options, and at a moderate cost.** Specifically, the Carbon Tax Shift options *by design* produce almost exactly the desired outcome; meanwhile, the TREES options, because they are focused instead on the more aggressive renewable energy target, exceed the carbon savings goal by roughly 10%. Still, each option evokes a trade-off regarding the other targets. For example, a Carbon Tax Shift also precisely achieves (again, by design) the mid-term GHG target of 50% by 2028, but falls significantly short of the 2050 renewable energy target (by up to 20%). Inversely, both TREES policies achieve the long-term GHG *and renewable energy* targets, but fall short of the mid-term (2028) GHG reductions goal.

**Figure 12: Emissions & Renewables: Policy Options Overview** (under both Biofuel Price scenarios)




| | BAU | TaxSHIFT (LoBio$) | TaxSHIFT (HiBio$) | TREES Basic (LoBio$) | TREES Basic (HiBio) | TREES Local (LoBio$) | TREES Local (HiBio$) |
|---|---|---|---|---|---|---|---|
| 2028 CO2 Emissions | 87% | 49% | 51% | 69% | 67% | 69% | 67% |
| 2050 Renewable content | 24% | 73% | 70% | 86% | 85% | 88% | 85% |
| 2050 CO2 Emissions | 89% | 27% | 22% | 15% | 14% | 15% | 13% |

Table 3 below provides somewhat more information, including most notably the addition of cost values. The *gross* emissions reduction costs presented show results in terms of both the percent increase in total costs needed to meet Vermonters' energy service needs (%) – including capital, operating, and fuel costs of all energy producing and using technologies –, as well as the *average* cost of reducing emissions ($/ton $CO_2$e). Both are expressed in present value (2013) costs.

As discussed previously, these costs are much lower than the highest marginal tax rates in the tax options. Indeed, as shown by the cost curves in Figure 11, when the tax rate is, say, $450/ton, the vast majority of the emissions reductions occur at much lower costs, so the average cost is always considerably lower than the marginal cost. Second, the costs as calculated are present value costs (using a 3% discount rate), so a reduction achieved at $450/ton in 2050 costs less than one-third as much in present value terms.

The reader will note that two costs are presented: the gross cost (top value), followed by the net cost (bottom value). The "net cost" was derived by assuming a "cost of inaction" of $100 per short ton of $CO_2$e, as directed by the VT PSD, representing the consequences of a warming climate on the state's economy (including adaptation costs).[32] Net negative costs indicate that the cost of action is lower than the assumed cost of inaction.

Finally, the costs presented in Table 3 do not account for likely economic benefits, including GDP, employment, and fiscal benefits, as Vermont shifts spending from primarily imported fuels (90% of statewide emissions), to a combination of imported *and in-state* renewables. Depending on the policy option, *in-state* renewables – with associated economic benefits – can contribute to as much as 60% of the state's total energy consumption, all sectors combined. Macroeconomic modeling could illuminate the full economic costs and benefits of these policy options.

Following Table 3 below, we discuss the results of each policy individually. More detailed model results, including sectoral emissions, electricity supply, and technology choice, and fuel consumption for transportation and space heating individually, are presented in Appendices C and D.

[32] The value adoption - $100 (in 2013 dollars) per short ton of CO2e – is the value recommended by the authors of the most recent *Avoided Energy Supply Costs in New England: 2013 Report* (Synapse Energy Economics, July 12, 2013; see page 4-23).

## Table 3: Final Policy Options Results Summary

| POLICY OPTION | | | CO2e EMISSIONS (% Change from 1990 Baseline) 2028 | | CO2e EMISSIONS 2050 | | RENEWABLE ENERGY* (% of Total Energy) 2050 | | COSTS† (% change re. BAU) 2012-2050• | | COSTS† ($/ton) 2012-2050• | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TARGETS: | 50% | | 75% | | 90% | | | | | |
| | | BIOFUELS PRICES: | LOW | HIGH | LOW | HIGH | LOW | HIGH | LOW | HIGH | LOW | HIGH |
| TAX SHIFT | LOW‡ | 2015 $10/t; 2028 $70/t; 2050 $450/t | -51% | n.a. | -73% | n.a. | **73%** | n.a. | **2.6%** (-4.2%) | n.a. | **$42** (-$68) | n.a. |
| TAX SHIFT | HIGH‡ | 2015 $10/t; 2028 $460/t; 2050 $1250/t | n.a. | -49% | n.a. | -78% | n.a. | **70%** | n.a. | **4.5%** (-2.9%) | n.a. | **$67** (-$43) |
| TREES | BASIC | | **-31%** | **-33%** | **-85%** | **-86%** | 86% | 85% | **2.2%** (-4.3%) | **5.4%** (-1.3%) | **$38** (-$72) | **$89** (-$21) |
| TREES | LOCAL° | 2020 22% in-state; 2042 40% in-state; 2050 60% in-state | **-31%** | **-33%** | **-85%** | **-87%** | 88% | 85% | **3.3%** (-3.2%) | **5.5%** (-1.3%) | **$56** (-54$) | **$90** (-$20) |

***NOTES***

*Green cell shading indicates where targets are effectively met or exceeded. Pink cell shading indicates where results fall short of targets.*
***Bold fonts** further indicate where variances from the target are considered significant.*

** Renewable energy content referred to above is exclusive of energy efficiency; this explains why renewable energy shares fall just short of 90% under the TREES standard.*

*† In the Cost columns, the top value in each cell represents Gross Cost, i.e. the additional costs for providing the energy services demanded by each sector, taking into account the pre-tax cost of fuel and the incremental technology cost. The lower values in parentheses represent Net Cost. Net cost accounts for Gross Cost minus the assumed societal cost of $CO_2$ emissions. Per Vermont PSD instructions, we used $100/short ton $CO_2e$ as an approximate reflection of the cost of inaction. Note that because we only account for carbon savings within the 2012-50 period, the full value of savings that take place in later years is understated (e.g. a measure adopted in 2048 with a 15-yr life will reduce CO2 emissions for 15 years, but our analysis only accounts for the first two of those years). On the other hand, and contrary to capital outlays, the future value of CO2 costs has not been discounted.*

*‡ The Carbon Tax scenario is shown for two different tax trajectories which achieve the targets under both the Low and High biofuel price scenarios. In the table we provide the tax levels at three time intervals (2015, 2028 and 2050). The tax ramps linearly between these values in the intervening years.*

*° The TREES Local scenario contains a constraint on the amount of renewable energy imported from outside of Vermont, resulting in a minimum local share of total energy consumed of 22%, 40% and 60% in 2020, 2042 and 2050 respectively.*

*• Cost results are presented for years 2012-2050, which represent milestone years for this project. In practice, the emissions and system costs had to be modelled over a slightly longer period (2011-2054).*

## POLICY A: CARBON TAX SHIFT

Both the low and high biofuels carbon tax cases are able to meet the 2028, as well as the 2050 statewide emissions goals. However, as discussed above under neither carbon tax case does reach the goal of a 90% renewable energy share of total Vermont energy by 2050.

As a general rule, a carbon tax shift strategy – because it provides the most flexibility in meeting the goals, and because it is squarely focused on the carbon goals – can be expected to represent the lowest-cost policy approach, at least insofar as carbon is concerned. This is borne out in the modelling results, with one, relatively minor exception (see discussion on page 45 below).

Significantly, the results presented in Table 3 underline the impact of biofuels prices on this analysis. If biofuels are available at a modest premium over liquid fossil fuels (the low biofuels price case), a carbon tax beginning at $10 and rising to $70/ton could be sufficient to reduce Vermont's carbon emissions by half by 2028. Having the carbon tax level continue to increase thereafter, to a maximum of $450/ton by 2050, could in turn reduce carbon emissions to 25% of their 1990 levels by that later year. Yet if the *high* biofuels price case better represents the future, it could require a carbon tax rising to some $460/ton by 2028, and $1250/ton by 2050, to reach the same reduction targets.

Put differently, whereas the low biofuels price case only requires a 2.6 % increase in the full, society-wide cost of meeting the state's energy service needs, the high biofuels price case, at 4.5% over baseline, requires nearly double that effort.[33] Hence implementing a successful carbon tax shift policy requires closely monitoring the evolution of fuel prices – particularly biofuels prices – and emissions results, with periodic adjustment of tax levels to meet emissions goals.

The gross cost of avoided $CO_2$ emissions over the 2012-2050 analysis period would be $42/ton with low biofuels prices and the lower carbon tax rate. If high biofuels prices require the use of the higher carbon tax rate, the gross cost would be $67/per ton on average.

Figure 13 and Figure 14 illustrate this policy's carbon reduction and renewable content results. For more details on sector-specific impacts of the Carbon Tax policy option, please see Appendix C.

[33] The increased cost estimate accounts for all capital, operating, and fuel costs associated with all energy producing *and using* technologies in the state. It does not account for economic or environmental benefits flowing from these scenarios.

**Figure 13: Emissions & Renewables: Low Carbon Tax (Low Biofuels price)**

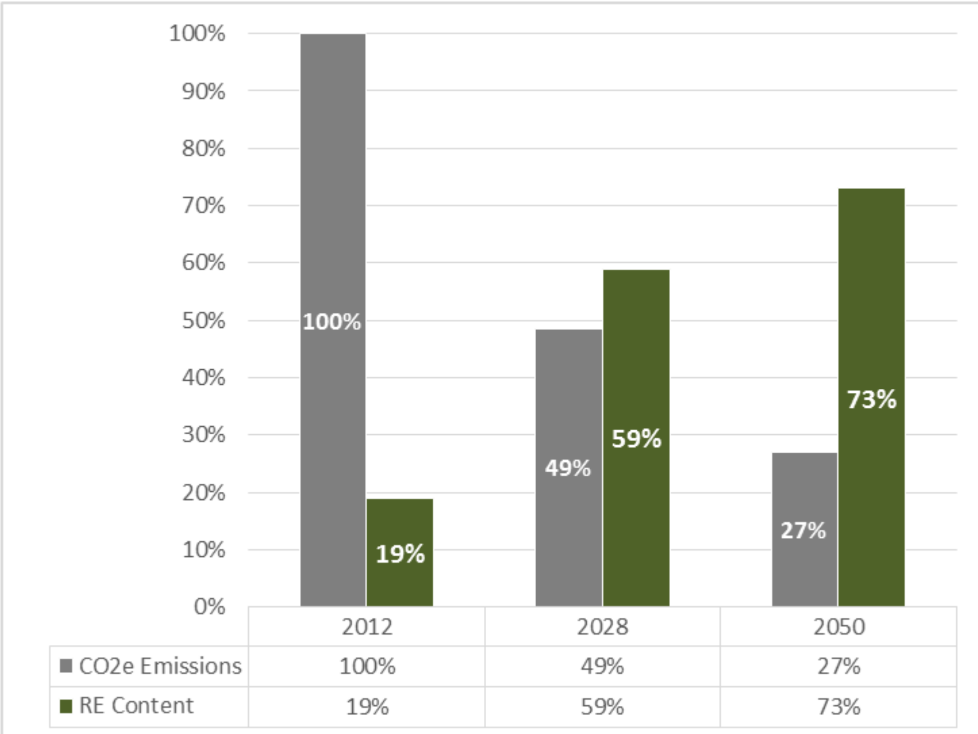
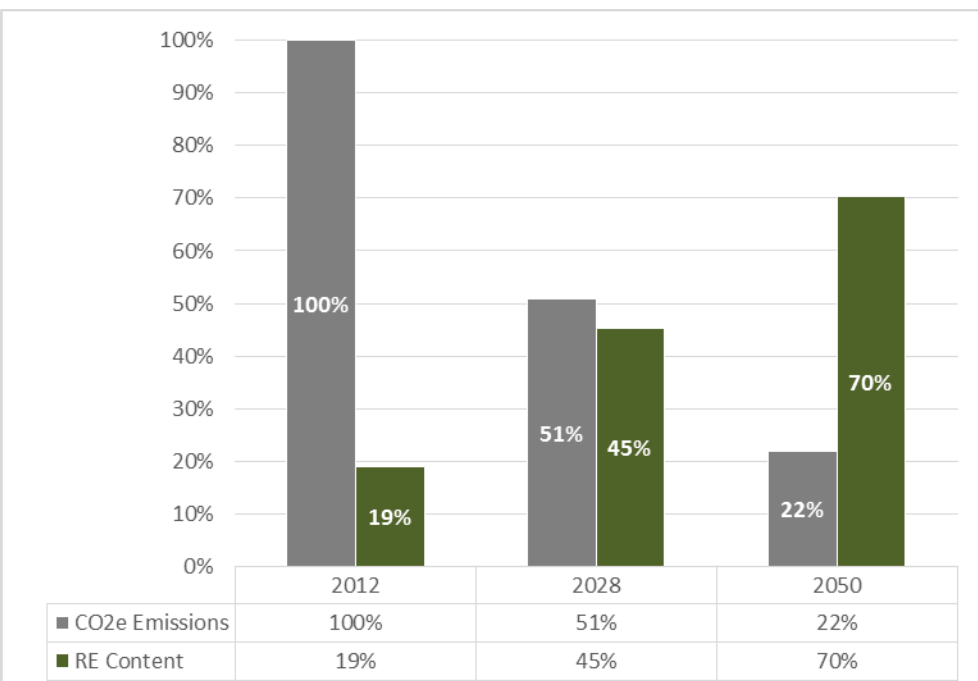



**Figure 14: Emissions & Renewables: High Carbon Tax (High Biofuel price)**



## POLICY B: TREES BASIC

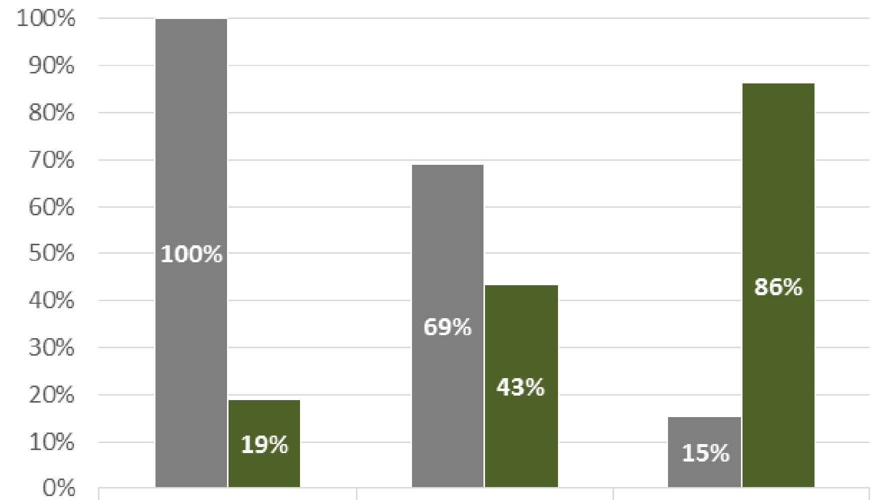
Under both the low and high biofuels scenarios, the TREES Basic policy is able to meet the 2050 renewable energy content goal, and far exceeds the 2050 carbon reduction goal. However, as discussed previously, under neither scenario does the TREES Basic policy reach the mid-term carbon reduction goal of 50% savings by 2028.

The Vermont FACETS model results presented in Table 3 suggest that the TREES Basic policy option would cost about the same per ton of avoided $CO_2$ emissions as the Carbon Tax policy option under the low biofuels price case, but these reductions occur far later in the policy time horizon. Under the high biofuels price case, the TREES Basic policy is approximately 35% more expensive per ton of avoided $CO_2$ than the tax policy. Under the low biofuels price case the TREES Basic approach results in a 2.2% increase in estimated gross expenditures for energy services during 2012-2050. This rises to a 5.4% increase under the high biofuels price case.

Under the simple linear trajectory used in this analysis, TREES Basic significantly overshoots the ultimate emissions goal, both with low and high biofuels prices, achieving a reduction of $CO_2$e emissions from energy use of some 85% from 1990 levels by 2050. It almost achieves the 2050 renewable energy goal, bringing renewables to 86% (low biofuels price) and 85% (high biofuels price) of total energy supply.

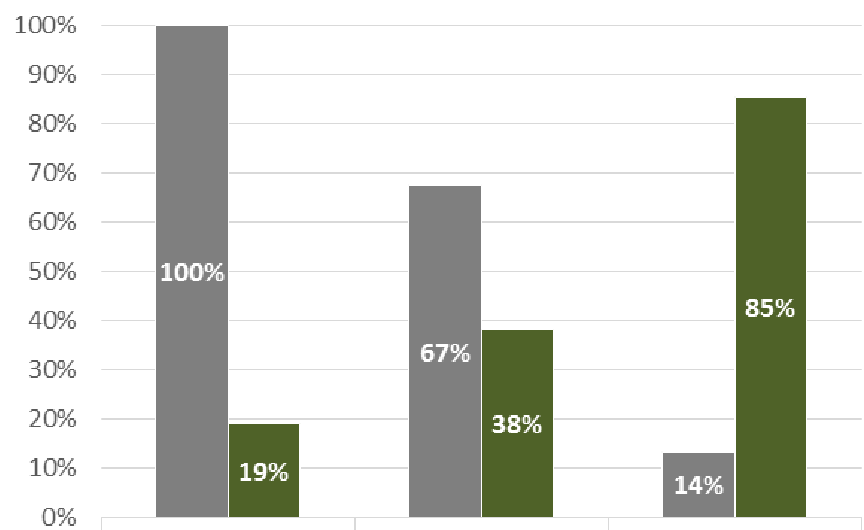
In practice, the trajectories could be adjusted to meet both emissions goals more precisely. Because this would entail a greater stringency to the TREES standard and lower emissions early on, this would increase the cost of the TREES Basic policies. For more details on sector-specific impacts of the TREES Basic policy option, please see Appendix C.

**Figure 15: Emissions & Renewables: TREES Basic (Low Biofuels Price)**




| | 2012 | 2028 | 2050 |
|---|---|---|---|
| CO2e Emissions | 100% | 69% | 15% |
| RE Content | 19% | 43% | 86% |

**Figure 16: TREES Basic - High Biofuels Price**




| | 2012 | 2028 | 2050 |
|---|---|---|---|
| CO2e Emissions | 100% | 67% | 14% |
| RE Content | 19% | 38% | 85% |

## POLICY C: TREES LOCAL

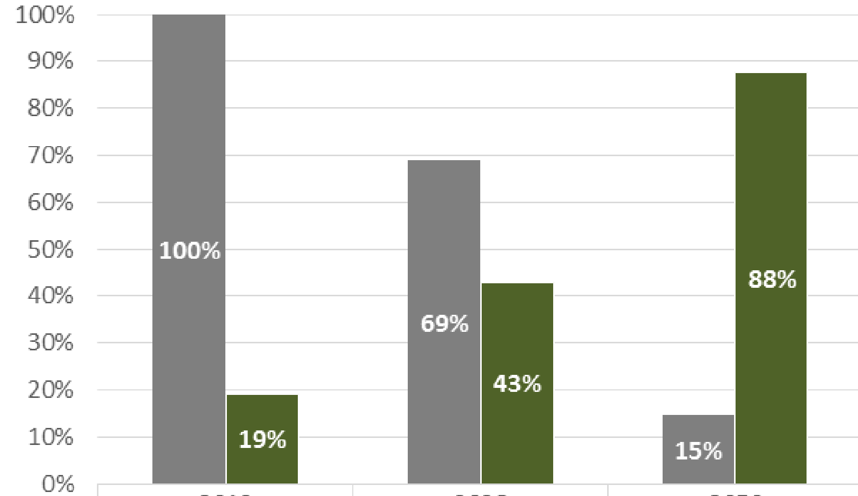
Like TREES Basic, TREES Local exceeds the 2050 emissions goal, by achieving $CO_2$emissions reductions from energy use in Vermont of 85-88% of 1990 levels, depending on assumed biofuels prices. TREES Local does not meet the 2028 emissions goal, but achieves the 2050 renewable energy goal in the low biofuels case and nearly meets it in the high biofuels case.

FACETS results for TREES Local are quite similar to TREES Basic, under the high biofuels price case, because it already has greater in-state content due to low biofuels imports. Unsurprisingly, the more constraining TREES Local policy option is the most expensive of the three policy options when biofuels prices are cheap, costing over 35% more per ton of avoided $CO_2$ emissions than the Carbon Tax policy option in the low biofuels price case. Yet under the high biofuels price case, the incremental cost is almost the same as under the TREES basic approach.

Under the low biofuels price case, the TREES local approach results in a 3.3% increase in estimated gross expenditures for energy services during 2012-2050. This rises to a 5.5% increase under the high biofuels price case.

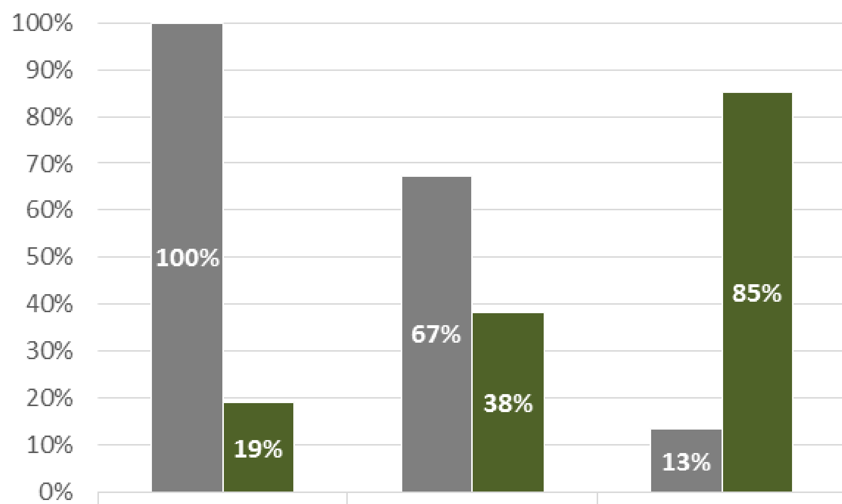
For more details on sector-specific impacts of the TREES local policy option, please see Appendix C.

**Figure 17: Emissions & Renewables: TREES Local (Low Biofuels Price)**




| | 2012 | 2028 | 2050 |
|---|---|---|---|
| CO2e Emissions | 100% | 69% | 15% |
| RE Content | 19% | 43% | 88% |

**Figure 18: Emissions & Renewables: TREES Local (High Biofuels Price)**




| | 2012 | 2028 | 2050 |
|---|---|---|---|
| CO2e Emissions | 100% | 67% | 13% |
| RE Content | 19% | 38% | 85% |

## Can a TREES really cost less than a TaxSHIFT?

Economic theory would suggest that a carbon tax would be a more economically efficient policy to achieve carbon emissions reductions than TREES, because it targets carbon emissions directly and offers more options to achieve savings, whereas TREES targets fossil and nuclear energy use, and so has a less direct impact on carbon emissions. As such, we might reasonably expect that a tax could achieve the statewide emissions reduction goals at a lower cost.

Yet discounting of future costs affects the inter-scenario comparability of the average costs reported in Table 3 above. Notably, the TREES Basic policy (under low biofuels pricing) achieves a similar cumulative emissions reduction as the Carbon TaxSHIFT policy (also under low biofuels pricing), but *because the TREES emissions-reducing investments take place later in the model horizon*, the discounted average cost of the TREES is actually lower. In a sense, this is a result of the carbon goals focusing on both mid- and long-term horizons, while the renewable energy goal is concentrated solely in the long-term.

If the TREES trajectory were adjusted to comply with both the 2028 and 2050 goals, we would expect to see the cost of the TREES scenario rise above that of the corresponding tax scenario. Higher costs are seen in the high biofuels TREES Basic scenario compared to the corresponding tax scenario, because more high cost biofuels are needed to reach the more stringent 2050 renewable target than the 2050 emissions target.

Although a quantity-based policy, such as TREES, runs a greater cost risk than a tax policy, TREES offers an advantage over a tax policy when it comes to assurance that a goal will be met. If the tax trajectory from the low biofuels case were imposed, and biofuels prices turned out to be high, a rigidly implemented policy would fall short of meeting its emissions goals.

# KEY FINDINGS AND RECOMMENDATIONS

## DISCUSSION OF KEY FINDINGS

The comprehensive energy system modelling conducted for this project sought to provide answers to three key questions:

1. Are Vermont's sustainable energy goals achievable?
2. If so, at what cost?
3. What resources are needed to get us there, and what are the key trade-offs?

Given the inputs, constraints and assumptions built into the study, our key findings are set out below.

### *1. ARE GOALS ACHIEVABLE?*

- Vermont's long-term goal of reducing greenhouse gas emissions by 75% by 2050 **is clearly achievable under each of the three policy options** examined.
- Vermont's mid-term goal of reducing greenhouse gas emissions by 50% by 2028 **is achievable under the Carbon Tax Shift** policy, assuming the tax level is adjusted to account for biofuel prices. However, both TREES options as modeled fall short, achieving only 34-38% reductions in the mid-term. A different TREES trajectory could achieve the 2028 goal, with most likely a modest increase in cost.
- Vermont's long-term goal of sourcing **90% of its energy from renewable resources by 2050 is largely achievable under both TREES policy options**. However, the results fall significantly short, at 71-72%, under the Carbon Tax Shift policy.

### *2. AT WHAT COST?*

- The tested policy options, which in most cases met Vermont's GHG and renewable energy goals, **require only modest increases** to the total cost of meeting Vermont's energy needs over the 2012-2050 study period.
- The least expensive case, a TREES Basic policy operating in a low biofuel price scenario, **adds 2.2 % to the cost of meeting the state's energy needs**, spread over the 2012-2050 period. The Carbon tax shift scenario when biofuels price are low is only slightly more expensive (2.6%).

- **Under low the biofuel price scenario nearly three-quarter of the 2050 emissions reductions can be achieved at a cost between $10 and $100 per ton, and *all of the 2028 target* can be achieved at less than $70/ton.**
- The TREES Basic policy under a low biofuel price scenario achieves cumulative emissions reductions similar to the TaxSHIFT policy (also low biofuels scenario), but because the TREES emissions take place later in the model horizon, the present value cost of the TREES option appears lower. If the TREES trajectory were adjusted to comply with both the 2028 and 2050 goals, we would expect to see the cost of the TREES scenario rise somewhat above that of the corresponding tax scenario.
- The most expensive case, TREES Local with a focus on in-state sourcing of renewable energy and operating in a high biofuel price scenario, **adds 5.5% to the cost of meeting the state's energy needs**, spread over the 2012-2050 period.
- The choice of policy approach made a significant difference in total costs, under both biofuels price cases, with a carbon tax proving to be more economically efficient than TREES (with the only exception of TREES Basic under a low biofuel price scenario).
- In real-world implementation, the emissions reduction results of a given tax rate would be at higher risk of deviating from projections, depending on the costs of fuel and technology options. Conversely, a TREES policy would have more certain emissions reduction results, but more uncertain costs.

### *3. HOW?*

- There are three pillars of the "greening" of Vermont's energy system:
    1. Increasing energy efficiency and conservation, beyond current projections;
    2. End-use substitution: biofuels and electricity in vehicles; woody biomass and electricity in buildings; and
    3. Growth in renewable power generation to support emissions-free electrification.
- **Improved energy efficiency** is achieved, even beyond the already strong baseline established by current Vermont policy (and aided by new federal standards). All policy options lead to greater energy efficiency through two primary means: price elasticity, and the switch to electricity for transportation services. Indeed, since electric-drive engines are approximately 60% more efficient than fossil fuel-powered engines, the electrification of transportation results in large energy efficiency gains across the system.
- **End-use substitution is critical**, and one in which "competition" between biofuels and electricity for transportation is the primary unsolved issue looking forward. Liquid biofuels (i.e. ethanol and biodiesel) in particular, being a relatively nascent industry that is heavily reliant on federal regulation and subsidies, face an uncertain trajectory — some anticipate relatively low

biofuel prices, while others forecast those prices (for the same carbon content) at multiples higher.

We accounted for this uncertainty by conducting a biofuel price sensitivity analysis on all policy options. We also adjusted the level of the carbon tax shift accordingly. As a result, we find that the share of liquid biofuels and woody biomass consumed may nearly double under a given policy option when biofuel prices are low. Similarly, gross costs are roughly half under a low biofuel price scenario than a high one, for the same policy option.

**Risk from biofuels availability and cost – as well as whether biofuels can be produced at low lifecycle carbon intensities – emerges from this study as a key risk for Vermont to manage as it moves towards it energy and environmental goals.**

We note that biofuel supplies (primarily ethanol) are expected to be almost entirely imported. Inversely, woody biomass (cordwood, pellets and chips) is an in-state resource[34], but for which growth beyond business-as-usual is relatively limited.

- **Renewable power supplies can be grown sufficiently to power the electrification of light-duty transportation.** The TREES policy approaches have a significantly stronger influence on the growth of renewable power generation, both in- and out-of-state.

  In the near- and mid-terms, growth in renewable power can be secured at far lower cost through large-scale / centralized resources, with relatively low associated risks. These resources are most likely to be sited out-of-state. In the longer term, in-state, distributed power sources, including solar power, can grow to play a significant if not dominant role, with both costs and risks expected to decrease over time.

[34] In this study, we modeled pellets as largely imported. Pellets could also be produced in Vermont in larger quantities than they are now.

## RECOMMENDED NEXT STEPS

Vermont's ambitious sustainable energy goals are achievable, assuming new, relatively aggressive, and sustained policies can begin to be implemented in short order.

Recognizing the critical uncertainties before us – in particular re. the evolution of biofuel prices and/or carbon content – we recommend the following near-term steps be taken.

***IMPROVE KNOWLEDGE:*** *Beyond the work conducted for this study, additional knowledge of key near- and long-term opportunities should be developed.*

- **Assess biomass potential.** While Vermont has already invested substantively in converting some institutional heating loads to biomass, near-term opportunities would appear to remain in the medium and large commercial and non-school institutional markets (wood chips), as well as in Vermont homes and small businesses (pellets). Vermont can immediately move to assess the potential for increased use of biomass resources, including the feasibility of policies aimed at growing a more comprehensive biomass supply chain, with an emphasis on delivery vehicles and storage.

- **Closely monitor biofuels evolution.** The scope of this study was limited to a cursory assessment of future biofuel prices (and to an assumption re. carbon content). Given its importance in model outcomes, Vermont would be well-advised to examine this issue more closely, including projections of the likely prices *and* carbon content of biofuels that could be delivered to the state over the coming 10-20 years.

- **Electrification of transportation:** While this study accounted for electrification opportunities in light-duty vehicles, we did not seek to assess opportunities in medium- and heavy-duty vehicles. Better understanding of these opportunities would be useful.

***NEAR-TERM ACTIONS:*** *Immediate, targeted policy action can be taken while the state considers more comprehensive options. Options include:*

- **Electric vehicle promotion.** The electrification of light-duty vehicles will clearly play an important role in any low-carbon energy future. The state can (and has already begun to) aggressively promote electrification, through a variety of policies including rebates and/or tax exemptions for vehicles and in-home chargers, installation and/or cost-sharing and promotion of public high-voltage chargers, and high-value privileges (e.g. parking meter exemptions in conjunction with towns), among other targeted policies.

- **Non-electric shell conservation.** Similarly, energy efficiency improvements in buildings will continue to play a key role in minimizing carbon emissions. Vermont can continue to – and perhaps intensify – its efforts at non-electric building efficiency, in particular through measures aimed at improved building shells in homes and businesses currently heated by unregulated fuels (oil, propane).

- **Collaboration with regional partners.** Finally, continued collaboration with regional partners, given the regional nature of most markets for both energy supply and usage technologies (e.g. heating equipment), will remain a critical component of the state's efforts going forward.

### *EVALUATING POLICY PATHS*

- **Evaluating TaxSHIFT and TREES.** Ultimately, Vermont will have to choose among policy options. This project identified two critical options most likely to achieve the state's goals – a revenue-neutral fiscal shift from current taxed items to carbon, and a renewable energy standard that encompasses all fuels and end-uses, including transportation (with or without an additional emphasis on in-state sourcing).

  These pathways elicit clear tradeoffs, in terms of primary focus (carbon or renewable energy); risk (of achieving secondary targets); cost (see report findings); sensitivity to key uncertainties (e.g. biofuels); administrative burden (a carbon tax requires relatively little administration; a TREES would be more demanding); compliance and enforcement; stateside economic benefits including job creation and fiscal revenue (including among the two TREES variants); other environmental benefits or costs; and political feasibility.

  Perfect information will never exist. Still, the choice among fundamental policy options would benefit from a feasibility study designed to examine most or all of these parameters. This study should be undertaken in close conjunction with state officials, and involve key legislators. Moreover, it will need to be launched expeditiously if policy decisions are to be made, implemented, and ramped-up on time to achieve the initial emissions reductions targets. Given the extent of change required of Vermont's energy system to meet the 2028 goals, fourteen years will be none too many.

# APPENDIX A: THE FACETS MODEL

## BACKGROUND

The Framework for Analysis of Climate-Energy-Technology Systems (FACETS) model is a multi-sector, multi-region model of the United States energy system. FACETS analyzes the costs and benefits of policy and technology options over all sectors of the energy system – resources, electricity generation, transportation for people and freight, and industrial and building energy use. Diverse policies and measures can be combined and assessed simultaneously, rather than simply being added up, identifying potential synergies and offsetting effects between approaches. It captures all efficiency-supply interactions, and enables analyses of options that may simultaneously transform multiple sectors, such as widespread use of electric vehicles.

FACETS represents real energy technologies and the infrastructure that connects them. For example, in the power sector, it models individual power plants and their dispatch, retrofit, and retirement options. In the residential sector, dozens of devices utilizing different fuels, at different efficiency levels, compete to deliver energy services including heating, cooling, refrigeration, and lighting. Unlike many other powerful energy models, FACETS is transparent, easy to explain, and flexible enough to explore technology futures far from the current energy system. Multiple scenarios can be run and interpreted quickly and easily, to allow for exploration of uncertainty about key variables, assess multiple possible policy variants, and design robust strategies. As a multi-region model, FACETS captures the geographical relationships – such as those between renewable resources, electricity loads, and transmission capacity – that are key drivers of the costs of energy system transition.

FACETS was created using the TIMES (The Integrated MARKAL-EFOM System) model generator was developed as part of the IEA-ETSAP (Energy Technology Systems Analysis Program) [35], an international community which uses long term energy scenarios to conduct in-depth energy and environmental analyses. The TIMES model generator combines two different, but complementary, systematic approaches to modelling energy: a technical engineering approach and an economic approach. TIMES is a technology rich, bottom-up model generator, which uses linear-programming to produce a least-cost energy system, optimized according to a number of user constraints, over medium to long-term time horizons. This design makes TIMES well-suited for analyses, such as the Vermont Total Energy Study, that require the exploration of diverse possible energy futures based on contrasted scenarios that differ greatly from business-as-usual system evolution.

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[35] See http://www.iea-etsap.org/web/Times.asp.

## INPUTS AND MODEL DESIGN

The FACETS model represents the Vermont energy economy using a Reference Energy System (RES), i.e. a network that links resource supplies, energy conversion and processing technologies, end-use devices, and energy services, tracking the flows of energy and associated emissions. The data collected for the FACETS model of the Vermont energy economy falls into the following broad categories.

- Existing energy flows, typically captured by the energy balance and energy statistics; e.g. imports/exports, production and consumption by fuel and by sector.
- Resource stocks, e.g. estimated fossil fuel reserves and production limits, renewable potential.
- Existing stocks of supply technologies; e.g. capacity and retirement schedule of existing power plants, pipelines, electricity transmission lines, and their associated running costs, efficiencies and other operating characteristics.
- Existing stocks of demand technologies, e.g. air conditioning units, types of appliances, industrial boilers, vehicle types, etc.
- Socio-economic drivers for energy services demands, e.g. projected population and GDP growth by economic sector and their sensitivities to each of the demand services.
- Planned future supply projects, e.g. planned pipelines, transmission lines, power plants; associated investment costs, operating costs and efficiencies.
- Anticipated future supply and demand technologies, e.g. investment cost and efficiency of new conventional and renewable power plants, various types of automobiles, air conditioners, etc.
- Hourly load curve for electric demand, and the breakdown of consumption by sector and end-use application.
- GHG emission coefficients for fuel combustion and some industrial processes.

Much of FACETS data is derived from high quality national databases, including as the NEMS (National Energy Modeling System) model[36] used by the U.S. Energy Information Administration (EIA) for the publication of their Annual Energy Outlook, and the U.S. Environmental Protection Agency's National Electric Energy Data System[37] database of power plants. In addition, the Vermont FACETS model includes a complete set of future technology options from other existing models and recent reports from the US EIA, the technology briefs of the ETSAP program of the IEA (International Energy Agency)[38], the IRENA (International Renewable Energy Agency)[39], etc. These data have been reviewed to ensure

[36] http://www.eia.gov/

[37] http://epa.gov/airmarkets/progsregs/epa-ipm/BaseCasev513.html#needs

[38] http://www.iea-etsap.org/web/E-TechDS/Technology.asp

[39] http://www.irena.org

that the cost and performance data used to characterize these future technology options is fully up to date and is adjusted as appropriate in the context of Vermont.

The Dunsky Team complimented these data sources with guidance provided by the VT PSD and from Vermont stakeholders with sector-specific knowledge. In particular, as the FACETS model originally described Vermont as part of the New England region, a significant amount of Vermont specific data was gathered to define the unique characteristics of the Vermont energy system, enabling it to be broken out as a distinct region in the model, as well as to reflect the objectives and constraints that will help achieving GHG and renewable energy goals in Vermont. Appendix B lists some of the most important assumptions guiding the characterization of Vermont's greenhouse gas emissions reduction potential.

For all Vermont FACETS scenarios the GHG emissions analysis was guided by the definitions established in 10 V.S.A. § 578, and by the structure established by the Vermont Agency of Natural Resources' GHG emissions inventory. This analysis does not include GHG from the embedded energy in products, but does account for emissions from electricity generated elsewhere and then consumed in Vermont. The PSD supplied the carbon contents for the solid biomass (cordwood, pellets, and chips), biogas, and biofuels.

# APPENDIX B: POLICY OPTIONS PROPOSED FOR EVALUATION

The Dunsky team initially assessed 15 technology options (grouped into four technology pathways), as well as 14 policy instruments (grouped into 5 policy sets), before settling on the three policy options to model. The table below illustrates the initial set of options considered.

### Table 4: Policy Options Considered for Early Assessment

| TECHNOLOGIES | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distributed/Local/Diversified | • | | | • | | | | | | • | | | | | |
| Economies of Scale | | • | | | | • | | • | | | • | | • | | |
| Electrification | | | • | | • | | • | | | | | • | | | • |
| Biomass/Biofuels | | | | | | | | | • | | | | | • | |
| **POLICY INSTRUMENTS** | **Carbon Tax Shift** | | | **Prescriptive Taxes and Rates** | | | | **CO2 revenue and new programs** | | **Statewide Clean Energy Standard** | | | **New England Regional Policy** | | |
| Tax on CO2 eq emissions equal to societal cost of emissions. | • | • | • | | | | | | | | | | | | |
| Tax credits for voluntary program participants | • | • | • | | | | | | | | | | | | |
| Continue EEU structure for fuels | • | • | • | • | • | • | • | • | • | | | | • | • | • |
| Use CO2 tax to fund programs that advance state energy goals | • | • | • | | | | | • | • | | | | | | |
| RPS standards | | | | • | • | | | | | • | • | • | • | • | • |
| RE and EE standards for non-electric energy suppliers | | | | | | | | | | • | • | • | | | |
| Utility regulatory models adapt to encourage fuel switching | | | | • | • | • | • | • | • | | | | | | |
| Encourage net metering | | | | • | • | | • | | | | | | | | |
| Excise tax on fossil fuel content in heating fuels | | | | • | • | • | • | | | | | | | | |
| Feebate purchase and tax structure for vehicles | | | | • | • | • | • | | | | | | | | |
| VMT-based transportation funding | | | | • | • | • | • | | | | | | • | • | • |
| Land use policy incentives and Smart Growth | | | | • | • | • | • | | | | | | | | |
| Voluntary RE planning targets for energy suppliers | | | | | | • | • | • | • | | | | | | |
| Regional infrastructure and incentives for vehicles funded by regional tax/fee structure | | | | | | | | | | | | | • | • | • |

# APPENDIX C: ADDITIONAL MODEL RESULTS

## SCENARIOS

This appendix provides additional modelling results – and preceding discussions – regarding four factors:

1. Carbon Emissions by Sector
2. Transportation Needs by Fuel and by Vehicle Technology
3. Space Heating Needs by Fuel
4. Electricity Supply

Results are provided for seven scenarios: the Business-As-Usual scenario, and each of the three modelled policies using both low and high biofuel price scenarios. Finally, results are provided for both 2028 and 2050 timeframes.

Legend for policy option runs in the following sections:

| | | |
|---|---|---|
| BAU | = | Business as usual. Evolution of the current energy system with no additional policies |
| Tax-HiBio | = | Carbon tax grows from $10/ton of $CO_2$in 2015 to at $1250/ton by 2050 with high biofuels price |
| Tax-LoBio | = | Carbon tax grows from $10/ton of $CO_2$in 2015 to at $450/ton by 2050 with low biofuels price |
| TREES-HiBio | = | Total Renewable Energy and Efficiency Standard, high biofuels price |
| TREES-LoBio | = | TREES, low biofuels price |
| TREES-HiBio-Local | = | TREES with constraints on out-of-state fuel imports; high biofuels price |
| TREES-LoBio-Local | = | TREES with constraints on out-of-state fuel imports; low biofuels price |

## CARBON EMISSIONS BY SECTOR

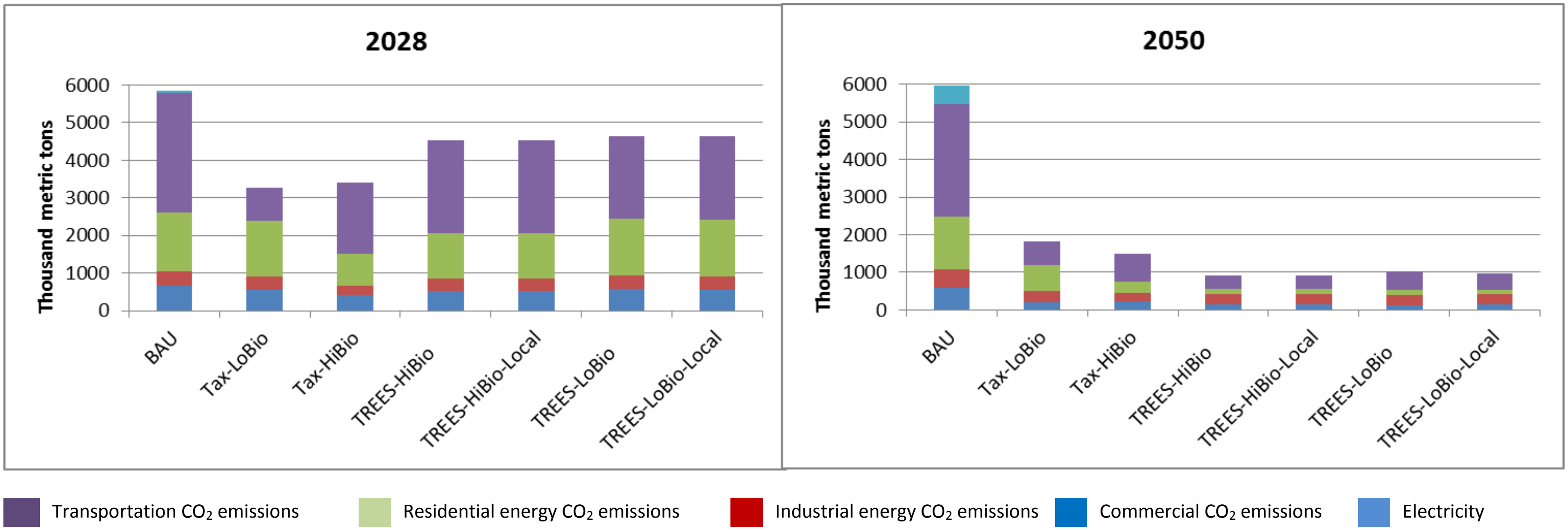
Under the tax policy, the sources of early emissions reductions are quite different, depending on the biofuels price. When biofuels are cheaply available, early reductions can be made at low cost in the transport sector by substituting biofuels for gasoline and diesel. When biofuels prices are high, early reductions are more cost-effective in the buildings sectors. By 2050, steep reductions are required in all sectors, so the differences between the two scenarios decrease, but residential emissions are still twice as high in the low biofuels price scenario as in the high price scenario.

**As discussed in the Results section above, because of the particular Total Renewable Energy and Energy Efficiency Standard (TREES) trajectory modeled, all of the TREES policy options fail to meet the 2028 emissions goal and overshoot the 2050 goal. A different standard trajectory would lead to a different emissions trajectory. One important reason for the slow initial emissions reduction under TREES is that nuclear electricity imports are charged an effective efficiency of approximately one-third, similar to a low efficiency coal plant, in keeping with the broad policy goal of not encouraging nuclear power. As there are opportunities to use fossil fuels directly with much greater efficiency, for example, for end use heating, the nuclear imports are one of the first non-TREES compliant resources eliminated by the standard, as shown in Figure 24: Electricity Consumption by Source**

Figure 25 below. Replacement of nuclear imports with renewable energy is a low-cost option for meeting the TREES standard, but of course does not contribute to reduction of carbon emissions.

The biofuels price has a similar, but lesser impact on the sectoral distribution of emissions reductions under TREES than under a tax policy, because the TREES trajectory tightens faster, later. The TREES Basic and TREES Local policy options produce similar emissions results.

### Figure 19: GHG Emissions by Sector



## ENERGY SUPPLY – TRANSPORTATION FUELS AND VEHICLES

It is in the transportation sector that the influence of biofuel prices on the relative value of the Carbon TaxSHIFT and TREES options become most evident. Currently in Vermont, about 80% of vehicle fuel sold is gasoline, with the remaining comprised primarily of diesel.[40] Under the Carbon TaxSHIFT policy option with low biofuels cost (Tax-LoBio), with no constraints on substituting biofuels for petroleum fuels, a $70 carbon tax in 2028 rising steadily to approximately $450 in 2050 is sufficient to meet the emissions goals for those years. In this scenario, substituting biofuels for petroleum in the transportation sector is a key strategy for achieving emissions goals, as shown in Figure 20 above.

Current "flex-fuel" vehicles run on any combination of gasoline and ethanol blend, and Figure 20 implies that under the low biofuels price scenario a majority of Vermont's vehicles would switch to new technologies and be either flex-fuel or diesel powered (by biodiesel) by 2028. It is worth noting, however, that the model assumes that cost alone drives stock turnover, i.e. it does not account for other drivers (e.g. innovators and early adopters whose adoption of new technologies may precede cost-effectiveness) or barriers (e.g. consumer perceptions or habits; lags in stocking changes; etc. that may slow mass adoption).

Under the Carbon Tax policy option with high biofuels cost (Tax-HiBio), and all TREES policy options, uncertainty regarding the pace of the transition to new vehicle technologies remains, but the share of petroleum in transportation fuel drops more gradually over time allowing a smoother transition than under the Carbon Tax with low biofuels cost (Tax-LoBio). Electricity's share of transportation fuel is significantly higher by 2050. Given the greater efficiency of electric drivetrains, this implies that electric vehicles' share of the Vermont vehicle market is higher than electricity's share of the energy supplied for mobility purposes.

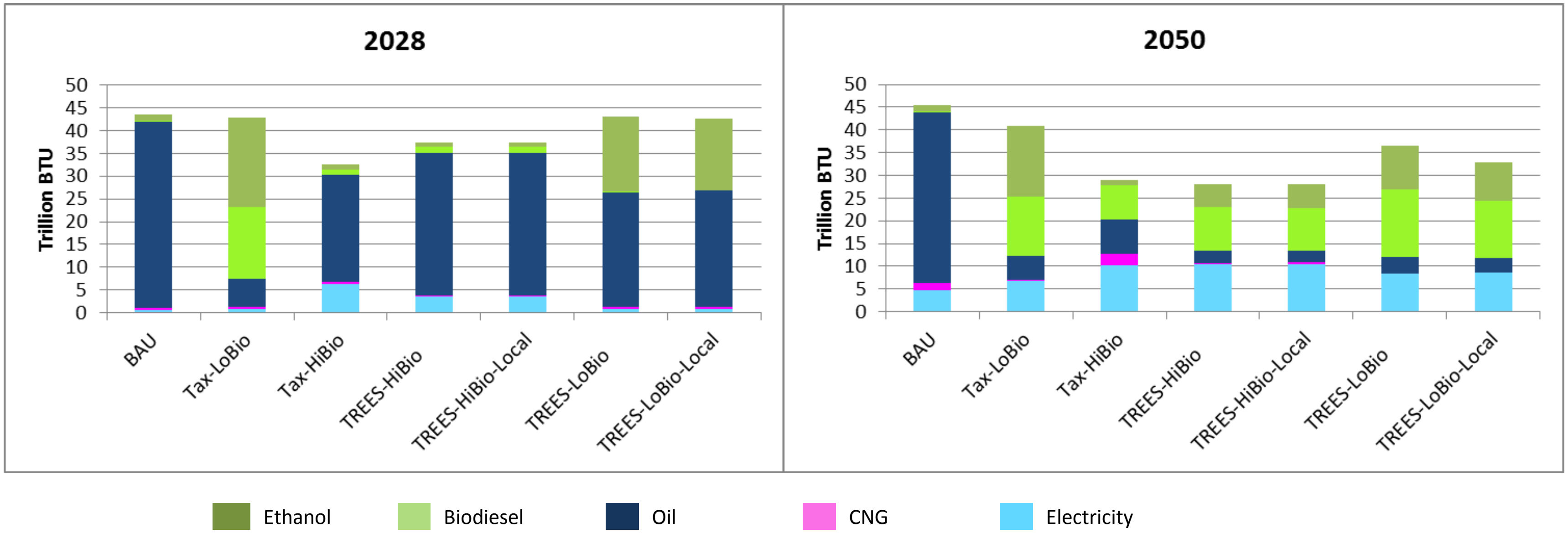
Figure 21 shows the role of different vehicle technologies in the light-duty vehicles subsector, and the pronounced differences between the low and high biofuels prices cases. Electrification of vehicles is important even in the BAU scenario, with just over one-third of vehicles being electric by 2050. In the low biofuels price policy cases, electrification by 2050 is enhanced to over half of the vehicle fleet, but it is not accelerated, as liquid biofuels prolong the use of liquid fuel-powered mobility. In the high biofuels price cases, electrification is strongly accelerated, and by 2050, virtually all light-duty vehicles are fully electric or plug-in hybrids.

[40] Data from the U.S. Energy Information Administration.

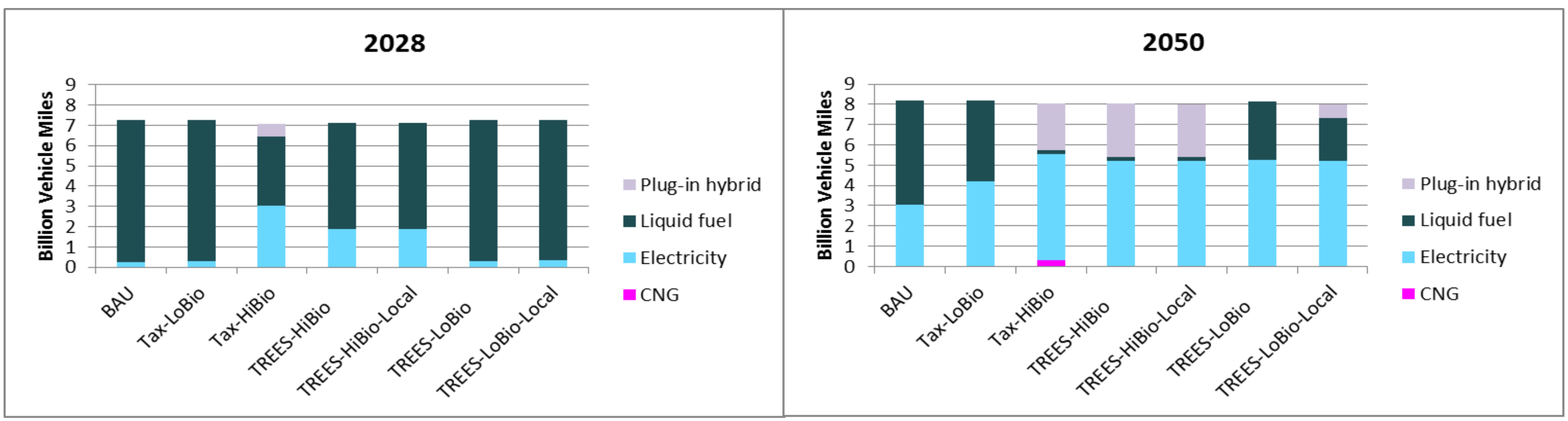
The light-duty segment is the only portion of the transportation sector for which electrification options were modeled in this study.[41] Other transport modes – including medium-duty and heavy-duty truck travel, which make up more than 20 percent of Vermont's transportation energy consumption in 2012, and up to 40 percent in some scenarios by 2050 – are reliant on a liquid-fuel mitigation technology. Although heavy vehicle efficiencies increase substantially in the high biofuels price scenarios, the demand for biofuels remains strong, because biofuels were the only options considered that could achieve deep emissions reductions. Should electric mobility options emerge for this segment, costs could diminish substantially under the high biofuel price scenario. Similarly, should biofuels not be available, or have an unacceptably high carbon content, Vermont would not achieve its goals without an alternative freight transportation technology.

[41] The 2014 *Energy Technology Perspectives* study from the International Energy Agency explores electrification technologies and strategies for freight and other transport modes. http://www.iea.org/etp/

### Figure 20: Transportation Energy Consumption




### Figure 21: Transportation - Vehicle Miles Travelled (Light Duty Vehicles)



## ENERGY SUPPLY – SPACE HEATING

Figure 22 shows energy consumed to produce space heat, while Figure 23 shows the portion of space heating *demand* contributed by each technology type (for example, the 2050 electricity bars are much higher in Figure 23 than in Figure 22 because of the high efficiencies of electric heat pumps.)

The differences between the policy options are less dramatic in the Space Heating sector here than in Transportation, but there are still significant differences between the low and high biofuels price cases. In this crucial sector of Vermont's energy economy, there is no one silver bullet technology. All options rely on a mix of efficiency, fuel-switching, electrification, and biofuels use, although in different proportions and with different time evolutions.

Technology patterns in this sector are influenced by a number of model constraints intended to represent consumer preferences and the diversity of housing stock. In 2028 the share of biomass remains at current levels. Increased penetration of cord wood is not limited by availability or price, but by a technical constraint which estimates the maximum share of households that will find managing cord wood feasible or desirable. The use of pellets for space heating is not constrained, but the high capital costs of pellet boilers prevent pellets from penetrating beyond a small share of households that are assumed to be able to retrofit existing boiler systems at lower cost. It is assumed that some share of households' currently using propane and heating oil are unable or unwilling to switch fuels by 2050. This minimum share is set at 5% each by 2050. Biodiesel is allowed to substitute for heating oil in all households where heating oil is used.

Under current Department of Energy-projected natural gas prices, gas is the cost-effective space heating fuel in the BAU scenario wherever it is available, reaching over 50 percent of space heating fuel consumption by 2050.[42] In the low biofuels price scenarios, natural gas use for space heating is prolonged by the ability to get cheaper reductions from biofuels use in the transport sector. Under the tax policy, gas retains a substantial portion of the space heating demand, and a correspondingly high share of remaining emissions by 2050. The TREES and TREES-Local policies, with their explicit constraint on fossil fuel use, dramatically reduce gas use by 2050.

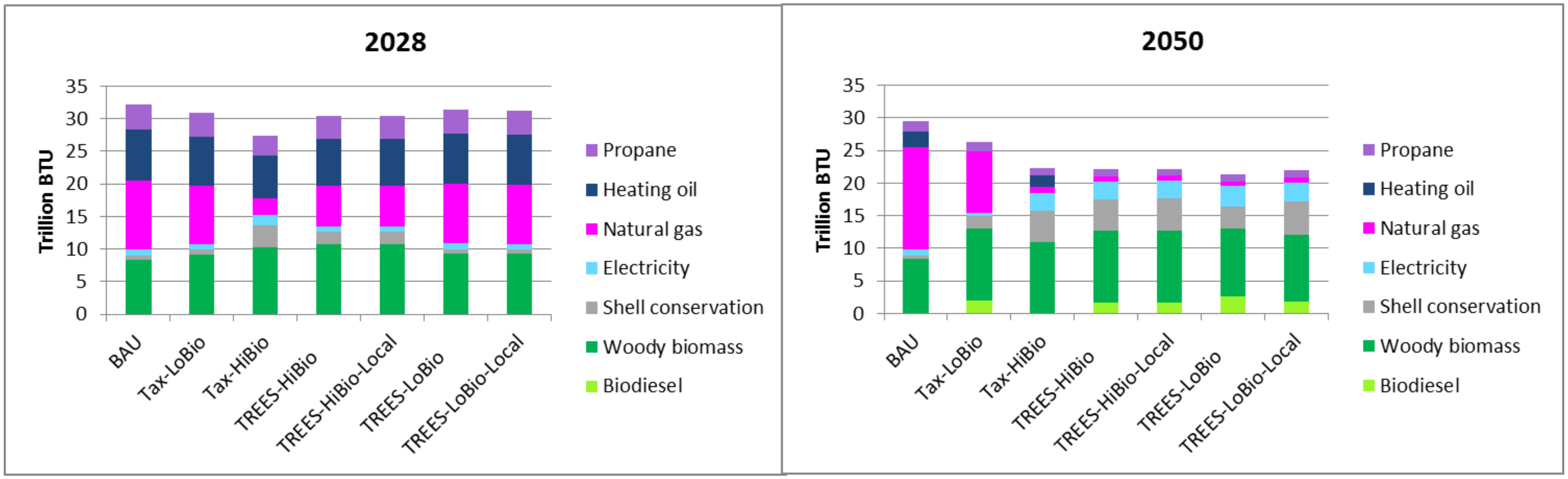
Improvements in building shell efficiencies play an important role in all scenarios except the Tax-Lo scenario, reducing heating demand by more than 20 percent in the high biofuels policy cases. Shell efficiency is also a major in-state resource for complying with the TREES-Local policy even under low biofuels prices. Electrification in the form of advanced air-source heat pumps also plays a major role in

[42] No explicit costs for extending natural gas distribution infrastructure were modeled. This extension was assumed as part of the Business as usual scenario.

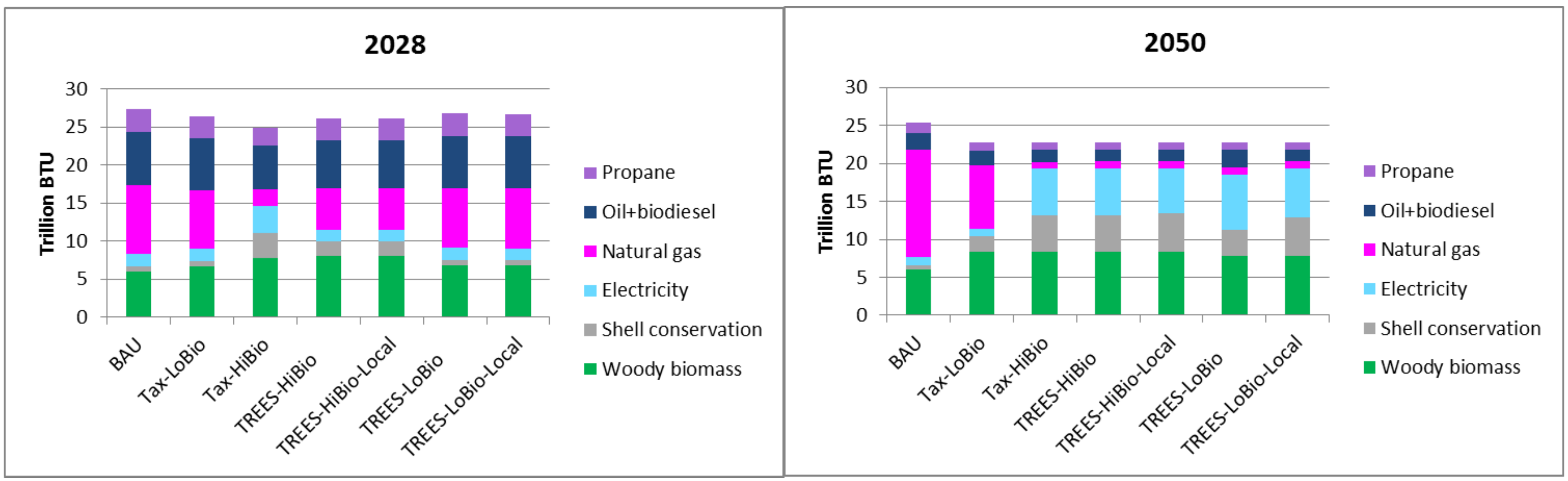
all scenarios except the Tax-Lo scenario. Biofuels are used to substitute for heating oil by 2050 in all but the Tax-Hi scenario.

Given the importance of biofuels price risk for the cost of meeting Vermont's emissions goals, these results suggest that an early investment in space heating measures, particularly building shell efficiency, is a key opportunity to hedge against risk.

### Figure 22: Space Heating Fuel Consumption




### Figure 23: Space Heating Delivered



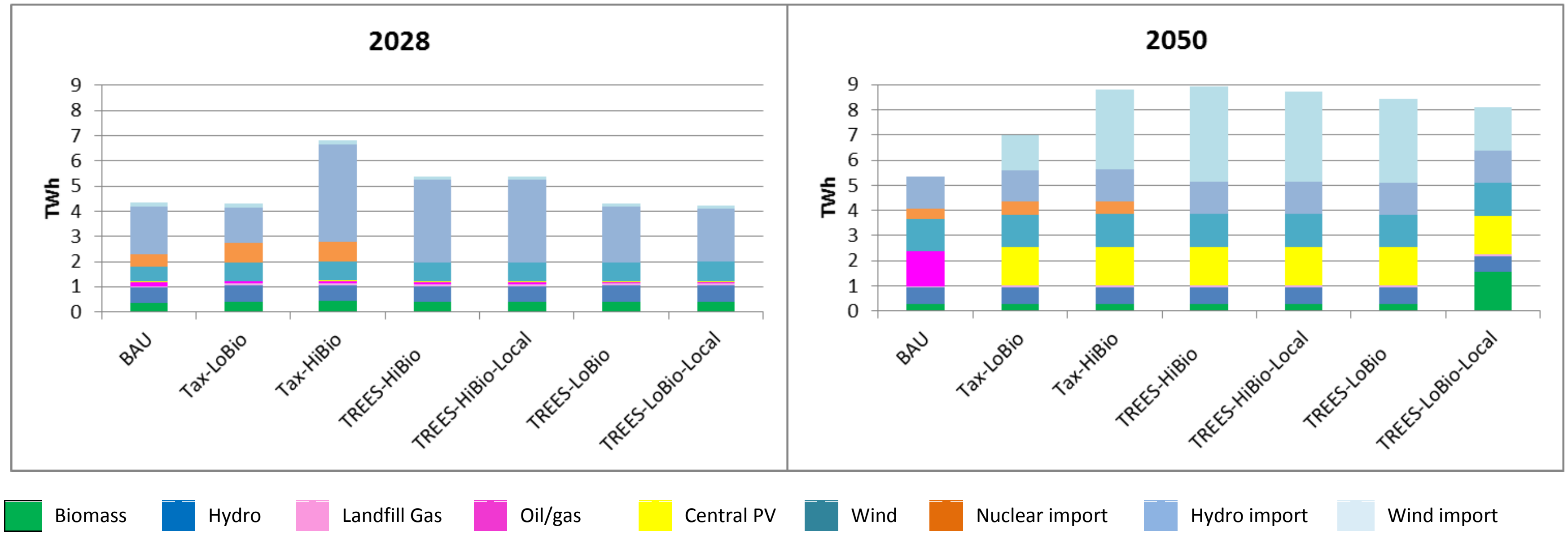
## ENERGY SUPPLY – ELECTRICITY

In general, the high biofuels price scenarios use more electricity than the low, due to greater and earlier electrification in transport and heating. Much of this electricity comes from imports of hydroelectricity from Quebec and, later, wind electricity from New England. These additional imports are needed because all of Vermont's wind capacity and distributed PV capacity are used in the Business as usual scenario. All of the policy options also fully utilize Vermont's assumed utility-scale solar PV capacity by 2050.

All TREES options eliminate nuclear imports early, because of the high fossil-equivalent efficiency charge built into the model. Direct fossil use in other sectors is more economically efficient for the TREES constraint, relative to nuclear electricity.

The TREES-Local scenario under low biofuels prices meets the in-state requirement by reducing wind imports and bringing on additional biomass generation. This resource has very low efficiency, and is cost-effective only in this scenario, because of the combination of low prices for imported biofuels and the in-state resource requirement.

## Figure 24: Electricity Consumption by Source



# APPENDIX D: RELATED DOCUMENTS

In addition to the enabling legislation and regulations that establish Vermont's statewide greenhouse gas reduction and renewable energy goals, this report also mentions four other related documents[43] (in chronological order):

***Meeting the Thermal Efficiency Goals for Vermont's Buildings***
(Published by the Vermont Public Service Department, January 2013)

The Vermont Energy Efficiency and Affordability Act (2007-2008 legislative session Act 92; 10 V.S.A. § 581) established building efficiency goals for the state. This report was produced by the Vermont Thermal Energy Taskforce as part of the ongoing effort to improve the energy efficiency of Vermont's buildings. It includes a wealth of data and analysis regarding Vermont buildings that was used to create the scenarios described in this report.

***Policy Options for Achieving Vermont's Renewable Energy and Carbon Targets***
(Published by the Regulatory Assistance Project, June 2013)

This report by the Regulatory Assistance Project (referred to below as "the RAP report") was designed for use by the PSD to facilitate discussions with stakeholders about the statewide goals and the means to reach them. It provides an overview of the most promising technologies and policies available to Vermont.

***PSD Legislative Report***
(Published by the Vermont Public Service Department, December 2013)

The PSD issued this report to inform the Legislature and the public of progress to-date in carrying out the Total Energy Study. It also describes the renewable energy sources that are included in the Total Energy Study analysis, and talks about where and how non-renewable energy would continue to be used when greenhouse gas emissions have been reduced by 75%, and 90% of energy comes from renewable resources.

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[43] All documents are available on-line:

Meeting the Thermal Energy Goals for Vermont's Buildings is available at: http://www.leg.state.vt.us/reports/2013ExternalReports/285749.pdf

Policy Options for Achieving Vermont's Renewable Energy and Carbon Targets & PSD Legislative Report are both available at: http://publicservice.vermont.gov/publications/total_energy_study#

Vermont Comprehensive Energy Plan is available at: http://publicservice.vermont.gov/publications/energy_plan

***Vermont Comprehensive Energy Plan (Vols 1 & 2)***

(Published by the Vermont Public Service Department, December 2011)

The Comprehensive Energy Plan addresses Vermont's energy future for electricity, thermal energy, transportation, and land use. This document represents the efforts of numerous state agencies and departments, and input from stakeholders and citizens who shared their insights and knowledge on energy issues.

# APPENDIX E: DETAILED RESULTS PER POLICY OPTION

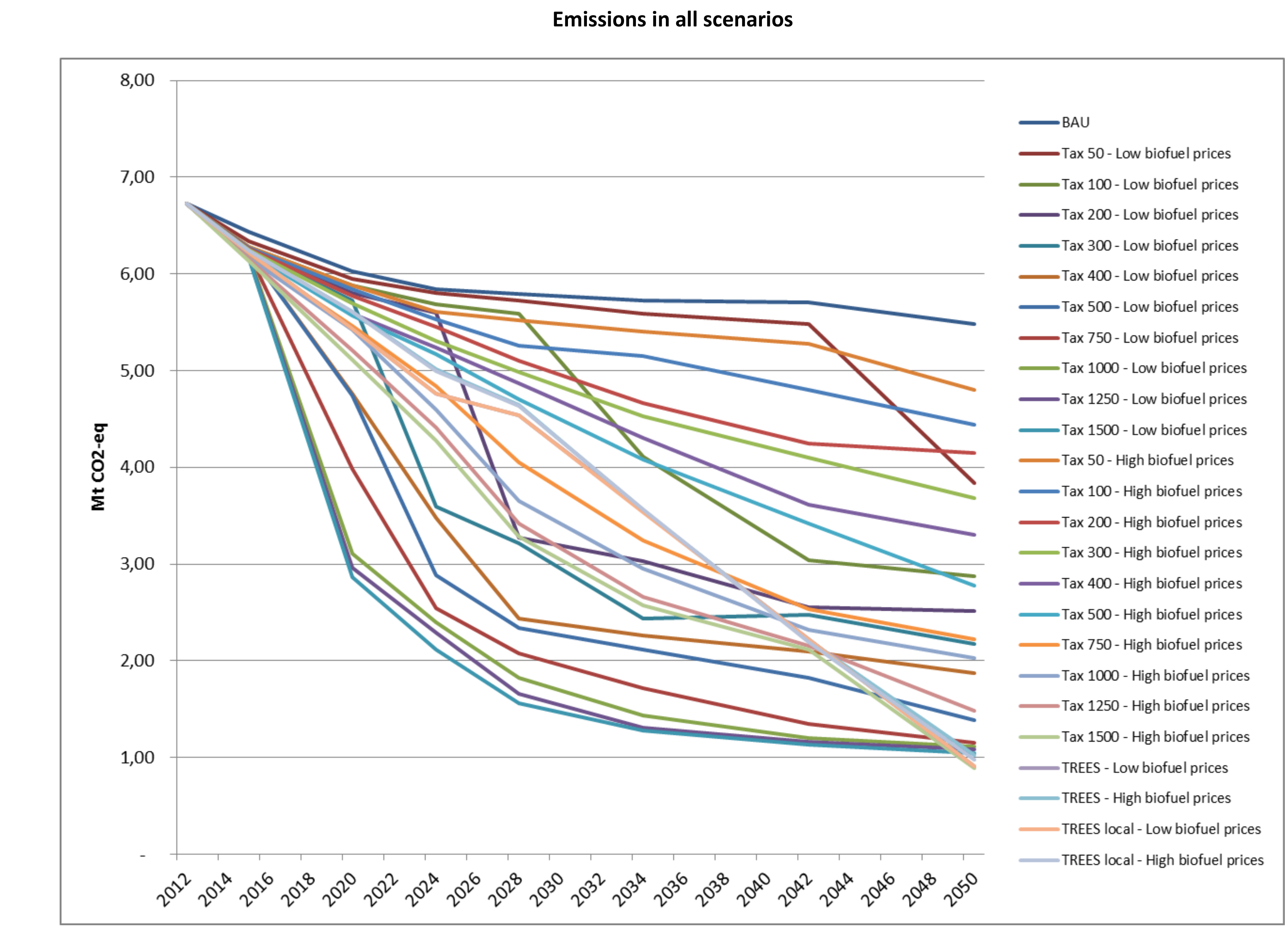
Below we provide visual illustrations of the full set of results derived from the modelling exercises. Each page provides results for one policy option under one scenario. For example, the "TREES low biofuel prices" provides results for the TREES Basic policy, under a scenario of low biofuels prices.

The reader is cautioned that the shorthand titles representing the Carbon Tax Shift policy options are indicative of the maximum carbon tax at the end of the full period. For example, the "Tax 400" policy represents a policy under which taxes are shifted from other areas of the economy to carbon, at a rate that begins at $10 and gradually increases to a maximum of $400 per ton of $CO_2$ by 2050.

To avoid any confusion, the reader will note that this appendix provides results for a broader set of carbon tax shift options than are discussed in the report. Indeed, the main report limits its discussion to two levels of carbon tax shift, chosen as sufficient to meet or exceed the carbon reduction targets under different biofuel price scenarios.

We also invite the reader to note that all results in this appendix are expressed in energy – not GHG, nor services – terms. For example, when examining the issue of electrification of transportation, the reader should note that because electric vehicles are significantly more efficient than gasoline or diesel-powered vehicles, the shares of electric *energy* used in transportation does not reflect the share of *electric vehicles*, or more accurately of vehicle miles travelled (VMT) using electric power. Put differently, a 10% electric *energy* share of transportation needs, as illustrated in one of the charts below, may in fact represent a 20-30% share of vehicles running on electricity, all else being equal.

Finally, we note that the FACETS model does not yet properly account for real-world lags in adoption of newly cost-efficient technology. As such, the more disaggregate charts presented below may include sudden – and somewhat unrealistic – jumps or declines in market share, when in practice these changes would likely involve a smoother adoption curve (both on the front and back ends).This should not materially impact the long-run targets.



Emissions in all scenarios
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
-
Mt CO2-eq
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
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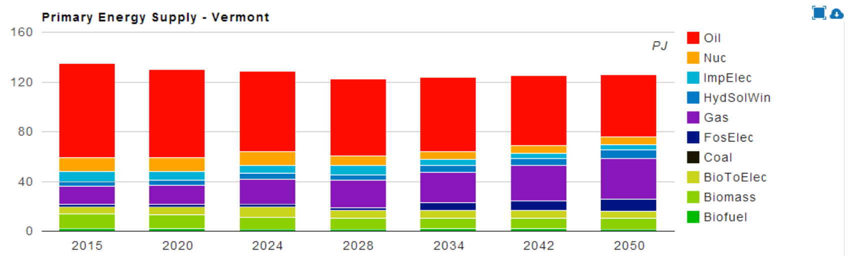
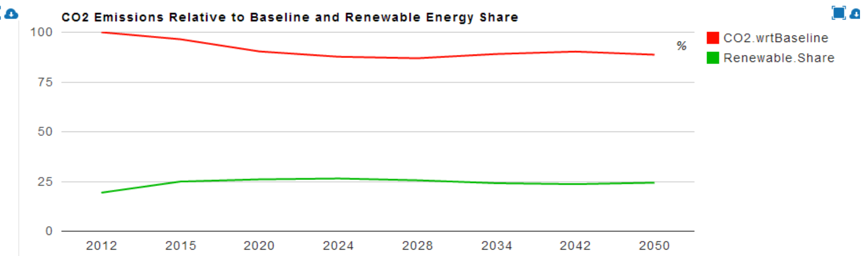
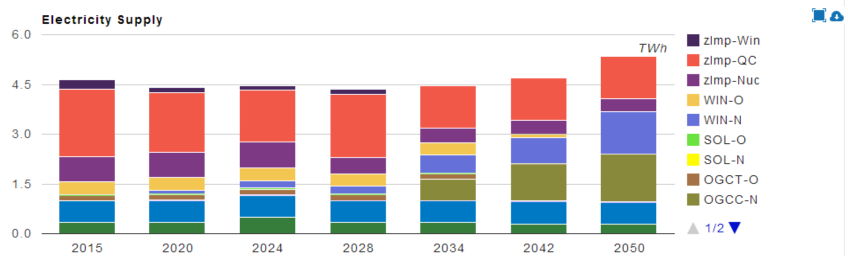
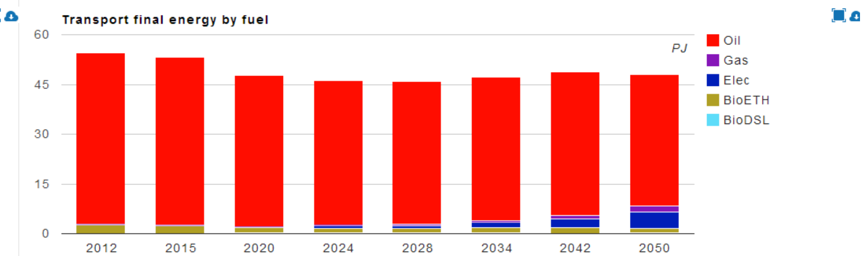
2044
2046
2048
2050
BAU
Tax 50 - Low biofuel prices
Tax 100 - Low biofuel prices
Tax 200 - Low biofuel prices
Tax 300 - Low biofuel prices
Tax 400 - Low biofuel prices
Tax 500 - Low biofuel prices
Tax 750 - Low biofuel prices
Tax 1000 - Low biofuel prices
Tax 1250 - Low biofuel prices
Tax 1500 - Low biofuel prices
Tax 50 - High biofuel prices
Tax 100 - High biofuel prices
Tax 200 - High biofuel prices
Tax 300 - High biofuel prices
Tax 400 - High biofuel prices
Tax 500 - High biofuel prices
Tax 750 - High biofuel prices
Tax 1000 - High biofuel prices
Tax 1250 - High biofuel prices
Tax 1500 - High biofuel prices
TREES - Low biofuel prices
TREES - High biofuel prices
TREES local - Low biofuel prices
TREES local - High biofuel prices

## Business-as-usual (BAU)

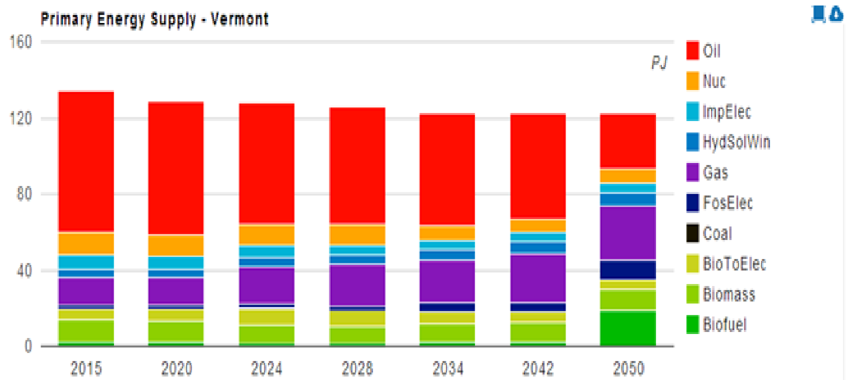


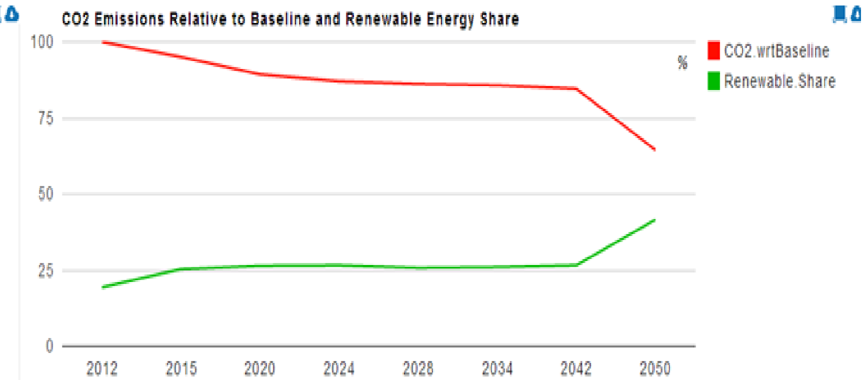



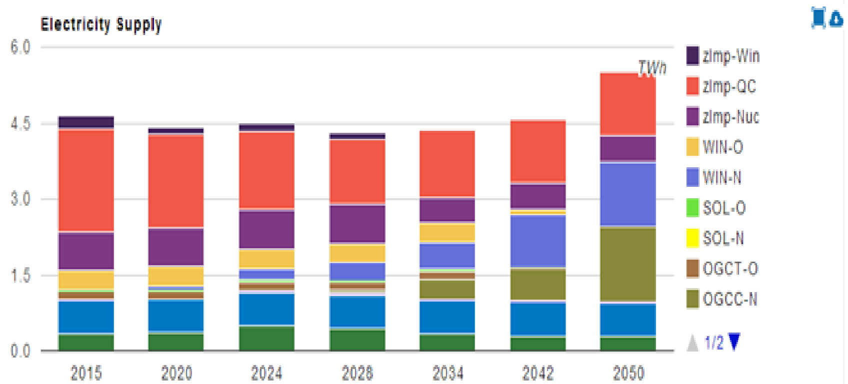



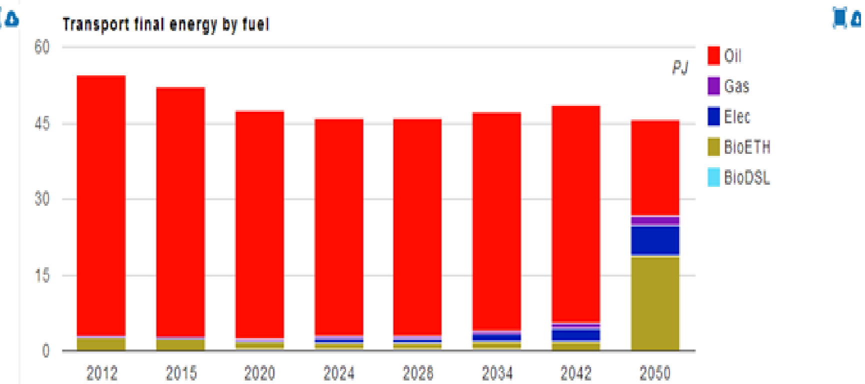



## Tax 50 - Low biofuel prices



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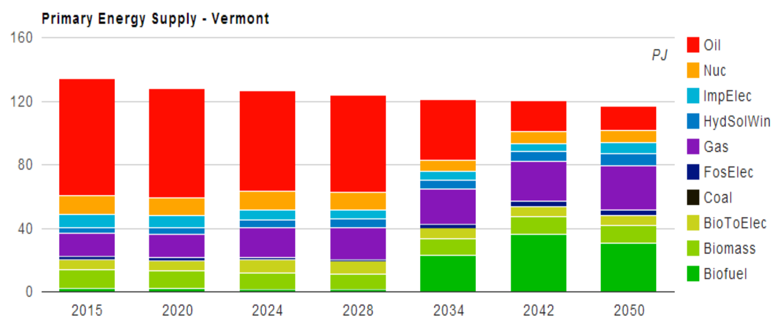


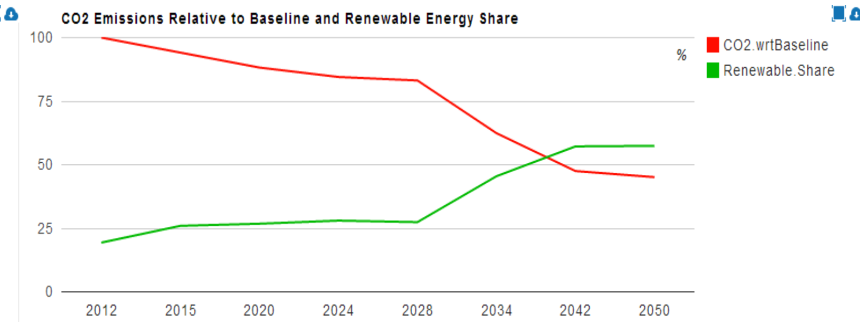


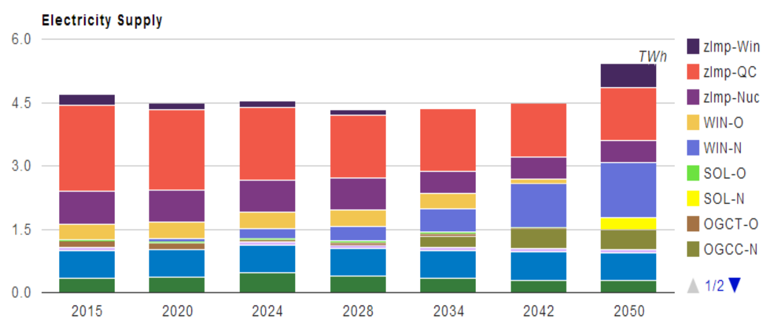


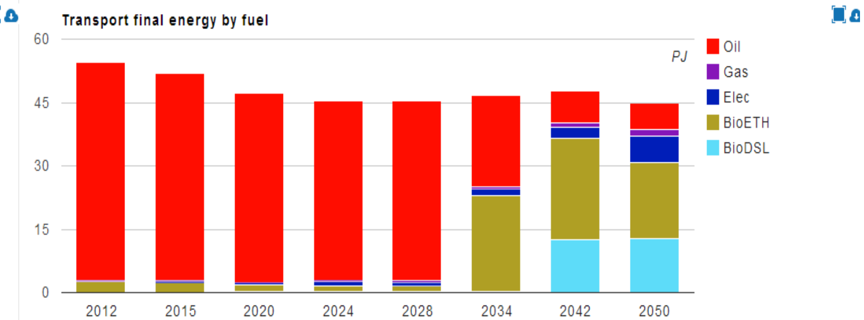

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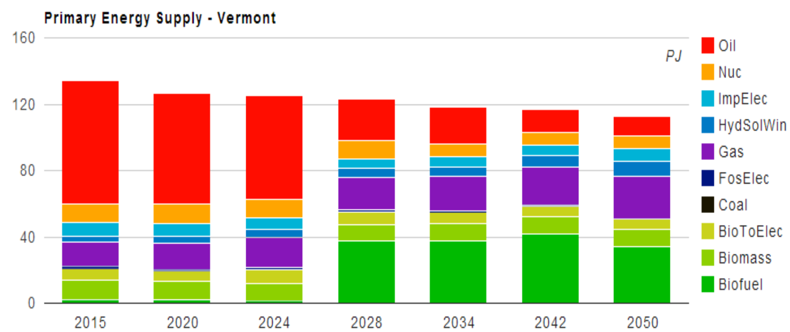


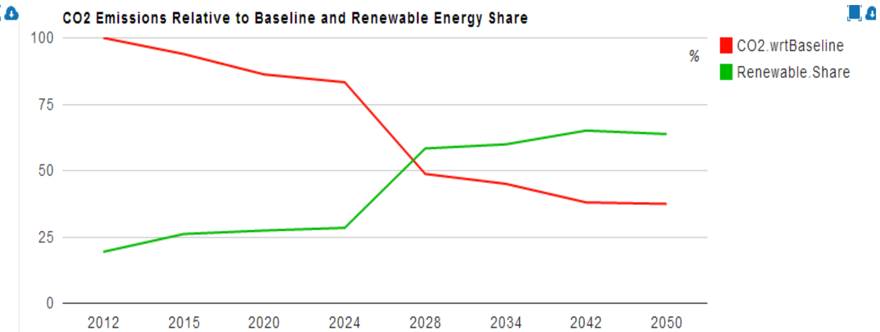


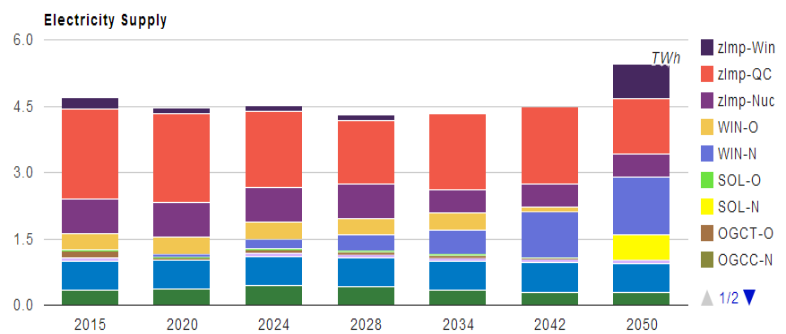


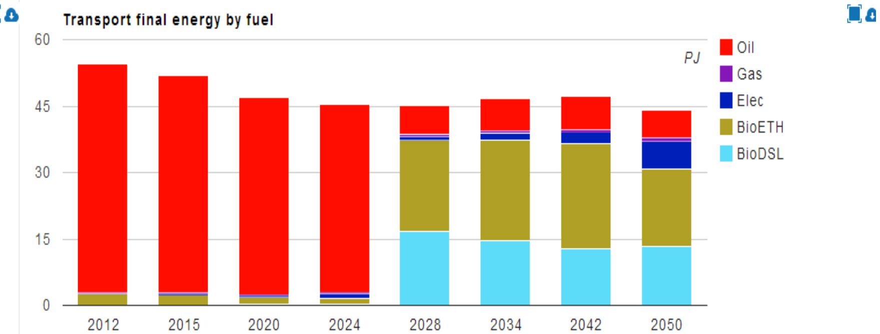

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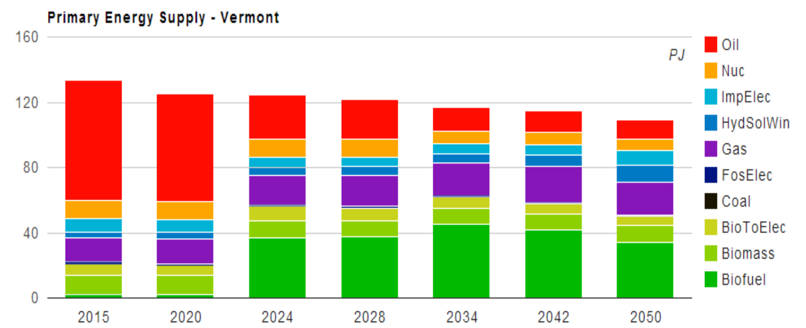


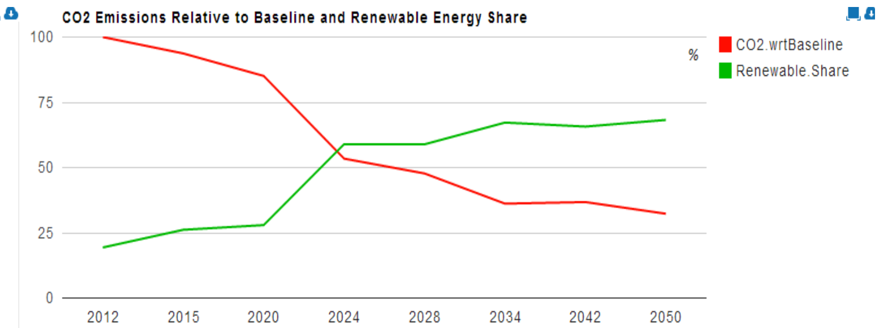


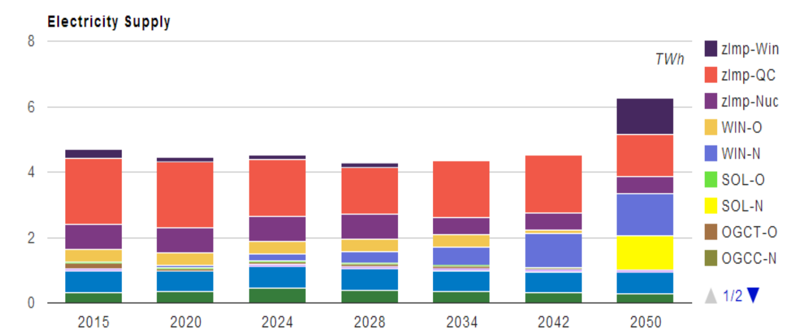


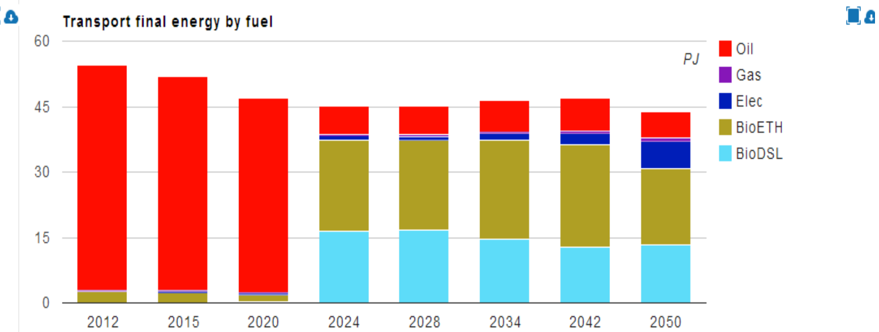

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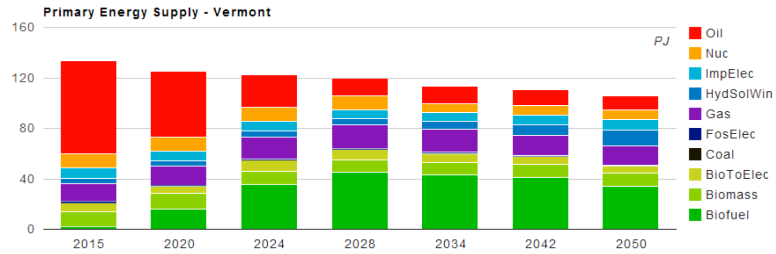
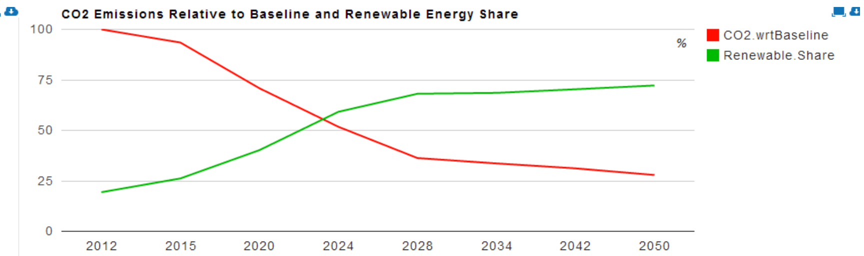
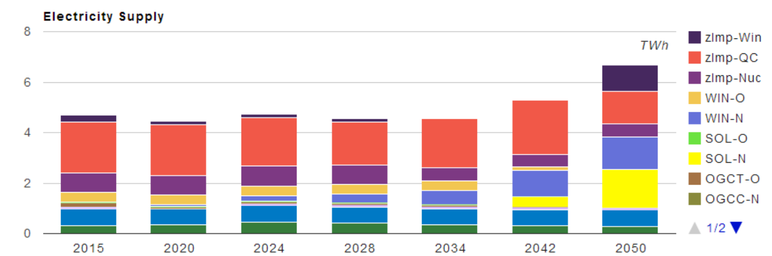
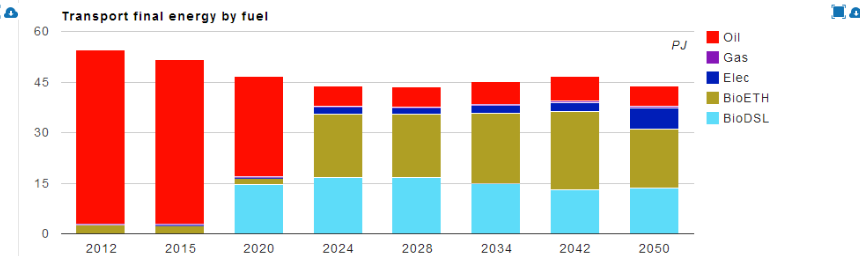
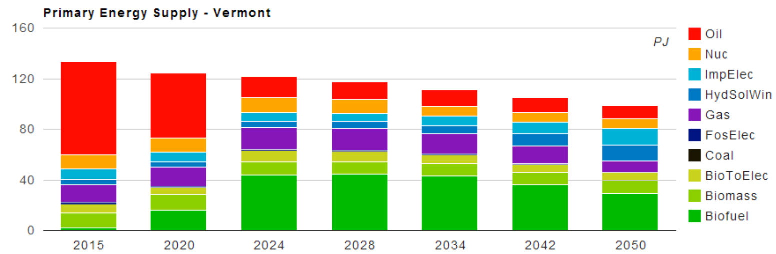


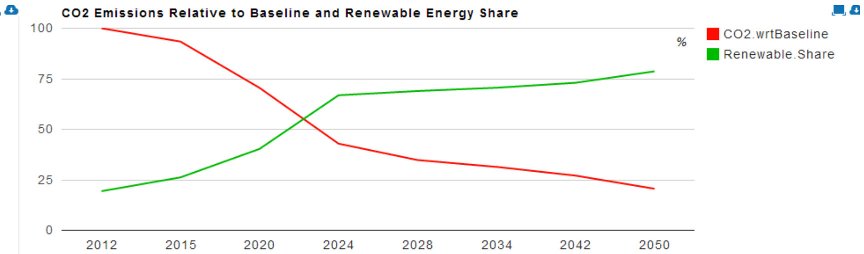



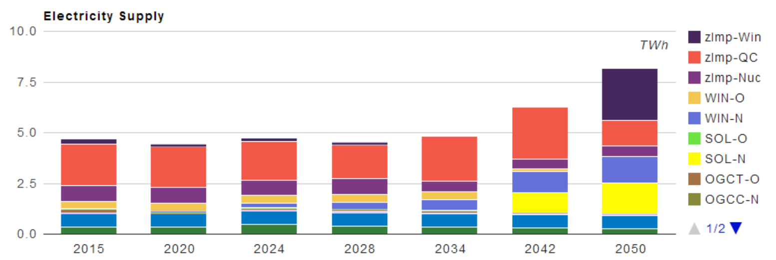



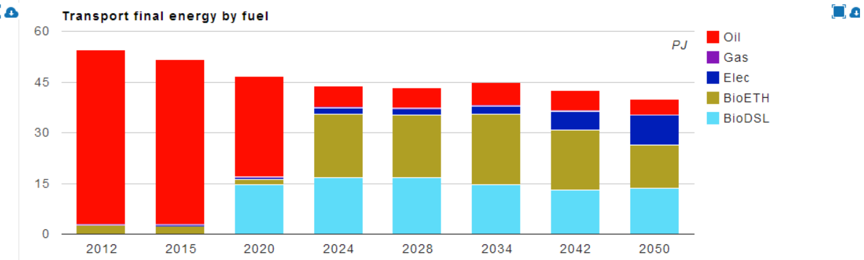



# Tax 500 - Low biofuel prices



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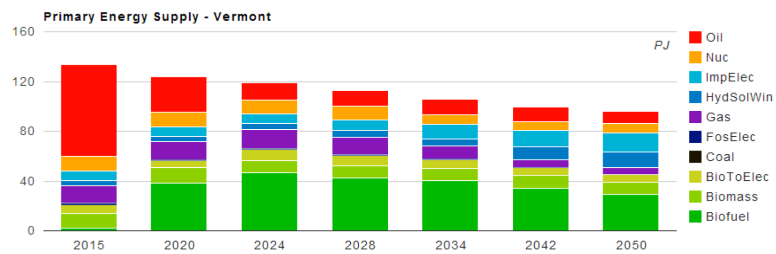
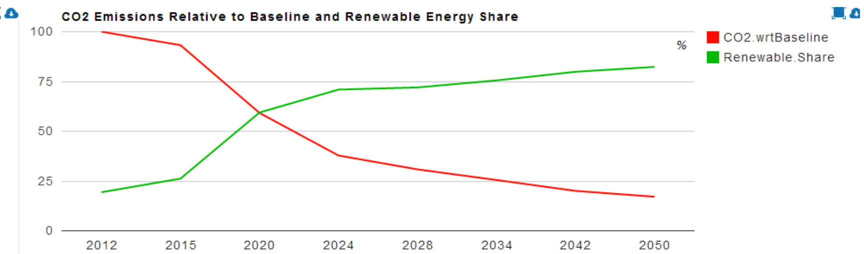
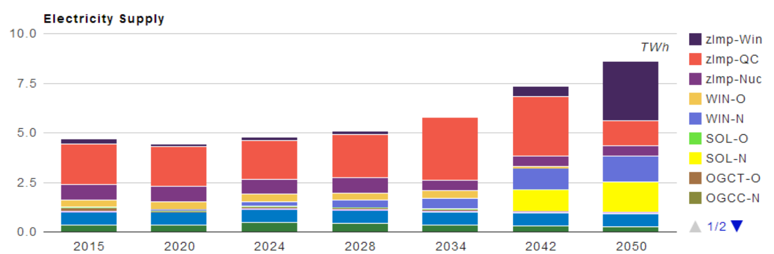
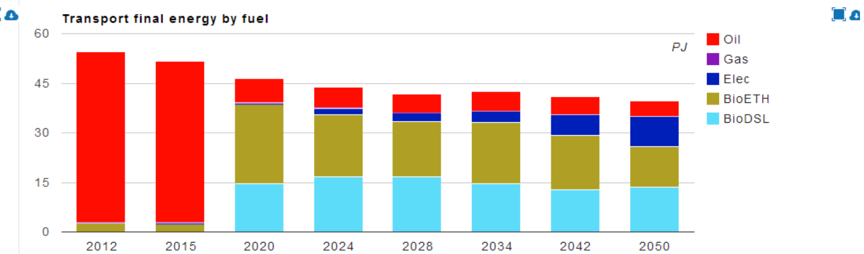
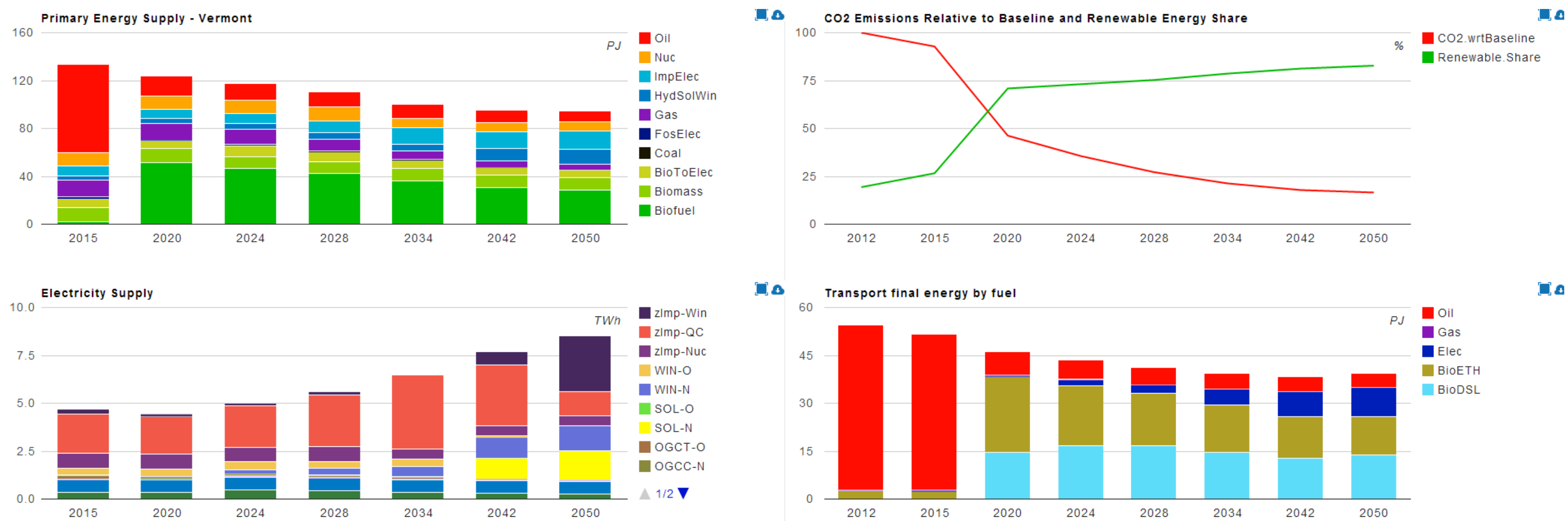


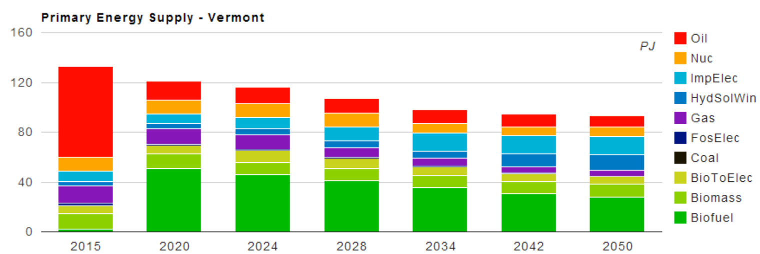



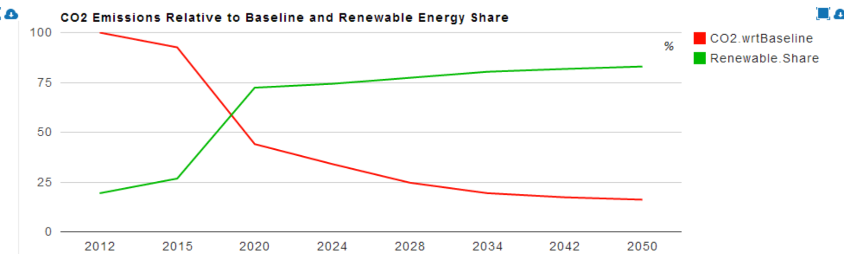



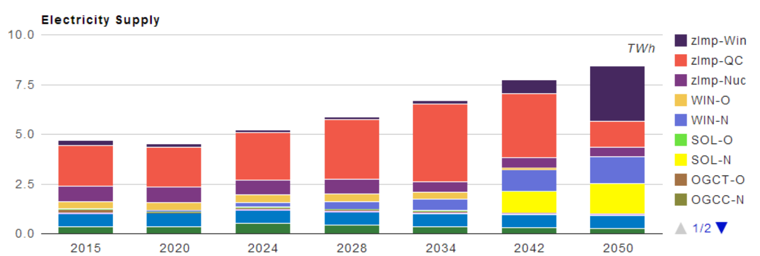
## Tax 1000 - Low biofuel prices

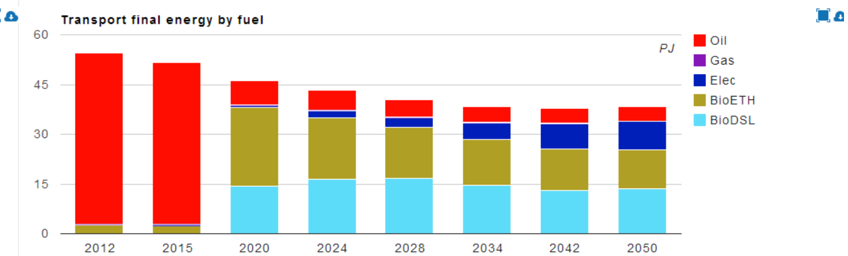


## Tax 1250 - Low biofuel prices

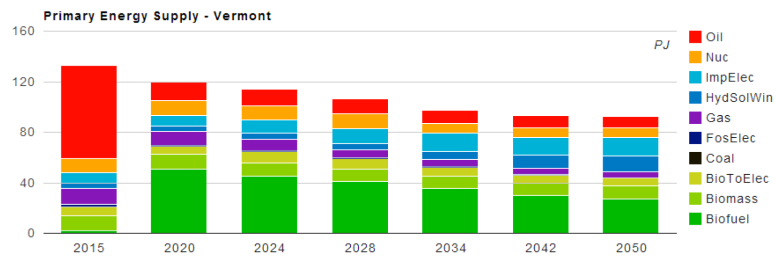


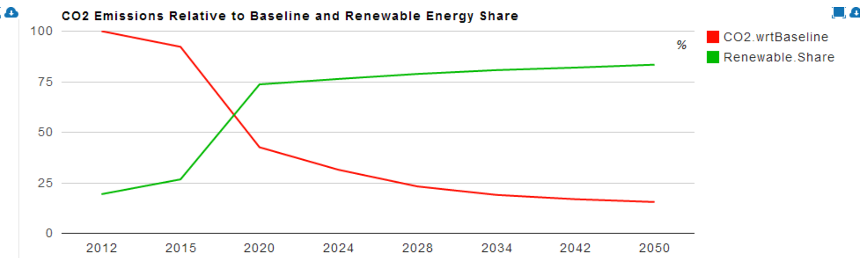



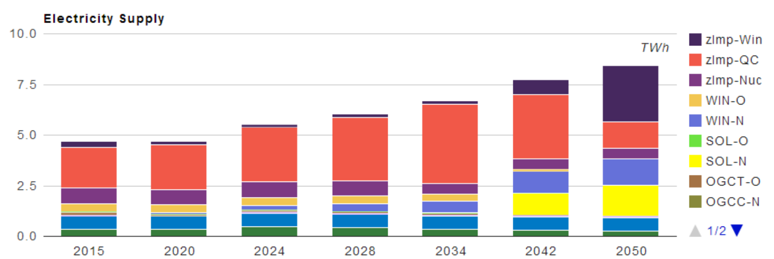



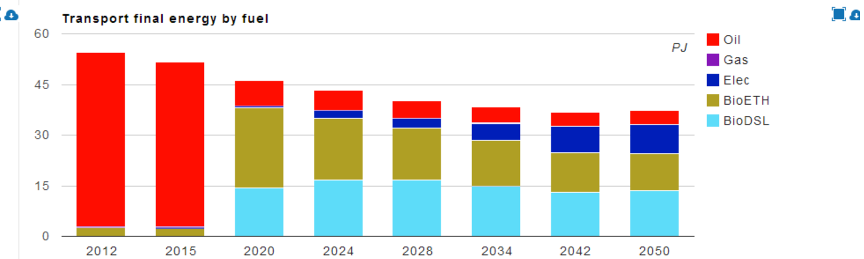



## Tax 1500 - Low biofuel prices

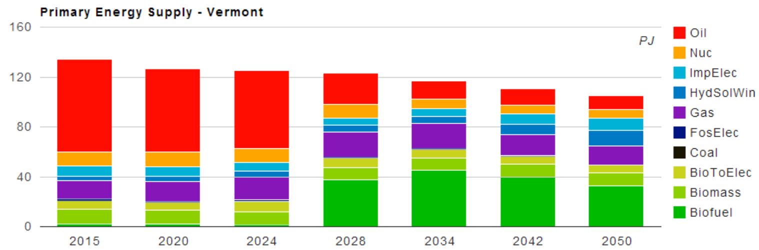


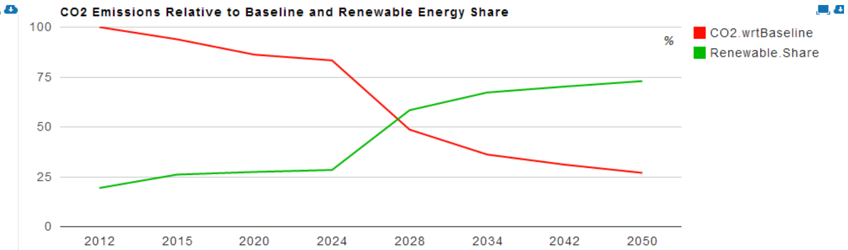



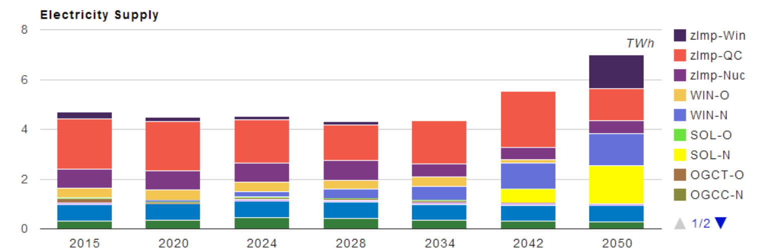



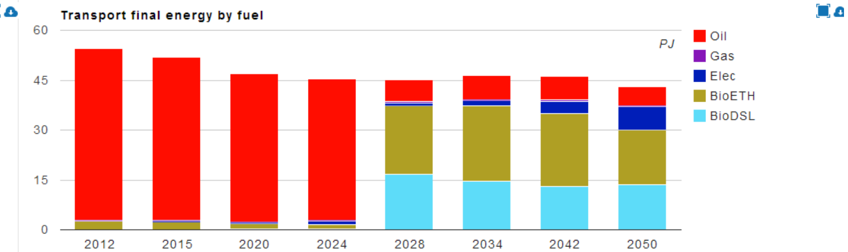



## Compliant - Low biofuel prices

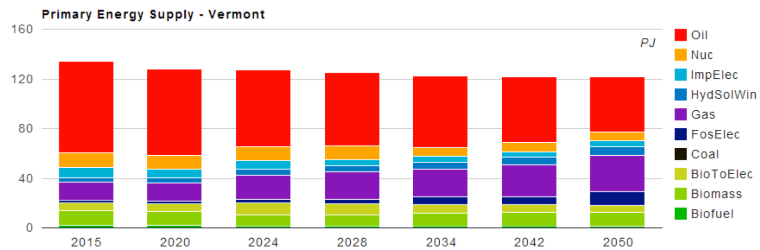


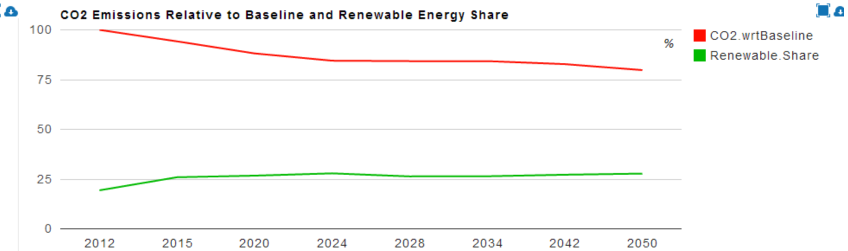



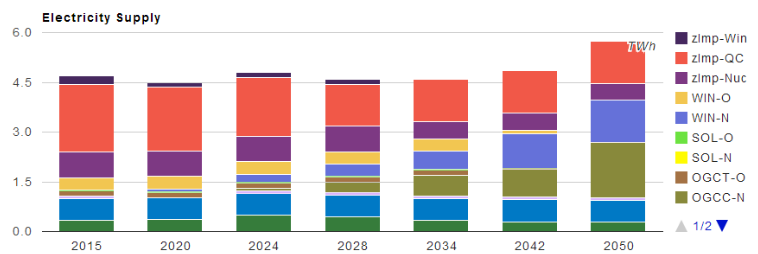



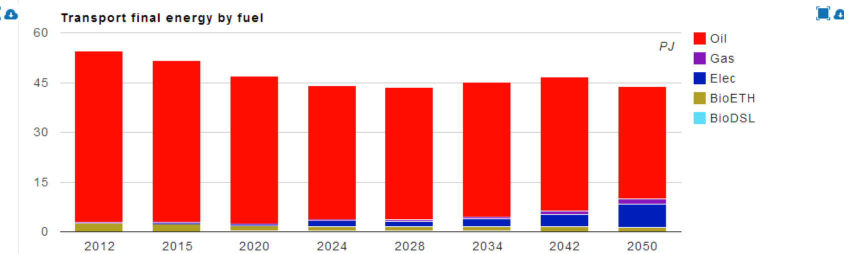



## Tax 50 - High biofuel prices



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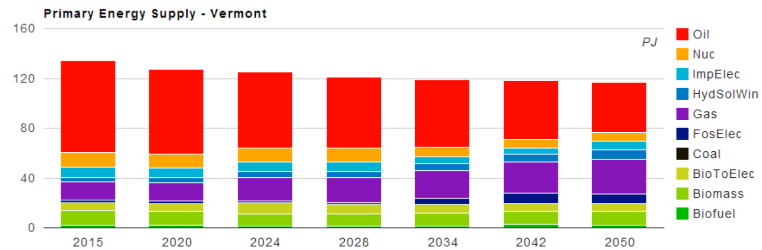
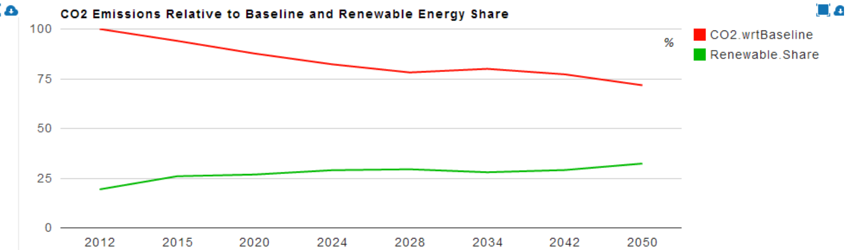
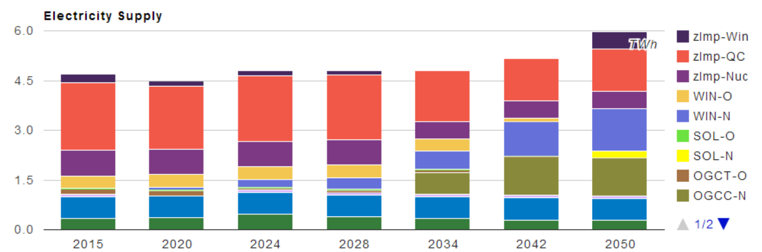
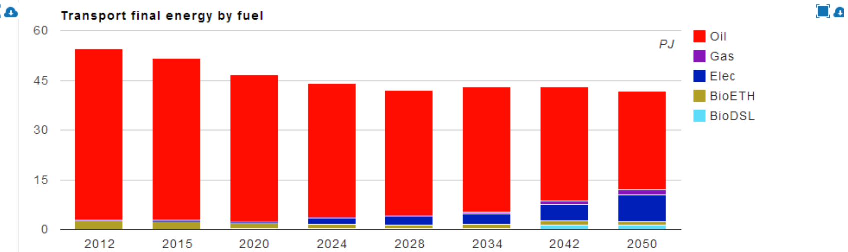
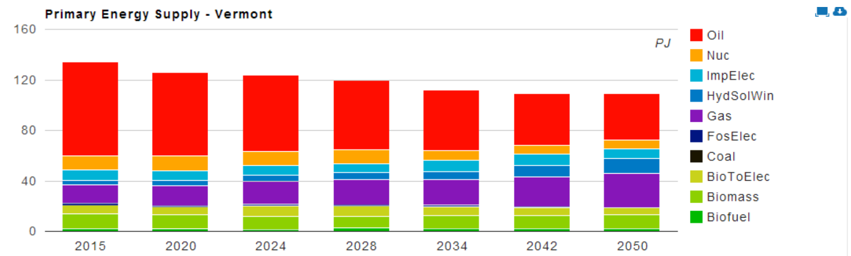


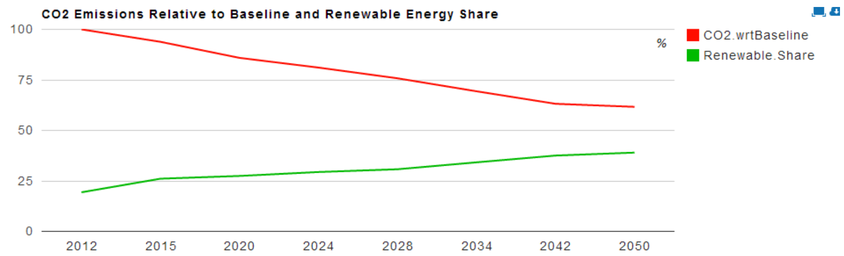



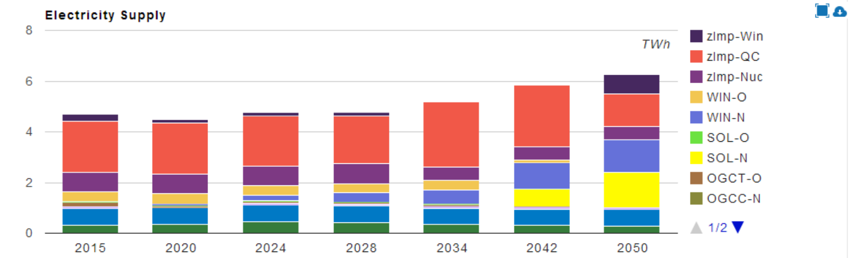



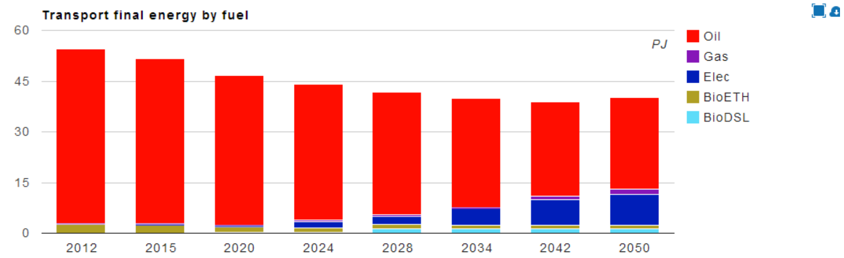



## Tax 200 - High biofuel prices

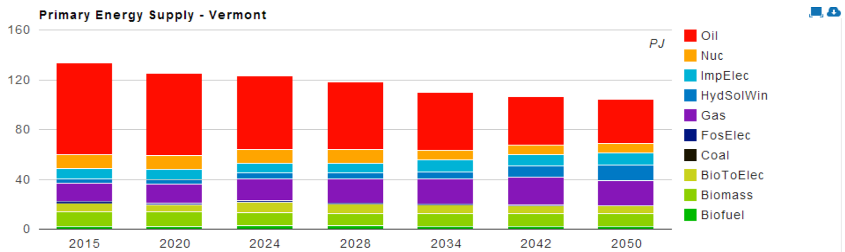


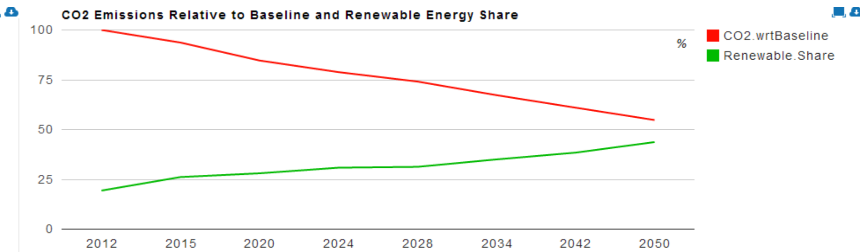



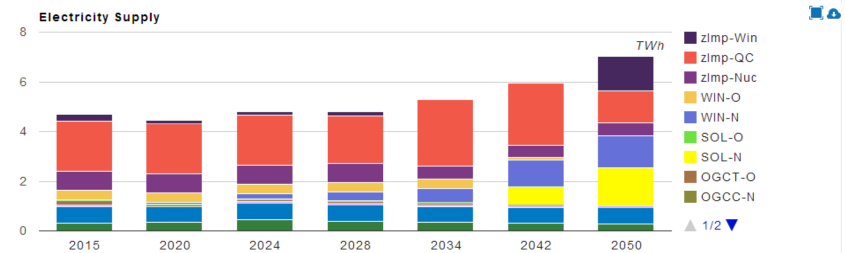



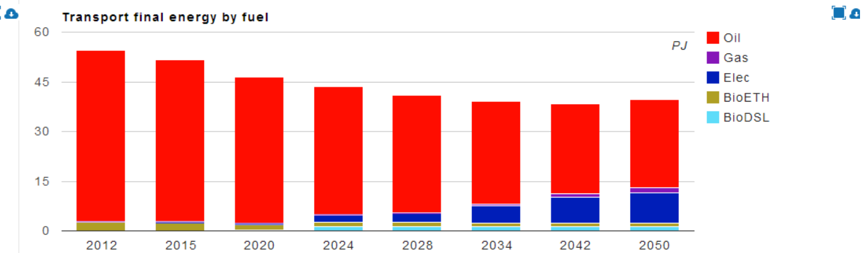



## Tax 300 - High biofuel prices



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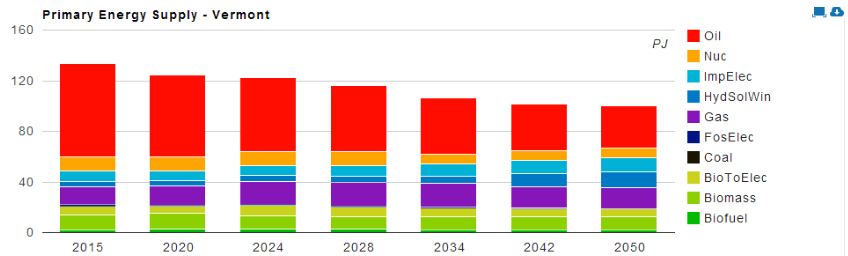
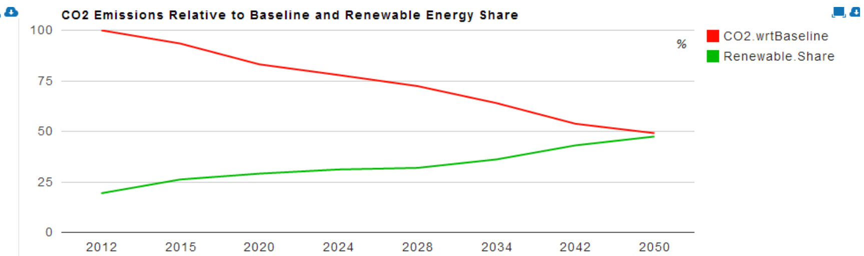
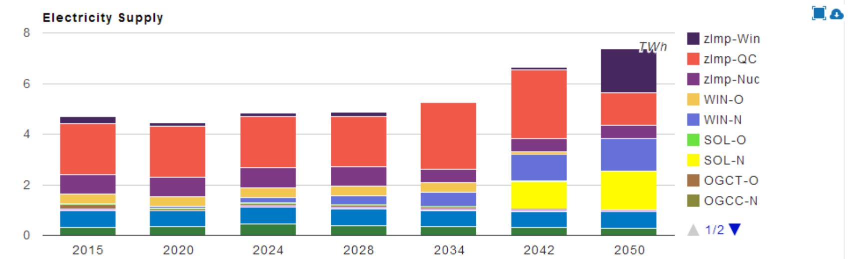
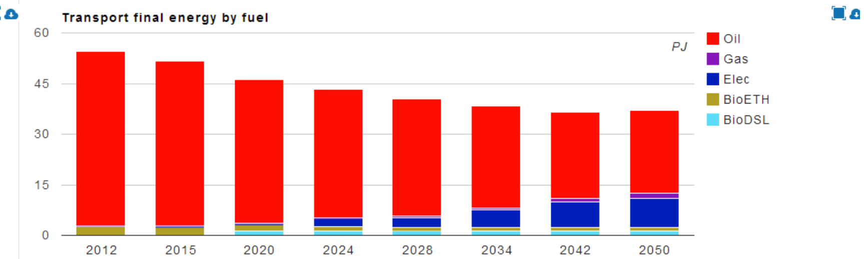
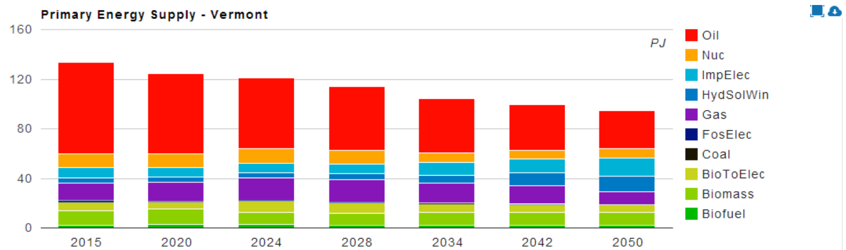


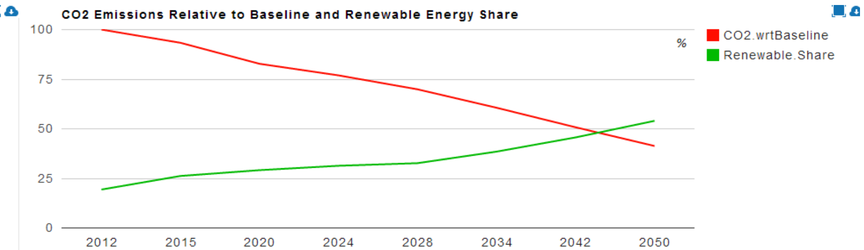



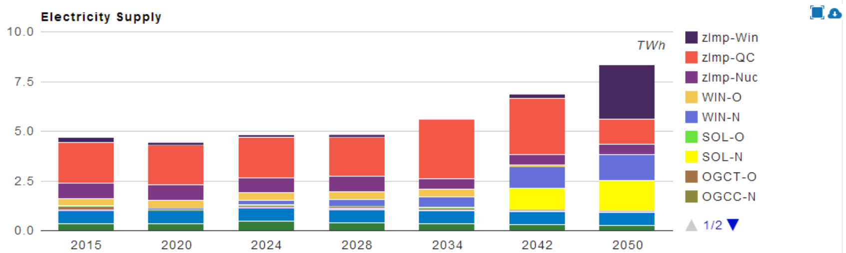



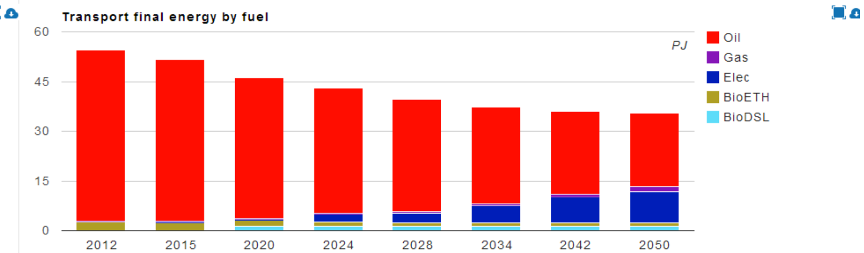



## Tax 500 - High biofuel prices

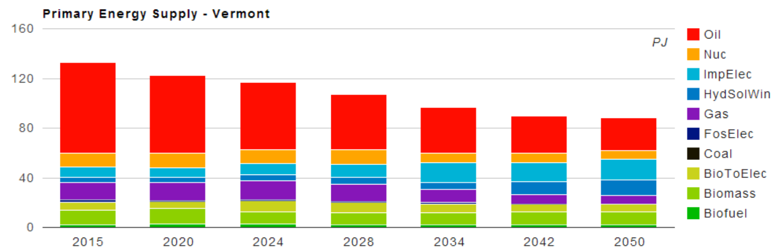


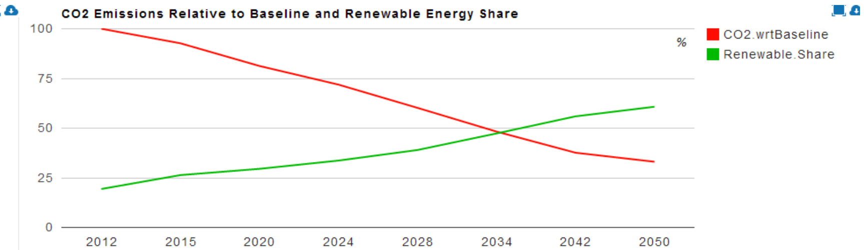



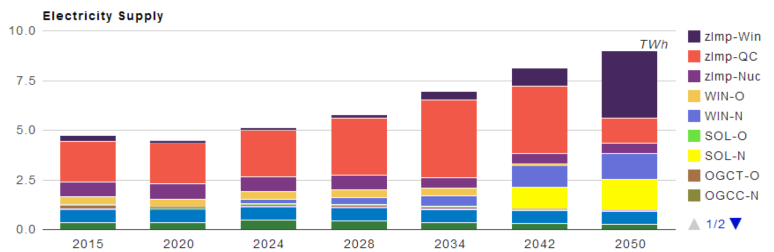



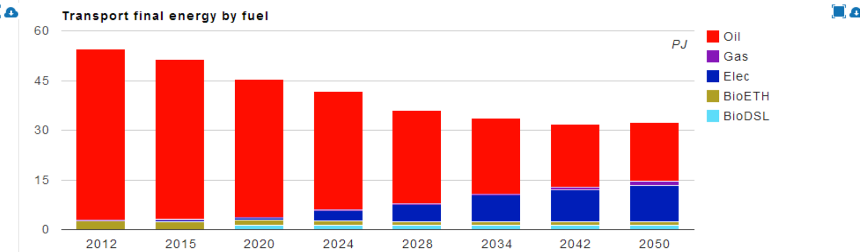



## Tax 750 - High biofuel prices

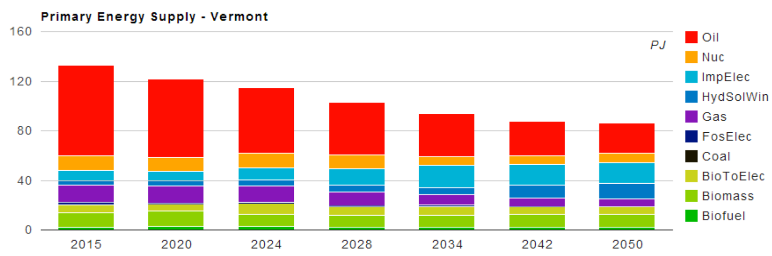


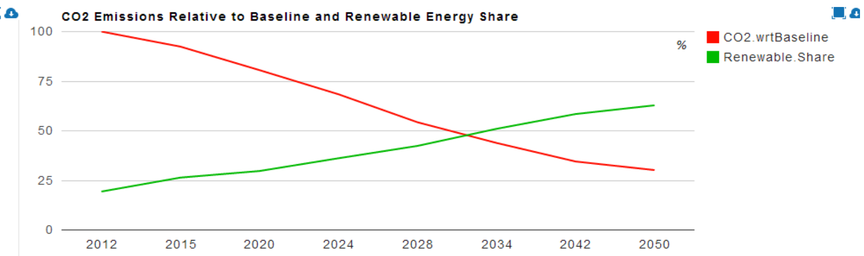



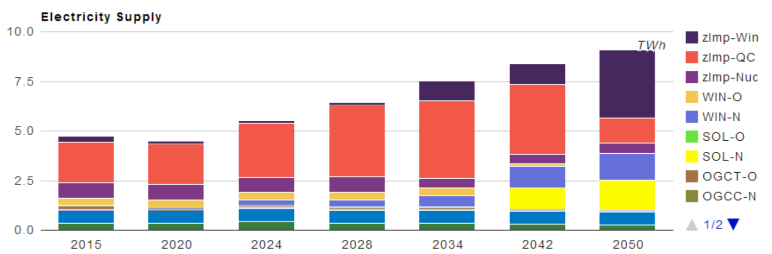



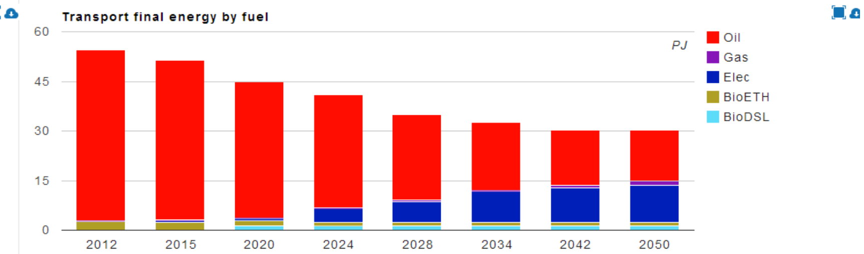



## Tax 1000 - High biofuel prices

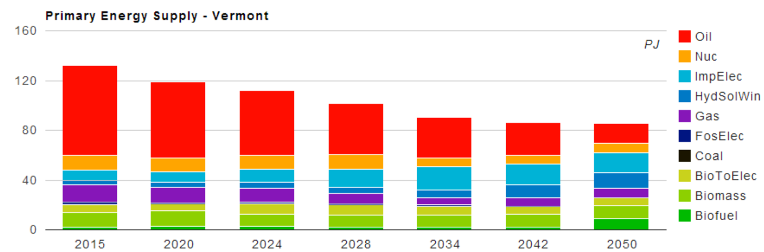


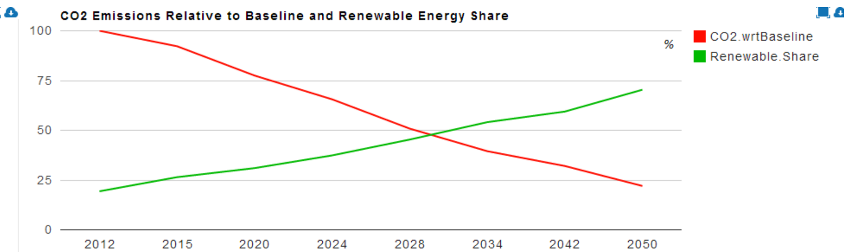



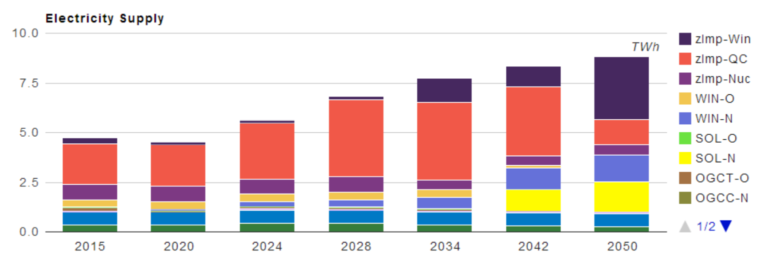



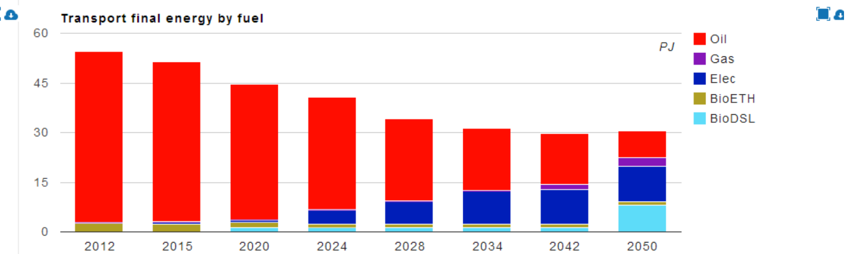



## Tax 1250 - High biofuel prices



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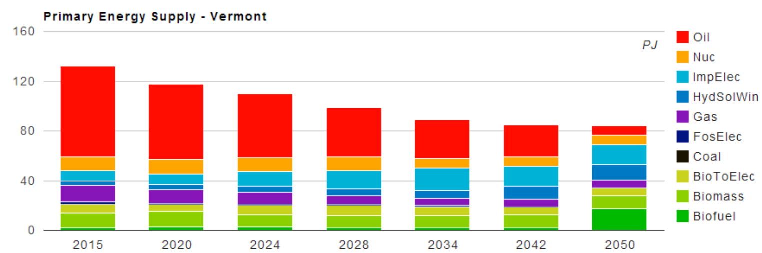
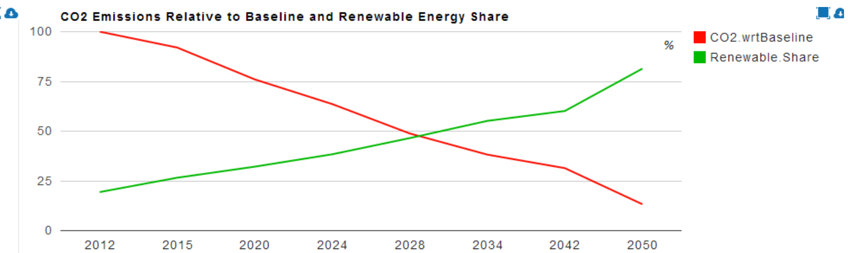
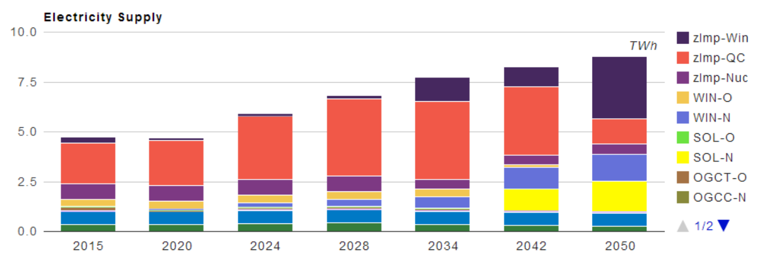
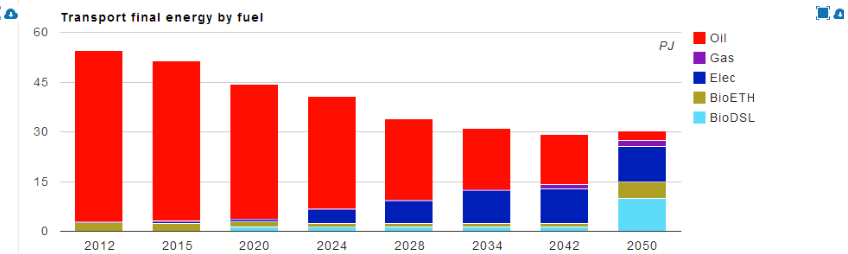
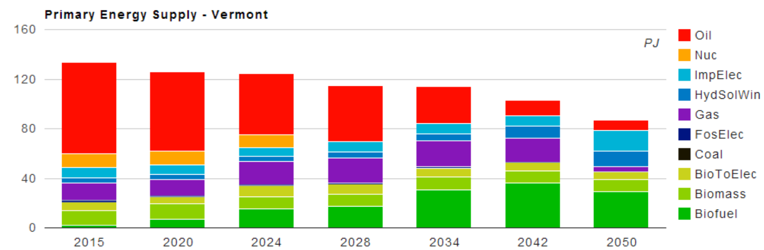


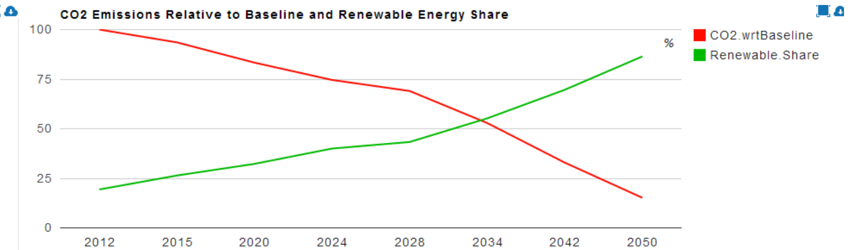



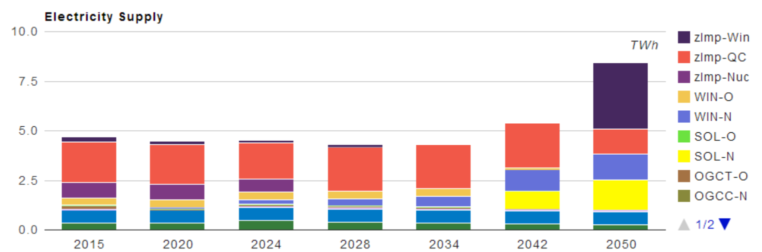



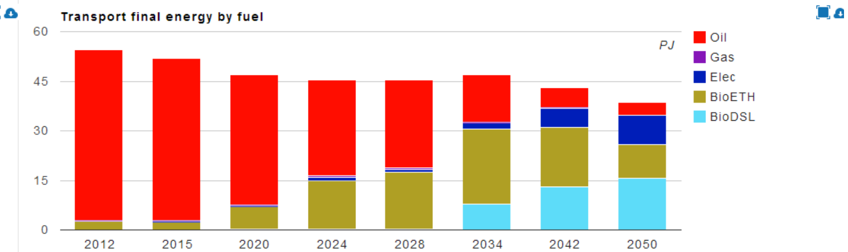



## TREES - Low biofuel prices

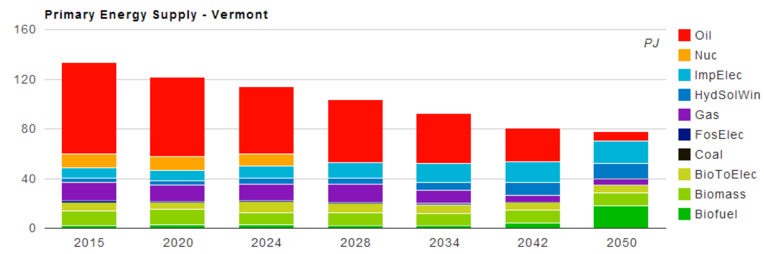


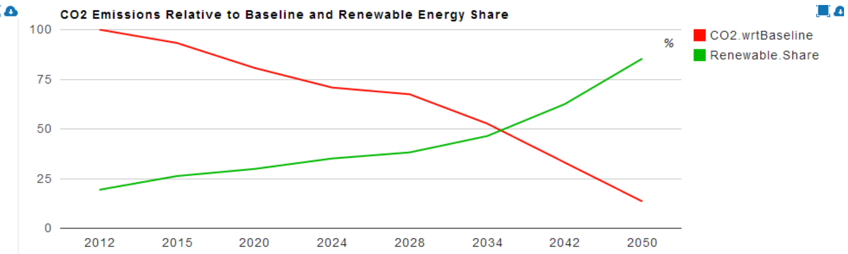



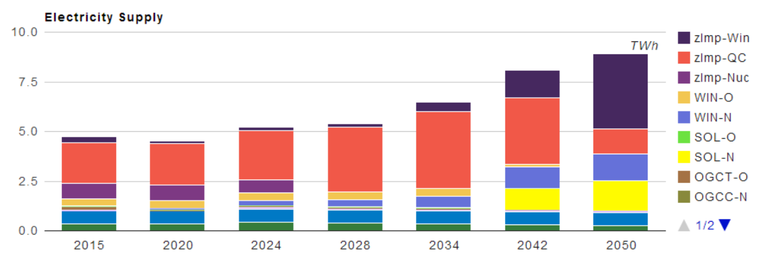



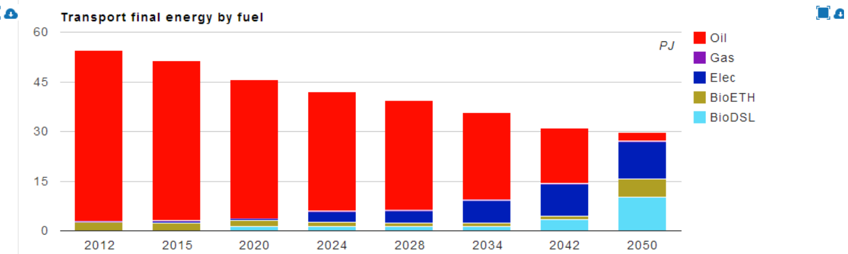



## TREES - High biofuel prices

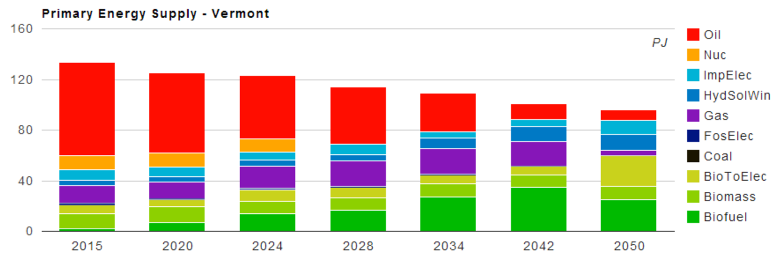


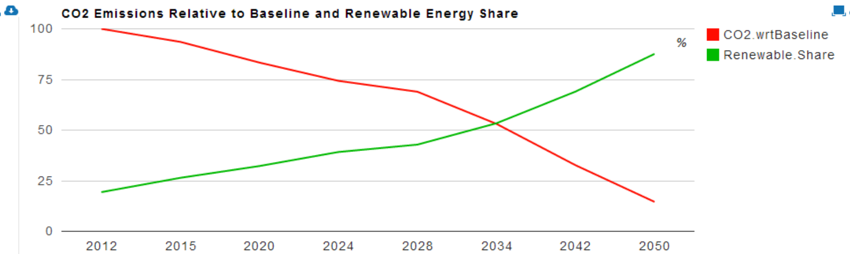



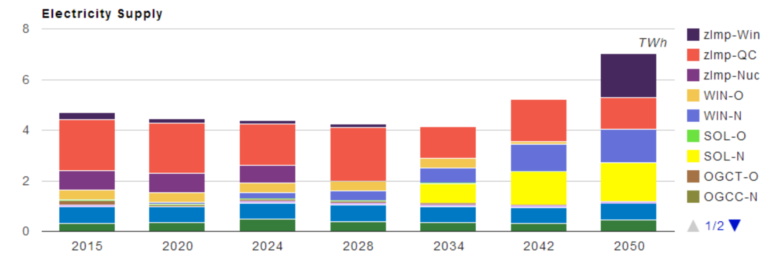



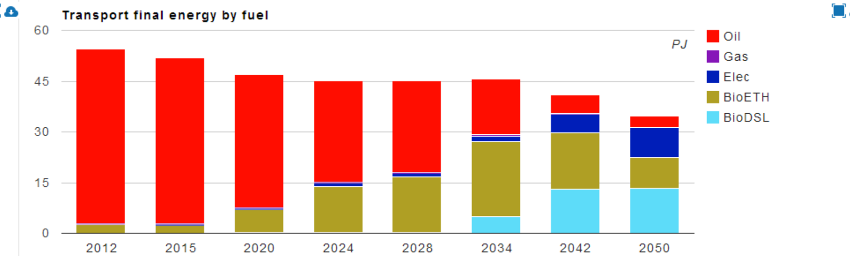



## TREES local - Low biofuel prices

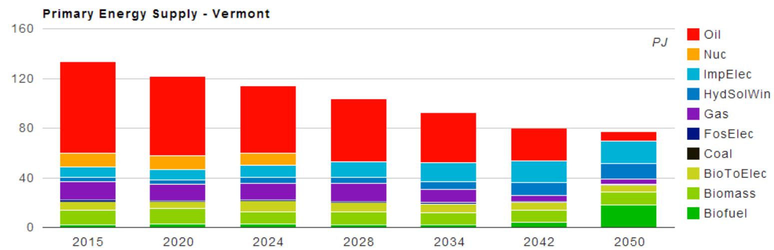


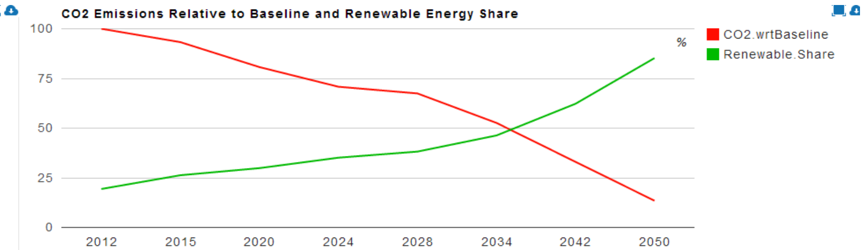



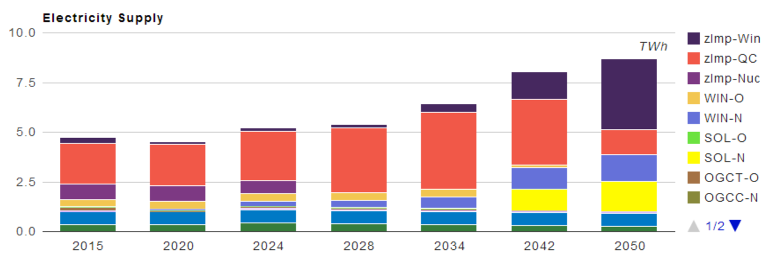



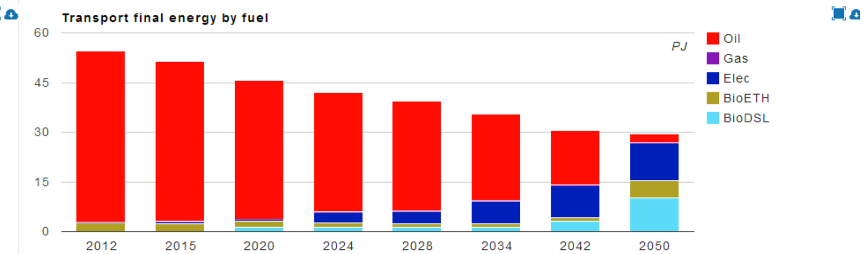



## TREES local - High biofuel prices



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