ACHIEVING AN ULTRA-LOW CARBON FUTURE: TECHNOLOGY AND POLICY PATHWAYS TO MEET VERMONT'S GHG GOALS

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ABSTRACT

Vermont is renowned for being an energy policy innovator, and its 2050 targets are no exception. The State's goals, which include reducing greenhouse gas emissions by 75% and securing 90% of all energy (including transportation) from renewable resources, are paving the way for Vermont's carbon-free future.

This paper presents how Vermont used a sophisticated energy model, incorporating Vermont-specific economic and environmental variables, as well as policy driven analysis and stakeholder consultation, to plot a realistic path toward its ambitious targets. With the support of Dunsky Energy Consulting, the team examined a variety of policy options; modelled their costs, benefits, risks, and ability to achieve the targets; and ultimately determined how Vermont can best reinforce its position as an energy and climate leader.

This paper explains the process and provides the results of Dunsky's modelling, including the likely impact of a carbon "tax and shift" policy, as well as of an innovative renewable portfolio standard applied to *all forms of energy,* not just electricity. We further highlight critical trade-offs and risk factors uncovered through the modelling effort, and discuss the broader engagement process – involving Vermont's legislators, stakeholders and public – that led to passage of the state's first steps down this path, including its new 2015 Renewable Energy Standard (RES) and its updated 2016 Comprehensive Energy Plan (CEP).

INTRODUCTION

In its 2011 Comprehensive Energy Plan (CEP), Vermont built on its aggressive, but ultimately necessary statutory goal of reducing emissions of greenhouse gases from 1990 levels by 50% by 2028, and by 75% by 2050[1], by establishing a goal of meeting 90% of *all* energy needs from renewable resources by that same year (PSD, 2011). Two years later, as directed by its legislature, the Vermont Public Service Department (PSD) launched a Total Energy Study (TES) to determine how best to achieve these ground-breaking goals (PSD, 2014).

The TES is a multi-phased process that began in January 2013 and involved decision-makers, experts and the general public. Its purpose was to identify the most promising policy and technology pathways to reach Vermont's renewable energy and greenhouse gas (GHG) reduction goals. To do so, it relied on comprehensive energy and policy modelling, conducted by Dunsky Energy Consulting (2014), and significant public input to help define key options. Its results informed Vermont's policy debate and led, as a first set of steps, to passage of the state's innovative Renewable Energy Standard and to adoption of its revised 2016 Comprehensive Energy Plan

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[1] Title 10 section § 578(a) of Vermont Statutes Annotated

(PSD, 2016). This paper presents a summary of the methodology and results of Dunsky Energy Consulting's study; readers can find more details in the final report (DEC, 2014).

VERMONT'S ENERGY MODELING ANALYSIS

The Dunsky team modelled the entire Vermont energy economy using the Framework for Analysis of Climate-Energy-Technology Systems (FACETS)[2] optimization model. FACETS was used to construct a Business as Usual 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.

The analysis accounts for Vermont's reasonably-available in-state resources, as well as available technologies to meet consumers' needs.[3] It allows 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.

Fig. 1: The Vermont FACETS Model in a Nutshell

- **Based on the TIMES model generator used in nearly 70 countries for climate policy analysis[2]**
- **Projects economic and environmental impacts of a wide range of different policy and economic scenarios, with a high level of sophistication**
- **Identifies least-cost solutions to meeting stated policy goals by assessing:**
    - **Available energy carriers** *(all solid, liquid, gas and electric fuel options)*
    - **Available(?) technologies** *(all types of power plants and major end-use equipment)*
    - **projected energy service demands** *(e.g. lighting, space conditioning, passenger miles)*
    - **physical and policy constraints** *(e.g. logging for biomass, wind siting, air quality)*
    - **other constraints** imposed on the system *(e.g., rate of technology adoption)*
- **Draws from a rich and up-to-date database of technologies, prices and usage data, augmented with VT-specific data.**
- **Contains over 20,000 combinations of technologies and commodities (e.g. light diesel consumption in heavy trucks).**

Vermont's Business-as-Usual (BAU) Scenario

In 2013, energy use accounted for 84% of Vermont's greenhouse gas emissions[4]: nearly half (45%) of Vermont's emissions came from energy used for transportation, and another quarter

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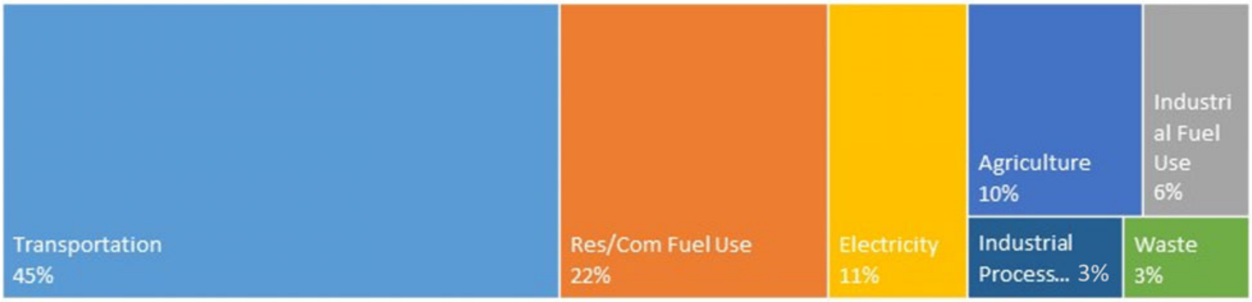
[2] FACETS is based on the TIMES (The Integrated MARKAL-EFOM System) model generator supported by the International Energy Agency (IEA) and used in nearly 70 countries for climate policy analysis (Fishbone and Abilock, 1981; Loulou et al, 2005). More information on the FACETS model is available at http://facets-model.com/.

[3] 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 small portion of the state's energy use – was also limited.

[4] The remainder came from agriculture, industrial chemical emissions, and landfills.

(28%) from fuels used to heat homes and businesses. By contrast, electricity generation was responsible for only 11% of emissions. Figure 2 provides the full breakdown of greenhouse gas emissions by sector.

Figure 1. Vermont's 2012 GHG Emissions Sources (DEC 2015)



The first step in the modeling process was to construct a Business as Usual (BAU) scenario representing the evolution of the current Vermont energy system, assuming no *new* policies directed at renewable energy or GHG emissions reductions.

Among the many assumptions that fed 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.[5] As shown in Figure 3 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 federal light-duty vehicle Corporate Average Fuel Economy (CAFE) standards, which require nearly a doubling of new vehicle efficiencies over the coming decades.

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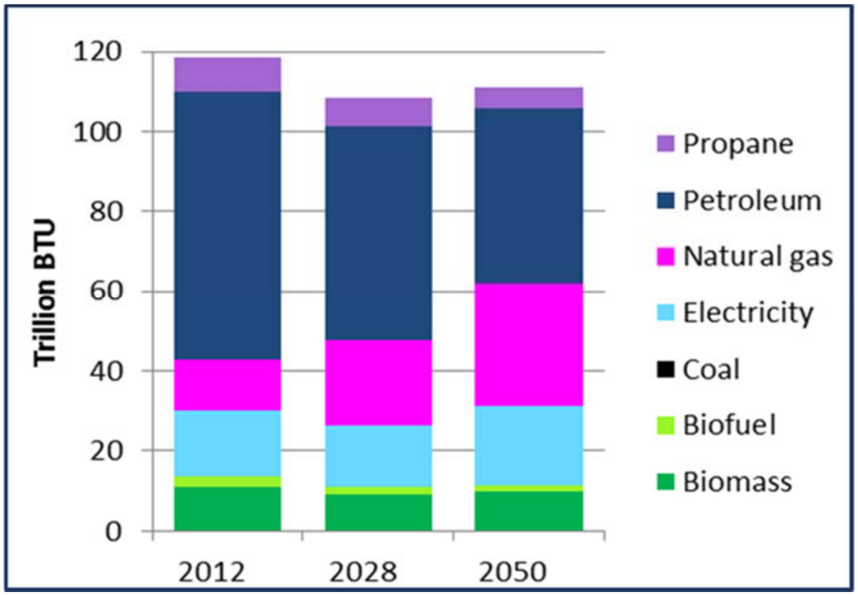
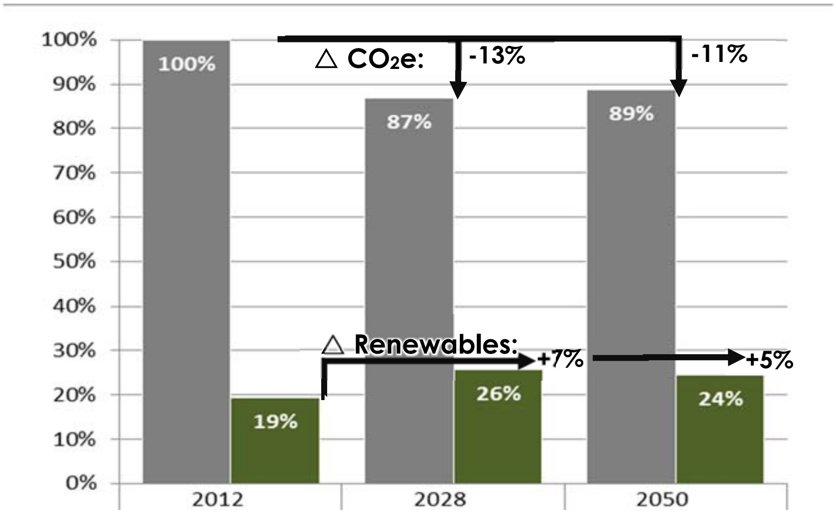
[5] It is also noteworthy that the electricity that Vermonters currently use is largely imported from outside of the state, and most of that is carbon-free. To fully reflect the actual flows of power into the state, the BAU scenario was built on a database that includes relevant Vermont, New England regional, and US energy system resources, including import/export options with Canada.

Figure 2: Vermont Energy Consumption 2012-2050 –BAU Scenario



Through a combination of this decrease in total energy consumption and anticipated fuel switching from oil toward natural gas, Vermont's energy-related greenhouse gas emissions are projected to decrease by 11% between 2012 and 2050 in the BAU case. Despite this slight reduction in energy usage and carbon emissions, achieving Vermont's long-term goals would require far more aggressive changes to the State's energy systems. As shown in Figure 4, GHG reductions of 11% by 2050, and growth in renewables content of 5% by that same year, are a far cry from the state's goals, namely a 75% reduction in emissions, and a 4.5-fold increase (from 19% to 90%) in renewables content.

Figure 3: GHG Emissions & Renewables Content: Business-As-Usual (BAU)



Achieving Vermont’s GHG emissions and renewables goals will require changes in the consumption patterns of all fuels across all sectors and end-uses. Significant new policies are therefore needed to drive Vermont’s clean energy transition fast enough, and far enough, to meet the statewide goals.

Policy Options for Meeting Vermont’s Statewide Goals

Following the modelling of the BAU, Dunsky Energy Consulting proceeded to model three policy options, developed in conjunction with the Vermont Public Service Department. The chosen policies were discussed and selected among a larger number of options based on such criteria as anticipated impacts (scope of emissions covered, leverage, applicability to different technologies), risk factors (acceptability, independency from other energy policies, responsiveness to technology changes, etc.), and the pace of implementation (short, medium and long term).

Each of these policy options represents a different degree of flexibility – or inversely, of constraint – on how market actors can achieve the overall goals. Our analysis showed that Vermont’s goals are technically achievable under each of the three potential policy approaches we modelled:

1. **Carbon Tax Shift:** a revenue-neutral tax[6] 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 (including vehicle fuels) 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.

During the analysis, it became clear that the ability of the energy system to change would be highly dependent upon the assumed evolution of liquid biofuel prices into the future. For this reason, we conducted a sensitivity analysis around two such price scenarios (“LoBio$” and “HiBio$”).

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[6] 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.”

KEY FINDINGS FROM TOTAL ENERGY STUDY

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

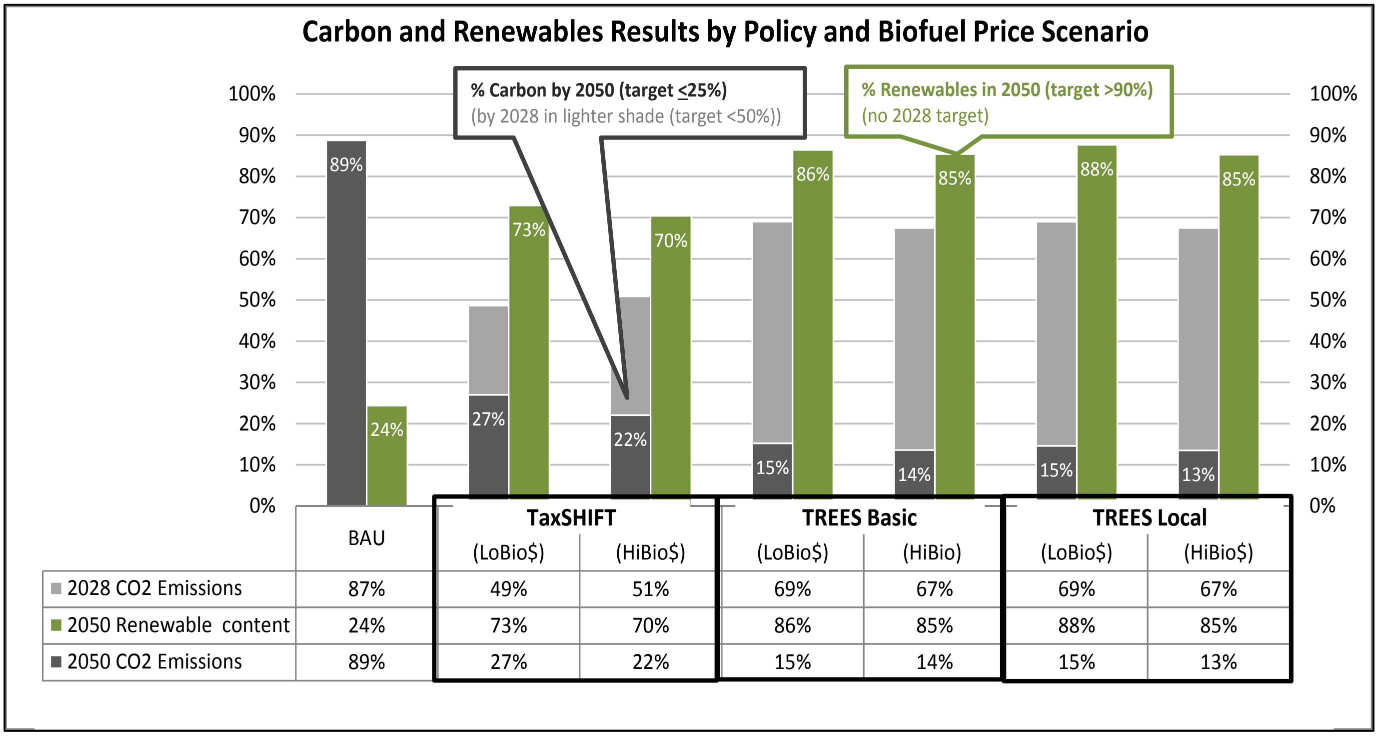
- Are Vermont’s sustainable energy goals achievable?
- If so, at what cost?
- Which policies can lead us there, and what are the key trade-offs?
- How will energy supply and consumption need to change?

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

Are Goals Achievable?

Figure 5 below illustrates the extent to which each of the three policy options – under each of the two biofuel pricing scenarios – can lead to reduced carbon emissions and increased renewable energy content.

Figure 4 Policy Options and Projected Results



	BAU	TaxSHIFT		TREES Basic		TREES Local	
		(LoBio$)	(HiBio$)	(LoBio$)	(HiBio)	(LoBio$)	(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%

As the reader can see, we find that Vermont’s long-term goal of reducing greenhouse gas emissions by 75% by 2050 is, by and large, achievable under each of the three policy options examined (falls just shy in one case). We also find that Vermont’s mid-term goal of reducing GHGs by 50% by 2028 is achievable under the Carbon Tax Shift policy. However, both TREES options as modeled fall short, achieving only 31-33% reductions in the mid-term; specific TREES requirements would need to be more aggressive to hit this target.

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 70-73%, under the Carbon Tax Shift policy.

Finally, each option evokes a trade-off regarding the other targets. For example, a Carbon Tax Shift achieves GHG reduction targets in both the long (2050) *and* mid (2028) terms, yet falls short of the 2050 renewable energy target. Inversely, both TREES policies achieve and in fact exceed the long-term GHG target and nearly meet the renewable energy targets, but fall far short of the mid-term (2028) GHG reductions target. There is a clear tension, therefore, between the GHG and renewable content goals, as well as between the 2028 and 2050 targets.

At What Cost?

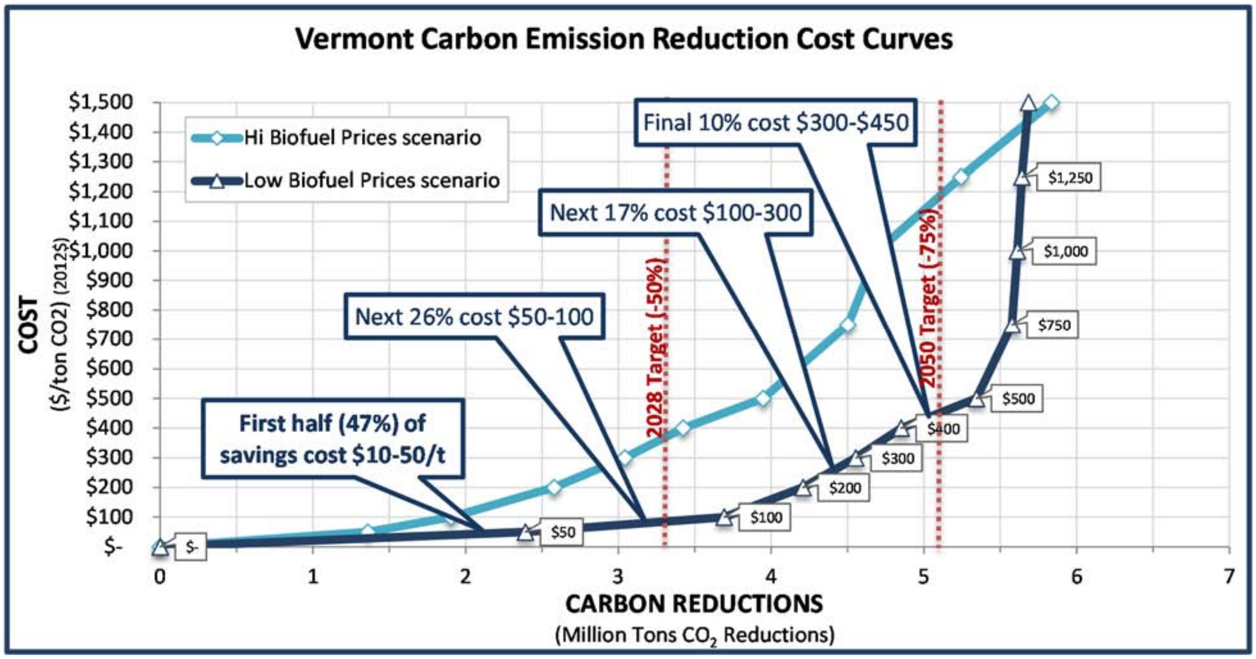
Results also show that achieving these significant targets comes at a moderate cost: depending on the policy option as well as assumptions regarding future biofuel prices, achieving the targets will add between 2.2% and 5.5% to the direct economic cost of meeting Vermonters' energy needs. (These cost values turn negative when we subtract an assumed cost of inaction, which Vermont pegs at \$100/tCO$_2$e.) 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 the more prescriptive TREES standard.

Figure 5: Change in Total Cost of Energy Services, 2012-2050

	COST OF POLICIES (relative to business as usual cost of energy services, 2012-2050)							
	GROSS COSTS *excluding cost of inaction*				**NET COSTS** *including assumed cost of inaction (\$100/tCO$_2$e)*			
	% change		*\$/ton*		*% change*		*\$/ton*	
Biofuel Price Scenario:	*LOW*	*HIGH*	*LOW*	*HIGH*	*LOW*	*HIGH*	*LOW*	*HIGH*
TAX SHIFT	**2.6%**	**4.5%**	**\$42**	**\$67**	**(-4.2%)**	**(-2.9%)**	**(-\$68)**	**(-\$43)**
TREES (BASIC)	**2.2%**	**5.4%**	**\$38**	**\$89**	**(-4.3%)**	**(-1.3%)**	**(-\$72)**	**(-\$21)**
TREES (LOCAL)	**3.3%**	**5.5%**	**\$56**	**\$90**	**(-3.2%)**	**(-1.3%)**	**(-54\$)**	**(-\$20)**

Figure 6 provides a "cost curve" of emissions reductions, assuming a carbon tax approach is used to influence market choices. 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, and *all of the 2028 target* can be achieved at less than \$70/ton. 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 approximately \$40 per ton of CO$_2$ in that 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.

Figure 5: Cost Curves for Carbon Emission 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.[7] While the FACETS analysis was limited to Vermont's energy system, the PSD subsequently used these results 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[8].

Using what policy levers?

As indicated previously, the choice of policy approach made a significant difference in total costs under both biofuel price cases, with a carbon tax generally proving more economically efficient than TREES (with the only exception of TREES Basic under a low biofuel price scenario).

The flipside to cost, in this instance, is risk. Specifically, while a carbon tax could arguably be more efficient, its results are also less certain. Indeed, GHG reductions from a tax are a modeller's game – a function of our assumptions around price-induced market choices (as well as the costs of fuel and technology options). Reductions from a TREES mandate, on the other hand, are an enforcer's game – a function of how well the mandate is overseen and

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[7] 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).

[8] This economic analysis is contained in PSD 2014; the appendix detailing the economic modeling can be found at http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/TES/D.%20Economic%20Modeling%20Analysis%20of%20TES%20Policies%2020141205.pdf.

compliance achieved. While both bear some risk, a carbon tax is arguably a far greater risk for achieving GHG reductions, while a TREES mandate shifts risk away from GHG targets, and over to the cost of achieving them.

How will energy supply and demand need to change?

Through the results of our work, we observe three pillars to the “greening” of Vermont’s energy system:

a) **Increasing energy efficiency and conservation,** 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, and since Vermont’s power supply is (and will be) largely decarbonized), the electrification of transportation results in large energy efficiency gains across the system .

b) **End-use substitution toward biomass and electricity is critical**. For heating loads, scenarios rely on a combination of biomass and heat pumps to largely replace existing oil and propane use. For transportation, competition between biofuels and electricity 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’ forecasts are 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[9], but for which growth opportunities beyond business-as-usual are relatively limited.

c) **Renewable power supplies can be grown sufficiently to power the electrification of heating and 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.

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

Summary of Findings

The analysis suggests that the transformation needed to achieve Vermont's greenhouse gas emissions reduction and renewable energy goals are ambitious but achievable. Furthermore, the cost of achieving these goals appears moderate. Under all cases, the added cost is lower than the assumed cost of inaction. In choosing a preferred policy approach, policymakers will need to make trade-offs (a) between targets and cost, (b) between cost and in-state economic benefits, and (c) between reduction targets themselves: mid- vs. long-term GHG reductions, and GHG vs. renewable content targets.

Our FACETS analysis did not account for other benefits to the state, including those associated with improved commercial balances from increased in-state economic activity, as well as from potentially improved air quality (given a reduction in air emissions associated with the electrification of vehicles and buildings, and/or from a shift to cleaner-burning fuels and technologies). In addition, other considerations around administrative burden, risks, cost, compliance, and of course political feasibility can be equally critical. Regardless of the selected approach, the study clearly found that achieving Vermont's ambitious goals would require a bold – and sustained – policy commitment.

THE NEXT STEPS: FROM MODEL RESULTS TO LEGISLATION AND A NEW CEP

The final Total Energy Study package delivered to the Vermont Legislature in December 2014 (PSD, 2014) included the energy modeling described above, along with macroeconomic modeling results showing that the net GDP impacts of the energy transitions under any of the policy and technology pathways examined in the TES were small. Net economic growth impacts were the result of changes in fuel consumption from imported liquid fuels to locally-generated electricity and woody biomass and a shift to capital infrastructure over fuel. If neighbouring jurisdictions also take comparable actions, Vermont's competitive position on energy costs would be less impacted, and the net economic impact of the transition is more positive. By choosing to lead, Vermont hopes to further establish itself as the home to future national clean energy businesses, building un-modeled economic benefits through exporting renewable energy and efficiency expertise and products.

Following the publication of the Total Energy Study, Vermont policy-makers who had committed to a broad policy debate led the way to the adoption of an innovative Renewable Energy Standard in 2015 and of an updated CEP in 2016 (PSD, 2016).

The 2015 Renewable Energy Standard (RES)

The TES identified the importance of building on the state's highly-renewable *electric* portfolio as a key part of meeting GHG and renewable energy goals in transportation and building heat as well. Working with stakeholders including utilities, clean energy businesses and advocates, the Public Service Department designed, and the state legislature adopted as Act 56 of 2015, a proposal for a Renewable Energy Standard (RES) that imposes three requirements on electric utilities:

1) **A "total renewable energy" requirement** to obtain 55% of electric energy from renewable sources in 2017, rising four percent every three years, to 75% in 2032.

2) **A "distributed generation" requirement** to obtain 1% of electric energy from small, in-state renewable generators in 2017, climbing 0.6% per year to 10% in 2032. This is a subset, or carve out, of the total renewable requirement.
3) **An "energy transformation" requirement** for electric utilities to reduce their customers' use of *fossil fuels* by an amount equivalent to 2% of electric energy sales in 2017, rising 2/3% per year to 12% in 2032.

The Energy Transformation requirement, which borrows largely from the TREES policy option assessed by the Dunsky team, is particularly noteworthy. The TREES policy would have established a wide-ranging new market for actions that reduced fossil fuel use through efficiency or renewable energy in *all* spheres of energy consumption, not just electricity. The energy transformation component of the RES tests this idea by requiring electric utilities to achieve parts of these goals through promotion of non-electric energy efficiency, use of bioenergy, as well as through carbon-negative electrification (e.g. by promoting efficient heat pumps in lieu of gas, oil or propane heat, and by encouraging adoption of electric vehicles in transportation).[10]

Further, the RES achieves these goals at a known scale and in a verified way. Vermont's existing energy efficiency utility structure provides a foundation of evaluation and verification expertise and processes on which this new policy can build.

The 2016 Comprehensive Energy Plan

The Public Service Department began the public process for updating the state's CEP in the summer of 2015, following the end of the legislative session. The CEP is built on insights gained through the Total Energy Study process, as well as other analysis and policy deliberations. In particular, the TES analysis gave the state a sense of the range of possible technical pathways to achieving 2050 objectives, identifying what could be expected, what would be particularly hard or expensive, and where to be either cautious or bold. The TES informed an extensive CEP stakeholder process, including four topic-specific stakeholder workshops and four public forums prior to the release of a public review draft, along with five public hearings after the draft was released. In total, the PSD received nearly 800 public comments.

Modeling various pathways between the present and 2050 allowed the state to establish a set of more specific GHG and energy targets, which are critical to achieving the statewide goals:

- *Total Energy Efficiency*: Reduce total energy consumption by 15% per capita by 2025, and more than one third by 2050;
- *Renewable Energy*: Meet 25% of the remaining energy need from renewable energy in 2025, 40% in 2035, and 90% in 2050;
- *Sectoral Targets:* Three end-use sector goals for 2025: 10% renewable transportation, 30% renewable buildings, and 67% renewable electric power; and
- *Total GHG:* Reduce energy-related GHG emissions 40% below 1990 levels by 2030 and 80-95% by 2050.

The total energy use reduction goal is based on the combination of three kinds of efficiency: 1) continued improvements in demand-side thermal and electric efficiency and conservation; 2) fuel switching away from combustion technologies to more efficiency electric technologies (e.g.

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[10] Electrification, expected primarily through the use of highly-efficient heat pumps and electric vehicles, results in a net reduction in fossil fuel use because of the high renewable energy fraction of electricity required by tier 1 of the RES.

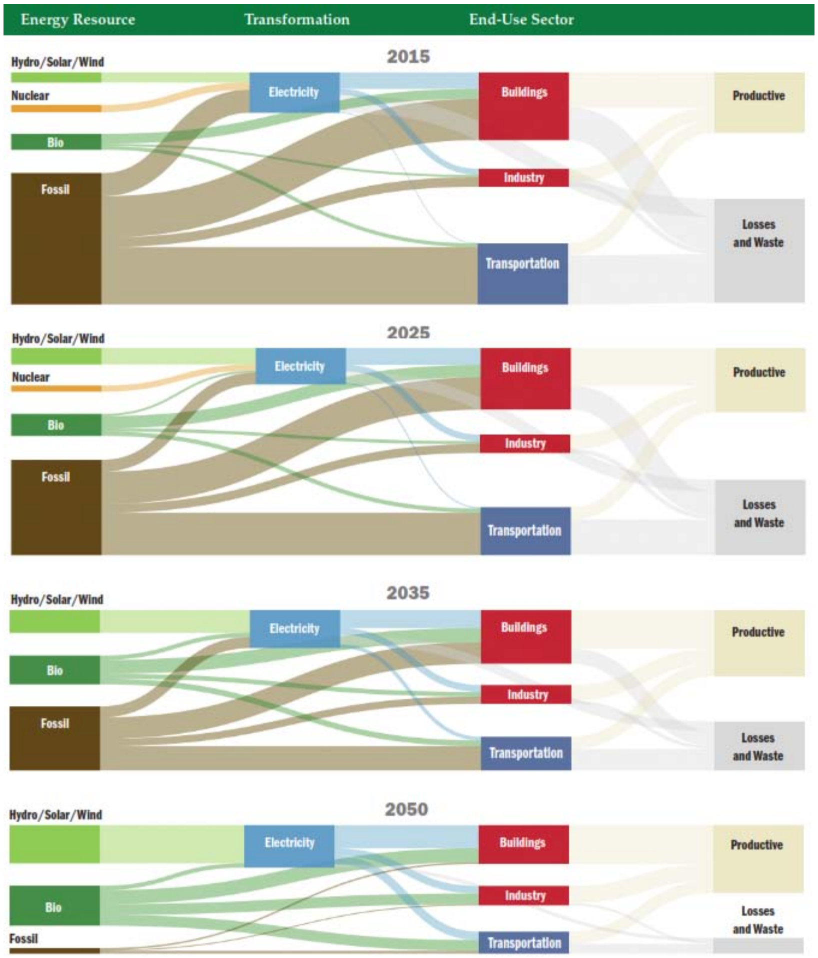
heat pumps and EVs); and 3) declining source energy requirements of electricity generation due to the continuing shift to non-combustion based sources such as wind, solar PV, and hydroelectricity.

After reviewing the TES results concerning the uncertainty regarding the availability of low-cost and low-carbon liquid biofuels, and the resulting impacts on the availability of different energy pathways to the state's goals, Vermont policymakers chose to embrace a direction that does not lean on biofuels other than biodiesel and its cousin, bioheat. For light duty transportation, the CEP embraces a clear focus on electrification. For heavy duty transportation, the state will pursue expanded use of biodiesel, while also watching for the potential of natural gas and electrification. Vermont is too small a market to move the fuel choice options for many kinds of heavy duty equipment. Bioheat to displace fuel oil shows promise as a bridge for homes and businesses during the period before they adopt woody biomass or electric heat pumps. Current heat pumps also require the use of a backup heating system, and bioheat makes sense as a fuel for that purpose.

The CEP establishes a goal of doubling wood's share of Vermont's building heat. TES modeling shows that this can be accomplished without straining Vermont's forests by combining expanded use of highly-efficient advanced wood heat technologies with the overall reduction in heating energy demand that comes from improved building shells and the use of heat pumps.

Figure 7 provides an illustrative path forward for the state that would meet all of the quantified goals for 2025, 2035, and 2050 (PSD, 2016).

Figure 6: Vermont Energy Flows in 2015, and Illustrative Paths to 2025, 2035, and 2050



As can be seen, the productive energy at each time period increases, reflecting Vermont's growing economy and improving quality of life. Meanwhile, total energy use declines significantly as waste and losses are reduced. Fossil fuel use falls throughout, but is particularly displaced between 2035 and 2050 by the combination of electricity and bioenergy (which is concentrated in uses where electrification is not possible or cost-effective). Electric end-use energy increases significantly, while primary energy used to generate electricity grows only slightly.

CONCLUSION

Vermont's unique Total Energy Study exercise, including the detailed modelling of technology and policy scenarios conducted by Dunsky Energy Consulting as well as the stakeholder consultations led by the Vermont PSD, succeeded in paving the way toward a set of legislative and policy directions that hold the potential to fundamentally transform Vermont's energy economy. While achieving the state's aggressive goals will be challenging, the paths forward are now clearly understood; critical decisions and tradeoffs have been made; and significant initial legislative steps have been adopted as a result.

REFERENCES

Dunsky Energy Consulting (2014). *Energy and Policy Options for Vermont: Technologies and Policies to Achieve Vermont's Greenhouse Gas and Renewable Energy Goals – Final Report*. Prepared for: Vermont Department of Public Service. 50 p. and annexes.

Fishbone L.G. Abilock H. (1981). MARKAL, a Linear-Programming Model for Energy Systems Analysis: Technical Description of the BNL Version. Energy Research 5, 353–375.

Loulou R. Remme U. Kanudia A. Lehtila A. Goldstein G. (2005). Documentation for the TIMES Model, Energy Technology Systems Analysis Program. http://www.iea-etsap.org/web/Documentation.asp.

Vermont Department of Environmental Conservation - DEC (2015). *Vermont Greenhouse Gas Inventory Update 1990-2012.*

Vermont Public Service Department - PSD (2016). *2016 Vermont Comprehensive Energy Plan.*

Vermont Public Service Department - PSD (2014). *Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals – Final Report*.

Vermont Public Service Department - PSD (2011). *Comprehensive Energy Plan (CEP): Vermont's Energy Future*. Volume 1, Volume 2 and Appendixes.