Vermont Solar Market Pathways

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Summary Report

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Vermont Solar Market Pathways

Becoming an Advanced Solar Economy by 2025

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Preface

This Summary Report for the Vermont Solar Market Pathways project is the product of two years of stakeholder engagement, data gathering, and analysis, the specific aims of which are to answer the question: What does it take to advance a state's solar economy sufficiently to meet one of the nation's most ambitious energy goals?

Vermont has such a goal: meeting 90 percent of the state's total energy needs with renewable energy resources by 2050, with several milestones at 2025 and 2035. In particular, this project sought to determine the policy actions necessary to meet 20 percent of that 90 percent goal with solar resources only.

The project's data gathering, research, and analysis depended on comprehensive stakeholder engagement, described throughout this report. With funding from the U.S. Department of Energy (DOE), this work supports the objectives of the Solar Market Pathways program of DOE's SunShot Initiative. In particular, it informs current and future efforts in demonstrating the increasing affordability and advisability of solar energy from the perspective of policy makers.

Acknowledgements

We wish to thank the stakeholders, who supplied a wide range of perspectives, drawn from their own fields and from their willingness to consider other stakeholder interests. **Appendix A, Stakeholder List,** provides the full list of participants in the work.

The team has worked extensively with the Long Range Energy Alternatives Planning System (LEAP), developed and supported by the Stockholm Environment Institute. We would like to thank Charlie Heaps and Taylor Binnington for their expert support and guidance on the use of the LEAP system.

Carl Linvill of the Regulatory Assistance Project led the study's investigation of net metering and alternative rate structures, presented in Volume 2. Critical assistance and guidance on Vermont's Statewide Energy Goals and the Comprehensive Energy Plan were received from Asa Hopkins, Andrew Perchlik, John Woodward, and Anne Margolis. Kim Jones of Green Mountain Power and Steve LeTendre of Green Mountain College provided helpful peer review comments.

We greatly appreciate the support and guidance from the staff of the Department of Energy's SunShot Initiative, including Angela Crooks, Elaine Ulrich, and Michele Boyd. Nicole Enright, Deb Perry and their colleagues at The Institute for Sustainable Communities provided overall coordination for the national Solar Market Pathway awardees. We would also like to thank our peers on the other Solar Market Pathway study teams for their feedback and insights.

Other staff at VEIC who contributed to the project and writing of the report include: Stephanie Baer, Christine Donovan, Suzanne Elowson, Allison Fode, Ethan Goldman, Nick Lange, Ingrid Malmgren, Dave Roberts, and Peter Schneider.

We look forward to continuing work with these and other stakeholders going forward. Any errors or omissions in the report are the responsibility of the primary authors.

Foreword: A Message from Senator Sanders

To my mind, climate change is the single greatest threat facing our planet. Virtually the entire scientific community agrees that human activity is a significant driver of global warming. The United Nation's Intergovernmental Panel on Climate Change warns that if we don't drastically reduce greenhouse gas emissions, the already serious effects of global warming will get much worse by mid-century — including more extreme weather, crop failures, increasing hunger and illness, and mass migrations of people.

While this prognosis is dire, most scientists also agree that we *can* avoid the worst consequences of climate change *if we act boldly*. That means radically transforming our energy system away from fossil fuels and toward renewable and sustainable sources of energy like solar. And that is why efforts like Vermont's Solar Market Pathways project are so important.

Funded through the U.S. Department of Energy's innovative SunShot Initiative and organized by the Vermont Energy Investment Corporation, the Solar Market Pathways project identifies various opportunities and challenges for the widespread adoption of affordable solar energy in Vermont.

I am proud that the state of Vermont has set ambitious sustainable energy goals, including getting 90% of its energy from renewables by 2050. With this report, VEIC and its partners are showing us how to get to that goal. What is more, Vermont's Solar Market Pathways shows that going solar will not only have enormous environmental benefits, but also will provide affordable energy for Vermonters, create new energy sector jobs, and ensure that more energy dollars stay in our state.

Vermont has already seen significant growth in solar. Our installed capacity has increased nearly tenfold over the past five years, and we now rank third in the nation in terms of solar jobs per capita. However, we must do more, and now that we have a roadmap, we must redouble our efforts to make it happen. After all, we have a moral responsibility to do everything possible to ensure our children and grandchildren inherit a planet every bit as habitable as the one we now enjoy.

Sincerely,

Bernie Sanders

United States Senator

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Executive Summary

Vermont is on its way to becoming an advanced solar economy—one in which solar power meets at least 20 percent of the total electric generation needs, statewide, by 2025. Current market trends and State policy both lead toward this level of solar saturation. This is a visible benchmark for considering the challenges and opportunities associated with increased solar, and with increased distributed energy resources.

Over the last two years, we have conducted in-depth scenario analyses and stakeholder engagement to examine the technical, economic, and regulatory policy issues and requirements for reaching this target. The findings clearly indicate that becoming such an advanced solar economy is possible, and that solar is likely to play an important role in Vermont's future economic and energy portfolio.

Solar Is Part of the Total Energy Economy

The work described here investigates the transition from a developed solar economy to an advanced one, across the full energy economy. We do not approach solar in isolation. Our research considers all energy supply and demand resources, across all sectors of the economy. Like any energy economy, Vermont has distinguishing characteristics not commonly shared by other jurisdictions. However, in considering the transition to an advanced solar economy, Vermont can offer insights on innovative policy and business models that make high amounts of solar and other renewable energy economically viable. These emerging features merit policy and business attention in other states and regions, and at the federal level. Vermont can add its own evidence of higher penetration to that of other leading jurisdictions—to prove solar's feasibility and to counter skepticism among lagging jurisdictions.

Challenges and Opportunities

Generating 20 percent of the projected electricity consumption in Vermont by 2025 will require an estimated 1,000 MW (1 gigawatt) of installed solar capacity. This represents an increase of over 10 times the capacity installed at the start of this research. Proper, careful siting of this much solar statewide will be informed and influenced by land use, existing structures and land improvements, aesthetics, natural and cultural resources, location of energy demand, and proximity and capacity of existing electricity infrastructure.

The planning scenarios presented in this study assume significant in-state investments in solar, energy efficiency, and electrification of transportation and space heating. Compared to the business-as-usual (or "Reference") scenario, the advanced solar scenario invests $850 million in efficiency and electrification across 15 years, and an additional $500 million in solar and other renewable generation, and grid infrastructure enhancements. These investments help Vermont avoid significant imports of fossil fuels and electricity, saving more than $1.2 billion over 15 years.

Vermont Solar Market Pathways: Key Findings

SOLAR IS WIDELY AVAILABLE TO HELP MEET VERMONT'S ENERGY NEEDS.
Vermont has sufficient solar resources well-dispersed across the state to meet 20 percent of electricity needs with solar by 2025. Careful planning and siting are important for lower cost and impact. To host enough solar to meet the 2025 target requires about 0.1 percent of Vermont's land area.

MEETING THE VERMONT SOLAR MARKET PATHWAYS TARGET CREATES SIGNIFICANT ECONOMIC BENEFITS.
Through 2025, the total investments and energy expenditures for the Reference (business as usual) scenario and the Solar Development Pathways scenario (SDP; the solar needed to achieve the advanced solar economy target) vary by less than 1 percent. The SDP scenario has higher investments in energy efficiency, solar, and new electric end uses. It also has much lower imports of electricity and fossil fuels. By 2050, the SDP scenario is estimated to create $8 billion in net benefits to Vermont compared to outcomes of the Reference scenario.

THE ELECTRIC GRID CAN HANDLE THE INTEGRATION OF HIGHER AMOUNTS OF SOLAR GENERATION.
To meet the target, Vermont must integrate 1 GW of solar capacity into Vermont's electric grid (which currently peaks at 1 GW). This will require more planning, investment, and upgrades to hardware and operations systems. Technologies and strategies available today can safely and reliably meet these challenges. Many initiatives, collaborations, and new business approaches in Vermont and elsewhere will help the state meet these challenges.

SOLAR CAN HELP LOW- AND MODERATE-INCOME HOUSEHOLDS AFFORD ENERGY.
Great opportunity exists for projects that combine solar and efficiency in increasing energy affordability for low- and moderate-income households. Applying social and energy justice in every project is critical for VEIC. Vermont already has business models, financial strategies, and philanthropic initiatives to support this segment of market growth.

SOLAR INTERACTS WELL WITH OTHER ENERGY TECHNOLOGIES AND EMERGING MARKETS.
Solar and energy efficiency are the most common examples of distributed energy resources (DERs). DERs can also be energy storage, electric load shaping, and demand response. DERs are reshaping energy markets and delivery infrastructure in Vermont and elsewhere. Technical and market advances in Vermont are making electrification of vehicles and space conditioning more attractive. As they accelerate, they will help drive the growth of solar energy, and be driven by it.

THE VERMONT SOLAR PATHWAYS TARGET WILL HELP THE STATE MEET ENERGY, ENVIRONMENTAL, AND OTHER POLICY GOALS.
Vermont has policy targets for meeting 90 percent of the state's total energy needs with renewable resources by 2050 ("90 x 2050"). Vermont Solar Pathways indicates solar is an important contributor for meeting this target in economically and socially equitable ways. Moreover, installing solar energy in Vermont keeps energy expenditures in the state, and reduces dependence on imported fuels. These economic benefits are consistent with Vermont's policy objectives and public opinion. Meeting these targets offers opportunities for Vermont's utilities and businesses to continuously improve and to innovate—and positions them to influence energy markets outside the state.

A Prudent Investment

The net costs for the advanced solar scenarios are only a small fraction of the state's annual energy expenditures and investments. In fact, through 2025, total expenditures in the Reference scenario and in the SDP scenario are within 1 percent of each other. Given variability in energy prices, and the minimal cost difference between the two scenarios, the results indicate that it is economically viable, and prudent for Vermont to invest in a cleaner and a more diverse energy portfolio, based on renewable resources, highly efficient end uses, and a de-carbonized electric supply.

The research results indicate that investments that support high amounts of solar energy generation in Vermont promise significant future economic return. Extending the analysis through 2050, the investments in solar and efficiency result in almost $8 billion of net savings to Vermont consumers. The SDP scenario also reduces greenhouse gas and other emissions, while securing energy resources with less volatile prices, resulting in a more robust and reliable energy system.

Accommodating Solar Generation This High Is Feasible

Solar is an intermittent and variable resource for an electricity grid that must meet the demand for power 24 hours a day, under all conditions. Issues arise from the distribution system, which delivers electricity to the customer, and at the bulk power system level, which interconnects Vermont to the larger regional power markets. Integrating 1 GW of solar capacity into Vermont's electric grid (peaks at 1 GW) will require ongoing research, investment, and upgrades to operations and planning systems. Today's technologies and strategies can safely and reliably meet these challenges, with the help of many initiatives, collaborations, and new business approaches.

Buildings that combine improved energy performance from efficiency with appropriately sited solar installations can lower and stabilize monthly costs for limited-income households. Traditional electricity markets see homes and businesses as energy loads. DERs, on the other hand, can shape and shift consumer energy demand to provide energy generation and storage. The markets, business models, and regulatory policies to expand DERs are still developing. Nevertheless, DERs are clearly reshaping energy markets and energy delivery infrastructure. Vermont's technical and market advances are making electrification of vehicles and space conditioning more attractive, trends that are likely to accelerate.

As the economics of solar continue to improve—through reductions in hardware and installation costs, and with evolving improvements in controls and storage—technical solutions for effective grid integration increase. With increased durability of business models for solar and related technology, more states will likely consider a high-saturation solar future. In addition, with more public attention paid to the social and environmental impacts of energy use, more states might adopt climate goals similar to Vermont's 90 x 2050 target. Helping to meet these targets will reduce serious environmental challenges and provide economic opportunity.

Vermont Solar Market Pathways: Consumer Perspectives from 2025

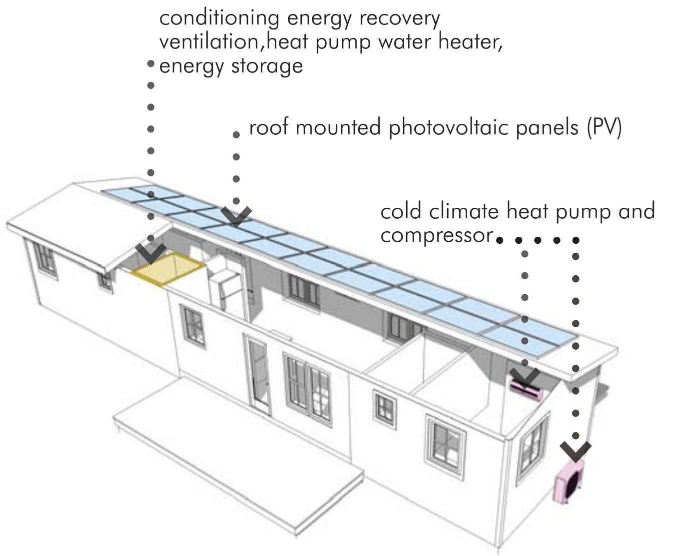
This Summary Report envisions the possible pathways to get to Vermont's advanced solar economy, with 20 percent of electric generation supplied from solar by 2025. Before presenting analysis and research results, we start with a visit to the future, looking at two types of Vermont household. These are imaginary examples, but they are grounded in market trends and possibilities that are emerging today.

The consumer perspective highlights how the value, benefits, and demand for solar and other energy services will drive many of the changes to come. Supported by strong policy and regulatory structures discussed in this report, solar and other energy services can respond to consumer demand and provide lasting value to Vermont in new and original ways.

We look first at the kinds of spaces Vermont households are occupying in this imagined future. One household resides in a relatively new home; the other occupies a classic Vermont farmhouse. What they have in common is that they are looking at energy in a different way from how households in 2016 Vermont look at energy. They are both paying less than their 2016 counterparts are, and they are engaged in new ways with the communities in which they reside.

High Performance and Affordable New Homes

It is a clear day, in summer 2025. You are sitting on the porch of your house, enjoying a cold lemonade. The porch is located at the back of the high-performance modular home you had a local company build and install in 2020. Back then, it was still an unusual concept: a house so efficient, its rooftop solar panels could supply all of the energy the household would need. It is called a *zero energy modular* (ZEM) home. Design and building practices in 2025 are increasingly bringing zero energy performance to modular homes and to other segments of the market. Today, almost all new homebuyers have the ability to compare design options and specify the benefits they want to receive from zero energy homes. The number of modular homebuilders and other builders of efficient housing has risen to meet demand.



Source: Pill Maharam Architects

That ZEM market began as an effort to replace housing damaged by flooding from Tropical Storm Irene in 2011. With a decade-long expansion of the high-performance modular housing market in Vermont, you are not alone in expecting to have as part of your investment: superior energy efficiency, on-site renewable energy generation, and advanced controls that reduce wasted energy in your home. In fact, the ZEM housing segment has been growing particularly rapidly. It is popular with a broad range of people, from first-time homebuyers to empty nesters who are downsizing their living spaces. Families and a large number of single-parent households are also drawn to the affordability, low maintenance, and superior indoor air quality of these units.

What began with one builder of these homes in 2012 has grown to more than a dozen in Vermont. The range for pricing and style choices has grown. Some options closely resemble traditional manufactured homes on the outside. Others are more cottage-like. A third, "modernist" style has also become popular.

Common to all these options are their superior thermal envelope performance, continuous indoor air quality monitoring, and heat recovery ventilation. They also have all been built with durable and non-toxic building materials; electric heat pumps for heating, cooling, and domestic hot water; and on-site or community solar generation with advanced inverters and controls. Since 2024, several senior living communities have invested in new clusters of independent units.

Enhancing Energy Performance for Vermont's Older Homes

Down the road from you is a 200-year-old house that a young family of four has bought and renovated. Their energy related upgrades included replacing the oil boiler with a new pellet boiler, returning to the homes original wood fuel. They considered investing in solar on their own property, but instead decided to participate in a community solar installation located on a nearby farm. This family is also a customer-member of a community-supported agriculture "farm share" program. They decided to join the community solar group associated with their farm share membership after comparing it to another community solar option hosted by the couple's employer (both of them work for the local school district). Neither community solar option required up-front payments, and both offered shares that would cover roughly 75 percent of the family's annual electricity consumption.

Solar array vegetation managed by Prairie Restorations Inc.

The family joined the farm share community solar program primarily because it was easy to sign up. When picking up their farm share, they have always been able to see the vegetables growing, and now they have seen the installation of the solar array. The farmer explained that instead of mowing around the panels, she is going to plant a field with wildflowers and other native plants that will attract bees and other pollinators that will then benefit the vegetable fields. The family has also enjoyed the camaraderie they share with other community members and the farm's owners.

Once burdened with a way of living that typified most family life just 10 years earlier, with unpredictable utility costs from air conditioning in the summer and high utility costs from heating fuels in winter, this family decided to invest some of their own savings in a "deep energy retrofit" a few years ago. They supplemented their savings with low interest financing through their credit union. These funds made it possible for them to complete the retrofit: sealing and insulating the walls, basement, and attic of their house, and installing high-efficiency appliances. The retrofit project also enabled them to enhance and repair some structural features, while fully retaining the centuries-old New England character of their home.

Pathways to the Solar Future

The transition to becoming an advanced solar economy is already under way and is contributing to Vermont meeting the broader target of obtaining 90 percent of the state's total energy from renewable resources by 2050.[1] In this study, we investigate requirements for reaching 20 percent of the total electric generation by 2025, and we present these results and analysis in the context of Vermont's progress toward the longer-term goals for 2050. **Table 1** presents a snapshot of how the advanced solar economy compares to Vermont today.

Table 1. Total energy and electricity consumption in Vermont's advanced solar economy

Total energy		Electricity		Solar		
Total energy demand (TBtu)		Electricity demand (GWh)	Electricity share of total energy demand	Solar generation (GWh)	Share of electricity from solar	Installed capacity (MW)
2015*	116	5,700	17%	280	4.9%	225
2025	106	6,200	20%	1,300	20%	1,000
2050	69	8,800	44%	2,500	28%	2,000

* 2015 values are estimates used in scenario modeling, using the best available data; they are not historic actuals. Vermont's Certificate of Public Good data show just over 250 MW permitted by the end of 2015.

Table 1 shows that solar generation must grow by more than four times the amount produced in 2015 to meet the goal this decade. When this project was conceived, some observers considered the goal of 20 percent of total generation by 2025 to be beyond reach. However, continuing growth trends in Vermont and other jurisdictions with favorable regulatory and market conditions suggest this level of solar saturation can reasonably be expected. Through stakeholder engagement, scenario modeling, and market analysis, the findings indicate that such sustained market growth is technically and economically achievable.

Becoming an Advanced Solar Economy by 2025 Helps Meet Vermont's 2050 Goals

Referenced in this report as *90 x 2050,* this target addresses the electric generation sector, transportation, and space heating, which are the largest consumers of fossil fuels in the state. Research and analysis confirm the findings of the State's *Total Energy Study* [2] and Vermont's *Comprehensive Energy Plans,*[3,4] and reiterate the following as key elements required to meet the 90 x 2050 target:

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[1] The goal is articulated in "2016 Comprehensive Energy Plan - Executive Summary" (Montpelier, VT: Vermont Department of Public Service, 2016), http://legislature.vermont.gov/assets/Legislative-Reports/Executive-summary-for-web.pdf.

[2] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals" (Montpelier, VT: Vermont Department of Public Service, December 8, 2014),http://publicservice.vermont.gov/publications-resources/publications/total_energy_study.

[3] "2011 Comprehensive Energy Plan" (Montpelier, VT: Vermont Department of Public Service, December 2011),http://publicservice.vermont.gov/publications-resources/publications/energy_plan/2011_plan.

[4] "2016 Comprehensive Energy Plan" (Montpelier, VT: Vermont Department of Public Service, December 2015),http://publicservice.vermont.gov/publications-resources/publications/energy_plan/2015_plan.

- Energy efficiency across all sectors and end uses;
- Fuel switching from fossil fuels (particularly for space heating and transportation) to electricity and biomass; and
- Decarbonization of the electric grid through increased solar and other renewables.

Reflecting these trends, the SDP scenario estimates total energy demand decreasing by 8.6 percent from 2015 to 2025, and by 32 percent by 2050, as shown in **Figure 1**. Some savings are expected to happen through federal standards and changing costs, but the graph also shows additional avoided energy use because of ongoing efficiency and a transition from fossil fuels to electricity in supplying energy for transportation and heating. Given the inherent efficiency of electric drive propulsion and heat pump technology, less primary energy is needed; therefore, the SDP avoids energy that would be required in the Reference scenario.

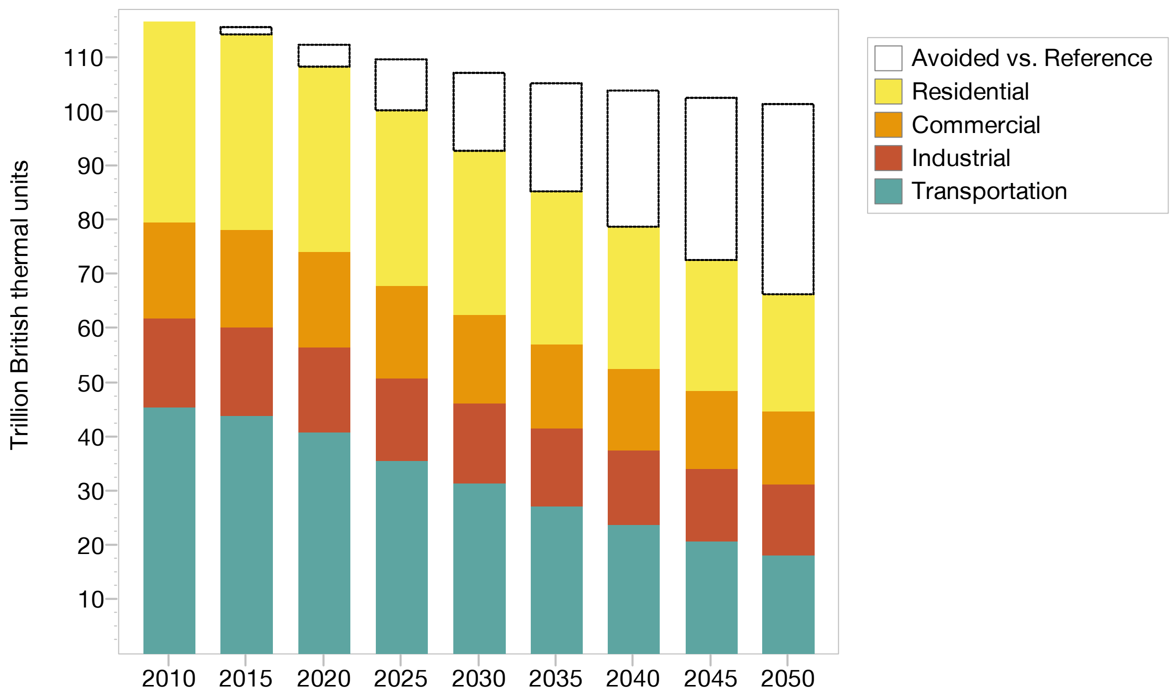

Figure 1. Vermont site energy demand, by 5-year increments, and by market sectors, showing the effect of more aggressive efficiency and fuel switching in the SDP scenario. The white indicates the net gains in the amount of energy not needed ("avoided" energy supply) under the efficiency and fuel-switching SDP scenario, relative to the Reference scenario (business as usual).

Figure 2 illustrates the transition away from fossil fuels toward electricity and renewables that is required to meet the 90 x 2050 goal under the SDP scenario. Reaching the 2050 targets will mean that Vermont has fully transitioned to a renewable energy economy. **Figure 2** also illustrates that as total energy demand will fall, electricity consumption will rise as people switch from fossil fuels to electricity for heating and transportation.

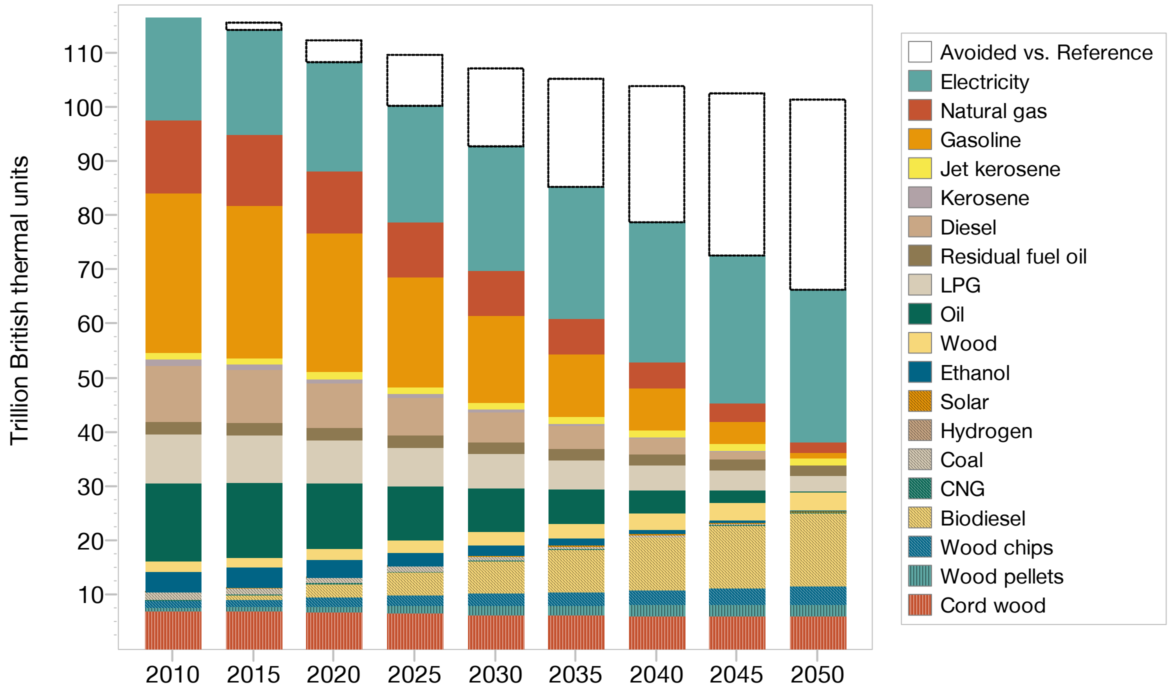

Figure 2. Progress in Vermont toward meeting the 90 x 2050 renewable energy target, by fuel.

Figure 3 shows the growing supply and the increasing mix of renewable resources used to meet that growth in electricity consumption. **Figure 3** also demonstrates the effects of the 2014 retirement of the Vermont Yankee nuclear power station, seen in the drop between 2010 and 2015. In the projection, Vermont moves steadily toward renewables. This will take place through coordinated efforts by residents, businesses (including industry and agriculture), environmental organizations, the utilities, and the State.

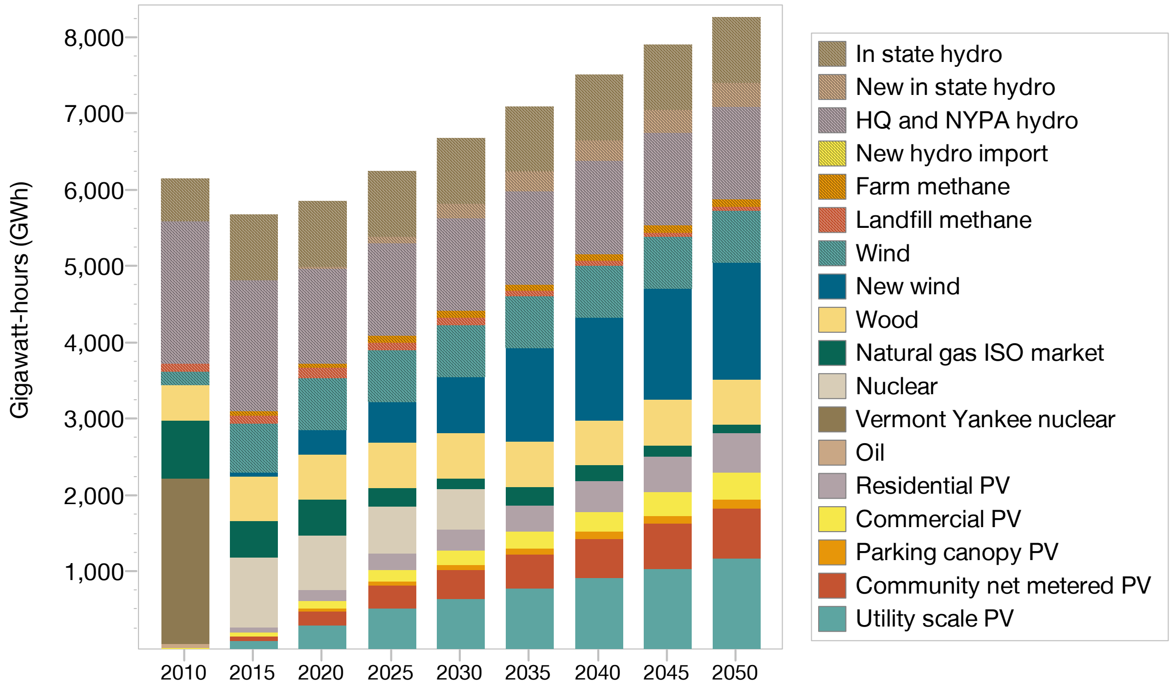

Figure 3. Actual and projected Vermont electricity supply in the SDP scenario, in 5-year increments, and by energy source.

The changes that occurred between the inception of this Solar Market Pathways project in late 2014 and today in early 2017 show that Vermont is moving quickly toward achieving these targets. The changes reflect (1) the Vermont General Assembly's 2014 decision to increase the net metering cap from 4 percent to 15 percent of peak load, (2) the achievement of state's largest city (Burlington) in meeting 100 percent of its electricity needs with renewables, (3) the legislative approval of a renewable portfolio standard, and (4) several of the utilities' reaching the net metering cap ahead of schedule.

High Solar Penetration in Vermont Is Achievable

The level of solar and renewable penetration in the SDP scenario requires careful planning. Although Vermont is a solar leader in many ways, it benefits from the experience of other regions that are achieving high penetration sooner: Germany, Hawai'i, and California are examples. Other places have not gone so far as Vermont has in targeting their solar capacity to equal the grid's peak demand. Thus, Vermont might be breaking new ground by 2025 with its requirement of 1 GW of solar to meet the 20 percent goal, although other energy leaders will likely have made significant progress by then, too. It is worth reiterating that the 1 GW does not count the electrification of transportation and heating systems.

To determine how to reach that target, the Vermont Solar Market Pathways Project Team has evaluated the technical, economic, business model, and regulatory implications of 1 GW of solar. For example, the technical analyses have considered, at a high level, the state's bulk power mix and strategies for integrating solar electricity into the energy distribution system.

Economic Outcomes

Transitioning to an advanced solar economy requires shifts in the types and magnitude of expenditures on energy by Vermont consumers and service providers. Overall, our analyses of the SDP scenario indicate that during the next ten years a total net annual cost for the transition will be approximately $21 million annually. This net cost is much less than 1 percent of expected annual energy expenditures. **Table 2** summarizes the comparative economic results between the SDP and Reference scenarios.

Thus, a transition to the advanced solar economy is economically viable, with a relatively minor difference between the total net costs and benefits, relative to the advanced solar economy under the SDP scenario (and its variants) and the Reference scenario through 2025. Note that these results do not put a value on environmental benefits from reduced emissions, nor on enhanced building durability and occupants' health impacts associated with energy efficiency investments. If a value were put on those factors, the benefits would be even greater.

Table 2. Cumulative costs and benefits of the SDP scenario, relative to the Reference scenario, 2010-2025, discounted at 3 percent to 2015

	SDP vs Reference $ million (2015)
Demand	**$ 851**
Residential	$ 416
Commercial	$ 261
Industrial	$ 58
Transportation	$ 115
Transformation	**$ 498**
Transmission and distribution	$ 13
Electricity generation	$ 485
Resources	**-$ 1,140**
Production	$ 83
Imports	-$ 1,222
Exports	-
Unmet requirements	-
Environmental externalities	-
Non-energy sector costs	-
Net present value	**$ 209**
GHG savings (million tonnes CO_{2e})	**7.1**
Cost of avoiding GHGs	**$ 29**

The largest distinction between the Reference and SDP scenarios is the investment in efficiency, illustrated by the net costs in the demand section of **Table 2**. Over $400 million of net investment in residential efficiency and over $250 million of net investments in the commercial sector will enable the reductions in total energy consumption, shown in **Figure 1** and **Figure 2**. There are also shifts in the production and distribution of electricity, which are represented in the Transformation section of **Table 2**. The present value of the net costs in the transformation sector for the SDP scenario is $498 million. The benefits from these shifts in expenditures and investments are reflected in a significant reduction in net resource imports, more than $1.2 billion.

By extending the analysis through 2050, the net benefits of the transition to an advanced solar economy far outweigh the costs, providing close to $8 billion of economic benefits to the state.

In the advanced solar economy, significantly less of Vermont's energy expenditure will go to energy providers outside the state. The SDP reduces money spent on fuel imports (money sent out of state) by approximately $1.2 billion from 2015-2025, compared to the Reference scenario. Additional economic results are presented in **Section 3.3** of this volume and in **Volume 4**.

Environmental Outcomes

The SDP scenario reduces greenhouse gas emissions by roughly 20 percent by 2025, and by more than 80 percent by 2050. **Figure 4** illustrates these effects.

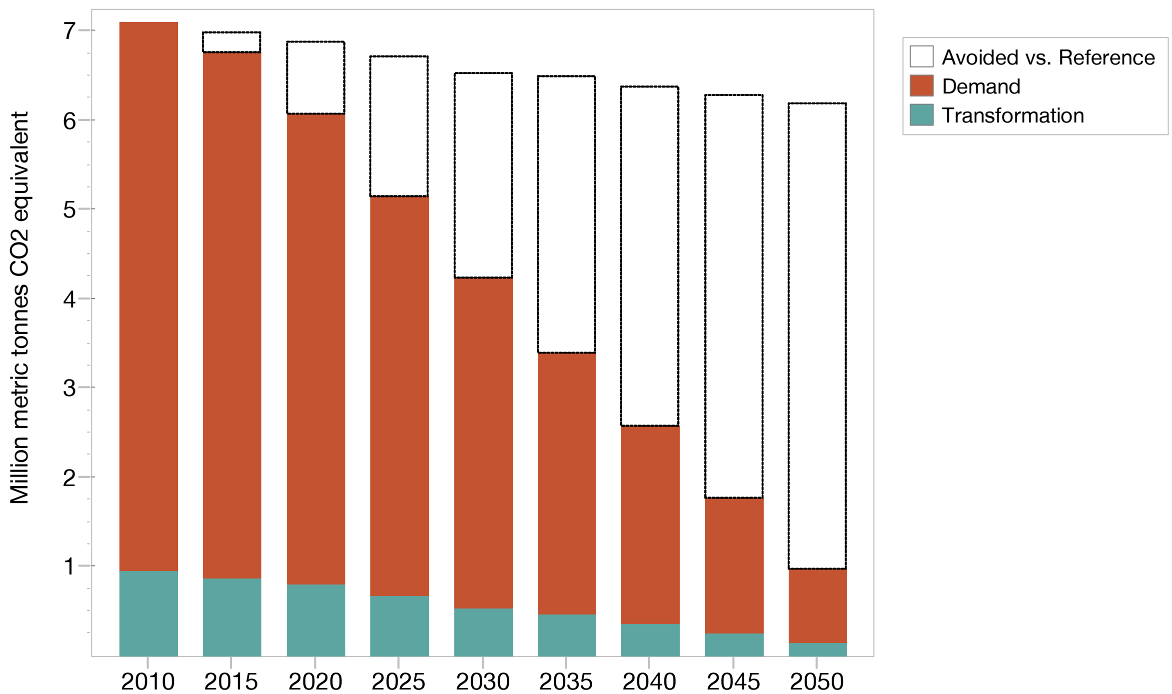

Figure 4. Emissions of the SDP scenario, compared to the Reference scenario.

By 2050, Vermonter's emissions per person fall below 2 metric tonnes per person, a limit suggested for mitigating climate change. Vermonters will see much more of the energy system as in-state renewable projects replace imported energy. Careful siting and project design can limit the impact.

Questions Answered by This Report

There are many issues and factors for states or a region to consider in becoming an advanced solar economy. **Table 3** lists some of the questions that are addressed in the Vermont Solar Market Pathways Report and refers to where in this document and other volumes more detail can be found.

Table 3. Questions answered by the Vermont Solar Market Pathways research

Question	Quick answer	Where to look in this report
Does Vermont have enough solar resource and sites to meet the target?	Yes, Vermont has plentiful solar resource.[5] By 2050, up to 0.2% of the state's land area could be used to meet close to 1/3 of total generation. Siting constraints for land use, and physical and cultural considerations, leave plenty of suitable "prime solar" siting areas for meeting energy needs. Results can support regional and local planning and siting guidance.	**4.1** Siting and System Integration **4.1** Space Requirement
How much will be ground versus roof mounted?	It depends. There is good flexibility to be able to meet targets with a mix of ground- and roof-mounted systems. Roof-mounted solar is not likely to account for more than 300 MW or 1/3 of the 1,000 MW required to meet the target of 20% by 2025.	**4.1** Business Models
Can this much solar be integrated into distribution system?	Yes. Individual sites will continue to need to be evaluated to determine possible distribution grid impacts. However, many sites can host additional PV without costly modifications. Options for storage, load shifting, demand response, and curtailment exist and are emerging to complement traditional solutions of distribution utility hardware upgrades.	**4.1** Distribution System
What about integration with the regional market and transmission system?	It can also be done. Mismatch of supply and demand in 2025 in the SDP is not unlike what utilities manage today. In addition to the distribution tools, utilities can use time-of-use rates and possible regional trading to balance the system. The value of trading will diminish as neighboring states add similar levels of renewable energy.	**4.1** Smart Grid, Demand Management, and Storage **4.1** Bulk Power System Integration
Will business models change?	It is likely. New approaches and business models will emerge across utility, building services, transportation, and solar industries. Innovation relying on advances in information technologies and systems integration will create new value and enable higher saturation solutions.	**4.1** Business Models **4.1** Utility Business Model
What about changes to regulatory and tariff structures?	These will also evolve and change. Rates and regulations enable and catalyze growth of integrated distributed energy resources. There is a mix of more and less regulated elements supporting businesses and consumers in making long-term investment decisions.	**4.1** Smart Grid, Demand Management, and Storage **4.2** Regulatory Considerations

[5] National Renewable Energy Laboratory, "Photovoltaic Solar Resource: Flat Plate Tilted South at Latitude" (U.S. Department of Energy, November 2008),http://www.nrel.gov/gis/images/map_pv_us_annual10km_dec2008.jpg.

Question	Quick answer	Where to look in this report
Does the solar future make economic sense?	Yes, the net costs of an advanced solar scenario equal to an annual investment of ~1% of Vermont's total energy expenditures through 2025. By 2050, present value of net benefits is almost $8 billion.	**3.3** Economic Outcomes
Can solar be socially equitable?	Yes, for example, high-performance housing with solar options combine to lower total housing costs, while enhancing occupant health and building durability.	**4.1** Addressing Low-Income People: A Societal Imperative
What about environmental impacts?	The Solar Development Pathways scenario reduces greenhouse gas emissions by ~20% by 2025, compared to the Reference scenario, and 90% by 2050.	**3.4** Environmental Outcomes

The Team further documents these issues, analyses, and potential solutions in **Volume 2, Net Metering and Focus Area Briefs, Volume 3, Barriers and Integration Brief,** and **Volume 4, Methods and Detail Tables**.

1. Introduction

1.1 SunShot Objectives.

This project is one of 15 receiving U.S. Department of Energy (DOE) Solar Market Pathways Program support, within DOE's SunShot Initiative. The specific aim of the SunShot Initiative is to reduce the levelized cost of solar energy systems to $.06 per kWh by 2020. As of the halfway point in the timeline for achieving this goal, SunShot officials estimate that approximately 70 percent of this goal has been met. Since SunShot's launch in 2011, the average price per kWh of energy from a utility-scale photovoltaic (PV) project has dropped from about $0.21 to $0.11.

A major goal of the Solar Market Pathways Program is to make solar deployment faster, easier, and less expensive than it was in 2011, across the United States. The case studies and lessons learned from the 15 awarded Solar Market Pathways projects will provide examples that can be replicated in other jurisdictions—in support of this goal.

1.2 Vermont Solar Market Pathways Objectives

The essential objective of this Vermont Solar Market Pathways project is to examine what is required to attain 20 percent solar generation by 2025, and what the effects of a transition to such an advanced solar economy would be.

Comprehensive solar planning can contribute to lower solar costs through specific mechanisms. By taking a long-term planning perspective and integrating the growth of the solar market into the state's overall energy economy, Vermont Solar Market Pathways will help policy makers, local planning commissions, and the market understand both the potential and the potential barriers to an advanced solar market. This understanding will improve the chances for sustained market growth and investment.

Comprehensive solar strategies and plans can provide greater certainty to businesses, institutions, and utilities investing in solar. This certainty is expected to help lower the soft costs associated with solar energy. By sharing experience and approaches to identifying and addressing barriers to achieving high levels of solar, plans such as this one will also help lower the costs of addressing these barriers.

Moreover, Vermont Solar Market Pathways supports general objectives of regional planning, public discourse, and decision making on increasing the use of solar energy by individuals and businesses.

1.3 Vermont Background

Strong Policy Supports an Advanced Solar Economy

The Vermont Department of Public Service undertook its *Total Energy Study* (TES) in 2014, publishing the results in December of that year. Its primary conclusion was that "Vermont can achieve its greenhouse gas emission reduction goals and its renewable energy goals to do so will require significant changes in energy policy, fuel supply, infrastructure, and technology."[6]

In 2015, the Vermont General Assembly passed the state's first renewable portfolio standard, known as the Renewable Energy Standard (Act 56), which encourages increases in renewable energy supply as a way to reduce total energy use and costs.[7] The Renewable Energy Standard does not contain a carve-out for solar credit. Because of this, the Standard did not create solar renewable energy certificates (SRECs), a common mechanism for advancing accompanying renewable portfolio standards. Nevertheless, the Standard requires 10 percent of electricity to come from distributed generation; we expect solar to provide most of that requirement. Vermont's Renewable Energy Standard is unique in compelling distribution utilities to support the reduction of fossil fuel consumption through actions like weatherization, thermal efficiency measures, and electrification of energy uses traditionally powered by fossil fuels such as heat pumps and electric vehicles.

Vermont's Demographics

Vermont has a small population (626,000 inhabitants), occupying 326,000 housing units, most of which (71 percent) are owner-occupied housing units—primarily single-family houses.[8] Excepting Burlington area, the U.S. Department of Agriculture considers the state's population to be rural. Winters are relatively long, and energy burden is a challenge for many Vermont households. The median Vermont household income is $54,000, only slightly higher than the national average of $53,000.[9] Nevertheless, with a state goal of meeting 90 percent of total energy needs from renewable sources by 2050 (90 x 2050), Vermont policy makers have an advanced vision for achieving energy security and environmental benefits for its inhabitants.

Over 130 MW of net metered solar supplies energy to homes, farms, businesses, and communities.[10] Further, the presence of renewable energy in the supply mix has kept electricity costs at or below the rate of inflation.[11]

The Vermont Department of Public Service estimates that nearly 5 percent of Vermont's workforce (16,000 jobs) is in the clean energy sector.[12]

A Recent History of Energy Supply and Use in Vermont

Vermont has a single transmission system operated by the Vermont Electric Power Company (VELCO). Seventeen local distribution utilities (municipalities, rural electric cooperatives, and an investor-owned utility) provide retail service.

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[6] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals."
[7] General Assembly of the State of Vermont, *An Act Relating to Establishing a Renewable Energy Standard*, 2015,http://legislature.vermont.gov/assets/Documents/2016/Docs/ACTS/ACT056/ACT056%20As%20Enacted.pdf.
[8] "Quick Facts: Vermont," *U.S. Census Bureau*, 2015, www.census.gov/quickfacts/table/PST045215/50.
[9] Ibid.
[10] Department of Public Service, Certificate of Public Good data: VT Generator Data 7-25-16 HC.xlsx
[11] "2016 Comprehensive Energy Plan."
[12] Ibid.

Prior to 2000, all of Vermont's electric utilities (at the time, there were 22) delivered energy efficiency programs to their customers. This well-intended policy had consequences, because investor-owned utilities were caught in a conundrum: To ensure good returns for their shareholders, they needed to sell more electricity; but to ensure compliance with regulators, they needed to promote investments that would reduce electricity sales. Further, energy efficiency program administration was difficult to accomplish effectively for the customers of each of the 22 utilities. Accurate accounting for each utility's contribution to saving energy via retail sales of energy-efficient products in their service territories was also elusive. That is, a store in one utility's location could easily have customers from other utilities buying and installing products—giving the other utilities no information to support a claim to regulators for energy savings.

The Vermont General Assembly created a new entity in 2000, a statewide energy efficiency utility (EEU) for all territory outside the City of Burlington (which maintains its own EEU through the Burlington Electric Department (BED)). The Vermont Energy Investment Corporation (VEIC) has operated the statewide entity, known as Efficiency Vermont, ever since. A 12-year Order of Appointment began in 2010, replacing the earlier 3-year contract cycles, and allows for better planning, greater stability in program offerings, and more strategies for achieving more clean-energy potential than was possible under the shorter cycles.

Throughout Efficiency Vermont's tenure as the statewide EEU, avoided costs of energy supply have been an essential metric in demonstrating the efficacy of energy efficiency. Helping customers use less electricity—through efficient products and appliances, air-sealing and insulation of houses and other buildings, improvements in commercial building energy performance, and many other measures—has a lower average levelized cost than all other new power supply options.[13]

Sustainable energy advisors frequently refer to "efficiency first, then renewables" as a smart path for customers who want to lower their energy costs and carbon footprints. With such a strong and lengthy background in statewide electrical energy efficiency, Vermont has been well positioned to advance its renewable energy economy.

The growth of renewable energy is accelerating: As of late July 2016, 412 MW of wind and solar capacity were online or permitted—of which 70 percent is from solar*.* Net metering of solar energy to local utilities and the grid has seen a 25 percent increase. It now accounts for 167 MW of solar, compared to 134 MW at the end of 2015.[14] These data signal not only a net increase in renewably supplied energy, but also a disproportionately large jump in energy supply from solar sources.

Figure 5 illustrates the rapid growth of solar and particularly net metering. This market expansion has been propelled by liberal policy toward group net metering; simple permitting; and strong financial performance from a regulated, solar credit adder on utility bills for net metered generation; and the feed-in tariff.

[13] "How Much Does Energy Efficiency Cost?" (American Council for an Energy-Efficient Economy, March 17, 2016), http://aceee.org/how-much-does-energy-efficiency-cost.
[14] Department of Public Service, Certificate of Public Good data: VT Generator Data 7-25-16 HC.xlsx

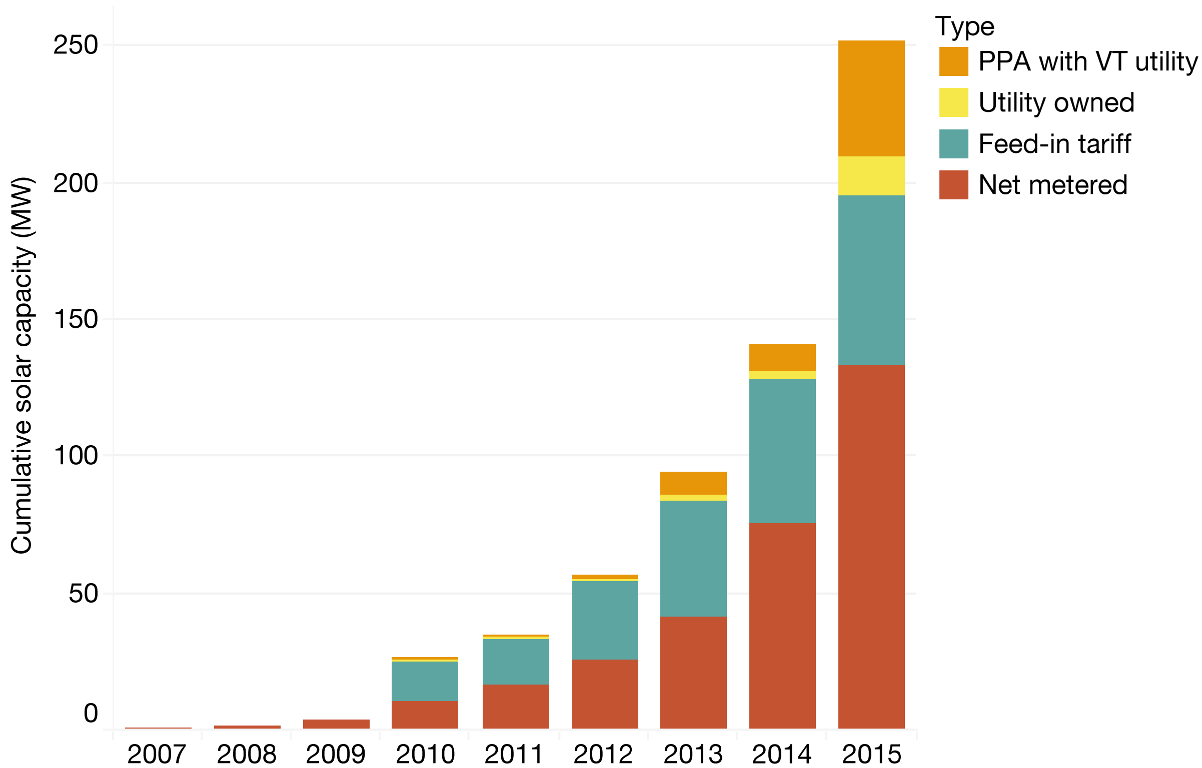

Figure 5. Cumulative permitted solar capacity in Vermont has grown quickly in the last five years, reaching 251 MW by the end of 2015.

Vermont has put a priority on environmental stewardship and energy self-sufficiency for decades. The political decision to commit quickly to an energy mix dominated by renewables is just one of the latest events in a long history of progressive policy decisions on energy. Some highlights of this ongoing effort:

- Land use planning regulation (Act 250, passed in 1970).
- Community-level incentives and technical assistance for revitalization of downtowns (Downtown Designation, administered by the Agency of Commerce and Community Development).
- Statewide EEU concept created via legislation in 1999 (see the beginning of this section).
- Small Scale Renewable Energy Incentive Program (2003) offered upfront rebates for residential, small commercial, and non-profit installations. The administration of this program ceased for most systems at the end of 2014.
- Greenhouse gas reduction goals set in 2005: 25 percent by 2012, 50 percent by 2028, 75 percent by 2050, compared to 1990 baseline (Vermont did not meet the 2012 goal. Actual emissions were very similar to 1990, not 25 percent below).[15]

[15] "Vermont Greenhouse Gas Emissions Inventory Update 1990 – 2012" (Department of Environmental Conservation Air Quality and Climate Division, June 2015), http://climatechange.vermont.gov/sites/climate/files/documents/Data/Vermont_GHG_Emissions_Inventory_Update_1990-2012_June-2015.pdf.

- Sustainably Priced Energy Enterprise Development (SPEED, 2005) feed-in tariff for new utility scale renewable energy projects.
- Streamlined solar registration provided a permit in 10 days for small systems.
- A solar adder, a credit on electric bills for each kWh a solar installation produces, began to pay 19 to 20 cents per kWh for net-metered solar generation.
- In 2011, the Vermont Department of Public Service set a 90 percent renewable total energy target by 2050.
- Standard Offer annual auctions replaced SPEED for new utility scale renewable energy projects (2012).
- *Total Energy Study* (Department of Public Service, 2014) considered paths and viability of 90 x 2050 target.
- Act 56 (2015) established a renewable portfolio standard: energy supply from renewables must be at least 55 percent by 2017, 75 percent by 2032.

Vermont is capitalizing on this foundation to transition away from the use of imported fossil fuels to locally owned renewable energy for electricity, transportation, and thermal needs. The state's consumption and generation is small compared to its neighbors, consuming 4 percent of the electricity on the New England grid, and using less than 1 percent of Hydro Québec capacity.

Vermont could rely on imported electricity, or use these resources to balance in-state renewables. However, many Vermonters are unwilling to export the impact of their energy use and want to model local sustainability, with a high penetration of renewables, balanced and managed with the state's own resources.

Fast growth of wind and solar power drew opposition in the early 2010s. The General Assembly responded with a Siting Task Force. The State also funded the Regional Planning Commissions to account for energy in their regional plans. This can help site renewable energy projects where locals want them, because it gives towns a voice in Vermont's permitting process if they create town energy plans that help support the state's renewable energy goals.

The changes that have occurred between the inception of this Solar Market Pathways project in late 2014 and today in late 2016 show how quickly Vermont is moving toward achieving these targets:

- The General Assembly raised the cap for net-metered renewable capacity from 4 percent to 15 percent of the connected utility's peak load, in 2014.
- Later in 2014, Burlington Electric Department, the state's third-largest utility and operating its own EEU, acquired a 7.4 MW hydropower station to complete its efforts to supply 100 percent of its energy from renewable sources.
- In June 2015, the General Assembly passed a renewable portfolio standard that allows credit for reducing fossil fuel use in building and transportation sectors, and is among the

most aggressive policies in the United States.[16] It requires 75 percent of electricity to come from renewable sources by 2032.

- In November 2015, Green Mountain Power (GMP), an investor-owned utility (IOU) serving 71 percent of the state's utility accounts, reached the net metering cap, 15 percent of peak. It decided to continue to allow small systems to interconnect, as well as 7.5 MW of strategic larger systems. The utility created a map to guide new solar to areas of the grid that have ample capacity to accept it.[17]
- By the close of 2015, Vermont Electric Cooperative (VEC; the second-largest utility), Washington Electric Cooperative (WEC; the fourth-largest utility), and three smaller municipal utilities reached, or were approaching the 15 percent net metering cap.
- In August 2016, The Public Service Board issued new net metering rules that removed the program cap, added incentives for preferred siting and REC treatment, and slightly lowered the total incentive most systems would get.[18]

1.4 Implications for Broader Applicability

Vermont is ahead of the curve in becoming an advanced solar economy. Because it is a small state and operates—even at the policy level—on a community scale, issues that arise as solar saturation increases are frequently addressed quickly and with well-informed deliberations. The State and its stakeholders typically seek options for mitigating issues relating to net metering or siting, for example. The state also enjoys good working relationships among the utilities, and has explored many different approaches for modifying rate structures and incentives. For example, regulators, the statewide energy efficiency utility, and distribution utilities, are discussing concepts around distributed energy resources (DERs) and fuel switching under Tier III of the new Renewable Energy Standard.[19]

The approach in this report is to use scenario analyses to help provide a framework for stakeholders to examine options and implications for alternative pathways towards becoming an advanced solar economy. This approach, the structure of the analyses, and the process of stakeholder engagement are all exportable to support solar market growth in other markets and jurisdictions.

1.5 Structure of This Report

This report is the outcome of the first 24 months of the project work. A "peer review" draft of this volume and volumes 2 and 3 were circulated to stakeholders and external experts for comments

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[16] Cara Marcy, "Hawaii and Vermont Set High Renewable Portfolio Standard Targets," *U.S. Energy Information Administration*, June 29, 2015, http://www.eia.gov/todayinenergy/detail.cfm?id=21852.
[17] "Solar Map," *Green Mountain Power*, accessed September 21, 2016, http://www.greenmountainpower.com/innovative/solar/solar-map/.
[18] Vermont Public Service Board, *Revised Rule 5.100 Pursuant to Act 99*, 2016, http://psb.vermont.gov/statutesrulesandguidelines/proposedrules/rule5100.
[19] Vermont Public Service Board, Order Implementing the Renewable Energy Standard, IV, pp. 20 – 80. http://psb.vermont.gov/sites/psb/files/8550%20Final%20Order.pdf.

and review in June 2016. This is the final Vermont Solar Market Pathways document (with a fourth volume and a condensed version for the public).

The Vermont Solar Market Pathways Report results comprise four volumes:

Volume 1: Summary Report. Objectives, background, approach, high-level findings, and strategies for becoming an advanced solar economy

Volume 2: Net Metering Brief and Focus Area Briefs. Narrative and analysis on key market segments and strategies related to solar market growth: net metering and alternatives; electric vehicles; heat pumps; storage, load shifting, and demand response; high-performance manufactured housing; and incentives. This volume also contains a broad analysis of pathways to an advanced solar economy, submitted as a Phase II Roadmap for the Smart Electric Power Alliance (SEPA) 51st State initiative.[20]

Volume 3: Barriers and Integration Brief. Investigation and analysis of technical, market, and policy barriers and strategies. Analysis of distribution and bulk power system implications for high-saturation solar.

Volume 4: Methods and Detail Tables. Methodology, assumptions, and results from scenario modeling, using the Long Range Energy Alternatives Planning System and other tools.

[20] "The 51st State," *Smart Electric Power Alliance*, accessed September 26, 2016, http://sepa51.org/phaseII.php.

2. Investigation Methods and Approach

The general approach for this study is the investigation of the implications of becoming an advanced solar economy within the context of the total energy economy. We start by defining, and then refining, various scenarios where solar can provide 20 percent of total electric consumption. With stakeholder review and feedback, we then use those scenarios to investigate the implications across technical, economic, regulatory, and business models. Undoubtedly, transitioning to an advanced solar economy will require shifts for consumers, utilities, solar companies, and other businesses. Transitioning will create those shifts, too. The transition will also require and create shifts for regulators and policy makers. The point of this Summary Report and the analyses is not to predict or define each of these, but to use the scenario modeling and the ensuing discussions to encourage dialogue and innovation.

2.1 Stakeholder Engagement

The project was defined by, and has benefited greatly from, an active, non-binding stakeholder engagement process. This process informed the creation of the Reference scenario, the initial SDP scenario analyses, revisions to those scenarios, and alternative advanced solar scenarios discussed in **2.2 Scenario Modeling**. As of this report, the Team has conducted nine stakeholder meetings, with participants from Vermont distribution utilities, the transmission operator, public service regulators, state agencies (economic development, transportation, agriculture, and natural resources), the statewide energy efficiency utility, solar vendors, environmental activists, the Vermont Law School, and universities and colleges with active environment and energy programs. (See a list of **Stakeholders** at the end of this document).

Figure 6. Second stakeholder meeting, April 2015 in Rutland, VT.

The original list of invited participants contained more than 100 names, and grew to over 150 through referrals and forwarded invitations. Meeting attendance varied; on average, 18 stakeholders attended each meeting. The Team also invited stakeholders to comment on documents and modeling results as they became available. Over 100 individuals have attended a meeting, provided written comments, or have otherwise participated in the project.

2.2 Scenario Modeling

LEAP, the Long-range Energy Alternatives Planning System, is energy policy analysis software developed at the Stockholm Environment Institute. LEAP offers a framework for energy supply and demand accounting, enabling users to work with existing data sets to construct and compare future energy scenarios. Its flexible energy accounting capabilities help create models of different energy systems and scenarios. It is demand driven: The user models energy consumption within the system before adding supply, which is matched to the demand. Users can examine graphic and tabular results on energy flows, costs, and environmental impacts and modify them at multiple levels from end use devices, up to the limits of a total energy economy.

Software specialists have refined LEAP for more than 20 years. It has been used to conduct integrated energy and environmental planning in more than 190 countries (further LEAP modeling information is in **Volume 4** of this report).[21] LEAP modeling typically begins with the development of a demand tree that represents energy demand across various devices, end uses, subsectors, and sectors within an economy. **Figure 7** offers an example of a demand tree structure. The Team used recent data to create "current accounts," which then became the basis for forecast changes in the Reference and alternative SDP scenarios.

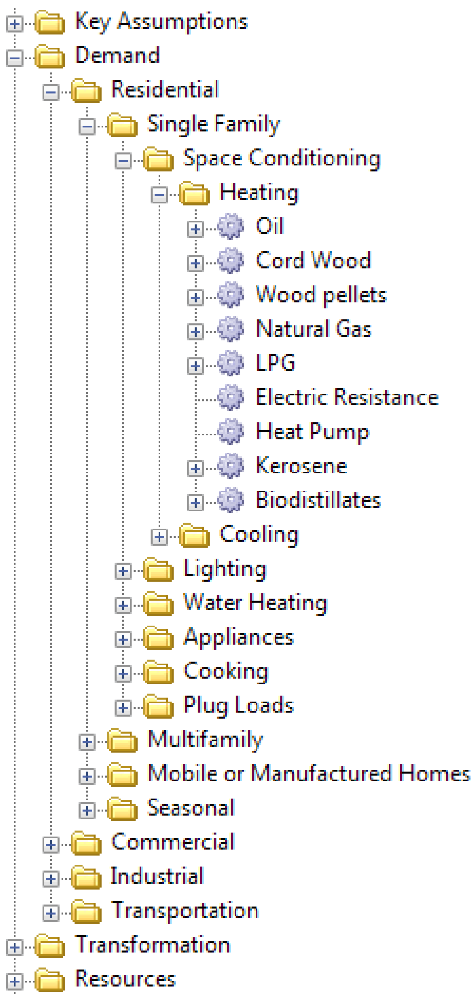

Figure 7. Sample demand tree structure in the LEAP system.

The Team entered current and projected energy use in the demand tree, across all of its branches, to calculate the energy demand by fuel type and sectors. Examples of the type of embedded and analyzed information within the structure are: projected changes in energy

[21] Heaps, C.G., *Long-Range Energy Alternatives Planning (LEAP) System*, version 2015.0.24 (Somerville, MA, USA: Stockholm Environment Institute, 2016), https://www.energycommunity.org/default.asp?action=introduction.

efficiency for end use devices, the demand for specific end uses, and shifts between different devices for a specific end use (for example, greater use of electric or plug-in hybrid vehicles). The structure also reflects fundamental demographic and economic levels as activity drivers; examples are population, household size, commercial area, and vehicle miles traveled.

Once the demand for various types of energy is determined, LEAP calculates the necessary resources to meet that demand, and includes other real-world factors such as transmission losses. For electricity, the time of demand and available supply also comes into play. **Figure 8** shows how resources at the left in the SDP scenario in 2025 move through one or more transitions to serve end uses at the right. This Sankey diagram shows only the energy that ends up being used. There are losses at each step that add up to more than half of the original resources in most fossil fuel economies.

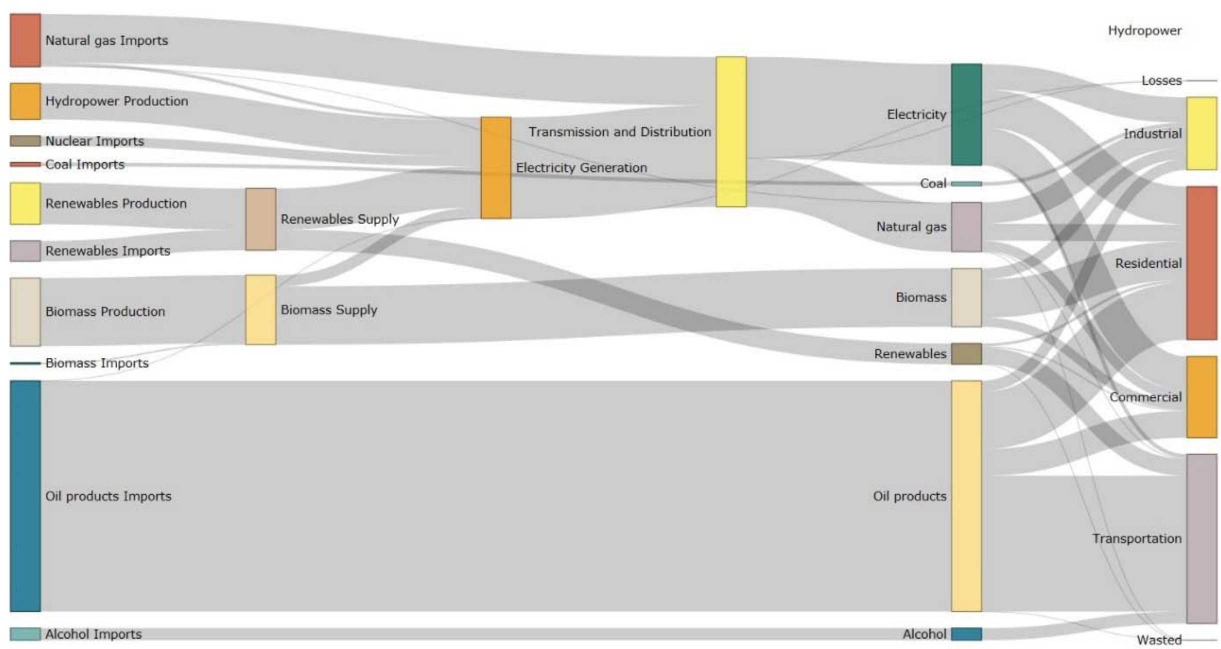

Figure 8. A Sankey diagram representation of how LEAP uses energy resources to meet total energy demand.

The Team drew historic information primarily from the Public Service Department's *Utility Facts 2013* [22] and U.S. Energy Information Administration (EIA) data to fill in the demand tree. The Team used projections from the Department's TES, the utilities' committed supply from their Integrated Resource Plans, and stakeholder input. The Department provided the data from selected Integrated Resource Plans filed by Vermont distribution utilities for the "Committed Resources" graph on page E.7 of *Utility Facts 2013.* [23]

[22] "Utility Facts 2013" (Vermont Department of Public Service, 2013), http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/Utility_Facts/Utility%20Facts%202013.pdf.
[23] Ibid.

Demand Drivers

Each sector has a unit that measures activity in the sector. That unit is the "demand driver." LEAP multiplies it by the energy intensity of the activity to calculate energy demand.

The population is assumed to grow at 0.35 percent per year.[24] The number of people per household is assumed to decrease from 2.4 in 2010 to 2.17 in 2050.[25] These assumptions combine to give the number of households, the model's basic unit for **residential energy consumption.**

The Team based the projected change in the **energy demand from the commercial sector** on data in the TES. The demand driver for the commercial sector is commercial building square feet.

The Team entered total **industrial consumption** by fuel estimates directly from the TES into the model.

Transportation energy use is based on vehicle miles traveled (VMT). This metric has risen throughout most of American history.[26] In Vermont however, VMT peaked in 2006 and has since declined slightly.[27] Given this trend, and Vermont's efforts to concentrate land development and to support alternatives to single-occupancy vehicles, VMT is assumed in the model to remain flat, while population and economic activity grow slightly.

The Team based **electricity supply** on the TES,[28] the utilities' Committed Supply, and other necessary sources to meet the demand projected in the model and the 90 x 2050 goal, and to supply 20 percent of annual electricity from solar. The Department provided the data from selected Integrated Resource Plans filed by Vermont distribution utilities for the "Committed Resources" graph on page E.7 of *Utility Facts 2013.*[29]

2.3 Scenarios

Once the Team entered historic data into the demand, transformation, and resources modules, it could build scenarios on Reference projections, and on alternative scenarios. For example, the Team examined the implications and requirements for meeting 20 percent of all electricity generation from solar by 2025, and the broader 90 x 2050 total energy targets. **Table 4** summarizes the scenarios derived from the research and informed by stakeholder feedback, review, and further analysis. The SDP is further refined into Low Net Metering and Delayed Deployment versions.

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[24] Ken Jones, Ph.D. and Lilly Schwarz, "Vermont Population Projections – 2010 - 2030" (State of Vermont, August 2013), http://dail.vermont.gov/dail-publications/publications-general-reports/vt-population-projections-2010-2030.
[25] Dr. Ken Noble, "Vermont Data_DSM.xlsx" (Vermont Department of Public Service, 2012).
[26] "Annual Vehicle Miles Traveled in the U.S.," Alternative Fuels Data Center, August 2016, http://www.afdc.energy.gov/data/10315.
[27] "Vermont Annual Vehicle Miles of Travel (AVMT) and Highway Fatalities" (Vermont Agency of Transportation), accessed November 16, 2016, http://vtrans.vermont.gov/docs/highway-research.
[28] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals."
[29] "Utility Facts 2013."

Table 4. Scenarios for the Vermont Solar Market Pathways, with major data sources, and showing the progression from current accounts to the SDP scenario

Scenario	Represents	Data sources
Current accounts	Description of current energy supply and demand balance. Historic information is from 2010-2015 depending on available data. Basis for all other scenarios.	*Utility Facts 2013*, EIA, *Vermont Residential Fuel Study,* device-specific data from various sources
Reference	Business as usual. Involves expected baseline levels of energy efficiency such as continued Efficiency Vermont operations and improvements in vehicle efficiency through Federal Standards. Renewable generation and natural gas growth continues.	*Total Energy Study* BAU scenario
90 x 2050_{VEIC}	Meeting the 90 x 2050 target. Based on the economic modeling done for the TES.	Adapted from *Total Energy Study* TREES Local scenarios
SDP[30]	Solar Development Pathways scenario. Reaches the 20%-of-generation target by 2025 and also the 90 x 2050 goals for 2050	Based on 90 x 2050: Demand is the same, supply is shifted toward solar

The **Reference scenario** contains energy use values and assumptions as they are today, but it assumes increases in vehicle efficiency, because of updated Corporate Average Fuel Economy (CAFE) standards,[31] and some increased use of natural gas—which, although a cleaner fuel to burn, is still a fossil fuel. The Reference scenario is based on the business-as-usual (BAU) scenario of the Vermont TES. The Vermont Solar Market Pathways Team revised the model to reflect less growth in natural gas use, after the cancelation of the planned second phase of a pipeline project.

The **90 x 2050_{VEIC} scenario** has stronger efficiency, quicker fuel switching, and accelerated renewable energy adoption to achieve the State's goal of meeting 90 percent of total energy needs with renewable sources by 2050. This scenario is based on the TES Total Renewable Energy and Efficiency Standard (TREES; local energy) scenario.[32] The TREES Local scenarios consist of two pricing outcomes, one that assumes a high cost of biomass and biofuels, and one that assumes a low cost. These scenarios test policies requiring all Vermont energy distributors to source an escalating percentage of their supply from in state, Vermont renewables or energy efficiency resources. The 90 x 2050_{VEIC} scenario combines the high and low biomass cost versions of TREES Local.

The Team created **SDP scenarios** for this project to meet the SDP goal to supply 20 percent of annual electric generation from solar by 2025. The demand side is exactly the same as that of

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30 The SDP scenario is further refined into Low Net Metering and Delayed Deployment versions.
31 "CAFE - Fuel Economy," *National Highway Traffic Safety Administration (NHTSA)*, accessed September 22, 2016, http://www.nhtsa.gov/fuel-economy.
32 "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals."

the 90 x 2050_{VEIC} scenario, but supply shifts more toward solar, and away from imported hydropower and wind.

The initial draft of this scenario was completed during the first six months of the project. Presenting the draft inputs and results to various audiences elicited feedback from participants who collectively offered many different perspectives. The stakeholders undertook detailed reviews of the scenario, which led to many improvements to the model. The Team presented the results and model in the following ways:

- Webinar for the U.S. Department of Energy (DOE), SunShot systems integration, June 25, 2015
- Regional Planning Commissions (RPCs) webinar, June 25, 2015
- Bennington RPC, July 13, 2015
- American Solar Energy Society “Solar 2015” conference, July 28, 2015
- Stakeholder meetings, May 19 and October 6, 2015
- Northwest Regional Planning Commission, October 7, 2015

The results did not change radically from the initial review and feedback sessions, but the model became more accurate, flexible, and robust:

- Added hourly production data for solar, wind, and hydro to the dispatch model.
- Smoothed forecasted changes in consumption to avoid unrealistic step changes.
- Aligned heat pump efficiency projections with updated, more aggressive estimates.
- Reduced the assumed number of homes using natural gas.
- Made small changes to residential shell and heating equipment efficiency expectations, to more closely align with TES consumption projections.
- Changed the transportation model from top-down to bottom-up, which allowed the team to use stronger and more detailed assumptions.

These changes were the basis for a revised SDP scenario, a high solar model that the Team has continually refined. A significant issue came up from using more data with greater temporal detail. The Team used the LEAP model to dispatch electricity to meet the demand in the first version of the model. Although it contains many detailed data, and can concurrently calculate several regions and scenarios, the model cannot handle high levels of temporal detail. The Team sought greater detail about the times of over-generation and unmet need, so that it could investigate load shifting, curtailment, storage, and electricity trading. To address the temporal data limit in the LEAP model, the team created a script that uses simple logic to “dispatch” generation for each hour of the year, giving the Team a chance to model 8,760 (hourly) time slices—365 times more than LEAP was using.

Additional scenarios. The SDP scenario is one way to reach 20 percent solar penetration by 2025, just as the 90 x 2050_{VEIC} scenario is one way to meet Vermont’s 90 percent total-energy-from-renewables goal by 2050. The Team encouraged stakeholders to suggest alternatives that would be worthy of investigation. Stakeholders suggested the following:

- **Low Net Metering.** The SDP scenario assumes solar grows with a similar distribution pattern of residential, commercial, and utility capacity as it has to date. However, Vermont has a higher proportion of net-metered solar than most other states with advanced solar markets. The lower net metering scenario offers more typical distribution, with much more utility capacity. This scenario addresses concerns expressed by some utilities about the rate impact of a 10-fold increase in solar generation under the current reimbursement model. This scenario might also reflect a new reality. Although no systems larger than the 2.2 MW limit of the Standard Offer had been built in Vermont by 2016, several larger systems have been proposed. **Figure 9** shows the distribution of system types in the low net metering scenario compared to the SDP.

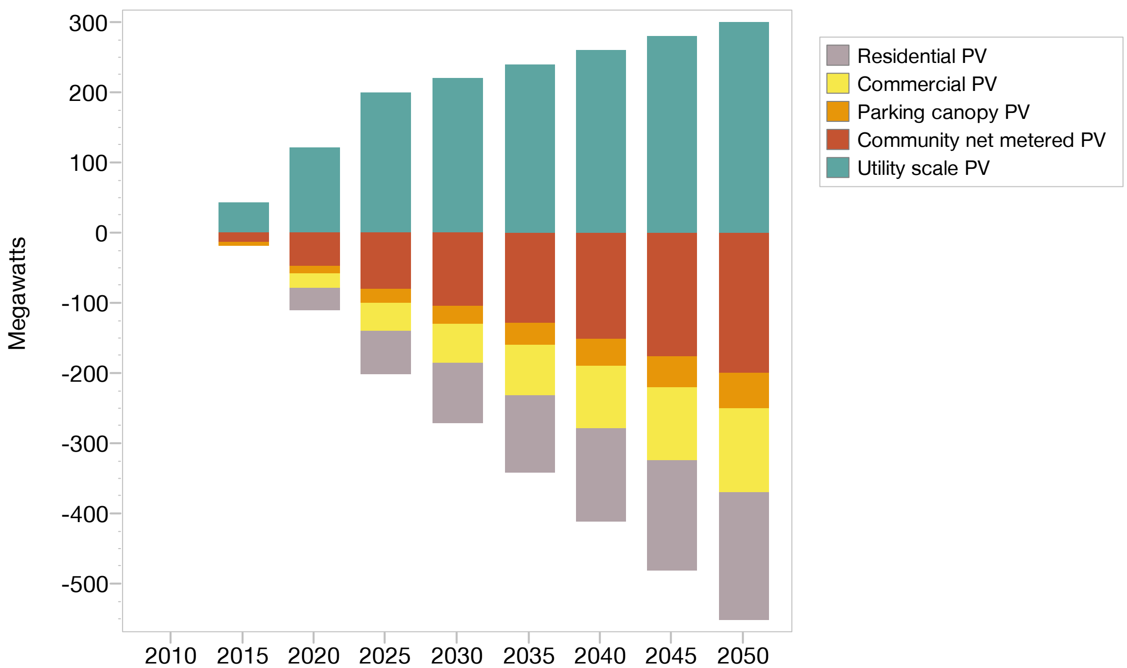

Figure 9. Difference in solar capacity by sector over time in the Low Net Metering scenario, compared to the SDP scenario.

- **Delayed Solar Deployment.** One utility stakeholder suggested this scenario to see the effects of installing more solar capacity in the future, when costs are likely to be lower. A delay would also allow time for the new standard for advanced inverters and time for planning and updates to the grid and to policy. Conversely, it would move more of the investment beyond the phase out of the federal Investment Tax Credit. The scenario is identical to the SDP except that the capacity installation is shifted later by 10 years. Capacity currently installed is the same, but 2025 targets become 2035 and 2050 targets shift to 2060. **Figure 10** shows the solar capacity added in this scenario alongside solar added in the SDP scenario. The SDP installs more in the first 15 years while the Delayed Deployment scenario continues adding solar beyond 2050.

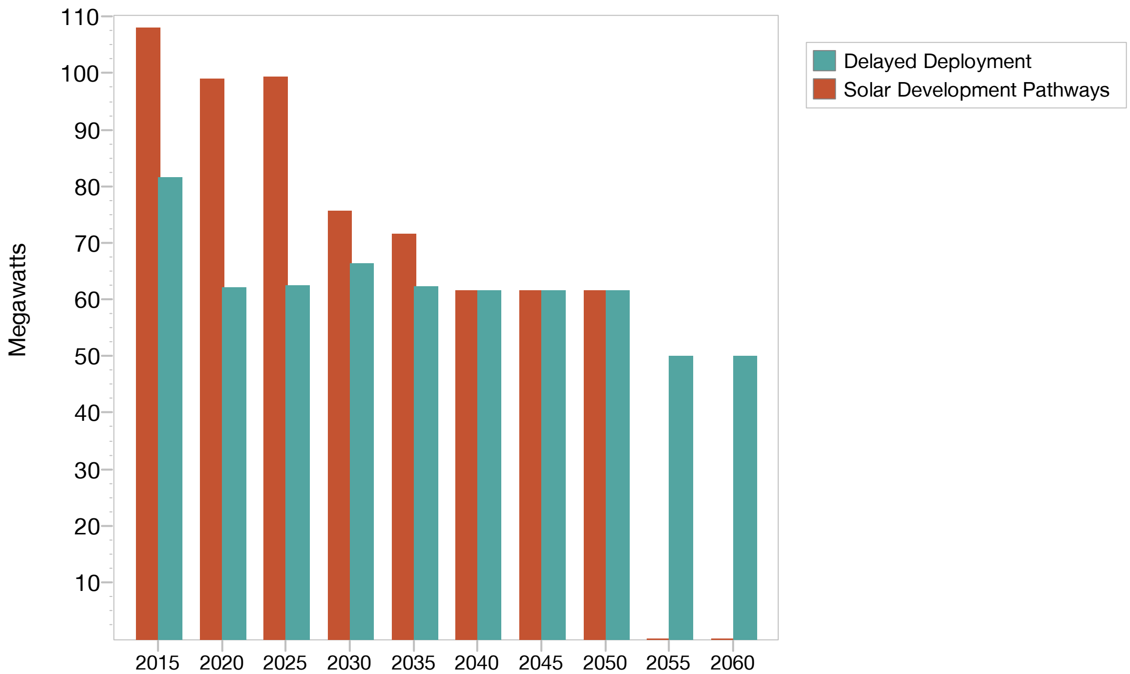

Figure 10. Difference in solar capacity added by year in the Delayed Solar Deployment scenario, compared to the SDP scenario.

- **Act 56, the Renewable Energy Standard.** Now that Vermont has an RPS to move toward the 90 x 2050 goal, the State suggested a scenario to reflect the new law. This scenario will be very similar to the 90 x 2050_{VEIC} scenario, but it will benefit from a few years of new information and market trends.
- **Poor Siting.** This scenario was suggested to reflect the additional grid upgrade costs that would be required if solar systems were sited poorly. The SDP scenario includes integration costs, but at a level that assumes relatively thoughtful siting and smaller investments. The Team and stakeholders decided this would be an appropriate sensitivity analysis, rather than a scenario.

2.4 Costs

The Project Team added costs to the model to estimate the investment required to transform the energy system and to estimate the resulting change in annual energy spending. Each part of the model has a cost: efficiency in all sectors of the demand side, new generation that is added during the model timeframe, grid updates to host high-penetration renewables, and the cost of fuel used directly or in power plants. The sources and assumptions used for cost projections are:

- The Team estimated costs from Vermont-specific data if available, and the best regional or federal estimates otherwise.

- Initial solar costs are from the 2016 *Vermont Solar Cost Study* by the Clean Energy States Alliance (CESA).[33]
- Future solar costs use that baseline and decrease according to a profile VEIC previously developed using national trends. These are shown in **Figure 11**.

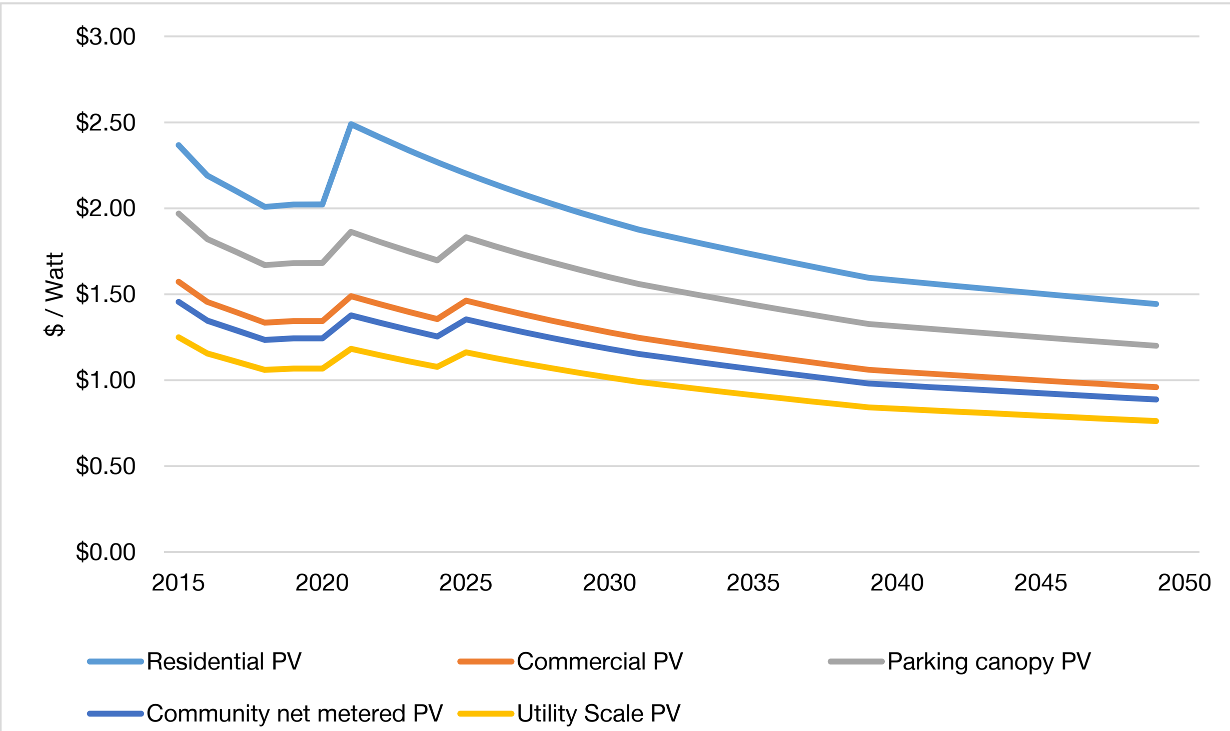

Figure 11. Projected future after-tax installed cost of solar PV in Vermont. Assumes the Investment Tax Credit fully expires in 2025.

- The Team derived efficiency costs from the 2013-2014 Vermont Demand Resources Proceeding, as approved by the Vermont Public Service Board.
- Fuel costs, delivery costs, and capital costs for energy generation and supply reflect costs estimated by Open Energy Information (OpenEI), EIA, CESA, the National Renewable Energy Laboratory (NREL), and the DOE's *Clean Cities Alternative Fuel Price Report.*

Details of cost sources and other assumptions are presented in **Volume 4**.

[33] Leigh W. Seddon and L.W. Seddon, LLC, "Vermont Solar Cost Study: A Report on Photovoltaic System Cost and Performance Differences Based on Design and Siting Factors" (Clean Energy States Alliance, Vermont Department of Public Service, and the Clean Energy Development Fund, February 2016), http://www.cesa.org/resource-library/resource/vermont-solar-cost-study-a-report-on-photovoltaic-system-cost-and-performance-differences-based-on-design-and-siting-factors.

3. Results

This section discussed the primary results from the Team's work to date. For greater detail on the scenario results, see **Volume 4**.

3.1 Changes in Energy Use and Supply

Energy efficiency is a key resource for meeting the high renewable energy goals. In each of the high renewable scenarios (90 x 2050_{VEIC} and the SDP scenarios) total consumption by sector declined through 2050. Vermont has mature energy efficiency programs, so the Team assumed an appropriate amount of baseline energy efficiency in the Reference scenario as well. The Team projected growth in population and commercial space as a base assumption, but total energy consumed declines in all scenarios. This efficiency comes from many places, including ambitious home weatherization, national automotive efficiency standards, and—most significantly—electrification of heating and transportation. As explained in Vermont's 2016 Comprehensive Energy Plan, "heat pump and electric vehicle technology is capable of supplying the same level of energy service as its combustion-based counterparts, with a third or less of the site energy requirements." The impacts of electrification and the extent of efficiency improvements are detailed below.

The savings from thermal shell improvements, more efficient end use equipment, and more efficient vehicles combine to reduce total energy consumption by roughly 10 percent by 2025, and 40 percent by 2050, compared to 2010.

Efficiency Is a Key Resource in All Scenarios

Figure 12 shows the results of investment in efficiency across all sectors of the economy. The costs and savings for efficiency improvements in the building sectors are based on historical experience with Vermont's efficiency efforts, and are consistent with projections from the State's forecasting Demand Resources Plan and its Comprehensive Energy Plan targets.

Figure 13 shows the forecasted cumulative SDP scenario's investments in efficiency and fuel switching, relative to the Reference scenario. This graph reflects only the efficiency investment, not the fuel savings. The transportation segment goes below zero because electric vehicles, which are simpler than combustion-powered vehicles, have lower maintenance costs and are expected to become less expensive to purchase in the second half of the analysis period. The additional savings from gasoline and other fuels is shown within the "Resources" in **Table 7**.

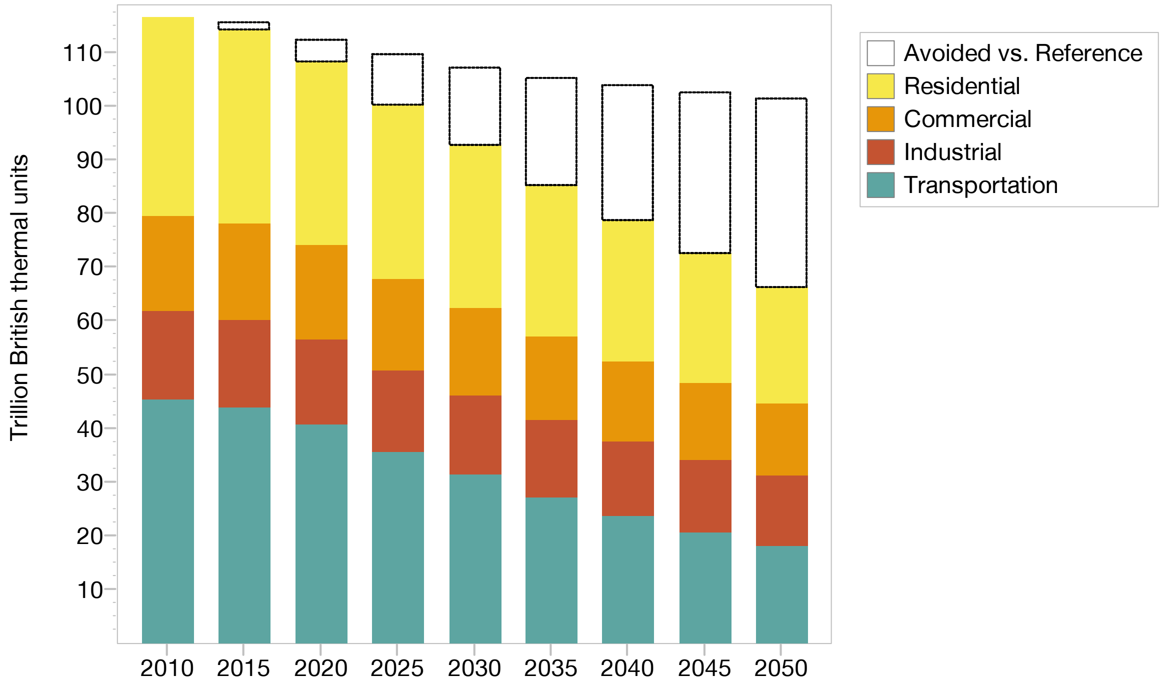

Figure 12. Vermont site energy demand, by 5-year increments, and by market sectors, showing the effect of more aggressive efficiency and fuel switching in the SDP scenario, compared to the Reference scenario.

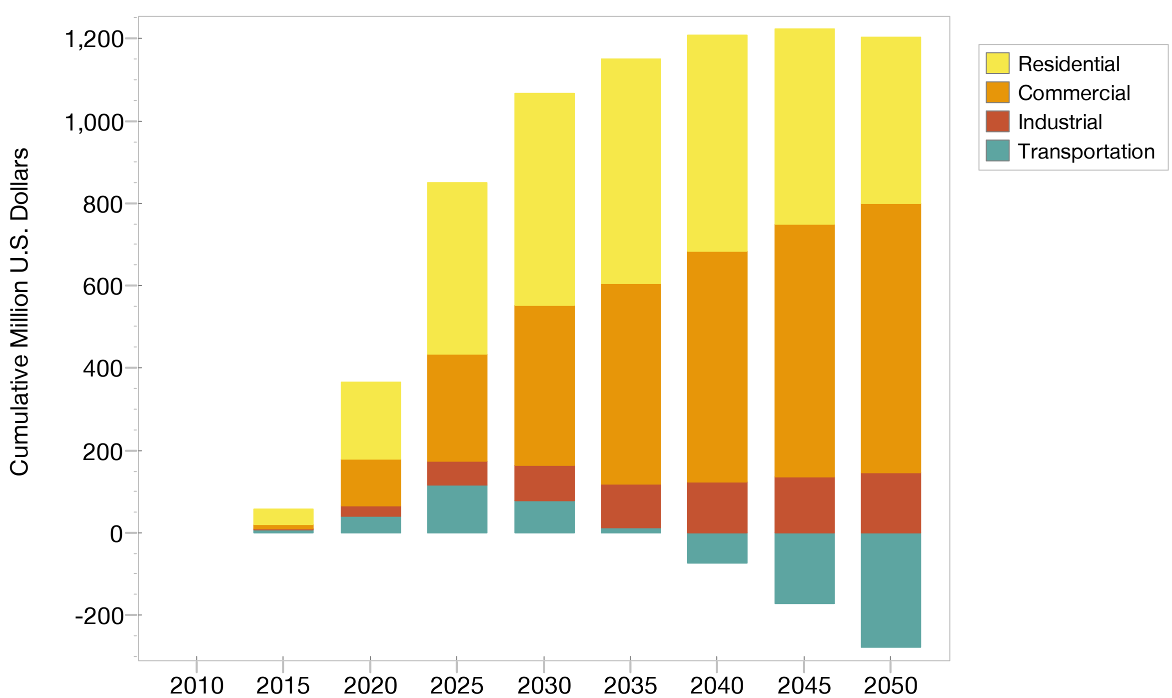

Figure 13. Cumulative discounted investments under the SDP scenario, compared to the Reference scenario.

The costs for these savings represent a significant investment by Vermont in more efficient buildings, equipment, and vehicles, amounting to approximately 1 percent of annual energy spending. The benefits include avoided energy resource costs, mostly from imported fuels, with a present value through 2025 of more than $1.2 billion. Across time, the long-lasting investments in efficiency result in significant positive net benefits.

Strategic Electrification – Heat Pumps

Heat pumps use electricity to move heat. There are many variations of the technology, but the attention here is on air source heat pumps that use energy in outdoor air to provide space heating and cooling. Heat pump water heaters work in a similar way and are another product that is contributing to growth in “smart” electrification in Vermont.

The customer economics are most compelling for homes using electric resistance, propane, or kerosene for heating, as described in **Table 5.** For homes with more expensive heating fuels, a heat pump could be paid off in as little as four or five years. Operating costs are nearly the same as those for natural gas and wood, so people are not likely to rush to switch, but might consider heat pumps when replacing failed systems.

Table 5. Annual savings from heat pumps, for a typical home (75 MMBtu / year), assuming 80 percent fuel offset, and fuel prices in Table 6

Fuel	Savings / year
Natural gas	-$206
Fuel oil	-$142
Wood	-$66
Pellets	$172
Kerosene	$364
Propane	$758
Electric resistance	$1,508

Heat pumps are least efficient when outdoor temperatures are very high or low, so they pose a challenge for utilities by possibly increasing demand during peak periods. Currently in Vermont, summer peak typically causes the most concern to utilities. However, there are areas that experience winter peak concerns. With additional solar, utilities are seeing many localized summer peaks shift from mid-day to after sunset. There are also circuits, where solar is causing the peak to shift from summer to winter. Both equipment controls and solar supply can help lower the summer peak, though storage or other means are necessary to deal with peak demand after sunset. Winter peak issues can be addressed with controls that pre-heat during time of solar output or shift heating to existing fossil systems during peak conditions.

Heat Pump Market Conditions. Vermonters generally are enthusiastic about heat pumps for displacing fossil fuel heating, as shown in Efficiency Vermont and GMP data:

- The most common search term on www.efficiencyvermont.com is *heat pumps.*
- The fourth most common search term on that site is *heat pump* (the singular form).
- In 2014-2015, VEIC’s Customer Support group reported 200 customers who have contacted them and are waiting for Efficiency Vermont to launch a heat pump program.

- Customer support staff for Green Mountain Power's (GMP's) lease program took more than 600 calls in the first few days of its announcement. The utility had to stop accepting calls because it could not satisfy the high volume of requests.

Technical Advances. Cold-climate heat pumps are advancing quickly in the marketplace. Initially only available as single-head units, there are now multi-zone and multi-head systems. These systems come with more installation options for the indoor units that address some of the barriers listed below. Soon, heat pumps designed to connect to conventional duct and water pipe distribution systems will be available, as will be combined space and water heating systems. These improvements increase the number of homes and businesses that can use the technology.

Efficiency is also increasing. Researchers are now designing systems that can use carbon dioxide as a highly efficient and low-impact refrigerant. Solid-state heat pumps are another area of research. In Vermont, heat from heat pumps currently costs less than all fuels except cordwood, fuel oil, and natural gas, as shown in **Table 6**. Fuel oil has a higher historical average, but has recently dropped in price. With increasing efficiency, electric heat pumps might overtake these three fuel sources.

Table 6. Relative cost-effectiveness of electric heat pumps, compared to other fuel types

Fuel type	Unit	Btu / unit	Efficiency	$ / unit	$ / MMBtu
Natural gas	CCF	100,000	80%	$1.41	$14.88
Fuel oil	Gallon	138,200	80%	$2.10	$15.96
Wood (green)	Cord	22,000,000	60%	$227.00	$17.21
Electricity (heat pump)	kWh	3.412	250%	$0.15	**$18.32**
Pellets	Ton	16,400,000	80%	$278.00	$21.19
Kerosene	Gallon	136,600	80%	$2.67	$24.40
Propane	Gallon	91,600	80%	$2.27	$30.96
Electric resistance	kWh	3.412	100%	$0.15	$43.46

Source: Adapted from Vermont Fuel Price Report[34]

Figure 14 illustrates the growth of heat pumps as a share of space conditioning for single-family homes.

[34] "Vermont Fuel Price Report" (Vermont Department of Public Service, October 2016), http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/Fuel_Price_Report/2016/October%202016%20Fuel%20Price%20Report.pdf.

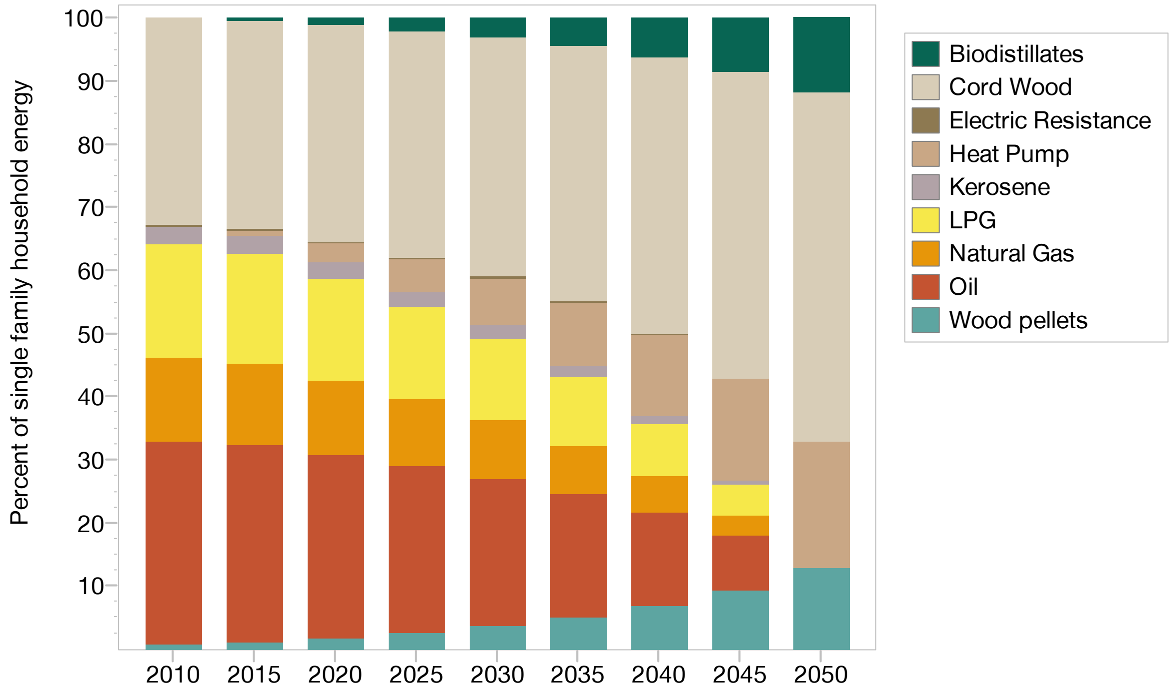

Figure 14. Share of heating energy in single family homes, by five-year increments, and fuel, with electricity and biofuels growing to displace fossil fuels.

Strategic Electrification – Electric Vehicles

The development of an advanced solar market in Vermont will provide significant opportunities for increasing the number of renewably powered vehicles in the state. The primary benefits of renewably powered transportation are reduced emissions of greenhouse gases and other harmful pollutants, reduced cost and volatility in transportation energy expenditures, and support for economic development by shifting monies from fuel expenditures to capital for investment or spending. Further, electric vehicles (EVs) can support the electric grid by boosting demand side management (DSM) through controlled charging and distributed energy storage using EV batteries. Both controlled charging and the storage capability can respond to short-term fluctuations in power generation that might occur if more solar PV generation is brought on line. Grid upgrades may be necessary for fast charging stations or if several charging stations are concentrated in a small area, to avoid overloaded transformers, voltage drop, or other distribution grid problems.

Technology and Market Description. There are two basic types of plug-in EVs:

- **All-Electric Vehicles (AEVs),** powered solely by electricity with a range of 60 to over 100 miles for vehicles under $40,000. AEVs manufactured by Tesla (purchase price of $70,000) can travel up to 270 miles without a charge. AEVs accounted for 25 percent of registered EVs in Vermont in 2015 and through the third quarter of 2016.
- **Plug-in Hybrid Vehicles (PHEVs**) offer 10 to 75 miles of electric range on a battery, and then the vehicles switch without interruption to gasoline for extended-range operation.

PHEVs accounted for 75 percent of the registered EVs in Vermont in 2015 and through the third quarter of 2016.

Most EVs in Vermont are passenger vehicles and travel about 3 miles per kWh of energy. Given the census of EVs in Vermont, this means an annual consumption of about 2 MWh for the average Vermont vehicle.

Reference scenario. The *Vermont Zero Emission Vehicle Action Plan* contains detailed information on activities under way in Vermont to support automakers in complying with zero-emission vehicle (ZEV) program requirements. **Figure 15** illustrates the anticipated continued growth in the market. This is particularly the case for 2017 and beyond, after the expiration of the existing travel provision, which allows manufacturers to meet their requirements by selling EVs only in California. The ZEV program requirements have credits for different vehicle technologies, so actual experience of sales could differ from the scenario presented below. A relatively conservative estimate under existing policies would be approximately 10,000 EVs in Vermont by 2023, or nearing about 2 percent of the fleet of registered vehicles.

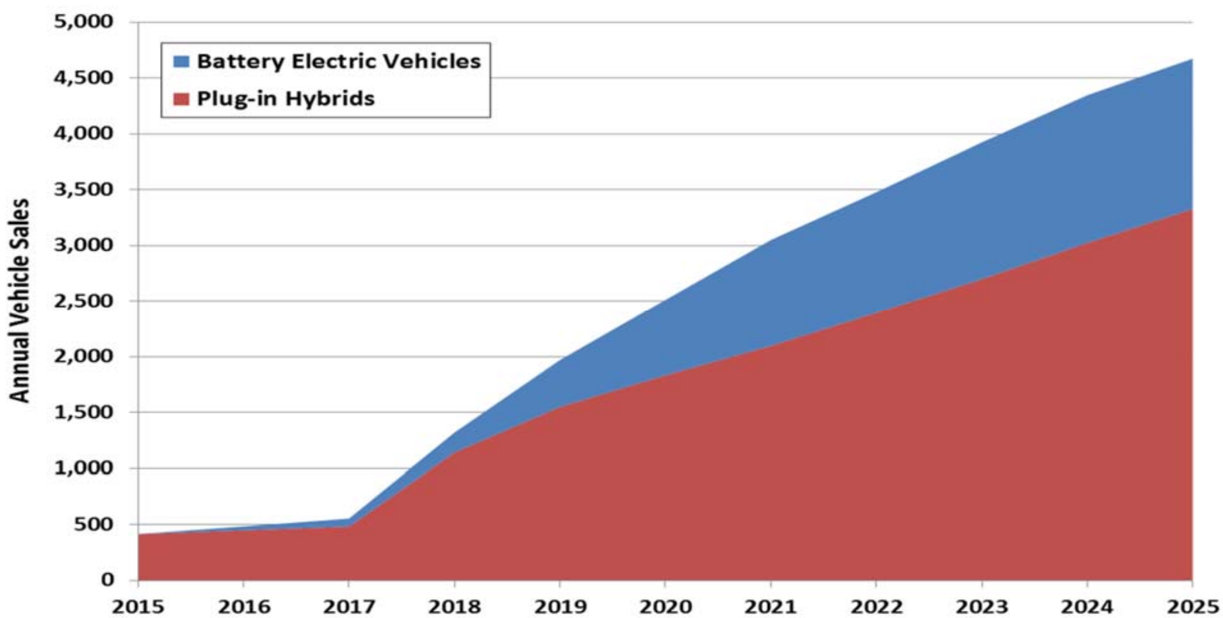

Figure 15. *Vermont ZEV Action Plan* compliance scenario.[35]

90 x 2050 and SDP scenario. The Vermont *Comprehensive Energy Plan* includes goals for 25 percent of vehicles to be powered by renewable energy in 2030 and 90 percent by 2050. These values translate to approximately 143,000 EVs in 2030 and 515,000 EVs by 2050. Achieving this rate of growth will depend on vehicle availability at competitive pricing, and sustained programs to transform the new and used vehicle markets.

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[35] "Vermont Zero Emission Vehicle Action Plan" (State of Vermont: Agency of Natural Resources, September 2014), http://anr.vermont.gov/about_us/special-topics/climate-change/initiatives/zev.

Technical advances. Advancements in EV technology and battery capacity are beginning to make possible longer ranges for driving at the same or even a lower purchase cost than older EV models. While most cost-competitive all-electric vehicles currently have a range of around 100 miles, rapid technological advances are underway. The Chevy Bolt, an all-electric vehicle with a range of 238 miles and priced just under $30,000 (once the federal tax credit is factored in) is now available for purchase.[36] The lines separating energy generation, storage, and use are also beginning to blur. Shareholders from Tesla and SolarCity, a panel manufacturer, recently approved a merger for the two companies.[37] The new company plans to combine solar generation, battery storage, and transportation.

Figure 16 shows the projected change in fuel supplying light-duty vehicles in the model. Change starts slowly, but electricity powers more than half the demand by 2040 and almost all of it by 2050.

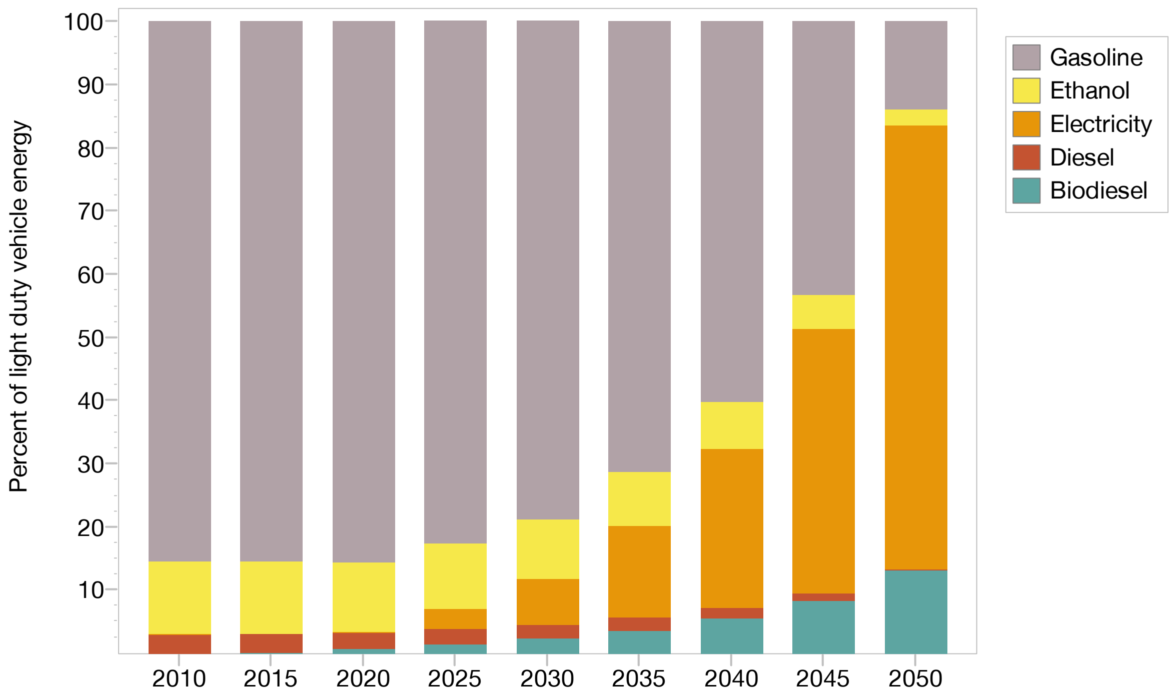

Figure 16. Share of light-duty vehicle energy provided by fuel, with electricity growing later in the period.

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36 Eric Tinwall, "Chevrolet Bolt EV," *Car and Driver*, October 2016, http://www.caranddriver.com/chevrolet/bolt-ev.

37 Michael J. De La Merced, "Tesla and SolarCity Shareholders Approve Merger," The New York Times, November 17, 2016, http://www.nytimes.com/2016/11/18/business/dealbook/tesla-and-solarcity-shareholders-approve-merger.html.

Renewable Generation in the Decarbonized Grid

The shift to greater electrification heating systems and transportation provides a benefit if the electricity supply is clean. Vermont already has the lowest carbon intensity electricity generation in the country,[38] but a major change is still required to meet our 2025 and 2050 goals, especially after Vermont Yankee's low-carbon nuclear generation was partially replaced in 2014 with electricity from natural gas power plants.

Figure 17 shows the transition of Vermont's grid in the model. The data are based on utilities contracted supply through 2030. The Vermont Department of Public Service provided the data from selected Integrated Resource Plans filed by Vermont distribution utilities for the "Committed Resources" graph on page E.7 of *Utility Facts 2013.*[39] All in-state renewables are expected to continue beyond the contract periods. In-state nuclear generation is replaced by nuclear elsewhere in New England, and then disappears. By that time, solar and new wind have grown to provide more annual generation than Vermont Yankee had in the past.

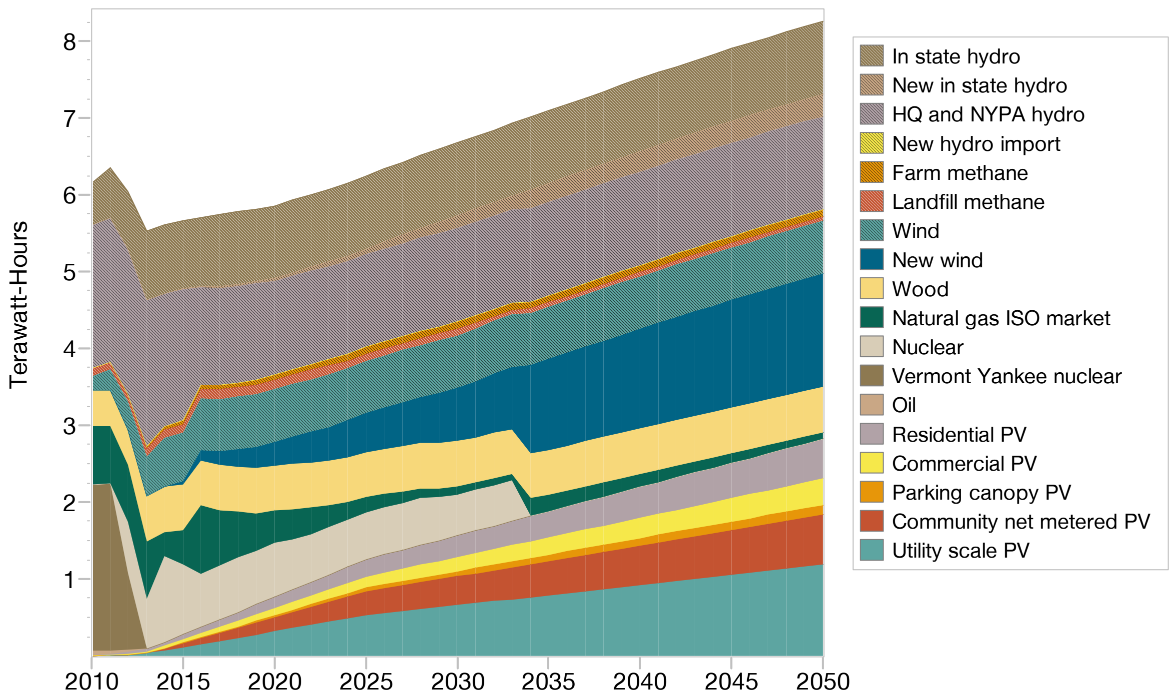

Figure 17. Electricity generation by year and source in the SDP.

Figure 18 compares electricity supply in the SDP scenario compared to the Reference scenario. Solar ramps up more quickly, but by 2050 wind and solar make roughly the same contribution to electricity demand. A small amount of new in-state hydropower adds to this to offset a large

[38] "State-Level Energy-Related Carbon Dioxide Emissions, 2000-2012," U.S. Energy Information Administration, October 26, 2015, http://www.eia.gov/environment/emissions/state/analysis/.
[39] "Utility Facts 2013."

amount of natural gas-fired electricity from the New England grid. The new hydropower capacity is from upgrades to existing facilities or adding generation equipment to existing dams; no new dams are assumed. In September of 2016, Green Mountain Power purchased fourteen hydropower facilities in New England with a combined capacity of 17 MW.[40] The Team updated the energy model to reflect this new capacity, adjusting for the Vermont dams that were already included.

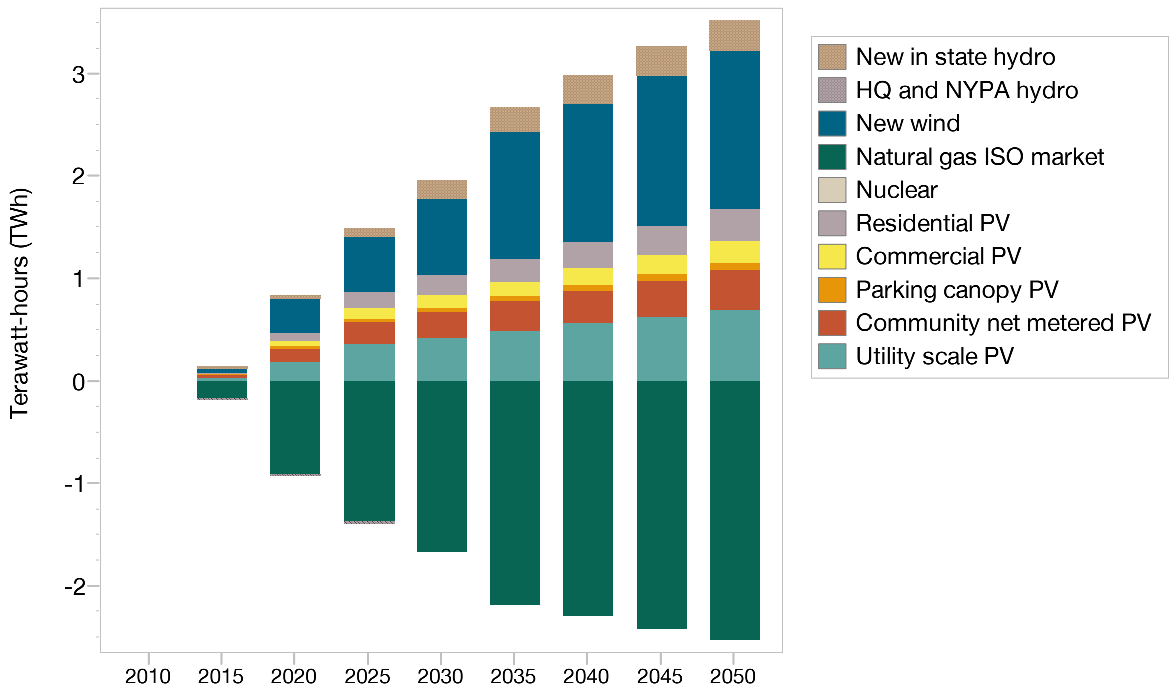

Figure 18. Difference in annual generation between the SDP and the Reference scenarios, showing a diverse mix of renewables displace natural gas-fired power from the New England grid.

3.2 Grid Impacts

The California "duck curve"[41] brought the issues of low daytime net load and high evening ramp rates to the attention of the solar industry, utilities, and regulators. Shawn Enterline, Director of Regulatory Affairs at GMP, and an active stakeholder on this project, used hourly forecasts and simulations to create the Vermont "Champ Curve" shown in **Figure 19**. "Champ" is a mythical creature residing in Lake Champlain, the state's major body of water. The creature is rumored to have the body of an Elasmosaurus.[42] Champ's belly goes below zero between 2025 and 2030, as the installed capacity increases beyond 1 GW.

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[40] Polhamus, Mike. "Green Mountain Power To Buy 14 More Hydroelectric Dams." https://vtdigger.org/2016/08/17/green-mountain-power-agrees-buy-14-hydroelectric-dams/.
[41] Paul Denholm et al., "Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart" (National Renewable Energy Laboratory, November 2015), http://www.nrel.gov/docs/fy16osti/65023.pdf.
[42] Robert E. Bartholomew, *Untold Story of Champ, The: A Social History of America's Loch Ness Monster* (SUNY Press, 2012).

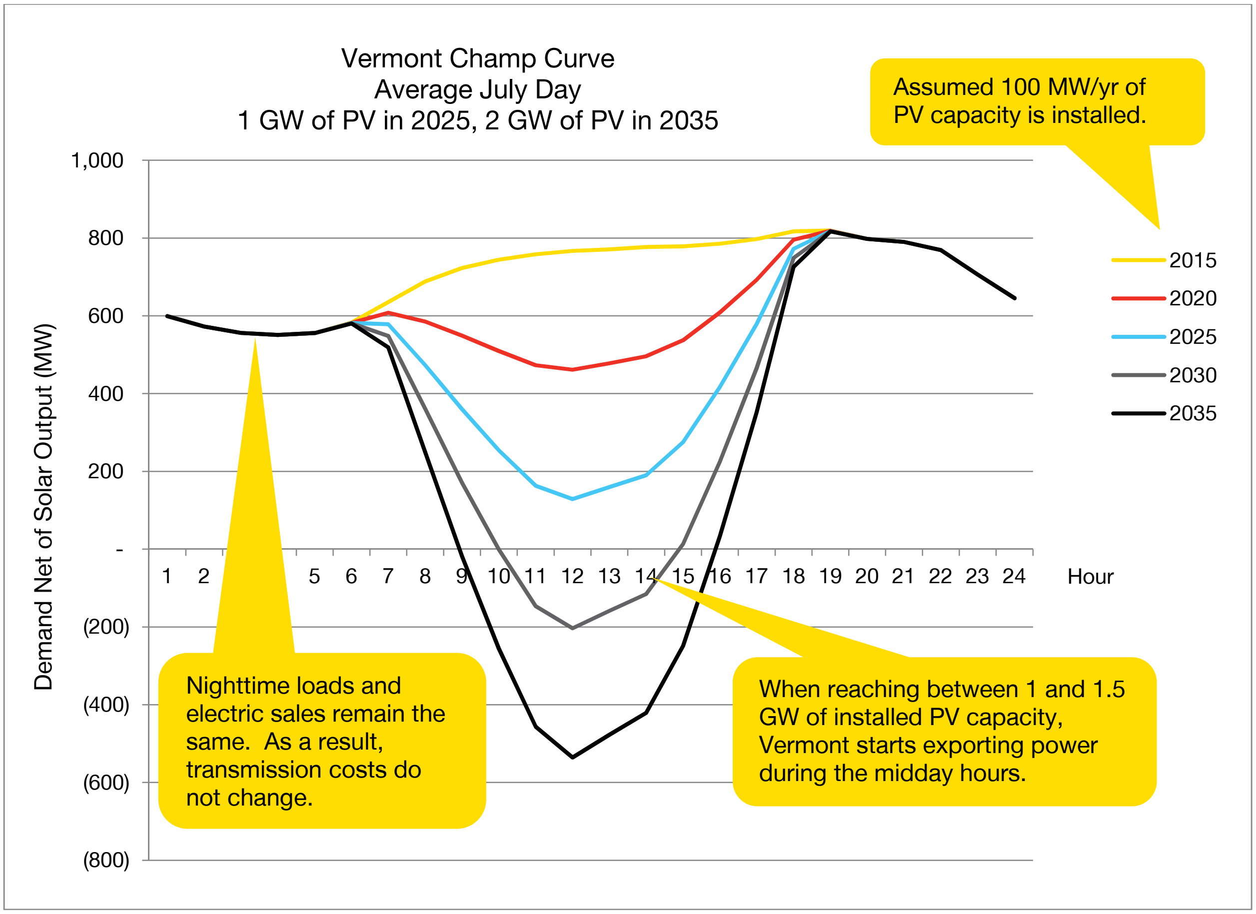

Figure 19. Vermont Champ Curve, showing the net load on an average July day.[43]

The potential for over-generation is a challenge. **Figure 19** considers only solar generation, so other generation would also need to be shutdown or curtailed during hours of negative load. Curtailment requires controls and other infrastructure and has economic impacts on projects, so is not a preferred strategy.

See **Figure 27** for a comparison of demand with all generation on three sample days in 2025. Ramping down hydropower generation has ecological impacts from rising water in the reservoirs. Curtailing wind or solar has economic impacts. Must-take contracts would need to be re-negotiated before this situation, or else utilities would have to pay for power they do not use. Demand response / load shifting and storage might mitigate this likely problem. These data raise many issues that can be addressed with several possible strategies, discussed in **Section 4.1 Bulk Power System Integration.**

3.3 Economic Outcomes

The team has conducted economic analyses for three advanced solar scenarios. These are the SDP, Delayed Deployment and Low Net Metering (NM) scenarios. These can be compared to

[43] Enterline, Shawn. “Vermont Champ Curve.” Green Mountain Power, 2015.

the Reference scenario and to the 90 x 2050_{VEIC} scenario. The Reference scenario does not meet the statewide target of meeting 90 percent of total energy needs with renewables by 2050. The 90 x 2050_{VEIC}, SDP, Delayed Deployment and Low NM scenario all meet the 90 x 2050 target. The SDP and Low NM scenario also meet the advanced solar economy target of supplying 20 percent of total electric generation from solar by 2025.

In 2015, Vermont's solar industry employed 1,367 workers.[44] This project envisions four times more solar installed in 2025 than in 2015. However, the annual addition of solar capacity across that decade is not expected to change drastically from the rate of added solar occurring now. Employment in the industry is more closely tied to the installation rate than to the total installed capacity, so the Team forecasts moderate growth in Vermont's solar industry across that period.

Vermonters spent $3.3 billion for energy in 2014.[45] By annually investing less than 1 percent of that amount in efficiency, fuel switching, and renewable energy, these high renewable scenarios can be achieved. Compared to the Reference scenario, all three SDP scenarios have higher net present value costs, ranging from $91 million to $209 million for the 2010-2025 period, as shown in **Table 7**. That is the timeframe for the 20 percent solar goal; if the period is extended, the three scenarios all show net positive economic results by the 2030s.

Table 7. Cumulative costs and benefits: 2010 – 2025, relative to the Reference scenario (discounted at 3.0% to 2015, in millions of 2015 U.S. dollars)

	90 x 2050_{VEIC}	**SDP**	**Delayed Deploy**	**Low NM**
Demand	**$851**	**$851**	**$851**	**$851**
Residential	$416	$416	$416	$416
Commercial	$261	$261	$261	$261
Industrial	$58	$58	$58	$58
Transportation	$115	$115	$115	$115
Transformation	**$306**	**$498**	**$319**	**$488**
Transmission and distribution	-$3	$13	$13	$13
Electricity generation	$308	$485	$306	$475
Resources	**$-1,079**	**$-1,139**	**-$1,078**	**$-1,148**
Production	$82	$82	$82	$82
Imports	$-1,162	$-1,222	-$1,160	$-1,230

44 "Vermont Solar Jobs Census 2015," *The Solar Foundation*, 2015, http://www.thesolarfoundation.org/solar-jobs-census/vt-2015/.
45 "Total Energy Consumption, Price, and Expenditure Estimates, 2014," *U.S. Energy Information Administration*, accessed September 22, 2016, http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_te.html&sid=US&sid=VT.

	90 x 2050VEIC	SDP	Delayed Deploy	Low NM
Exports	-	-		-
Unmet requirements	-	-		-
Environmental externalities	-	-		-
Non-energy sector costs	-	-		-
Net present value	**$77**	**$209**	**$91**	**$190**
GHG savings (million tonnes CO_{2e})	7.1	7.1	7.1	7.1
Cost of avoiding GHGs ($ / tonne CO_{2e})	$10.7	$29.3	$12.8	$26.7

Over time, the benefits from investments in efficiency and solar far outweigh the costs, producing significant economic value for the state. The model projects close to $8 billion in cumulative net positive benefits by 2050, as shown in **Figure 20**. Overall, the economic analysis results indicate that a slight net investment (<1 percent of annual energy expenditures) in developing the advanced solar economy through 2025 creates very large positive net benefits across time. Vermont policy makers and consumers are increasingly recognizing the benefits of this value proposition, driving the levels of investment and savings emerging in the market.

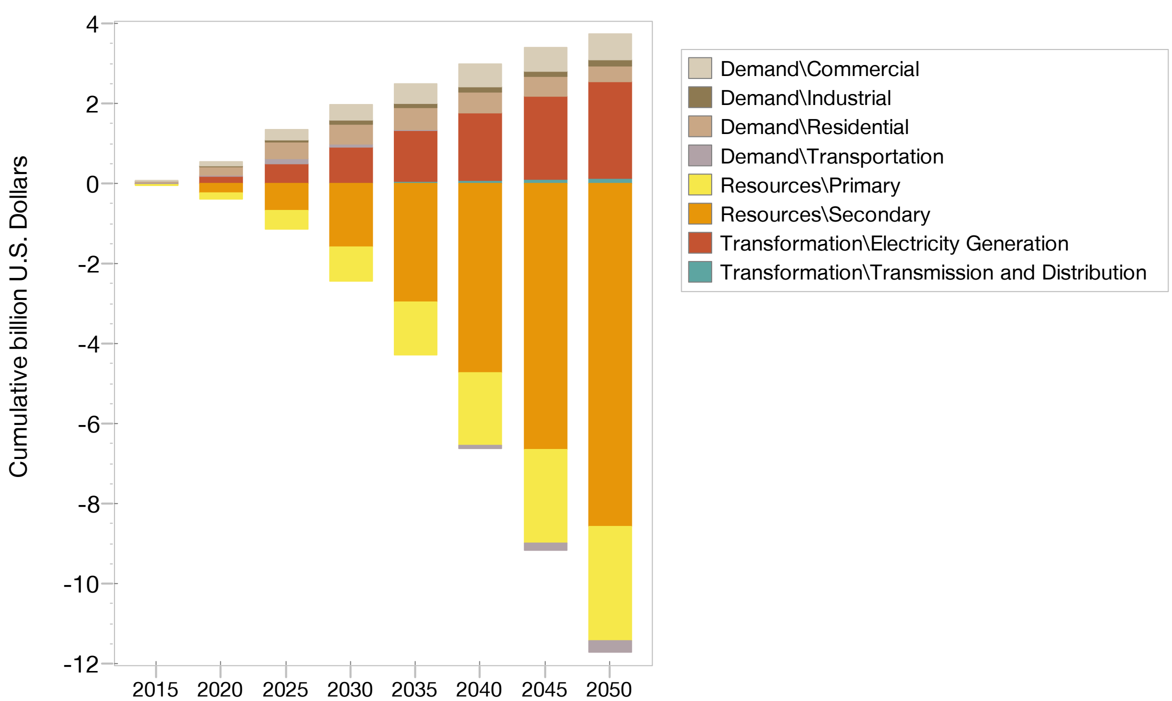

Figure 20. A comparison of cumulative discounted costs for electricity generation, between the SDP and References scenarios.

Figure 21 illustrates a comparison of the annual costs for electric generation between the SDP scenario and the Reference scenario. The SDP scenario has higher costs for solar, new wind, and new in-state hydropower. The increased costs for these resources are partially offset by a reduction in costs for natural gas-fired electricity imported from the regional power markets.

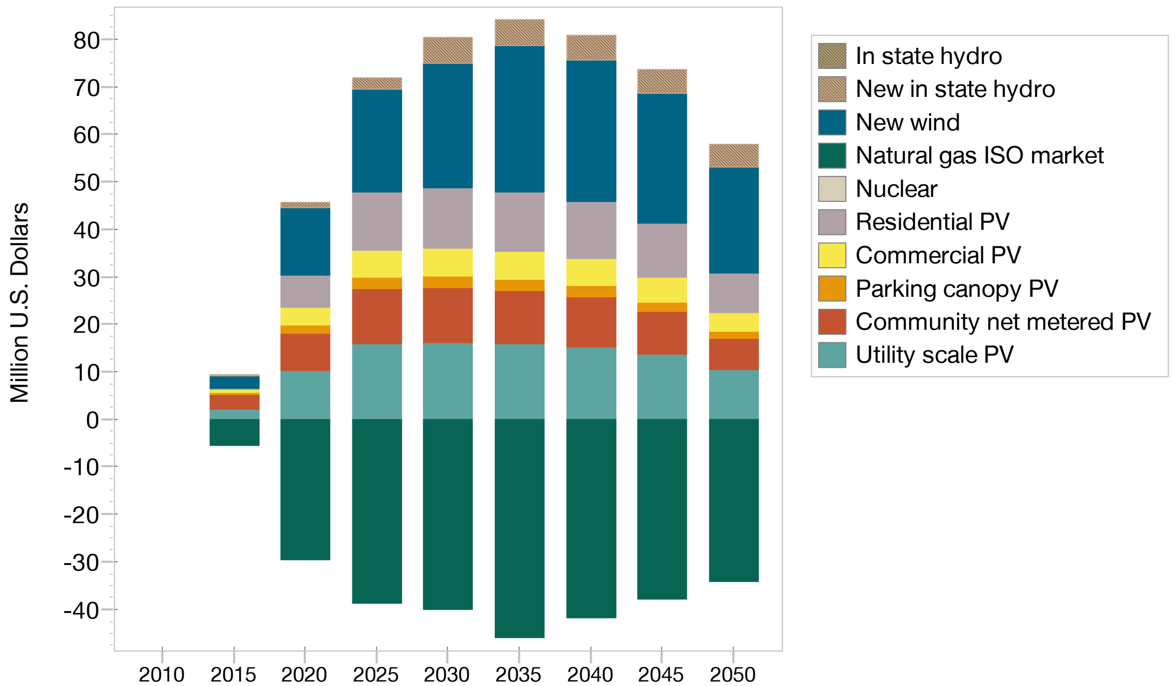

Figure 21. Annual discounted costs for electricity generation in the SDP scenario, compared to the Reference scenario.

3.4 Environmental Outcomes

The SDP scenario reduces greenhouse gas emissions by roughly 20 percent by 2025, and by more than 80 percent by 2050. **Figure 22** illustrates these effects.

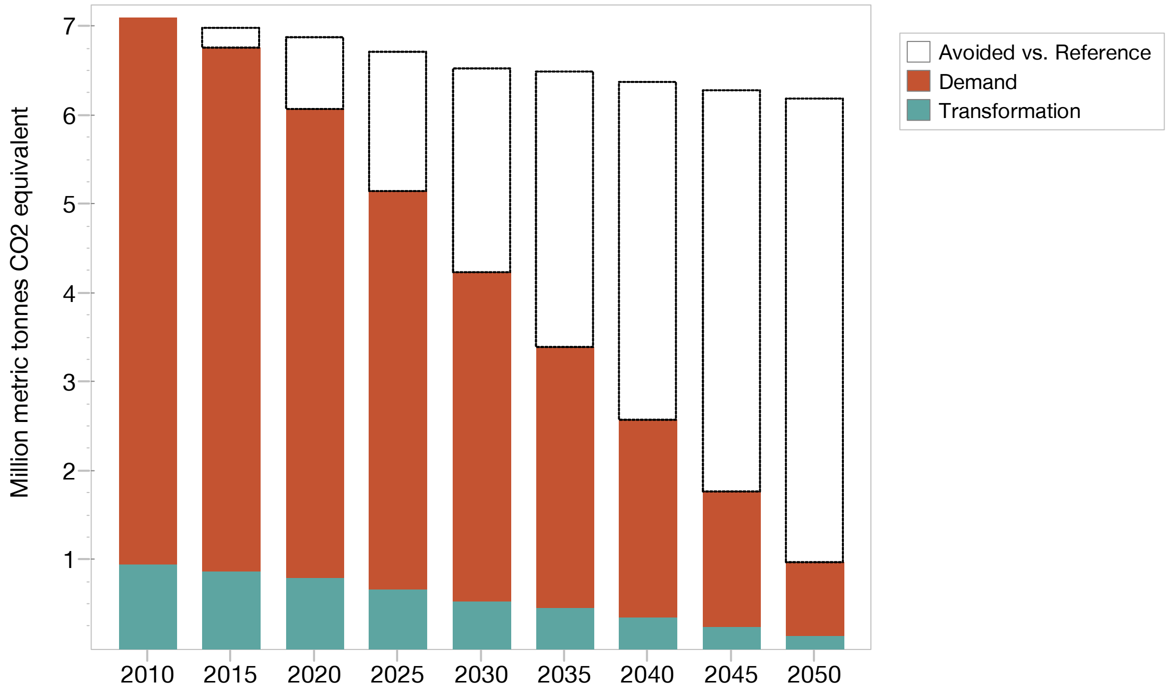

Figure 22. Emissions of the SDP scenario compared to the Reference scenario.

By 2050, Vermonter's emissions per person fall below 2 metric tonnes per person, a limit suggested for mitigating climate change. Vermonters will see much more of the energy system as in-state renewable projects replace imported energy. Careful siting and project design can limit the impact.

4. Strategies for Becoming an Advanced Solar Economy

4.1 How the Results Can Be Attained

Siting and System Integration

The Team identified the target of 20 percent of total electric needs met by solar power by 2025 as an ambitious but achievable solar energy goal. To achieve 20 percent of annual electricity supplied by solar in Vermont requires approximately 1 GW of solar, which is equal to Vermont's peak electric demand—before the electrification of transportation and heat.

To determine how to reach that target, the Team evaluated the impact of 1 GW of solar within the state's bulk power mix, and how that much solar would affect the distribution circuits where it would be connected.

This approach, identifying a goal and illustrating and exploring multiple ways of reaching it, allowed the Team to test several different scenarios. No predictive analysis will be 100 percent accurate, particularly one with a time span as long as 35 years. The end-oriented approach has provided a structure through which to test hypotheses and to elicit stakeholder feedback on likely issues. Other analyses screen for cost effectiveness or use economic optimizations. However, people do not always make consistent, rational economic decisions, nor do they immediately switch when a new, more cost-effective product or service becomes available.

This project describes a future that people want, even though they are not certain that it is achievable. The team built support for the 20 percent goal and then worked through issues to build confidence in the feasibility. **Volume 3, Barriers and Integration Brief** documented several possible problems from a future that offers high solar penetration. This section identifies potential solutions to each.

Space Requirement

Some observers cite the space requirements of solar as a reason for it not to play a major energy supply role. Although sunshine is one of the least dense forms of energy, and siting space might be a limiting factor in cities attempting to become energy self-sufficient, Vermont has more than enough space for solar. For an approximation of the space required for the SDP scenario, the Team examined land requirements based on the 2050 solar capacity, shown in **Table 8**.

At that point, solar produces close to one-third of annual generation, and the space requirements are just 2/10 of 1 percent. This finding helps to inform the public discussion of land requirements for solar, indicating that solar resource and land are not limiting factors.

Table 8. Land requirements for achieving the targeted 2050 solar capacity

	2050 MW	Percent on open land	MW on open land	Acres required[46]	Percent of state
Residential	360	25%	90	720	0.01%
Commercial	240	50%	120	960	0.02%
Parking canopy	90	0%	0	0	0.00%
Community	510	100%	510	4,080	0.07%
Utility	800	100%	800	6,400	0.10%
Total	**2,000**		**1,520**	**12,160**	**0.20%**

Even though the overall land requirements are modest, the proper siting of solar is an important topic, both for land use and grid integration. Recent Vermont Legislation requires RPCs to develop maps identifying the most and least acceptable areas for development for different types of renewable energy resources. Vermont's new net-metering law provides preferred pricing to net-metered generation located on disturbed sites, sites identified by municipalities as preferred sites for renewable development, or adjacent to the demand for the energy.

The Bennington County Regional Commission (BCRC) produced a map of "prime solar" land near existing power lines and away from floodways, wilderness areas, rare and irreplaceable natural areas, wetlands, agricultural soils, and other constraints. **Figure 23** shows a small section of the map and legend. The yellow prime solar land is near existing development and is not found in the forested mountains, which are shown by dotted elevation lines on the left side of the map.

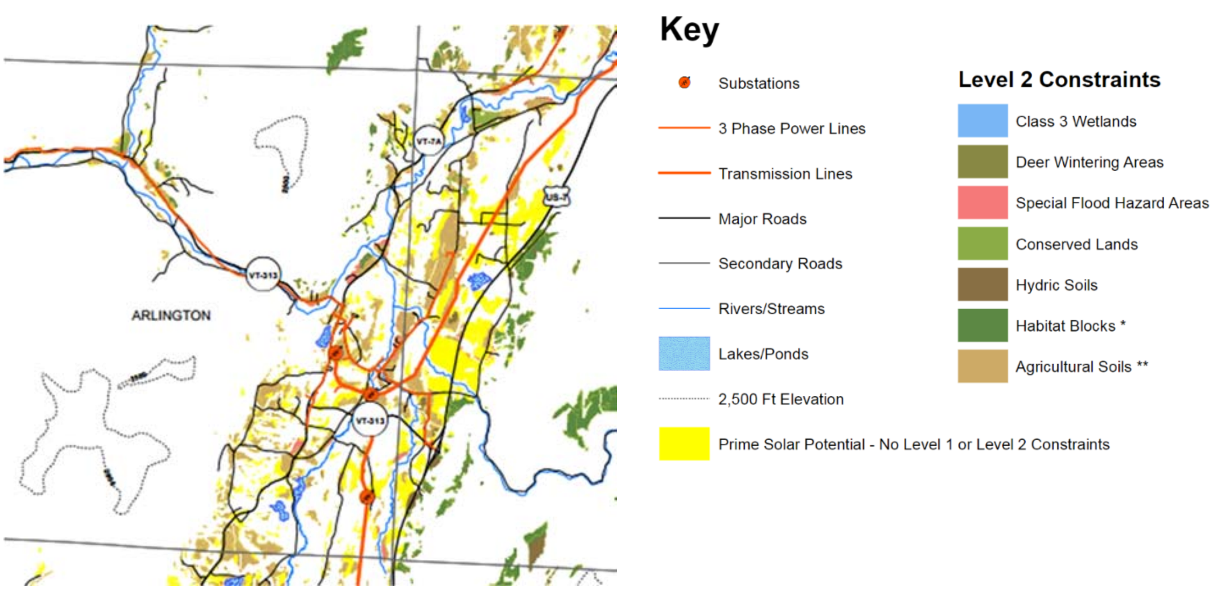

Figure 23. A section of a map showing "prime solar" land.

BCRC also analyzed the geography to summarize the availability of prime solar land in their region. **Figure 24** is an image they produced to help people visualize the vast amount of land,

[46] Sean Ong et al., "Land-Use Requirements for Solar Power Plants in the United States" (National Renewable Energy Laboratory, June 2013), http://www.nrel.gov/docs/fy13osti/56290.pdf.

and of prime solar land available, compared to the amount required for their contribution to the statewide target.

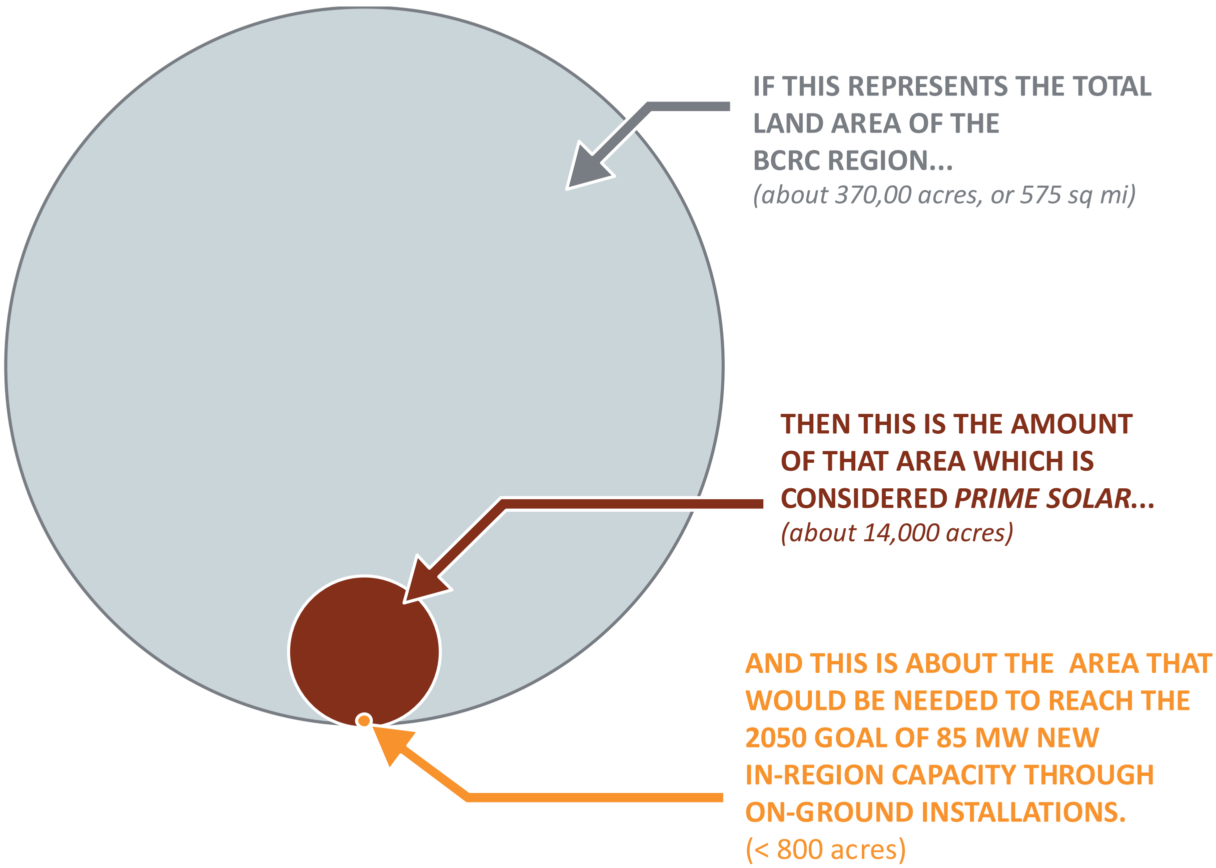

Figure 24. A Bennington County Regional Commission graphic showing more than enough prime solar land to site the targeted capacity of solar.

There are several ways solar can be added with minimal impact to the site. Rooftop systems are widely seen as low impact, and arrays over parking lots have the additional benefit of keeping the cars under them cooler. Ground mounted systems can be integrated into farms by locating them along existing fence lines or separations, in land with poor soil, or in the case of an apple orchard, in the low spots in the land where trees would be vulnerable to late spring frosts. Within large solar arrays, there are alternatives to mowed turf grass. Animals can graze, though some require taller or stronger solar racks to avoid damage. Wildflower and native grasses can be established to keep growth low and provide foraging habitat for bees and birds while those pollinators benefit nearby agriculture. Pollinator-friendly vegetation also has deeper roots than turf grass, helping retain soil and nutrients and controlling stormwater. Pollinator-friendly vegetation standards have been established in Minnesota and the approach is common in the UK.[47]

[47] Davis, Rob, "Can Solar Sites Help Save The Bees?" Bee Culture, July 25, 2016, http://www.beeculture.com/can-solar-sites-help-save-bees/.

Distribution System

A high percentage of solar and other renewables can cause problems on the distribution grid and in bulk power supply. Although this study did not conduct detailed distribution engineering analyses, the Team reviewed related work in other jurisdictions and is following the progress of the Vermont utilities' work with Sandia National Laboratory, funded through DOE's Grid Modernization Initiative.

Relevant outcomes of secondary research are summarized below. Well-designed and executed distribution study analyses provide the following results for substations and individual feeders. These findings are detailed on page 5-14 of Electric Power Research Institute's (EPRI) benefit-cost analysis of an integrated grid framework:[48]

- **Feeder-specific hosting capacity.** Individual feeders, and locations along an individual feeder, vary in their ability to host DERs without violating voltage and protection scheme thresholds. Generally, locations that are closer to the substation on a radial feeder will have a higher hosting capacity than locations at the end of the feeder line. The presence of DERs does not always result in negative impacts. For example, if the end of a radial feeder line is challenged to maintain adequate voltage, the development of DERs with appropriate controls may be able to alleviate the situation.
- **Substation-level hosting capacity.** The hosting capacity at a substation serving several feeders may or may not be the sum of the feeders' capacities. Determining substation hosting capacity helps to inform analysis of the bulk power system and analysis of overall supply adequacy and system reliability.
- **Energy consumption and loss impacts.** The levels of DER on a feeder affect the loading of the feeder which influences distribution system losses. For example, the high end of voltage operating windows results in higher line losses. If distributed generation causes higher current flowing back to the substation than the original load, line losses will increase in that condition. The operations of equipment along a feeder, such as the frequency of changes in voltage tap regulators, can also be affected by additional DER. Sometimes relatively simple solutions are available, whereas in other cases more expensive changes in the system are required.
- **Asset deferral.** The development of well-integrated DER can help to alleviate the need for distribution and substation capacity upgrades.

This type of analysis is already taking place at many leading utilities. An example of asset deferral is Consolidated Edison's Neighborhood program, which aims to defer the need for a $1.2 billion substation upgrade with investments in demand response and distributed resources.[49]

[48] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework" (Electric Power Research Institute, February 2015), http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004878.

[49] G. Bade, "ConEd Awards 22 MW of Demand Response Contracts in Brooklyn-Queens Project," *Utility Dive,* August 8, 2016, http://www.utilitydive.com/news/coned-awards-22-mw-of-demand-response-contracts-in-brooklyn-queens-project/424034/.

Data from Pepco distribution analysis shown in **Figure 25** echoes the EPRI study results:

- The ability of distribution feeders to accommodate solar varies widely and the average may not be meaningful.
- Some feeders have a high capacity to interconnect solar without any upgrade cost

Ideally, solar installations would be focused on feeders in the lower right corner of the graph, but without investing in studying each feeder's electric and loading characteristics, we do not know where feeders would appear on the chart. A utility stakeholder suggested patterns might emerge in this data if more information on the circuits were available. He expects that higher voltage feeders have higher hosting capacity.

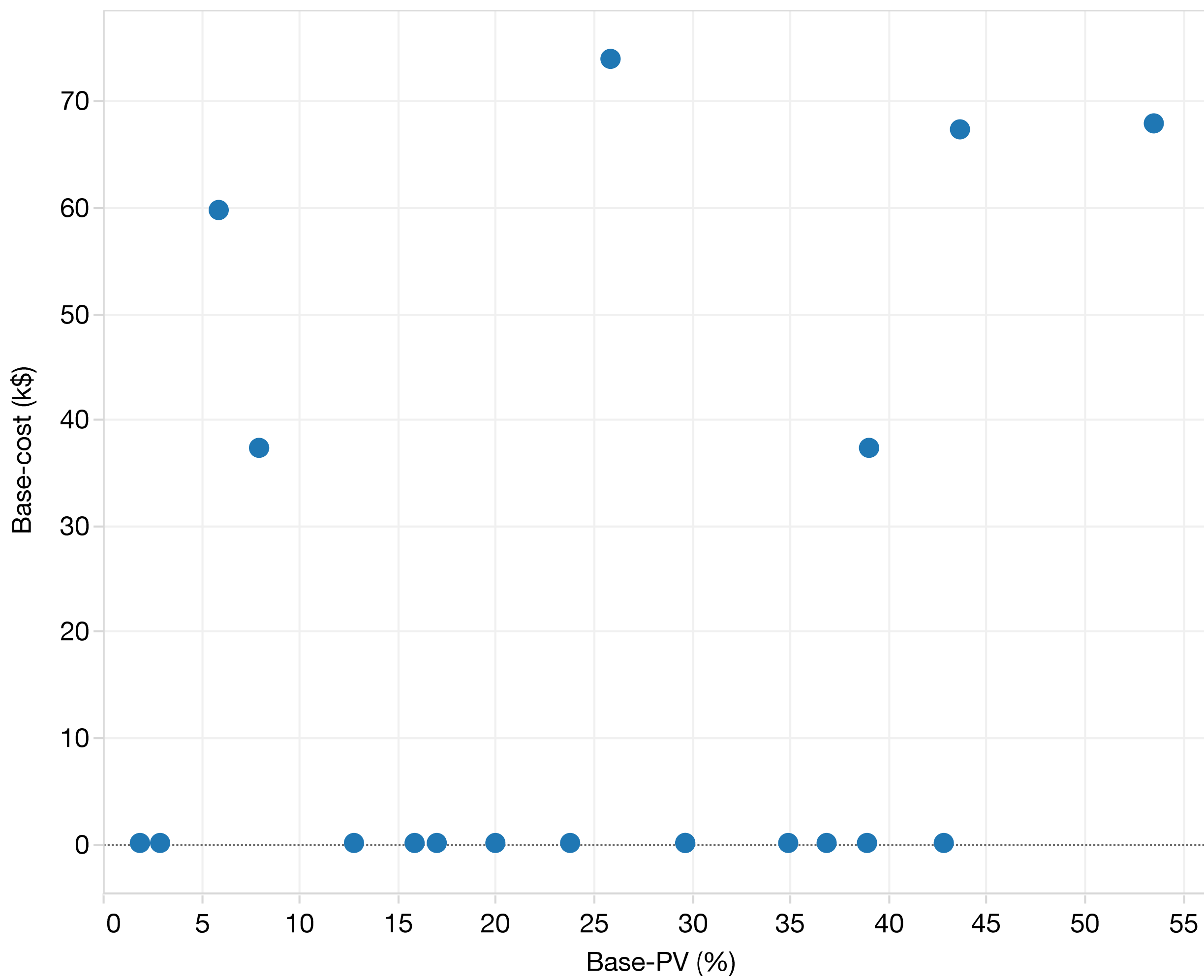

Figure 25. Solar capacity as a percentage of feeder rated capacity versus distribution system upgrade cost, the base case before optimizing for PV. Data from Pepco analysis is presented as part of "Preparing for a Distributed Energy Future: What Can Be Done Today to Integrate DERs Cost Effectively."[50]

[50] Walter Rojowsky, Steve J. Steffel, and Steve Propper, *Preparing for a Distributed Energy Future: What Can Be Done Today to Integrate DERs Cost Effectively* (Greentech Media, 2016),

Navigant performed similar analysis for the Virginia Solar Market Pathways project.[51] This analysis had similar results and showed that many feeders can host relatively high solar penetration without any upgrades. Very high solar penetration that generates power beyond the local needs and pushes power back onto the transmission or sub-transmission grid is likely to require utility upgrades.

Both of the Pepco and Navigant analyses also show that some feeders can host zero or small amounts of solar before requiring upgrades.[52] This highlights the needs for strategic siting. Vermont has many opportunities to apply these analyses in its siting practices.

In the typical process, a homeowner, business, or solar developer designs a solar system, applies for a permit (in Vermont it is a Certificate of Public Good) and applies for interconnection with the utility. If the project requires the utility to upgrade their equipment, the project is charged for the cost of that upgrade.

Stakeholders discussed two problems with this approach: First, it is inefficient and wastes system design time when cost-effective interconnection is not possible. Second, it may fully burden one project with upgrade costs that were partially caused by the systems that came before it, and systems that come later may get free use of the newly added hosting capacity.

Green Mountain Power provides potential developers with a Solar Map,[53] a section of which is shown in **Figure 26** that gives an initial indication of where projects are more or less likely to have high interconnection costs. This initial hosting capacity analysis has been helpful to guide development away from areas already constrained, but it is fairly simplistic. In 2017, GMP will implement circuit-level modeling to create a proactive distribution plan for every GMP circuit.

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https://www.greentechmedia.com/events/webinar/preparing-for-a-distributed-energy-future-what-can-be-done-today-to-integra.

[51] Navigant Consulting, "Virginia Solar Pathways Project, Study 1: Distributed Solar Generation Integration and Best Practices Review," April 30, 2016. http://solarmarketpathways.org/wp-content/uploads/2016/09/DVP_DG-Transmission-and-Distribution-Grid-Integration-Study.pdf.

[52] Vermont's long and lightly loaded rural feeders may be different from those studied. Results from the Grid Modernization study by Sandia will help the Team and stakeholders understand more about Vermont's feeders.

[53] "Solar Map," Green Mountain Power, accessed September 21, 2016, http://www.greenmountainpower.com/innovative/solar/solar-map/.

Figure 26. GMP's Solar Map shows areas of the grid that have capacity, are approaching the limit, or have little to no capacity available.

In new net-metering rules for 2017, Vermont added a siting incentive to encourage solar installations on buildings and disturbed land. A similar incentive could encourage siting based on the needs and capabilities of the distribution system. Publically available information about the needs of the grid could also encourage strategic siting. If a grid siting incentive were used, it should be fair, predictable, and should not unduly influence land values.

In addition to analysis and upgrades, the utilities can do to estimate and increase solar hosting capacity, technology on the project side of the meter increases capacity by reducing the project's impact. Advanced, or smart, inverters will become an important tool in reducing the impact of so much solar on the grid. The standard for their operation was not yet available in 2016, but by 2025 these inverters could alter their voltage in support of the grid and remain steady during short-term frequency fluctuations, thus helping avoid what one stakeholder described as "the largest power plant in the state cycling on and off as clouds pass." Additional improvement is available through load management and storage.

Bulk Power System Integration

Looking at Vermont as a whole, high levels of solar generation can cause different issues. Solar generation varies in predictable and less predictable ways according to the position of the sun and the weather. While solar generation prediction software is rapidly improving, the bulk power system must provide adequate, complementary generation. This report summarizes potential issues on the bulk power system and explores how Vermont's system might be affected.

As detailed in a recent EPRI report, bulk power system impacts can include the following: [54]

[54] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework."

- **Resource adequacy.** Are the existing and planned generating capacity levels sufficient to meet demand? For renewable resources, the daily and seasonal variability in output and the matching of generation to demand load shapes need to be considered. The National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS) system provides a national-level visualization of scenario modeling illustrating the mapping of generation loads and transmission in a high renewable energy future.[55]
- **Flexibility assessment.** The intermittent nature of solar and wind resources increases the need for resources on the system that are sufficiently flexible to adapt to increased ramping up and down.
- **Operational scheduling and balancing.** Operational processes and market structures to allow for adequate balancing of supply and demand, given the reliability, safety, and power quality standards and requirements.
- **Transmission system performance, deliverability, and planning.** Analysis and planning that considers constraints and congestion on the delivery of power on the transmission system. Increased renewable generation might result in generation that is both closer to load (in the case of DERs) and more distant from it (for example, large wind resources).

As levels of DERs increase and electrification of heating and transportation services changes the timing of demand, impacts from the distribution and sub-transmission levels affect the transmission system. Therefore, iterative analyses and planning processes are often required for a comprehensive assessment.

The Team simulated Vermont's electricity demand and supply in 2025 to look for these issues and determine the amount of flexible demand, storage, or additional supply needed. Using hourly data described in **Table 2** of **Volume 4,** the Team compared the sum of renewable and contracted supply to the forecast demand. The demand shape is from 2013, but is increased to reflect expected electrification.[56] **Figure 27** shows three sample days from the SDP scenario in 2025. When presented with similar graphs, **the utility stakeholders were not especially concerned with the mismatch between demand and supply;** they manage similar daily mismatches today using the regional spot market for wholesale electricity. The January day shows especially low generation, with both wind and solar at low levels. Large-scale storage such as pumped hydropower or additional winter supply might be necessary to manage extended periods of low renewable output.

One stakeholder noted that in times of low load and high solar, such as the example April day, the market price for power is likely to be low because the rest of the region, especially Massachusetts, would be experiencing the same situation. The excess power could sent the wholesale price of electricity below zero. Thus, selling the excess energy to other parts of New England might not be a good strategy. The supply mix is able to meet demand on the July

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[55] Mai, T. et al., "Renewable Electricity Futures Study: Executive Summary" (Golden, CO: National Renewable Energy Laboratory, 2012), http://www.nrel.gov/analysis/re_futures/.

[56] This increase in loadshape reflects the early stages of electrification. Further analysis should include additional electrification, and have increases reflect the loadshapes of heat pumps and electric vehicles as data becomes available.

summer peak, but solar output decreases much more quickly than demand. In the figure, the dispatchable wood+biogas plants turn off during the short midday period that would otherwise have over-generation. Given the deficit all afternoon, the wood+biogas could continue running midday to pre-cool homes and buildings and charge batteries in preparation for the afternoon.

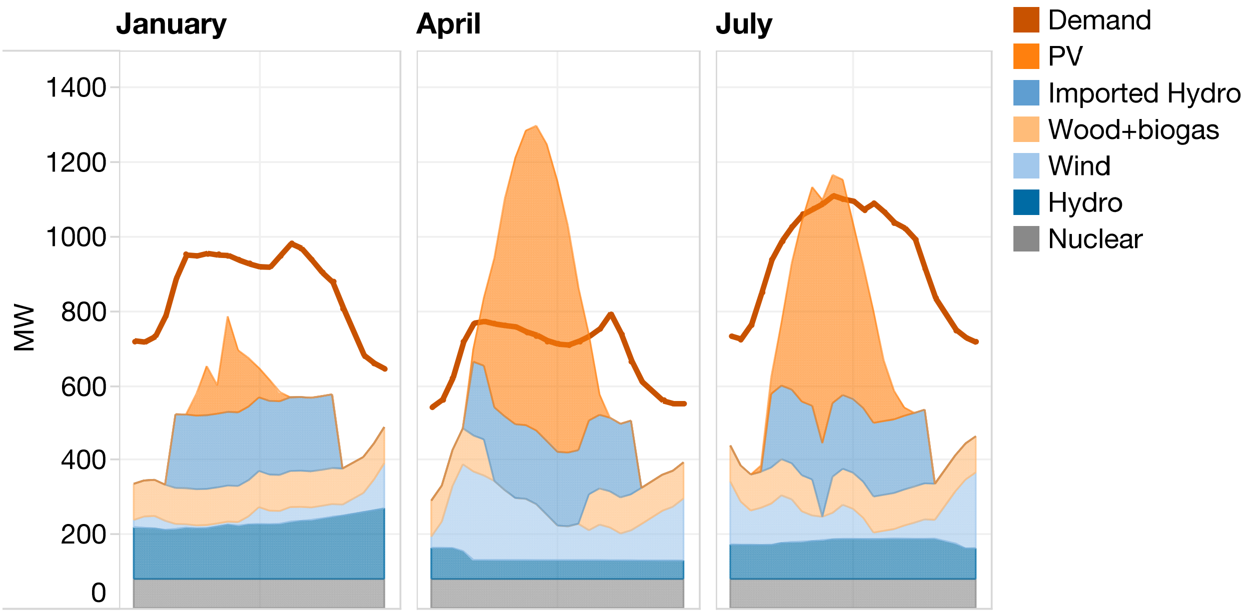

Figure 27. Projected supply and demand in 2025 show sample days with under-supply and over-generation. The January day suffers from a lack of wind and solar generation. The April day has lower load, some wind, and a lot of solar, creating 600 MW of excess capacity. The situation would be even worse if hydro was at a typical spring high. On the July day, supply matches demand in the afternoon.

Using the year of hourly data, the Team calculated the "imbalance" between demand and supply, defined as the sum of contracted supply and renewable output minus gross demand. In **Figure 27**, deficit imbalance is the white space below the demand line and above the stacked supply, and surplus imbalance is the area of supply above the demand line.

Optimal strategies for dealing with imbalance depend on the magnitude (MW), duration (hours), and the product of those, the energy imbalance in megawatt-hours. The choice of strategy also depends on proximity to an opposite balance, e.g. oversupply is easy to use effectively if it happens just before a period of shortage since the excess could be used for pre-cooling or pre-heating buildings and charging batteries. **Figure 28** shows the imbalance for each of the days in **Figure 27** and for the two days before and two days after. Unfortunately, this shows that the difficult conditions on the January and April days are the predominant conditions for several days. This limits the effective balancing strategies to additional generation or purchase, curtailment, or long-term storage. The days surrounding the sample July day offer a better balance of surplus and deficit conditions that offer more strategies.

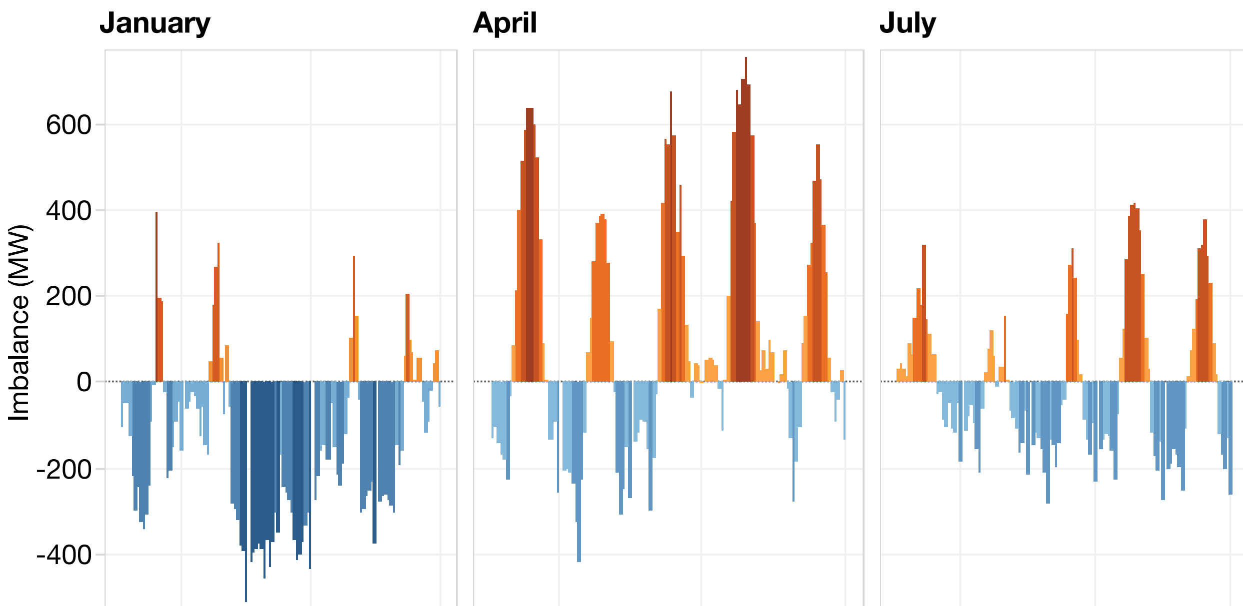

Figure 28. The demand/supply imbalance for each of the sample days above and two days before and after, show that the daily imbalance can be the prevailing condition for several days during the most challenging times of year.

To help determine whether investments in long-term storage or new generation are warranted, and if curtailment should be included in renewable energy financial planning, planners need to estimate how often each of these imbalance conditions occurs. The sample days were chosen because of the difficulty they presented, not because they characterize average days. The examples could be thought of similar to today's peak conditions—important but infrequent. **Figure 29** presents the year's imbalance in the shape of a load duration curve, one for daylight hours, and one for dark hours. Predictably, there is much more surplus during daylight.

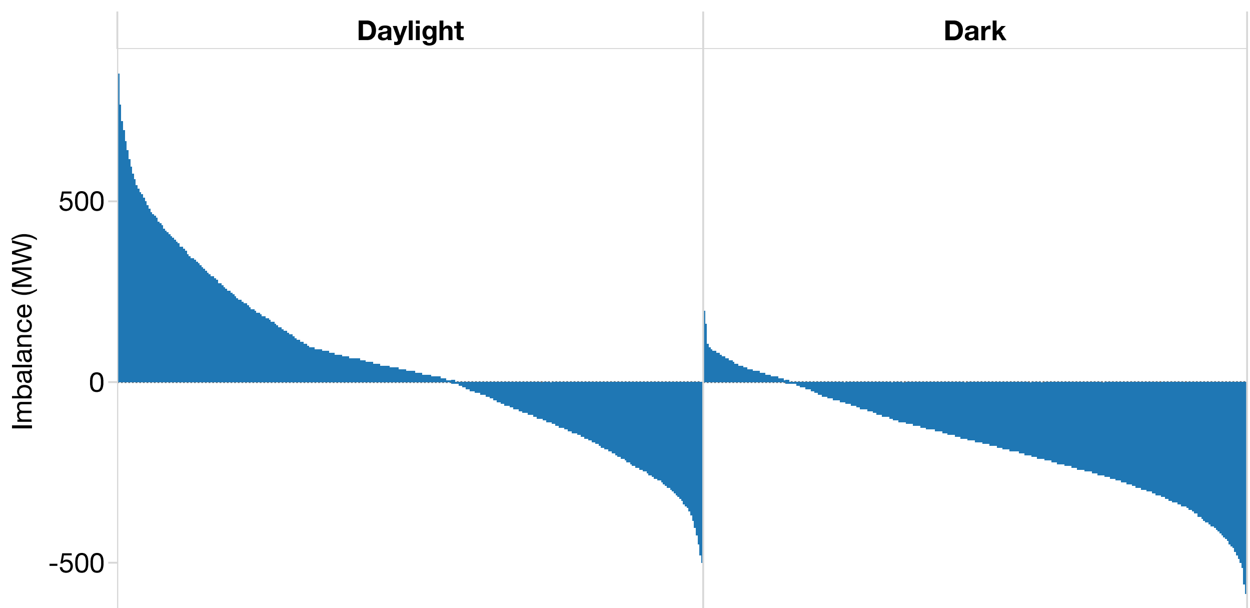

Figure 29. Imbalance Duration Curve by Daylight and Dark.

Figure 30 categorizes the imbalances in ways that inform the solutions: **Figure 30 A** shows that in the sample year, nearly all imbalances last for less than 25 hours, though a deficit can last for more than 80 hours and a surplus can last for more than 40 hours. Battery storage and demand management could likely address the most common, shorter duration imbalances. **Figure 30 B** provides a histogram of the magnitude of the imbalances. Most surplus imbalances are not more than 80 MW, and deficits commonly range up to 400 MW. The dual peak is because of the 97 MW of wood+biogas that is dispatchable in this model. **Figure 30 C** is the histogram for the energy of each imbalance period. Most surpluses and deficits are less than 500 MWh; deficits have a larger range of MWh than surpluses.

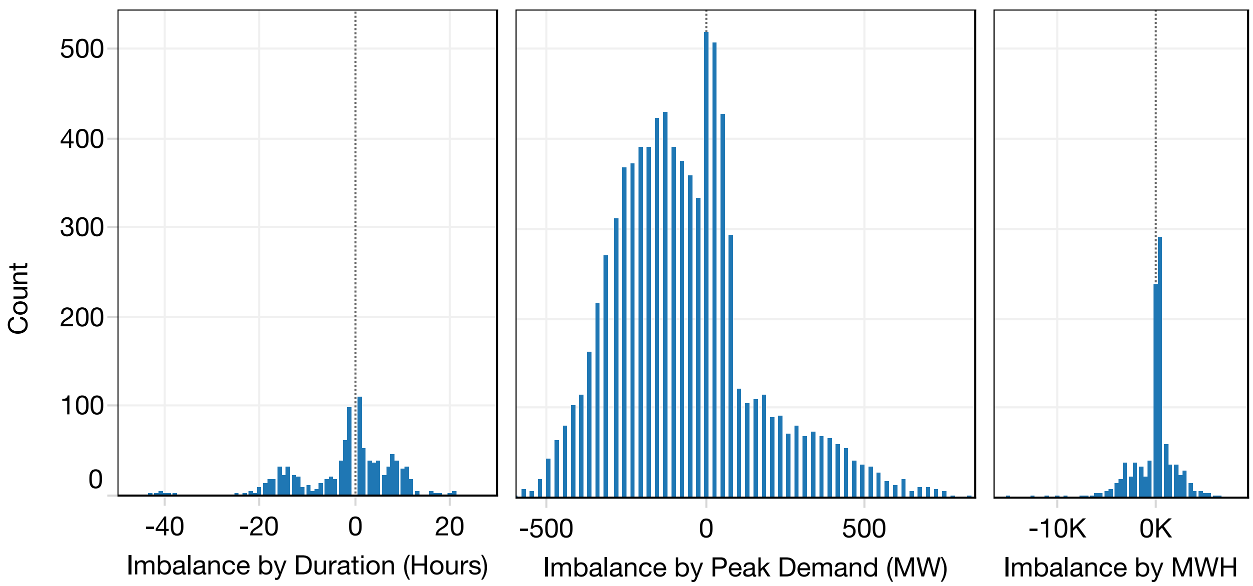

Figure 30. A. Imbalance by Duration (hours). B. Imbalance by Peak Demand (MW). C. Imbalance by MWH.

Smart Grid, Demand Management, and Storage

The smart grid offers opportunities to integrate improved forecasting (of weather, load, and generation) with grid system operations and management. The Vermont Weather Analytics Center, a collaboration between VELCO, IBM, GMP and others, is providing this type of cutting edge information today. Demand management through distributed customer-level equipment and devices can work with batteries and other forms of storage to enhance the capacity of the grid to support higher saturations of intermittent solar PV generation. The following are attributes of and future considerations for smart grid, demand management, and energy storage:

- The smart grid allows standards-based, real-time communication with inverters and generation meters. It also allows communication with responsive loads and storage (for example, electric vehicles, pre-heating and cooling, peak demand management). This communication and coordination helps manage the localized and system wide variability of PV system supply.
- As battery prices drop, "grid-scale" storage and distributed storage will be part of the smart grid capability to coordinate and optimize site and system energy.
- The location of controllable loads and storage, relative to sources of generation, will begin to matter at a certain level of solar penetration. It is important to note that location

will not be a primary concern for grid balancing, at first. However, the value of storage and demand response will vary by location, even in the relatively early stages. It is likely the variation in locational value will increase as saturations increase, overall.

- Providing sufficient system status, control, and forecast networks to distributed generation, controllable load, and storage will be challenging and must address concerns with cybersecurity and privacy protection.
- New rates models and interconnection rules and processes will likely be needed to fully realize the public and private cost savings potential of smart grid and energy storage. New utility regulatory paradigms which incentivize on-peak renewable generation and investments in non-traditional resources needed to decarbonize the grid may further bolster cost savings. Ensuing that utilities can recover the related investments in IT is also important.
- Smart grid, demand management, and storage can collectively provide insight into costs by location and time of use, to reflect the true cost and value of solar generation.

Business Models

The following two sections present several options for how business models and regulatory oversight can evolve in ways that are consistent with and supportive of an advanced solar economy. These are examples and are not meant to be prescriptive, or as predictions of the business and regulatory models that will necessarily emerge. The business models and regulatory structures associated with the actual development of Vermont's advanced solar economy will by necessity be informed and influenced by new market conditions and the process of public and stakeholder engagement, negotiation, and review.

Solar business models. The scenario analyses indicate that a mix of business approaches to solar projects will be required to accomplish the Solar Development Pathways target**.**

Individually and third-party-owned rooftop and ground-mounted systems will provide consumers with the opportunity to host or own solar generation on their properties. In the SDPα scenario, the share of solar expected to be located on site, in ground, and / or as rooftop systems is roughly 300 MW, by 2025.

Vermont's virtual net metering regulations enable **community solar,** one of the more rapidly evolving markets. Community solar allows a single system to provide credits for solar generation to virtually net-metered groups of customers who reside in the same utility service territory. Innovation, research, and market testing for community solar business models, including those offered by third parties and those offered directly by utilities, are under way in Vermont. This is also true of other parts of the country. Several of the other national Solar Market Pathways projects have community solar as integral components to their awards (the Solar Market Pathways projects addressing community solar are the Solar Electric Power Association, Cook County, the Center for Sustainable Energy, and Extensible Energy). Further, a community solar affinity group has been established to share information.[57] The U.S. Department of Energy has also launched a national community solar partnership with a specific emphasis on serving moderate- and low-income households. The White House announced this initiative on July 7, 2015.[58] In the SDPα scenario, the share of solar expected to be allocated to community solar is roughly 300 MW by 2025, with the majority of this being ground mounted.

The rooftop and community solar installations are based on principles of both direct and virtual net metering, and therefore offset consumption at retail electric rates. **Projects that have direct power purchase agreements with utilities** are also expected to play an important role in the growing market. Under Vermont's Standard Offer Program, projects of up to 2.2 MW are eligible for long-term contracts. Once online, these projects are made publicly available on the Vermont Standard Offer website.[59] Another option for larger projects is to apply for long-term contracts under Rule 4.100, Vermont's Small Power Production and Cogeneration structure for implementing the federal Public Utility Regulatory Policies Act (PURPA). Recently, the Vermont Public Service Board and VELCO received applications for several projects that are much larger (20 MW each) than what has currently been built in Vermont.[60] The process for review and interconnection of projects at this scale is not yet clear, but it indicates how evolving market strategies and business models will likely influence the technical and regulatory issues, and vice versa.

Complementary DER business models. Several distributed energy resources will enable, help to drive, and be driven by increasing solar saturation. The primary resources are storage (customer on-site, and storage located on the utility distribution system); electric vehicles with smart charging and vehicle-to-grid enabled capacities; controllable customer loads such as heat pumps, hot water heaters; and high-performance zero energy buildings, including high-performance modular housing. This project explicitly recognizes the importance of these markets and technologies through its Focus Area working groups. The project scenarios are examining the potential scale of development and potential barriers to progress in each.

Research conducted in Europe for the Power Perspective 2030 study illustrates the importance of integrating other DERs as part of the advanced solar scenarios.[61] These findings indicate that a shift of 10 percent of aggregate demand in a day results in a 20 percent reduction of investment required in the supply side infrastructure over a 15- to 20-year horizon.[62]

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57 "Solar Market Pathways," *Department of Energy: Office of Energy Efficiency & Renewable Energy*, accessed September 22, 2016, http://energy.gov/eere/sunshot/solar-market-pathways.
58 "National Community Solar Partnership," *Department of Energy*, accessed September 22, 2016, http://energy.gov/eere/solarpoweringamerica/national-community-solar-partnership.
59 Vermont Electric Power Producers, Inc., "SPEED Solar Online Projects - Comparison DC/AC" (Vermont Standard Offer, April 24, 2015), http://static1.1.sqspcdn.com/static/f/424754/26167074/1429817055967/SOLAR+AC-DC+ON+LINE+PROJECTS+4-24-15.pdf?token=1Yt%2FAygme2klyXP2dW2SjliFs2M%3D.
60 Erin Mansfield, "State Concerned about Proposal for Giant Solar Project," *VTDigger*, September 8, 2015, http://vtdigger.org/2015/09/08/state-concerned-about-proposal-for-giant-solar-project/.
61 Christian Hewicker, Michael Hogan, and Arne Mogren, "Power Perspectives 2030: On the Road to a Decarbonised Power Sector," accessed September 22, 2016, http://www.roadmap2050.eu/reports.
62 Ibid.

The distributed and networked attributes of the technologies contributing to an advanced solar economy increase the need and opportunities for aggregation of energy services. Community solar is one example. Another is aggregation of electric vehicles for coordinating charging or vehicle-to-grid services. The scale of service and value from an individual vehicle or other DER, such as an electric water heater, is not large enough to justify individuals' participating in a market. However, through aggregation, the coordination and value from a larger number of devices can be captured. Innovative approaches to aggregation can be combined. For example, through the coordination and aggregation of electric water heaters, a community solar power project in West Virginia was able to generate revenues sufficient to fund the investment required for installation of a community solar array on roof of the local church.[63]

Addressing Low-Income People: A Societal Imperative

A 2014 analysis by the Vermont Law School has sharpened statewide awareness of high-energy burdens on low-income households in Vermont.[64] The study found that those who spend more than 10 percent of their monthly income on energy services are considered "fuel poor." Further:

- One in five Vermonters lives in fuel poverty.
- People who lack sufficient energy to keep warm in winter face a higher-than-average risk of stroke, heart attack, influenza, pneumonia, asthma, arthritis, depression, anxiety, and accidents in the home.
- Between 1999 and 2011, Vermont averaged 172 excess winter mortalities per year.
- Annual excess winter deaths caused largely by fuel poverty account for more Vermont deaths than do car crashes.

It is a tenet of energy efficiency and renewable energy advocates that reducing the energy burden for people at risk strengthens economies. This message has relevance for the Vermont Solar Market Pathways stakeholders.

Of particular importance will be explicit goals for reducing the energy burden (the total costs for energy services as a percent of household incomes) for low- and moderate-income households.

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[63] "Shepherdstown Presbyterian Church," *Solar Holler, Inc.*, accessed September 22, 2016, http://www.solarholler.com/shepherdstown-presbyterian-church/.

[64] Teller-Elsberg, Jonathan et al., "Energy Costs and Burdens in Vermont: Burdensome for Whom? A Report for the Vermont Low Income Trust for Electricity, Inc." (South Royalton, VT: Institute for Energy and the Environment at Vermont Law School, December 2014), http://www-assets.vermontlaw.edu/Assets/iee/VLS%20IEE%20Energy%20Burden%20Report.pdf.

Building practices and systems, such as the high-performance modular home (see sidebar on the model for affordable living) will help shift the retail energy market from one that is concerned about annual energy operating costs to one concerned about investment opportunities in new construction and retrofits. **Figure 31** illustrates how the efficient construction practices and energy systems reduce consumption and result in lower total costs.

A Model for Affordable Living

Highly efficient housing and end use services will be prevalent in Vermont's advanced solar economy. So will be an attention to the nexus of energy security for low- income and at-risk populations and community-level economic security.

High performance modular housing in Vermont offers the highest levels of indoor air quality, building durability, energy system integration and monitoring. A continuous energy recovery ventilation (CERV) system and other high-performance systems, design, and construction give these units an average annual energy intensity of less than 27 kBtu / sq. ft. (regional average = 55 kBtu). www.vermodhomes.com.

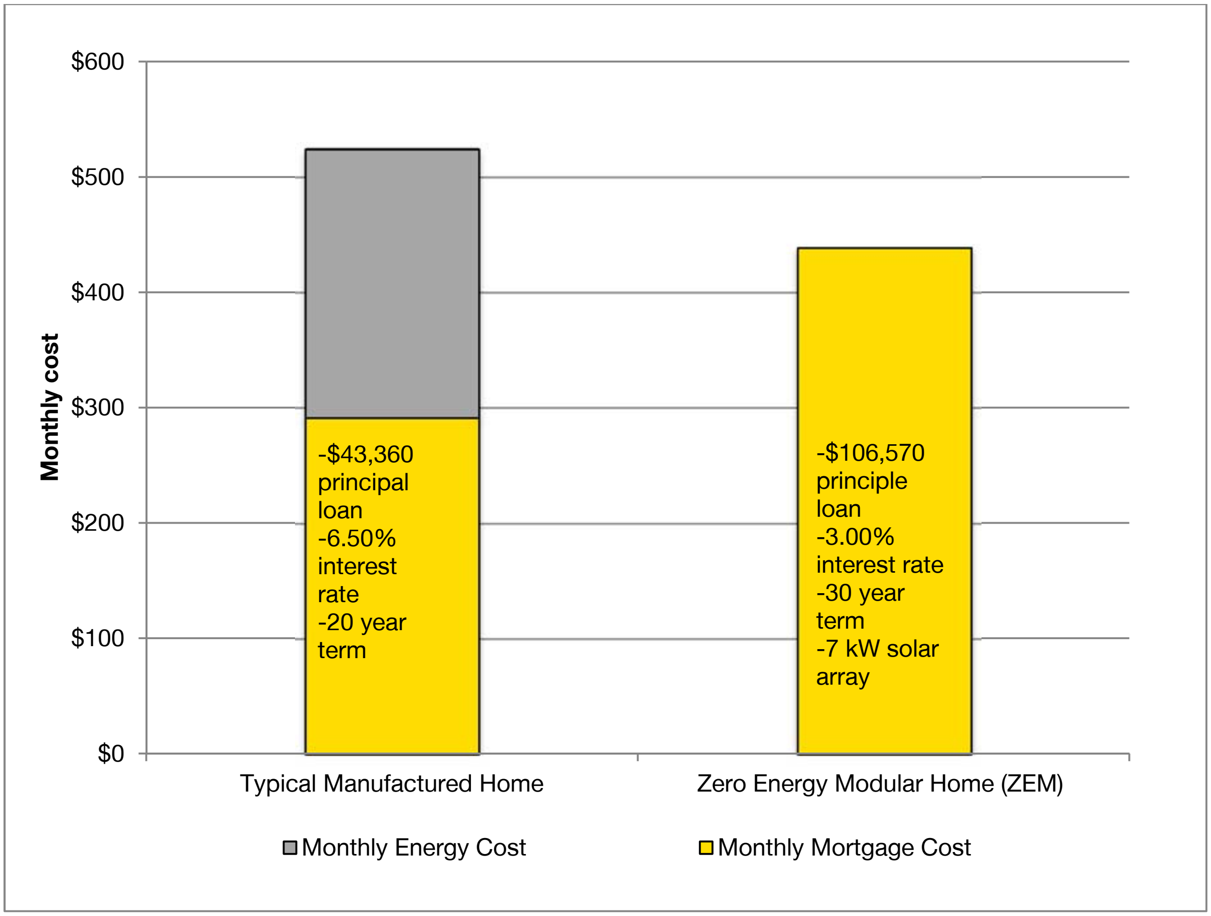

Figure 31. Comparison of total carrying costs for a typical manufactured home and a zero energy modular home.

Utility Business Model

The advanced solar economy opens the door to a wider range of customer service offerings for utilities, and can expand the portfolio of investments on the supply side of the customer's meter—and the demand side.

Current proceedings in California and New York, requiring the distribution utilities to develop and submit distributed energy resource plans, are an example of regulatory expansion of the scope of resources conventionally considered in distribution planning. In other cases, including examples from Vermont, utilities are offering incentives, financing, and leasing for equipment such as on-site storage, heat pumps, and solar generating equipment. These technologies have the potential for coordinated control and operations.

The distribution utilities may also have business opportunities related to the investments required to

What do "innovative grid services" look like?

Advanced, detailed meteorological forecasting—paired with operation and control of DER assets—are an example of the innovative, value-adding service that grid operators could provide. This can happen if they collaborate with partners, or if they invest in creating this kind of asset, in house.

support higher levels of saturation on the distribution system, whether these entail upgrades to distribution operation, communication, and control schemes—or direct investment in solar generation that is strategically sited on the distribution network.

The procurement of solar and other DERs and their inclusion in a utility's portfolio will affect the requirements for the balance of the portfolio. For example, they might require other power supply contracts to provide a higher level of flexibility.

Integrating and controlling a large number of DERs and solar will require greater visibility, communications, and control of resources. The required services might be provided by third parties, or directly by distribution and transmission system operators. A study conducted for the California grid operator, CAISO, estimated that the benefits from enhanced visibility and control of DERs far exceed the costs associated with the required costs for the communications and other required infrastructure.[65] Though dated and for a different market, this study might provide a first estimate of what Vermont may see with higher renewable saturation.

4.2 Regulatory Considerations

In some ways, Vermont's advanced solar economy will have a retail market structure that is similar to what we know today. Consumers will still receive basic electric service from a regulated utility under tariffs reviewed and approved by regulators. The tariffs will cover the costs of providing reliable grid service and commodity electricity. The service provided to the retail consumer will progressively reflect economic and environmental policy objectives by increasing the share of renewable resources in the electricity mix.

The mix of ownership of DER assets will vary across time and will be likely to vary from territory to territory, since the assets are tied to local conditions, priorities, and entrepreneurial assets. This progression from more to less regulated DER ownership is seen in **Figure 32**.

[65] KEMA, Inc., National Renewable Energy Laboratory, and Energy Exemplar, LLC, "Final Report for Assessment of Visibility and Control Options for Distributed Energy Resources" (California Independent Systems Operator Corporation, June 21, 2012), https://www.caiso.com/Documents/FinalReport-Assessment-Visibility-ControlOptions-DistributedEnergyResources.pdf.

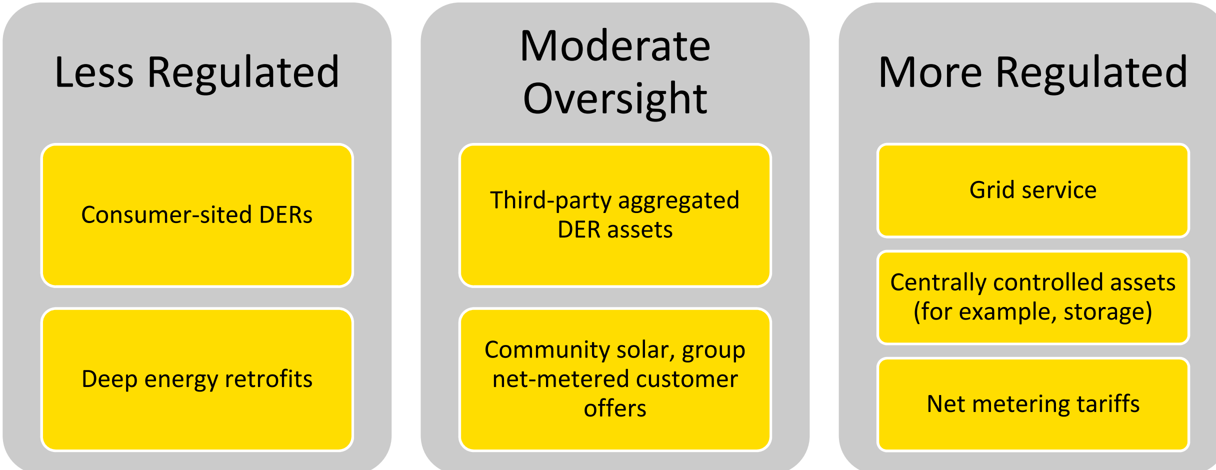

Figure 32. The array of options for consumer support services, under different regulatory levels, in a total service system.

Consumers will also benefit from, and have access to, services provided by a regulated public-benefit DER entity whose mission is to provide consumer support and market facilitation for distributed energy resources—primarily energy efficiency, renewable on-site generation, demand response, load shaping, and storage. We refer to this as a *consumer support entity.* The regulatory and policy oversight for both the grid services and consumer support entities will involve performance indicators and regulator-set metrics addressing the environmental and social economic impacts of energy consumption. The interaction of this type of entity is shown in **Figure 33**.

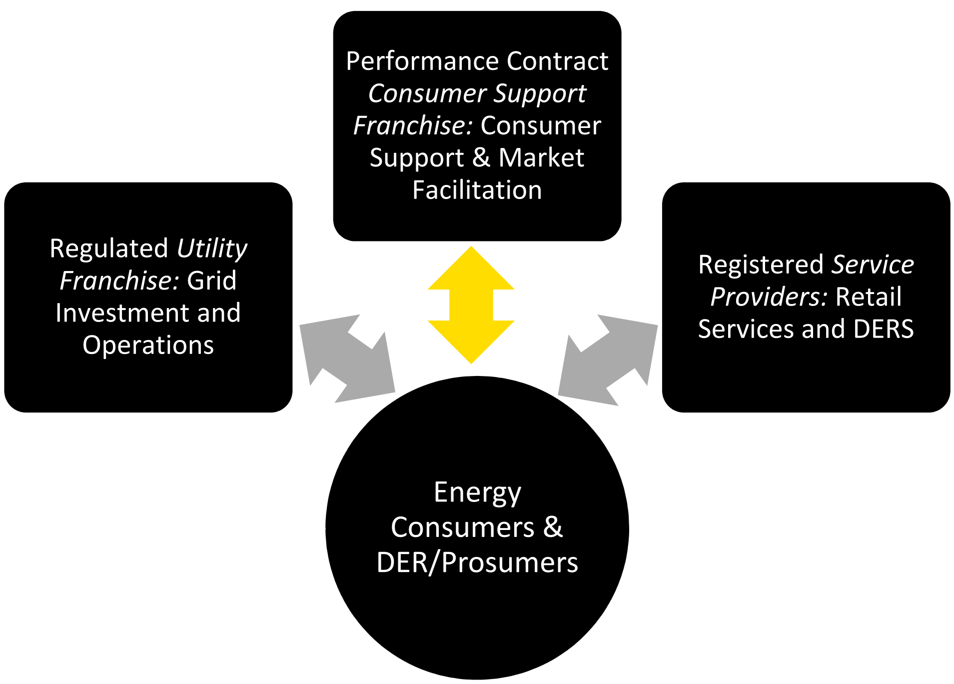

Figure 33. The relationship of various services and service providers in a new utility framework.

One reason to employ a "looking backward from the end" approach is that utility business models can change rapidly, greatly influencing the mechanisms for reaching solar goals. Currently, utilities provide electric power, maintain electric delivery infrastructure, and receive compensation from the rate of return on infrastructure upgrades. This system motivates utilities to sell more power and encourage infrastructure investments. A new utility model, in which utilities are compensated for creating and maintaining a clean, safe, reliable, and efficient grid is possible and will be invaluable in supporting an advanced solar economy.[66] Vermont utilities are already each creating innovative paths while adding new renewable energy. For example, GMP is piloting projects to install utility-operated batteries in homes that stabilize the grid while also benefiting homeowners by providing backup.[67]

[66] Scudder Parker and Jim Lazar, "The Old Order Changeth: Rewarding Utilities for Performance, Not Capital Investment," 2016 ACEEE Summer Study on Energy Efficiency in Buildings, http://aceee.org/files/proceedings/2016/data/papers/6_474.pdf

[67] "TESLA Powerwall," *Green Mountain Power*, accessed December 30, 2016, http://products.greenmountainpower.com/product/tesla-powerwall/.

Looking Forward

The most important conclusion of this study is that solar can provide 20 percent of Vermont's electricity by 2025, and can do so with costs that are less than 1 percent of total annual energy expenditures. Over the longer term, through 2050, the study analyses suggest net economic benefits from investing in Vermont's advanced solar economy are in the billions of dollars.

The Team and stakeholders have considered the most commonly cited limitations of solar—primarily cost, space requirements, and intermittency. They concluded it is possible and profitable to overcome those limits and move toward a future in which more of Vermont's energy comes from its own renewable sources, owned by Vermonters. In addition to cleaner air and billions of dollars a year stopped from leaving the state, there are co-benefits from enhanced affordability, occupant health, and building durability and resilience.

The study also highlights that more than one way to reach the end state exists and that further political, regulatory, and business planning work are all necessary. In places throughout this Summary Report, we have offered possible visions of business models and / or regulatory structures to help catalyze and advance the conversation.

Some elements are not in place, and some that are in place will evolve or disappear.

There will be changes not included in any of the analyses that will have important implications.

Nevertheless, there is a strong likelihood of economic and environmental benefits from a consumer-oriented, modernized system that reaches or surpasses the elements of Vermont's becoming an advanced solar economy.

Although there are many possible paths to a sustainable energy future, a continued reliance on imported fossil fuels supports destructive climate change, social inequality, and a continuous drain on the Vermont economy. Vermont has the opportunity to continue its longstanding environmental leadership and to demonstrate success in high-penetration solar and a transition to renewable total energy. The state can do this, while strengthening its economy.

The foundation is set; the work and the opportunity are just beginning.

Abbreviations and Acronyms

Abbreviation or acronym	Description
AMI	Advanced Meter Infrastructure
ARRA	American Recovery and Reinvestment Act of 2009
AWD	All Wheel Drive
BAU	Business-as-usual
BCRC	Bennington County Regional Commission
BED	Burlington Electric Department, the utility that serves the state's largest city
CAFE	Corporate Average Fuel Economy
CAISO	California Independent System Operator
CCF	hundreds of cubic feet
CEDF	Vermont Clean Energy Development Fund
CEO	Chief Executive Officer
CEP	Comprehensive Energy Plan
CESA	Clean Energy States Alliance
CNG	Compressed Natural Gas
COP	Coefficient of Performance
DER	Distributed energy resource
DHW	Domestic Hot Water
DOE	Department of Energy
DPS	Department of Public Service
DRP	Demand Resources Plan
DSM	Demand-Side Management
EEU	Energy Efficiency Utility
EIA	U.S. Energy Information Administration
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EVSE	Electric Vehicle Supply Equipment
FACETS	Framework for Analysis of Climate-Energy-Technology Systems
FIT	Feed-in Tariff
GHG	Greenhouse Gas
GMP	Green Mountain Power, the state's largest utility and its only investor-owned utility
GW	Gigawatt, a unit of power demand; 1 GW is about equal to Vermont's peak demand
GWh	Gigawatt-hour, a unit of energy demand equal to one gigawatt of power for one hour
GWP	Global Warming Potential
HDV	Heavy Duty Vehicle
HOV	High Occupancy Vehicle
HPH	High-Performance Home

Abbreviation or acronym	Description
HPMH	High-Performance Modular Home
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
ICE	Internal Combustion Engine
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor-owned utility
ISO-NE	Independent System Operator, New England
ITC	Investment Tax Credit
LDV	Light Duty Vehicle
LEAP	Long-Range Energy Alternatives Planning System
LIHEAP	Low-Income Home Energy Assistance Program
LLC	Limited Liability Corporation
LPG	Liquefied Petroleum Gas (Propane)
MACRS	Modified Accelerated Cost-Recovery System
MMBTU	Million British Thermal Units
MW	Megawatt, a unit of power demand; in Vermont, 1 MW is equal to the energy demand of approximately 500 homes
MWh	Megawatt-hour, a unit of energy demand equal to one megawatt of power for one hour
NARUC	National Association of Regulatory Utility Commissioners
NREL	National Renewable Energy Laboratory
NYPA	New York Power Authority
PHEV	Plug-in Hybrid Electric Vehicle
PPA	Power purchase agreement
PSB	Public Service Board
PURPA	Public Utility Regulatory Policies Act
RAP	Regulatory Assistance Project
RBES	Residential Building Energy Standards
REC	Renewable Energy Credit
RECS	Residential energy consumption survey
RESET	Renewable Energy Standard and Energy Transformation, Vermont RPS
RFS	Renewable Fuel Standard
ROI	Return on investment
RPC	Regional Planning Commission
RPS	Renewable portfolio standard
SDP	Solar Development Pathways, advanced solar scenario
SEP	Smart Energy Profile
SEPA	Smart Electric Power Alliance

Abbreviation or acronym	Description
SPEED	Sustainably Priced Energy Enterprise Development
SPEED	Sustainably Priced Energy Enterprise Development
SRECs	Solar Renewable Energy Credits
SSREIP	Small Scale Renewable Energy Incentive Program
TBD	To Be Determined
TES	Total Energy Study
TOU	Time-of-Use
TREES	Total Renewable Energy and Efficiency Standard
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey
VAR	Volt-Ampere Reactive
VEC	Vermont Electric Cooperative, the state's 3rd-largest utility
VEIC	Vermont Energy Investment Company
VELCO	Vermont Electric Power Company
VMT	Vehicle Miles Traveled
VSPC	Vermont System Planning Committee
WEC	Washington Electric Cooperative, the state's 4th-largest utility
ZEM	Zero energy modular home
ZEV	Zero Emission Vehicle

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Rep. Rebecca Ellis	Legislature
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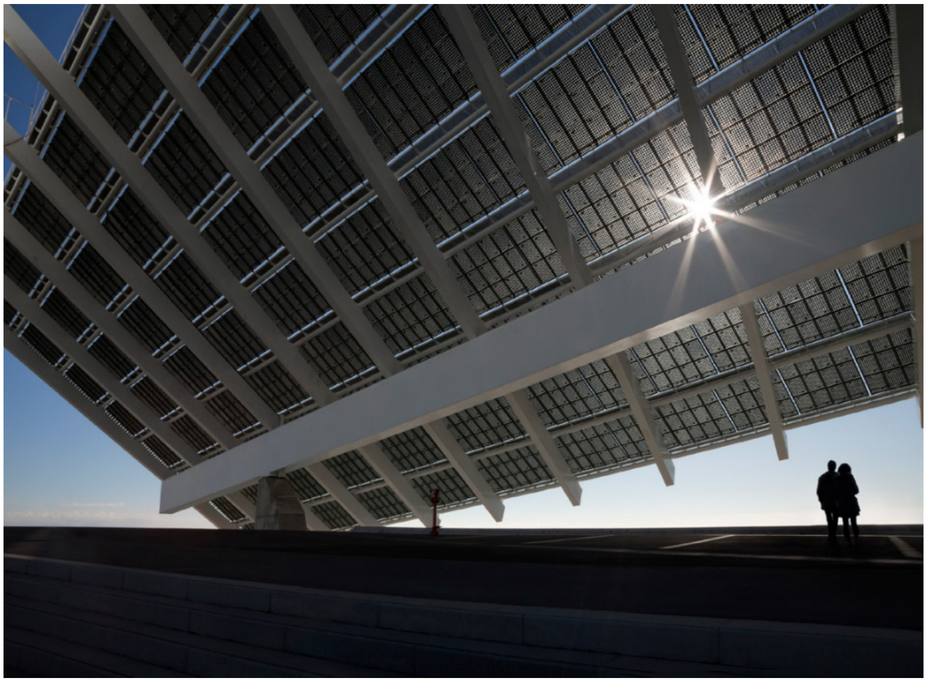
TJ Poor	VPPSA
Tom Buckley	BED
Tom Lyle	BED
Will King	AEDG
Will Smith	REV

Vermont Solar Market Pathways



Volume 2

Net Metering Brief and Focus Area Briefs

December 2016

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VERMONT

Preface

The growth of solar markets will create economic expansion in other segments of Vermont's energy market. In turn, it will also be driven growing consumer interest in electric vehicles and heating systems. These changes in Vermont's energy economy mean that this report and the research that has been undertaken for it have not considered the potential for solar growth in isolation, but as an interconnected feature of the larger energy economy.

Volume 2 of the Vermont Solar Market Pathways Report presents six briefs, each of which addresses a focus area that offers a significant feature of a higher-penetration solar economy. By describing current market conditions, emerging technologies, costs, performance, and other related topics, the focus area briefs in **Volume 2** look closely at topics and market segments expected to be closely inter-related to solar market developments. **Volume 1** (Summary Report) provides an overview of the project and recent results. **Volume 3** (Barriers and Integration) documents potential problems with high solar generation. The discussions and research in the project were supported by scenario analysis. The team built a model of Vermont's total energy system with scenarios that vary the levels of efficiency, fuel switching, and renewables. The model quantifies demand, supply options, costs, and emissions. **Volume 4** (Methods) provides sources for inputs and more comprehensive results than provided elsewhere in the report.

It is consistent with VEIC's mission (reducing the economic, environmental, and social costs of energy use), and important for the SunShot Initiative objectives, that the focus areas directly consider social equity and low-income implications of solar market growth. Over time, supported by appropriate policy, rates, regulation, and oversight, it is possible for solar to help improve energy affordability and performance for consumers at all income levels. Solar is not a do-good gimmick, or a nifty new technology for the wealthy. It is an imperative for making the benefits of a growing clean-energy economy available to those who are economically advantaged. Because of its distributed nature and scalability, solar is positioned, along with efficiency, to directly benefit many people. **Figure 1** illustrates the subjects covered by the focus areas briefs. **Volume 2** combines the discussion of energy storage and smart grid / demand management.

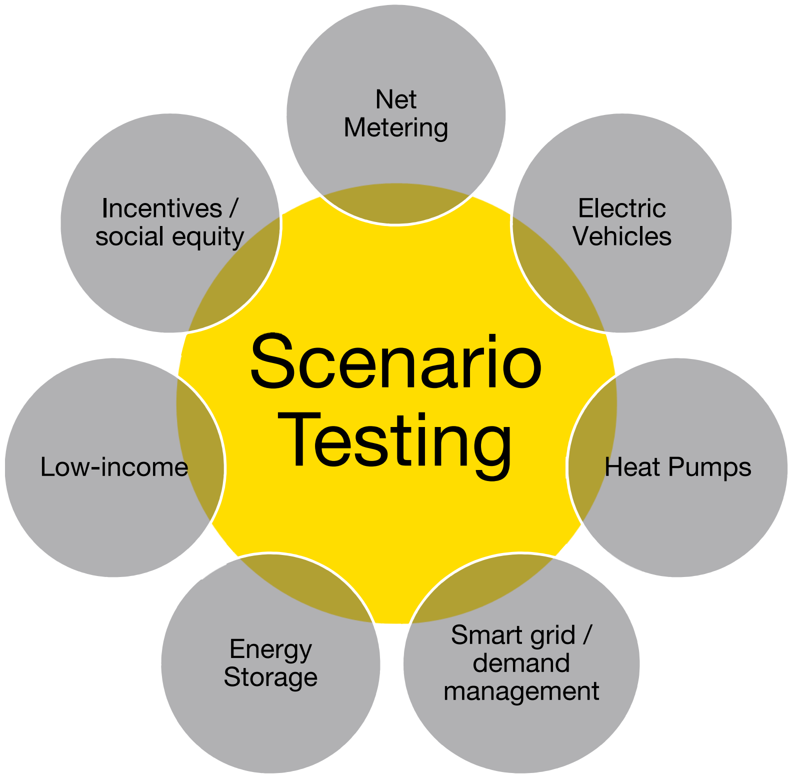

Figure 1. Vermont Solar Market Pathways focus areas involved in the scenario modeling.

Other key points from **Volume 2**:

- Vermont has **updated net metering rules and tariffs** that will go into effect on January 1, 2017. The Team drafted the brief on net metering just as Vermont's net metering rule-making process was starting. The brief identified several possible options for the evolution of net metering. Important elements in the final rule[1] are as follows:
    - Compensation at the retail level for behind-the-meter solar production, with potential positive or negative adjusters linked to siting, system size, and retention or transfer of renewable energy credits. By moving to five categories of net metered systems, the rules will encourage siting on rooftops, previously disturbed lands, and sites that are directly adjacent to electricity consumers.
    - Continuation of group net metering / community solar, providing a potential mechanism for offering solar to households that rent or which do not have rooftops well suited for hosting solar.
    - Removal of capacity caps for how much net metered solar a utility can host. Costs for required upgrades for new net metering system interconnections will generally be borne by applicants.

[1] Vermont Public Service Board, *5.100 Proposed Rule Pertaining to Construction and Operation of Net-Metering Systems*, 2017, http://psb.vermont.gov/about-us/statutes-and-rules/proposed-changes-rule-5100.

- Recognition that the impact of the revised net metering rules on market growth will be determined only with time. Generally, the new rules favor certain project categories based on siting and size. In all cases, the compensation from net metering will be lower than it has been. The Public Service Board will update the category criteria and adjustors every two years.

- **Electric vehicles** are a key element in scenarios that meet the State's 90 x 2050 targets. Electric vehicles (EVs) are an emerging technology, and ownership of both all-electric and plug-in hybrid vehicles (PHEVs) still represent a small fraction of the total market.

  - The operating and maintenance costs for electric vehicles are already lower than conventional vehicles. However, the cost of batteries still pushes the purchase cost of EVs above those of comparable internal combustion vehicles. EV battery prices have fallen from around $1,000 per kWh in 2010 to about $350 per kWh by the end of 2015.[2] Current estimates of Tesla EV battery costs for the upcoming Model 3 launch in late 2017 are "less than $190 per kWh."[3] As the EV market grows, battery costs and ultimately EV costs are expected to continue declining.

  - A combination of lower prices, larger battery capacity and range, greater selection of electric vehicle models, and lower total costs of ownership and operation are expected to create a market-driven shift toward EVs.

  - As the EV fleet expands, opportunities to enhance grid efficiency through smart charging, renewable load following, and vehicle-to-grid integration will grow.

  - In addition to light duty passenger vehicles, heavy-duty electric vehicles such as school buses, transit buses, and commercial vehicles are expected to become more prevalent in Vermont.

  - Complementary business models and infrastructure that combine solar and EV charging (for example, carports, solar parking lots, or shared EVs as part of a community solar project), present opportunities for new ventures and entrepreneurial growth.

- **Heat pumps** and high-performance biomass heating systems also make important contributions to 90 x 2050 goals. Using electricity to provide space heating with high-efficiency heat pumps will increase electricity use and displace fossil fuels.

  - The use of heat pumps for residential and commercial space conditioning is increasing, because the performance and economics of heat pumps are making them superior to other options in more situations.

[2] Angus McCrone et al., "Global Trends in Renewable Energy Investment 2016" (Frankfurt School of Finance & Management; UNEP Collaborating Centre for Climate & Sustainable Energy Finance, 2016), http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf.
[3] Fred Lambert, "Tesla Confirms Base Model 3 Will Have Less than 60 kWh Battery Pack Option, Cost Is below $190/kWh and Falling," *Electrek*, April 26, 2016, http://electrek.co/2016/04/26/tesla-model-3-battery-pack-cost-kwh/.

  - Improving the building shell, through measures like sealing air leaks, insulating, and installing high-performance windows, is usually very cost effective, and helps to reduce the need for heating and cooling. It is therefore a very good idea to combine a building shell upgrade at the time a heat pump is installed, or when doing new construction and renovations. Improving the building shell often means that a smaller and less expensive heat pump unit can be installed.

- **Smart grid and demand management** technologies help match the output of solar generation to the demand for energy at any given point in time or space.

  - Solar generation varies because of clouds and the apparent movement of the sun. Photovoltaics produce their maximum output when they have direct sunlight on them and when they are cool; shading or angled sunlight produces less electricity. **Smart grid equipment and strategies** use sensors, communications, controls, that help to integrate more solar into the electric generation mix through coordination, forecasting, and dispatch.

  - **Demand management** means that electricity use can be scheduled and managed to match output on the system. For example, smart charging of an electric vehicle can modulate the charge rate according to solar output. Another example is increasing the demand for a single (or group of) water heater(s) when solar output is high. The hot water can be used later when the sun is not shining.

- **Energy storage** further expands the potential to use solar generation to meet loads where and when the sun is not shining. There are several ways to store thermal and electric energy.

  - The use of stationary and mobile batteries is likely to increase as solar markets grow. Electric vehicles depend on battery storage, and significant research and investment in battery technologies and manufacturing are well under way—and are leading to global markets and declining prices.

  - Thermal storage systems using ice, water, or building materials also provide opportunities to capture energy output—for example, when it is windy in the middle of the night, or sunny in the middle of the day—and make that energy available when it is required. This concept is already widely deployed in residential water heaters and commercial cooling with ice making and storage systems.

  - The ability to export electric power into a broader regional market via transmission lines, and to import electric power at other times, is also a form of storage and load management. At the individual household level, exporting power to the grid when the sun is shining and then importing power when the sun is not out (via net metering) is similar. The analysis for Vermont Solar Market Pathways indicates that in a high solar future, there will be times when Vermont will have excess solar power that could be sold on the regional market, though the price at those times may not be attractive because of similar situations in neighboring states.

- High-performance modular housing illustrates how **low- and moderate-income** households can participate in, and significantly benefit from, advanced building techniques and solar energy.

- Through careful design and manufacturing, it is possible for affordable modular housing to offer lower total costs (for energy and mortgage payments) than those for conventional housing. With enough support through financing and electric rates, it is possible for solar to contribute to more affordable, more healthful, and more durable housing for individuals and families facing economic challenges. This has multiple social benefits that go beyond energy savings.

- Offering solar benefits to support low- and moderate-income consumers will expand the markets and create new and innovative approaches to finance, bundling of services, marketing, and business models.

- Well-designed **incentives** and rules are aligned with policy objectives and help markets emerge and mature. Incentives are not intended to be permanent supports. Over time, as market conditions change, it is natural to expect the need for incentives to change. Incentives can also be an important factor supporting market growth for potentially underserved markets, thus contributing to socially equitable outcomes.

    - As the market grows, there will continue to be opportunities for strategic market supports and incentives to catalyze markets and support equitable growth.

The next pages contain the briefs for each of the focus areas, essentially as they appeared in their initial release in June 2015. They demonstrate their functions in an advanced solar economy that supports achievement of Vermont's 90 x 2050 energy goals and of the U.S. Department of Energy's SunShot Initiative objectives, described in **Volume 1.**

One of the essential activities in creating the *Vermont Solar Pathways* report is the statewide articulation of key policy, regulatory, and market issues, by broad energy topic area. The Net Metering Topic Brief and the five Focus Area Briefs explore those issues in depth, and are the product of three stakeholder engagement meetings held in Vermont in early 2015.

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Topic Brief: Toward 20 Percent Solar by 2025 in Vermont
Net Metering and Alternatives

Originally released June 30, 2015

Background

The Vermont Solar Market Pathways Project goal is to set the necessary conditions for solar energy's ability to meet 20 percent of Vermont electricity demand by 2025. Meeting that 20 percent threshold will require planning, tariffs, and procurement mechanisms that do not exist in Vermont today. Although individual and group net metering tariffs, the solar adder (utility incentive credits), and the Standard Offer program (feed-in tariff) have attracted and are expected to continue to attract solar investment to Vermont, current trends do not suggest that current mechanisms will lead to 20 percent solar by 2025.

Vermont has introduced novel renewable energy procurement mechanisms in the past, like group net metering, so it is not only possible, but probable, that Vermont will introduce new and innovative ways of tapping more solar potential. However, with the mechanisms in place today, it is unlikely that Vermont will reach 20 percent solar by 2025.

It is important to note that 20 percent of energy from solar translates into approximately 1,000 MW (1 GW) of solar capacity. Net-metered solar capacity is approximately 65 MW and the ISO-NE Solar PV working group estimates that total installed capacity at the end of 2014 in Vermont was 81.85 MW. Net-metered solar installations are growing: the Standard Offer program has a 2022 cap of 127.5 MW of small, distributed generation, much of which is expected to be solar PV; it is likely that other distributed generation will involve utility power purchase agreement (PPA) projects. The ISO-NE Solar PV Forecast working group has determined that trends like these indicate an estimated 235 MW of solar PV in Vermont by 2024. Recent experience and current trends reflect significant growth in solar opportunity relative to just a few years ago, but these numbers do not imply Vermont is on a glide path to 1,000 MW by 2025.

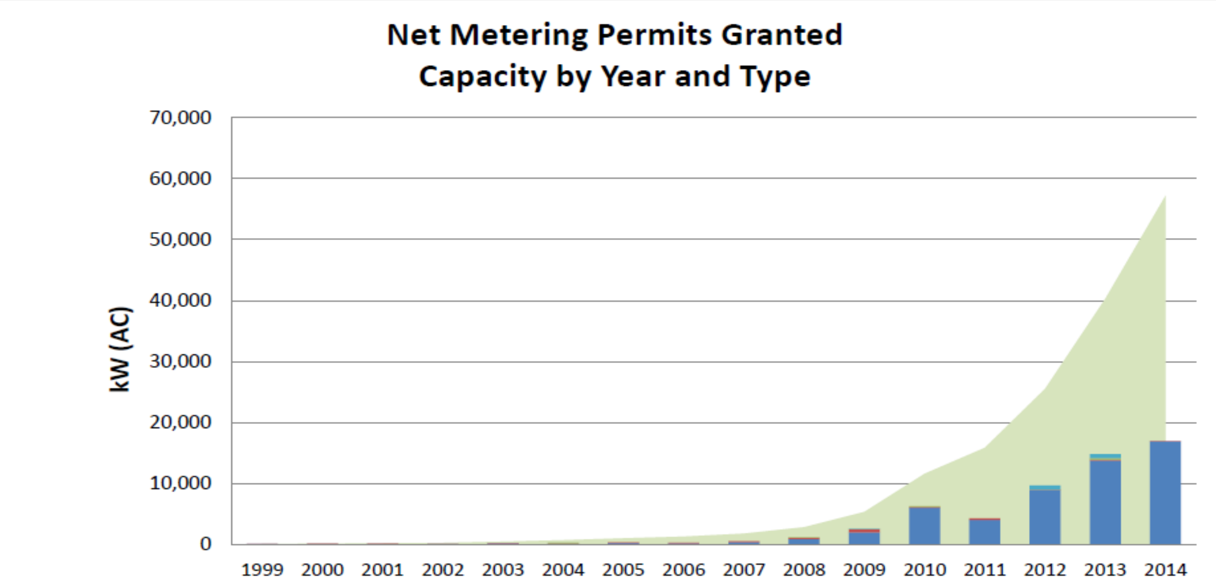
This topic brief explores the current and future mechanisms that will be required to facilitate the aggressive expansion in solar deployment over the next 10 years to meet the 20 percent target.

Solar Resources in Vermont Today

Solar resources in Vermont can be grouped into five basic parts: (1) residential rooftop; (2) commercial behind the meter; (3) group net metering, (4) ground-mounted projects in front of the meter, but less than 500 kW; and (5) ground-mounted projects greater than 500 kW. Projects greater than 500 kW are variously referred to as *grid scale, utility scale,* or *large-scale* projects. Of these projects, those less than 2.2 MW might qualify for the Standard Offer program. Projects greater than 2.2 MW must sell into the market, be procured by a Vermont utility, or be built and used by a utility. Meeting the 20 percent goal for solar by 2025 will likely require contributions from each of these solar resource "buckets." This topic brief summarizes the buckets that exist today and describes briefly how resources in each bucket are compensated.

Net Metering

Solar resources less than 500 kW qualify for net energy metering. Vermont has favorable tariffs and payments, as shown by the increasing amounts of solar built in Vermont since 1999. The Vermont Department of Public Service staff produced **Figure 1** in late 2014.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cumulatve Capacity	50	99	177	224	436	670	980	1,255	1,749	2,798	5,307	11,568	15,828	25,496	40,274	57,188
Hydro	-	-	-	-	-	-	-	-	-	-	18	-	-	716	664	-
Methane	-	-	-	-	-	65	-	-	-	19	39	127	-	49	248	-
Wind	32	10	28	31	98	72	123	102	147	158	482	154	239	66	125	12
Solar	18	39	50	16	114	97	187	174	347	872	1,969	5,981	4,021	8,838	13,741	16,902

Exhibit 3. *Capacity of net metering permits granted by type and cumulative capacity. (Data as of 9/26/14.)*

Source: Vermont Public Service Department

Figure 1. Net metering permits granted as of September 2014.

Until recently, Vermont law had limited solar expansion to 4 percent of peak capacity. As some utilities reached their 4 percent cap, the Vermont General Assembly voted in 2014 to increase the cap to 15 percent of capacity. Individual customers may participate in net metering and groups of customers may participate in group net metering; the size of installed facilities range from a few kW to systems up to 500 kW. **Figure 2** shows the distribution of system size in Vermont. The figure indicates small residential systems between 4 and 6 kW predominate.

The terms of the net-metering tariff determine the extent to which resources in the net-metering "bucket" are compensated. Whether the terms of the tariff are "fair" today is an active topic of discussion, and there are differences of opinion among stakeholders. The Vermont Public Service Board Act 99 Study (November 2014) posited methods for evaluating the fairness of the net-metering tariff. It looked at fairness from the perspective of society and from the perspective of ratepayers as a whole. The study found that current compensation is "fair" from the perspective of society, where net social benefits are consistently positive. The tariffs are also approximately “fair” from the perspective of all ratepayers, where the net benefits for ratepayers range from small and positive, to small and negative depending on the technology and size of system. Some utilities have questioned whether the revenue collected from net-metered customers constitutes a “fair” contribution to the costs of maintaining the electric system.

It is clear that individual and group net metering are successful today as a mechanism for effectively inducing increased investment and establishing compensation that is considered at least “approximately fair” to all ratepayers and society.

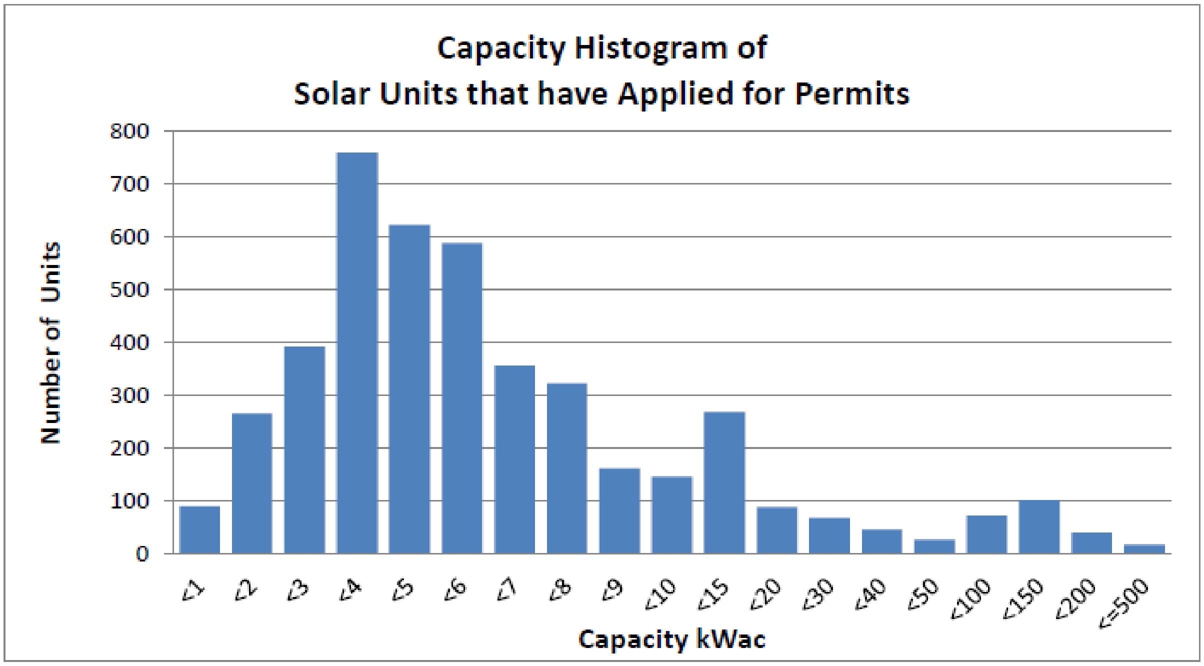


Exhibit 4. *Histogram by Capacity (in kW AC) of all net metered solar PV system permit applications (as of 9/26/14)*

Figure 2. Trends of distributed generation systems by kW size of system.

Within the net-metering category, projects of different sizes have different costs to the adopter. One stakeholder reported that a survey of recent bid prices for projects put the bid price for 5kW rooftop systems at about \$3 / W, for 150 kW ground-mounted systems at \$2 / W, and for 500 kW ground-mounted systems at about \$1.80 / W.

As increasing amounts of energy come from solar installations and as the Vermont electric system modernizes with more advanced real-time information, communications, and control capabilities, it is worth asking whether the existing net energy metering tariff terms are relevant terms for the low-carbon grid of the future. Increasing amounts of resource coming from solar generation are likely to present integration challenges in some locations that require adaptation in system operations. Location and temporal production patterns matter, and the introduction of advanced real time system capabilities mean that locational and temporal differences will be seen more clearly. Thus, net-metering innovation that compensates according to location and time might become possible and desirable. These issues will be taken up in a subsequent section.

Standard Offer Projects

Projects greater than 500 kW and less than 2.2 MW are eligible to compete for the Standard Offer Feed-in Tariff (FIT) program. Solar PV is one of six technologies eligible for being bid as a contract based on avoided costs. About 34 MW of standard offer solar PV was installed by the end of 2014. The Vermont Public Service Department has projected that about 110 MW of standard offer solar will be installed by 2024.

One stakeholder reported that a recent survey of installed cost bids for 2 MW ground-mounted systems came in at approximately $1.60 / W (without site costs).

Power Purchase Agreements, Utility Projects, and Market-based Projects

Utility-built projects and non-utility projects that do not qualify for the Net Metering or Standard Offer programs can market energy to retail customers through a power purchase agreement or utility self-build option, or they can sell into the regional wholesale markets. About 4 MW in PPA solar PV projects are in service today in Vermont and an additional 6 MW is expected by the end of 2016.

Solar Portfolios to Reach 1 GW

Reaching 1 GW of solar generation in Vermont will come from a portfolio of sources comprising rooftop net-metered solar, group net-metered solar, community virtually net-metered solar, commercial solar, and procured solar. The respective amounts of solar coming from these sources is uncertain, but it is clear that the amount that can come from small systems is going to be modest. Stakeholder discussions to date have produced a strong predisposition toward meeting the 1 GW goal with smaller distributed systems to the maximum extent possible. Stakeholders are skeptical that many systems larger than 5 MW can be sited in Vermont. Taking this perspective as a starting point, it is worth thinking through how much solar can come from smaller systems, and what will need to happen to tariffs and procurement mechanisms to maximize the small-system build-out.

According to the National Renewable Energy Laboratory (NREL), 22 to 27 percent of all rooftops are candidates for solar installation.[4] The remaining approximately 75 percent are not good candidates because (1) they are not south or west facing, (2) they are shaded, or (3) the structure is not sound enough to safely carry a solar installation.

If we can assume that all of Vermont's approximately 310,000 residential metered buildings had rooftops are candidates, then one can estimate that a little more than 75,000 are suitable for solar. If an average installation is about 5 kW, then about 375 MW could potentially sit on residential rooftops. The proportion of these 75,000 customers with a suitable rooftop who want

[4] Denholm, P.; Margolis, R. (2008). Supply Curves for Rooftop Solar PV-Generated Electricity for the United States. NREL/TP-6A0-44073. Golden, CO: National Renewable Energy Laboratory, http://www.nrel.gov/docs/fy09osti/44073.pdf.

a rooftop PV system is not known. Further, the cost per kWh of rooftop systems relative to larger-scale, ground-mounted systems is likely to lead some of these customers to participate in a shared renewable project, rather than install a roof-mounted system.

Therefore, although one could say that a 375 MW technical potential exists, the economic potential is far less. The 375 MW technical potential indicates that more than 625 MW will need to be on something other than a residential rooftops.

Reaching the economic potential of rooftop systems in Vermont will require a favorable tariff that compensates incremental participants at or above their marginal opportunity cost of participating. The marginal cost of attracting customers will grow as the number of solar-friendly customers increases from the smaller initial group of those who are enthusiastic to those who are indifferent or even reluctant to install solar units. The net-metering tariff available today is attracting enthusiastic and willing customers, but the tariff will need to evolve to attract indifferent and reluctant residential customers who have a good solar resource on their property.

One would expect that at some point, the marginal cost of attracting individual residential customers with viable rooftops will exceed the marginal benefit produced. However, it is uncertain at what quantity of residential rooftop this will occur. Making a decision on maximizing the amount of the resource coming from residential rooftop systems in Vermont is a policy decision. Therefore, policy goals will drive the tariff terms needed to reach the residential rooftop goal.

Designing the individual residential tariff to match participation with policy goals is the first critical question the Vermont Solar Pathway Plan participants need to explore further.

Large commercial rooftops, multifamily housing rooftops, parking lots, ground-mounted residential systems, and over-sized residential rooftop systems (net exporting systems) will also make a significant incremental contribution toward the 1 GW goal. The State will need an estimate of the technical potential that these resources can offer. This estimate will help inform a policy decision on how much of the 1 GW would come from these systems. It is safe to assume that the technical potential of these systems will fall well below 625 MW (the amount needed to complement the 375 MW from the residential goal to equal 1 GW).

A second critical question is how owners of these systems will need to be compensated to obtain their participation, consistent with the policy goal for behind the meter systems.

Residential and commercial systems sited behind the meter, to serve the customers and provide some net export to the electric system, will be a portion of the 1 GW goal. Nevertheless, given the economics of larger ground-mounted systems, it is likely that systems to serve multiple customers will play an important role. These systems could be group net-metered systems, community solar systems, or large-scale systems that sell into the regional market.

Additional critical questions therefore are:

- **How should group net metering be expanded?**
- **What should community solar tariffs look like?**

- **How much of the 1 GW will be met with grid scale systems that are owned by Vermont utilities, that are sold by purchased power agreement to Vermont utilities, or that sell into a regional market?**

The Evolution of Net Energy Metering for Residential Customers

Net metering is the current mechanism for interconnecting residential DG. Stakeholders were quick to point out that the first step toward approaching the technical potential of residential rooftops will involve raising the 15% of peak limitation on net metering. Vermont's peak electricity consumption is about 1 GW today and is projected to grow to no more than 1,200 MW by 2025. Limiting net metered DG to 15% of 1,200 MW would limit the contribution from this portion of the solar generation fleet to 180 MW, far below the technical potential of the residential sector and possibly below the economic potential. It is possible that policy makers will decide that going beyond 180 MW of residential behind the meter systems is desirable and so addressing the current 15% limit may be necessary.

In addition to considering raising the cap on net metering as it exists today, policy makers will want to consider evolving the structure of the net metering tariff. As distributed solar grows the value that solar provides and the costs it imposes will change and net metering will likely need to evolve as well. Options include:

- Modifying the existing tariff to keep the terms aligned with the changing value and cost
- Adopting a two way distribution tariff
- Implementing a value of solar tariff by way of net metering or a buy-all, sell-all approach

Aligning the customer value proposition presented by net metering or any alternative to net metering proposed for residential behind the meter systems will improve as information, communications and electric system control technologies mature. While the net metering tariff as it exists today has been found to be approximately fair in Vermont Public Service Board (PSB) studies, improved information on electric system costs and benefits will reveal more accurate estimates over time. Net energy metering is a crude tool that has worked well but improved information will allow more refined assessments and fine tuning of tariffs terms. Estimates of the value of electricity in specific places on the electric system will become better, estimates of the relative value of producing electricity at different times of the day will be better and the ability of distributed generation to provide ancillary services to the system will improve.

Option 1: Keep net energy metering, but evolve all tariffs toward time-of-use and locational pricing

As the necessary information becomes available it will be possible to design tariffs with time of use and locational pricing elements that reflect the relative value of producing and consuming electricity and will thus communicate pricing signals to all customers whether they happen to be consumers or prosumers (producing consumers). It is possible that simply evolving the tariffs that all customers pay will promote fairness. Determining whether this is the case will require valuation studies like the ones already done by Vermont PSB staff. The benefits of staying with a net energy metering structure while evolving the tariff that all customers pay include administrative simplicity, consistency in price signals provided to customers for conserving and producing, and financial certainty for solar investors.

Option 2: Adopt a two-way distribution tariff

If concerns arise that producing customers are not paying adequately to support maintenance and improvement of the distribution system infrastructure, utilities could introduce a two-way distribution tariff where all customers pay for every kWh of distribution service they receive to purchase from the grid as well as paying for every kWh of distribution service they receive to sell into the grid. A two-way tariff is not an alternative to time of use and locational pricing, it is an additional element to tariff pricing. The adoption of such a tariff should be driven by valuation studies that find that producing customers are systematically contributing too little toward distribution system maintenance and improvement and that non-producing consumers are systematically paying too much toward distribution system maintenance and improvement. If an inequity in distribution system support is found, this approach could directly address the inequity. This approach also has the virtue of maintaining consistency in valuation between conservation of energy and production of energy and maintaining the financial certainty associated with the net energy metering approach. The tariff is more complicated than option 1 and thus does not make sense unless an equity issue is demonstrated. A potential complication associated with implementing a two way distribution tariff is ensuring consistency in valuation between customer side of the meter energy production and grid side of the meter generation. Some adjustment in how grid connected generators pay to use the transmission and distribution system might be necessary to ensure fairness among generation resources.

Option 3: Implement a "value of solar" approach by way of net energy metering or a buy-all, sell-all approach

The valuation studies of net energy metering performed by the Vermont PSB could be said to already reflect a "value of solar" approach. A value of solar approach is simply taking account of the sources of benefit and cost considered in establishing a fair rate for energy produced from behind the meter solar generation. If net energy metering is found to reflect a fair valuation of solar relative to the sources of cost and benefit that policy implies, then net energy metering reflects a fair value of solar. If value components change as solar adoption grows or if policy changes and the elements to be included in assessing the fair value of solar change then the "fairness" of net energy metering is likely to change as well. Vermont PSB studies already attempt to track changes in the value of solar over time and to assess the fairness of the net energy metering tariff relative to those changes. In this sense, Vermont is already implementing a "value of solar" approach. Keeping tariffs consistent with the value of solar seems already implicit in the Vermont approach. Thus, one approach to implementing a value of solar approach is simply to commit to continuing to adapt net energy metering tariffs as the value of elements and the policy values evolve. This approach maintains simplicity and consistency over time, and has the virtue of managing any financial uncertainty introduced by leaving net energy metering. The disadvantage of seeking to implement value of solar through net energy metering is that at some point, the deviation between the marginal value of energy produced from solar and the marginal value of energy saved by conservation may deviate and economic inefficiency may result.

A buy all, sell all value of solar tariff can address persistent differences between the marginal value of customer generation and the marginal value of customer conservation appear, if those differences are not captured by locational and temporal pricing. A buy all, sell all tariff specifies that producing customers buy all of their energy at retail rates and sell all of their energy at a separate rate. A “buy all-sell all” implementation of a value of solar approach deviates from net energy metering but introduces the advantage of incorporating an explicit and separate valuation of energy production in tariffs. If policy dictates elements of cost and benefit beyond time of use and locational value elements should be incorporated explicitly into the compensation for solar energy production, a value of solar buy all, sell all tariff can incorporate those values.

Such a tariff could be implemented as a “feed-in tariff” or as a buy all, sell all tariff with no set long term value for sales. Implementing a buy all, sell all value of solar tariff as a feed-in tariff would make the “standard offer” to the producing customer a credit for all solar produced at the value of solar with the standard offer terms guaranteed for a term of 5, 10 or 20 years. A value of solar feed in tariff approach provides the financial stability of a long term contract while explicitly aligning compensation to a long term value of solar.

A buy all, sell all value of solar tariff without a long term “standard offer” for the value of solar would introduce significant financial uncertainty relative to a feed in tariff approach and relative to continuing with an evolved form of net energy metering. Immediately moving to such a tariff would be disruptive to further residential solar development. However, there may be some residual value of solar that is not adequately reflected in the options mentioned above that after time of use and locational pricing is implemented and reflected in tariffs.

Shared Renewable Programs

Shared renewable programs are larger scale projects where residential, public, and commercial customers may own or lease a portion of a project. Shared renewable programs are targeted at the development of solar and other renewable energy installations in the 50 kW to 5 MW range where electricity users have the opportunity to buy or subscribe to a share of the project to meet some or all of their electricity needs. Vermont has a head start on many states in developing shared renewable programs for solar. Vermont’s Group Net Metering program is cited by U.S. Department of Energy (DOE) and solar advocates as one example of a “shared renewable program.” Solar shared renewable programs are sometimes called “community solar programs” or “community solar gardens.” We will refer to the whole range of these programs as “shared solar programs.” A shared solar programs may be developed, owned and maintained by a utility, by a third party provider or by a group of customers in a community. It is most often proximate to the customers who subscribe or buy shares.

Shared solar projects have many benefits. The most important benefit for the purpose of this policy brief is that it greatly expands the pool of Vermonters who can own or lease a share of a project. Shared solar projects offer a solar option to residential consumers who do not have a viable space for PV. Shared solar projects can also offer an option to commercial, public and non-profit owners who do not have or who cannot afford a behind the meter installation. Some shared solar projects have also been developed to serve under-served communities. These projects even extend participation beyond the segment of the population who have an interest and are financially able to invest to those who are willing but may not have the discretionary income to invest. Shared solar projects can also be mixed ownership projects where owners come from residential, low income, commercial, public, and non-profit sectors. In some places, a portion of each shared solar project is reserved for low income participation.

The technical potential for shared solar projects will be driven by land and access limitations. Ground mounted solar PV requires about 7 acres per MW, so the amount of land required for shared solar installations in the 50 kW to 5 MW range require between 1/3 of an acre up to 35 acres (or more, depending on terrain and exposure). Shared solar projects are also usually near subscribers so proximity to subscribers and electric infrastructure affect the technical potential for shared solar. The electric systems of Vermont's many utilities vary and viable project size will be affected by characteristics of the host system. A physical assessment of potential sites needs to be performed to produce a technical potential estimate.

The tariff, ownership, and contracting terms of shared renewable programs vary widely. The most common approaches for shared solar programs are virtual net metering and buy-all, sell-all arrangements. With virtual net metering approaches, a subscriber buys or leases a portion of a solar PV project and receives credit for the energy produced by the project as if the project was located behind their meter. Virtual net metering approaches provide consistency in valuation between behind the meter solar PV and local solar PV projects so the economics of the respective projects can drive installations. Implementing virtual net metering well requires that any substantive differences in electricity system costs (for example, required distribution system upgrade differences) or benefits (for example, ability to control a project to maximize system benefits or line loss prevention benefits) be captured. In a buy-all, sell-all arrangement, the subscriber to a project sells all of the energy produced at a price (value of solar, standard offer, etc.) and buys all of their energy from the utility, and receives a credit against purchases for all sales. Special shared solar projects like community solar projects built specifically to serve low incoming housing may fall under the same tariffs as other shared solar projects or there may be tariffs constructed to match the public purpose goals of those projects.

Ownership of shared solar projects can take various forms. Individuals in a community can co-invest in a project for their mutual benefit, a third party may build a project and sell or lease shares to participants, or a utility may build a project and sell or lease shares.

It is our opinion that shared solar projects will play a very important role in meeting any future solar generation targets. The best shared solar program structures for Vermont should be informed by the wide array of efforts underway nationally, and other work being conducted under the DOE Solar Market Pathways project should be consulted as programs are developed in Vermont.

Agricultural, Commercial, Industrial, and Public Sector Projects

Shared renewable projects are one avenue for engaging the non-residential sector, but other options exist as well. The sites available for non-residential projects larger than 50 kW and smaller than 5 MW will overlap with sites available for shared solar projects. The vehicle used at present in Vermont is the Standard Offer program described in the opening section of the brief. The Standard Offer program currently includes sites up to 2.2 MW but it could be expanded to larger systems in the future. Stakeholders believe that 5 MW is a likely cap for most projects in Vermont in this category or in the shared renewable category.

Grid Scale Solar

The final section will discuss the possibility that grid scale solar installations between 5 and 20 MW may be needed to meet an aggressive goal like 1 GW by 2025. Solar requires 6 to 10 acres per MW, so a 20 MW installation would require 120 to 200 acres. Stakeholders have said that siting a project in this range in Vermont will be extremely difficult and the focus of the scenarios should be on maximizing the contribution of the smaller sized systems discussed above. To the extent that any systems get built in the 5 to 20 MW range in Vermont, they will likely be utility built projects or 3rd party PPA projects built to serve utility retail customers or to be sold into the regional market. Further consideration of these larger projects will happen in a subsequent version of this policy brief as the solar scenarios develop.

Conclusion

The purpose of this policy brief is to provide a context for considering how 1 GW of solar might be achieved in Vermont. A diverse portfolio of solar will be necessary. Residential rooftop, shared solar, and non-residential solar will be the primary contributors toward the 1 GW goal. Structuring tariffs, markets, and procurement for each of these three segments will be important. Net energy metering tariffs will need to evolve as the information, communications, and control technologies advance to the point that locational and temporal pricing become a reality and as the value of solar responds to changes in the grid and policy directions. At the same time, shared solar programs and non-residential contracting mechanisms will need to evolve to match value with compensation. It is important to consider the relative cost and value of projects among these segments (rooftop, shared renewable and non-residential) so that economically efficient choices are made by consumers.

To the extent that projects less than 5 MW do not sum to the 1 GW goal, some larger projects will need to be considered. The stakeholders as a group seem to strongly favor smaller projects, while stakeholders have different opinions on how much the rooftop segment will ultimately contribute. As technical potential estimates of the segments are constructed and scenarios are built, there will be a need to revisit the topic of tariffs and procurement mechanisms. As shared solar program research continues, it will be important to bring information from those efforts to inform this one. In addition, we have not considered the contribution and need for grid scale projects completely here. As the scenarios develop, we will likely need to revisit grid scale potential and mechanisms.

Focus Area Brief: Electric Vehicles

Introduction

Electric vehicles (EVs). Three essential synergies exist between plug-in vehicle and solar PV consumers:

- Overlapping consumer purchase preferences for both technologies
- Use of solar PV power for vehicle charging
- Use of plug-in vehicles for distributed storage and grid reliability assets to respond to fluctuating renewable energy production.

EVs in the Vermont Comprehensive Energy Plan

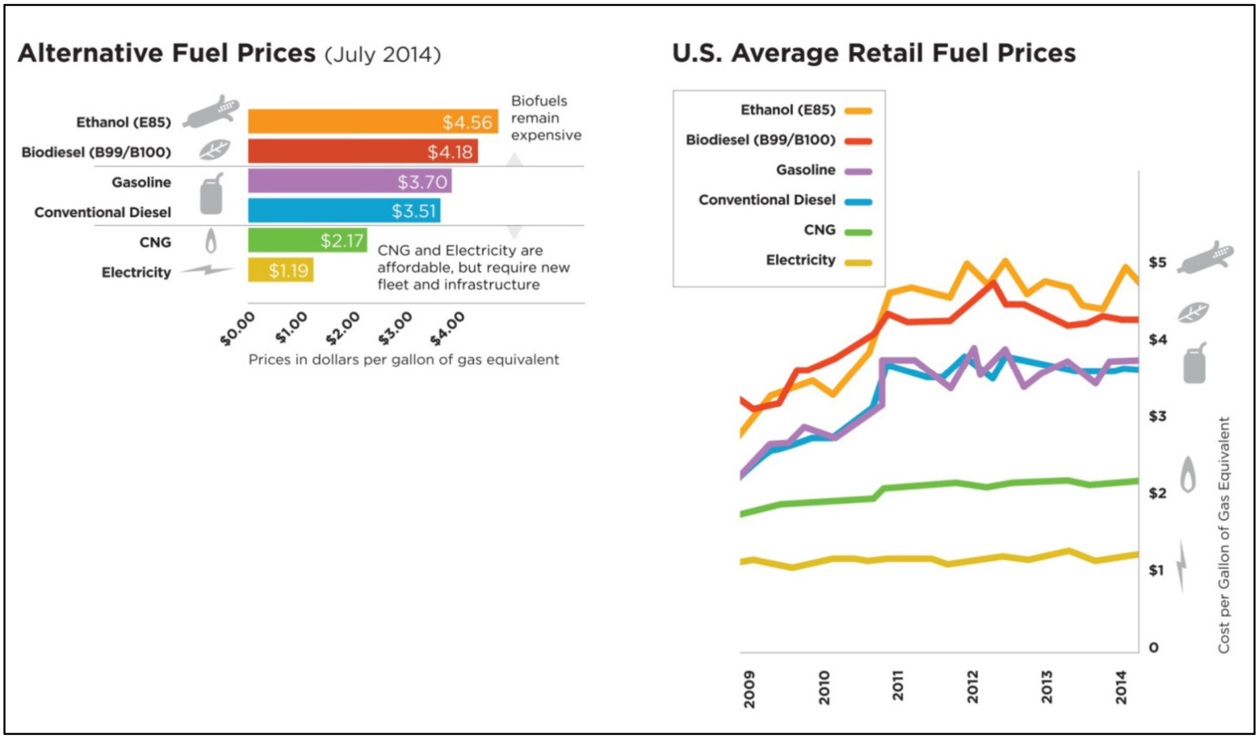
Vermont's transportation sector is currently fueled 95 percent by petroleum. To reduce the reliance on that fossil fuel and thus transform the transportation sector, the 2011 *Vermont Comprehensive Energy Plan* (CEP) identified two primary strategies:

1. Reduce petroleum consumption (Vol. 2, 9.6.2, p. 280)
2. Reduce energy use in the transportation sector (Vol, 2, 9.6.3, p. 284)

Because transportation accounts for the highest share of energy use in Vermont, policies that address this sector have a proportionately large impact on the state's overall energy consumption. Most transportation sector consumption involves gasoline and diesel fuels, both petroleum-based sources of energy. The shift to renewable energy sources for the transportation sector will likely occur at a slower pace than in other sectors, largely because of the limited control the state has over vehicle technology and regulations. For example, the federal government, not the states, set fuel economy standards. Higher upfront costs for plug-in vehicles and shifting technology are also sources of hesitation among consumers considering a switch.

To make significant progress toward the State's target of 90 percent renewable energy by 2050, the Vermont Agency of Transportation has set a goal that 25 percent of all vehicles registered in Vermont be powered by renewable energy sources by 2030. Business-as-usual projections for the number of plug-in EVs are modest. However, there are several reasons to believe that the next 20 years will be different from business as usual. Technological innovation in vehicle engineering, particularly as it relates to batteries, is occurring quickly.

The CEP contains an interim 2030 goal of 25 percent of the vehicle fleet to be powered by renewable energy. This will mean that more than 140,000 more EVs or other renewably powered vehicles will be registered in Vermont, relative to 2015. Biofuels already significantly contribute to renewably powered transportation in Vermont through the U.S. Environmental Protection Agency's (EPA) Renewable Fuel Standard (RFS). The RFS creates a requirement for ethanol blends. However, as **Figure 3** indicates, travel powered by electricity is much more cost effective than travel powered by gasoline or even other alternative fuels. Although these savings offset the relatively high initial cost of EVs for their owners, the savings can be significant today and will provide additional benefits as the technology matures.



Source: U.S. Department of Transportation, Beyond Traffic, 2015.

Figure 3. Prices for alternative fuels, compared to gasoline and conventional diesel.

The Vermont Public Service Department's 2014 Total Energy Study identified technology and policy pathways for achieving the CEP goal of 90 percent of Vermont's energy needs supplied by renewable sources by 2050. The Study also cited the importance of the State's continued recognition of electric vehicle technology as a critical strategy to meet its energy goals.

Survey responses from current and potential EV owners suggest a strong societal correlation between EVs and solar PV consumers. For example, the California EV rebate program has queried more than 16,000 rebate recipients and found that nearly 30 percent of them already have solar PV or are planning to install it. A total of 63 percent indicated they were considering future PV installation.[5]

The development of an advanced solar market in Vermont will provide significant opportunities for increasing the number of renewably powered vehicles in the state. The primary benefits of renewably powered transportation are reduced emissions of greenhouse gases and other harmful pollutants, reduced cost and volatility in transportation energy expenditures, and support for economic development by shifting the monetary savings from saved fuel expenditures to capital for investment. Further, EVs can support the electric grid, by boosting demand-side management (DSM) through controlled charging and distributed energy storage using EV batteries. Both controlled charging and the storage capability can be used to respond to short-

[5] Center for Sustainable Energy (2015). California Air Resources Board Clean Vehicle Rebate Project, EV Consumer Survey Dashboard. Retrieved 5 May 2015 from http://energycenter.org/clean-vehicle-rebate-project/survey-dashboard.

term fluctuations in power generation that might occur if more solar PV generation is brought on line.

Technology and Market Description

There are two basic types of plug-in EVs:

- **All-electric vehicles (AEVs),** powered solely by electricity with a range of 60 to 100 miles for vehicles under $40,000. AEVs manufactured by Tesla (purchase price of $70,000) can travel up to 270 miles without a charge. AEVs account for 25 percent of registered EVs in Vermont (2015).
- **Plug-in hybrid Vehicles (PHEVs**) offer 10 to 75 miles of electric range on a battery, and then the vehicles switch without interruption to gasoline for extended-range operation. PHEVs account for 75 percent of the registered EVs in Vermont (2015).

Most EVs in Vermont are passenger vehicles and travel about 3vmiles per kWh of energy. Given the census of EVs in Vermont, this means an annual consumption of about 2 MWh for the average Vermont vehicle. Energy is delivered to the vehicles through electric vehicle supply equipment (EVSE), commonly referred to as *charging stations*. **Figure 4** presents three basic types of EVSE.

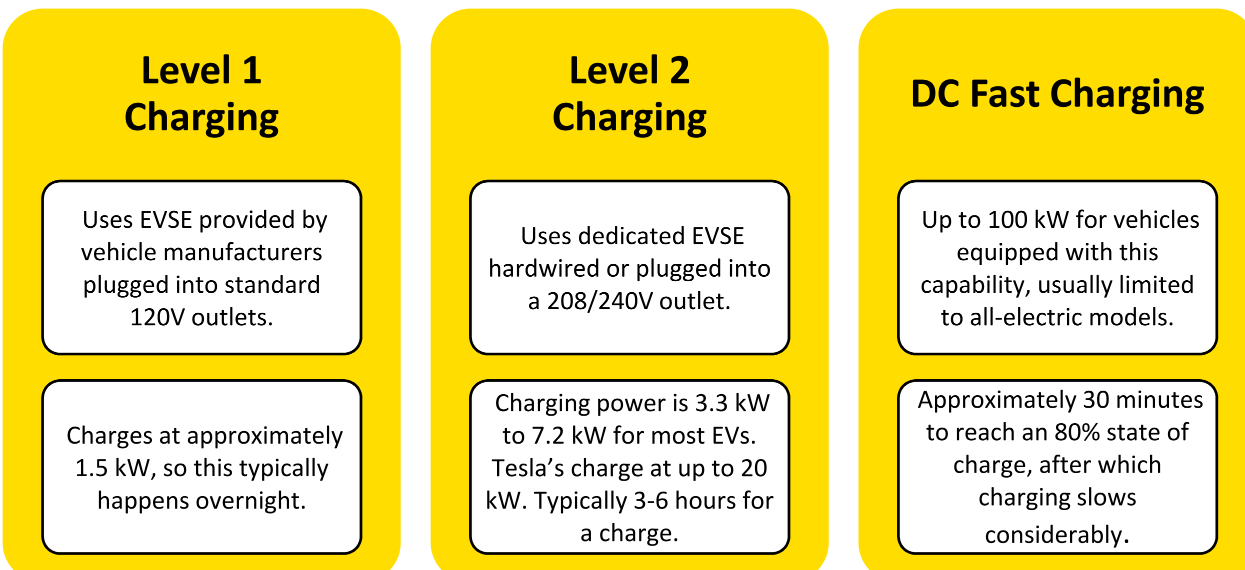


Figure 4. EV charging levels and their respective features.

Most EV owners charge at home overnight. Several Vermont electric utilities have optional residential time-of-use (TOU) rate programs that result in lower costs during overnight hours. The variability in rates is shown in **Table 1**. Workplace charging is the second most common option, when available. It also provides a helpful "second showroom" with DOE. That is, employees with access to charging are 20 times more likely to own an EV than those who do not have workplace charging stations—and the visibility of EVs and charging stations encourages EV purchasing. Public charging stations are necessary to increase the confidence of consumers considering an EV purchase, particularly for all-electric vehicles. Vermont currently has 60 public charging stations, 13 of which offer DC Fast Charging for EVs equipped with this capability. The number of charging stations has more than doubled over the past two years.

Table 1. Selected Vermont utility time-of-use rates, 2015

Utility[6]	Residential standard rate customer charge	Standard kWh rate	Residential TOU customer charge	TOU rate for on-peak use per kWh	TOU rate for off-peak use per kWh
Green Mountain Power	$0.43 / day (approximately $12.90 / month)	$0.147 / kWh	$16.26 / month	$0.257 4 consecutive hours between 7 a.m. and noon, and 3 consecutive hours from 4 to 10 p.m.	$0.114
Vermont Electric Cooperative	$17.22 / month	$0.087 / kWh up to 100 kWh $0.176 / kWh in excess of 100 kWh	$17.22 / month	$0.19789 / kWh 6 a.m. to 10 p.m. M-F	$0.142
Burlington Electric Department	$8.21 / month	$0.1088 / kWh up to 100 kWh $0.148 per kWh thereafter	$13.86 / month	$0.108 / kWh up to 100 kWh $0.23 / kWh above 100 kWh June 1 - September 30, M-F, 12:01 p.m. - 6 p.m. and December 1 - March 31, M-F, 6:01 a.m. to 10 p.m.	$0.108

Of the 112 new car dealers in Vermont, 28 offer EVs. There are no state incentives for EVs, but there is a federal tax credit of up to $7,500 for the first 200,000 EVs sold by manufacturer, nationwide. The exact amount varies depending on the size of the battery. Cumulative sales for the current EV market leaders, GM and Nissan, are approximately 70,000 vehicles each. At this pace, the incentives are expected to remain for several more years. It is possible that they could be renewed in the future.

[6] Other Vermont utilities, including municipal utilities, offer TOU rates.

Vermont is one of 10 states participating in the California Zero Emission Vehicle (ZEV) program, which requires automakers to sell increasing numbers of plug-ins and hydrogen fuel cell vehicles in the next 10 years. This requirement will result in up to 15 percent of sales by 2025.

EVs are registered in over 60 percent of Vermont communities and comprise about 0.1 percent of the total Vermont fleet of registered vehicles. EV sales over the past year have reached approximately 1 percent of new, light-duty vehicle sales in the state. As **Figure 5** illustrates, significant growth has occurred since 2012, with 891 plug-in vehicles registered in the state as of April 2015. Per-capita rates of EV ownership are highest in Lamoille County, indicating plug-in vehicles do work in rural areas.

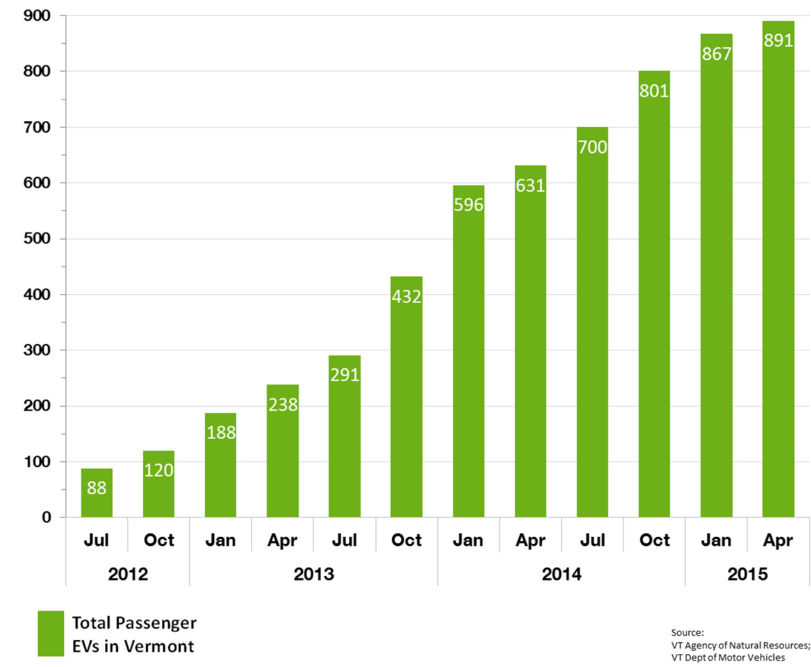


Figure 5. Vermont electric vehicle registrations since 2012.

Table 2 shows annual new EV registrations. The slowdown in new registrations in 2014 was assumed to be due to decreased inventory available at local dealerships and a "bridging" phenomenon that occurs in marketplaces when a new product appears: the enthusiasm of early adopters wanes for a short time and is subsequently supplanted with demand from more mainstream consumers. EV market volatility will likely continue in the near term as new models come into the market, and as generally improving economic conditions affect new vehicle purchases.

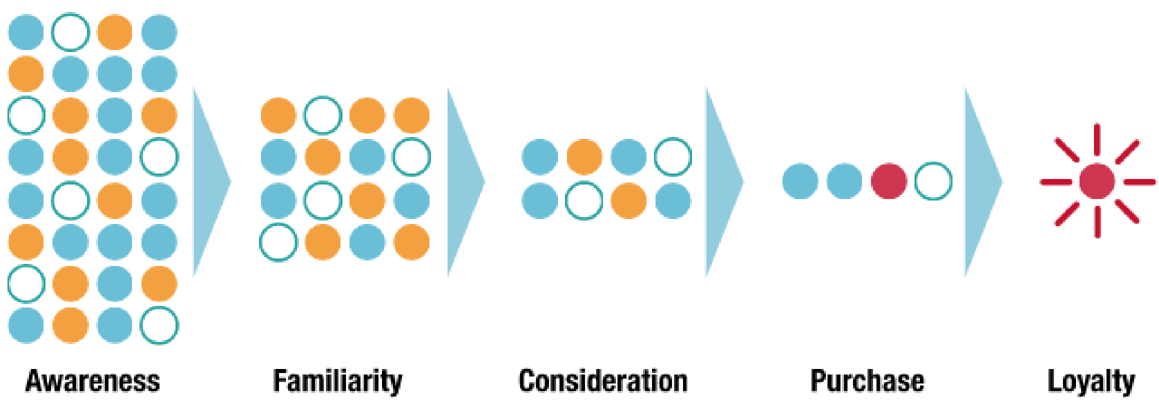
Table 2. Annual Vermont EV sales by type

Year	Plug-in hybrid vehicles	All-electric vehicles	Total
2013	326	82	**408**
2014	204	67	**271**

The current estimate of electricity use related to EVs in Vermont is approximately 1,900 MWh annually. This is approximately 0.03 percent of Vermont's retail electricity sales, so the impacts of EVs on the grid are negligible at this point. However, in some rare cases, local distribution networks must be upgraded because of high power draw (20 kW or more) associated with certain vehicles and charging equipment.

The ongoing growth in EV adoption is encouraging, even though much more work is needed to meet Vermont's energy transformation goal of having 140,000 renewably powered vehicles on the roads over the next 15 years. **Meeting this goal will require average sales of more than 9,000 additional EVs a year.**

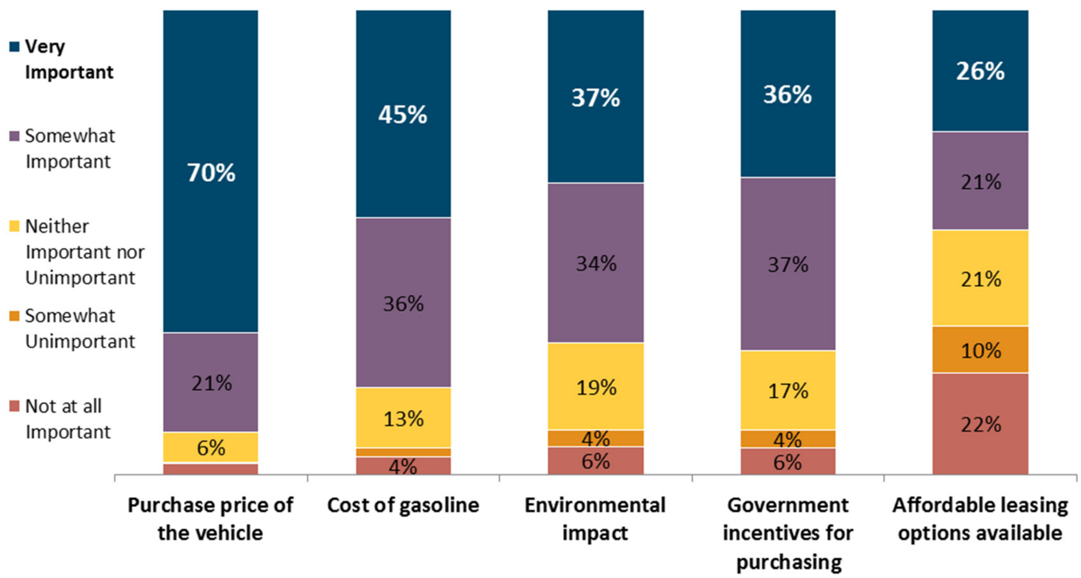
The Drive Electric Vermont program (http://www.driveelectricvt.com/) is working on many fronts to support these goals. The consumer decision funnel in **Figure 6** illustrates the process of consumer engagement from initial product awareness to familiarity, consideration, and purchase, and evolving into loyalty. Although social media and other technological changes now give consumers greater ability to skip these discrete stages, the funnel still provides a helpful framework for understanding the typical consumer EV purchase process. Drive Electric Vermont engages with consumers at each stage of this process.



Source: McKinsey & Co., 2009

Figure 6. Classic consumer engagement and decision funnel.

In 2014, VEIC commissioned a statistical survey of 495 Vermont consumers about their awareness and attitudes toward electric vehicles. The survey results have informed priorities for Drive Electric Vermont. The research found general awareness of electric vehicles was present in over 90 percent of the survey respondents, but many potential consumers wanted to know more about the options available to them. Vehicle cost was the most common barrier to considering EV purchases, followed by concerns about limited vehicle range and charging infrastructure. Purchase cost was also cited as the most important issue to motivate consumers to purchase or lease an EV, as shown in **Figure 7.**



Source: MSR Group, 2014

Figure 7. Factors motivating Vermonters in purchasing electric vehicles.

These data demonstrate that electric vehicles are a clear priority for Vermont in meeting its energy and environmental goals. Ongoing research and Drive Electric Vermont program development have highlighted critical areas for speeding market transformation of EV technology. The most urgent areas are increased consumer familiarity, dealer education to better inform customers considering new vehicle purchases, and the availability of consumer incentives to reduce barriers and increase motivation to move forward with an EV lease or purchase.

Market Conditions

Opportunities

Growth

Business-as-Usual Scenario. The Vermont ZEV action plan contains detailed information on activities under way in Vermont to support automakers in complying with ZEV program requirements. **Figure 8** illustrates the anticipated continued growth in the market, particularly in 2017 and beyond after the expiration of the existing travel provision, which allows manufacturers to meet their requirements by only selling EVs in California. The ZEV program requirements have a variety of credits for different vehicle technologies, so actual experience of sales could differ from the scenario presented below. A relatively conservative estimate under existing policies would be approximately 10,000 EVs in Vermont by 2023, or nearing about 2 percent of the fleet of registered vehicles.

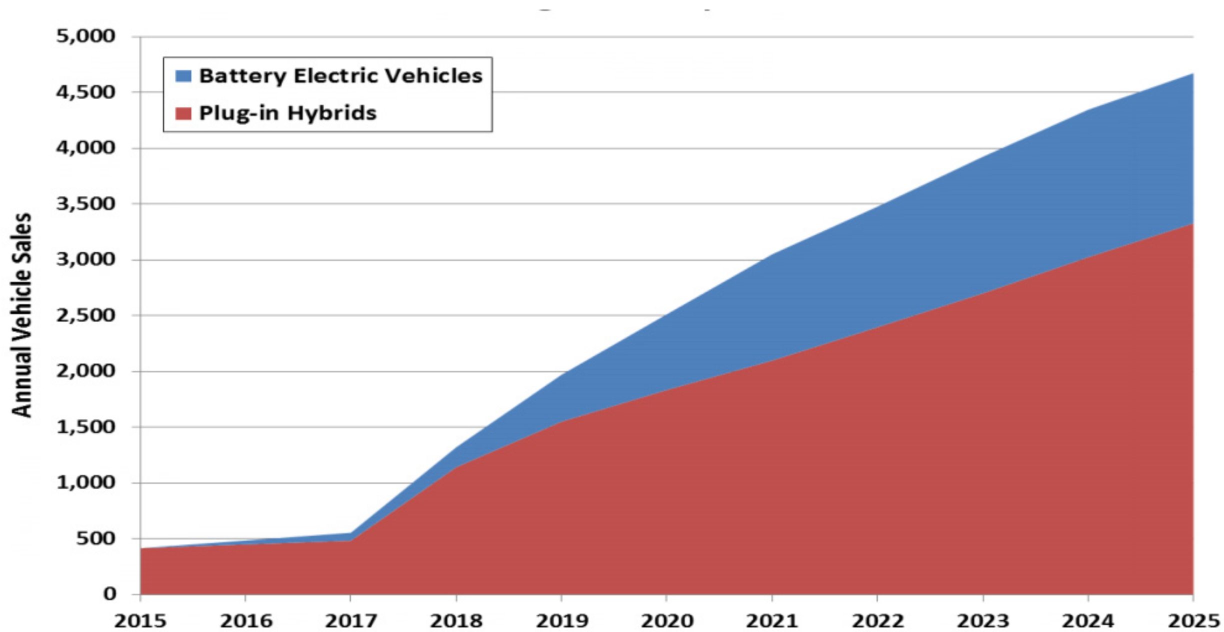


Figure 8. Vermont ZEV Program compliance scenario.[7]

90 x 2050 and Solar Development Pathways Scenario. The Vermont *Comprehensive Energy Plan* includes goals for 25 percent of vehicles to be powered by renewable energy in 2030 and 90 percent by 2050. These values translate to approximately 143,000 EVs in 2030 and 515,000 EVs by 2050. Achieving this rate of growth will depend on vehicle availability at competitive pricing and sustained programs to transform the new and used vehicle markets. VEIC is investigating growth curves that consider current adoption rates and long-term prospects.

Technical Advances

Advancements in EV technology and battery capacity are beginning to make longer ranges possible—at the same or even lower purchase cost of older EV models.

Challenges

Barriers

Although EV sales in Vermont have grown 10-fold in the last three years, they still make up a very small segment of the automobile market. Plug-in vehicles still represent less than 1 percent of new-vehicle sales in Vermont. When aligned with a Rogers's innovation adoption bell curve, this assigns *innovator* status to plug-in EV purchasers and lessors. Sales of non-plug-in hybrid vehicles has progressed along this continuum to the level in which purchasers fall into the *early adopter* category, as shown in **Figure 9**.

[7] "Vermont Zero Emission Vehicle Action Plan" (State of Vermont: Agency of Natural Resources, September 2014), http://anr.vermont.gov/about_us/special-topics/climate-change/initiatives/zev.

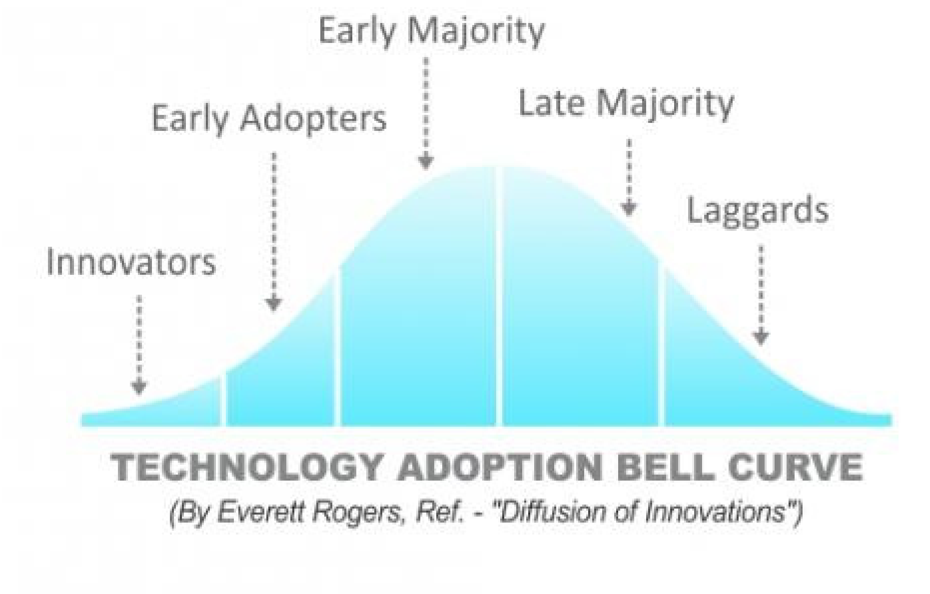


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Figure 9. Rogers' "diffusion of innovations" bell curve, which is applicable to EV adoption in Vermont and nationwide.

Price is still a major barrier for plug-in EV sales. As is evident in **Figure 7,** 91 percent of Vermonters answering the survey indicated that the purchase price of a vehicle is *somewhat* or *very important*. Even with incentives, EVs typically have significantly higher up-front costs than those of conventional vehicles. Affordable lease options are becoming more common, but these are not always well advertised, and cost is still perceived to be a major barrier.

As a rural, mountainous, northern state, Vermont is known for its challenging driving conditions in winter. Compared to the national average, Vermont has more than 3 times the all-wheel-drive (AWD) auto inventory per capita of the national average.[8] Although hybrid AWD vehicles are currently on the market, there is only one commercially available plug-in **electric AWD** vehicle available in Vermont. It retails at $75,000.[9]

Another major barrier to EV adoption in Vermont is **battery range**. Because of Vermont's low population density, commutes tend to be long and development less concentrated than in other states. The limited battery range is definitely problematic. Also EV technology performs at its highest efficiency in stop-and-go traffic (via regenerative braking), and on flat terrain. Most Vermont driving involves neither of these. Exacerbating the barrier of limited battery range is the lack of a comprehensive EV charging network. Vermont currently has 69 public EV charging stations. Expanding this network will facilitate EV adoption in Vermont.

Finally, **auto dealer engagement** is a powerful tool in selling electric vehicles. Many Vermont dealers do not offer electric vehicles at all. Dealers that offer them typically do not promote them.

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[8] Kelsey Mays, "Winter Weather Sends All-Wheel-Drive Inventory Up 20 Percent," *Cars.com*, February 20, 2014, https://www.cars.com/articles/2014/02/winter-weather-sends-all-wheel-drive-inventory-up-20-percent/.

[9] TESLA Model S (now available) and Model X (available in 2016); Toyota RAV4 EV has been discontinued.

Dealer staff is often not well informed about the products and will sometimes actively direct customers away from electric vehicle options.

Overcoming Barriers

As with any new technology, incentives and disincentives are powerful policy tools. Incentives might involve cash offsets, dealer inducements, and tax credits to customers. Several states offer EV incentives: California, Colorado, Georgia, Louisiana, Massachusetts, Utah, and (most recently) Texas. Some states offer registration fee exemptions or travel incentives such as free tolls or access to high occupancy vehicle (HOV) lanes. Incentives could also be offered in the electricity sector. **Electric rate structures for EV charging can provide significant benefits to Vermont's electric grid by encouraging EV owners to charge at night during off-peak hours.** Distribution utilities can charge rates that make EV charging extremely cost effective for EV owners. ConEdison in New York offers on-peak delivery rates of 19.4 cents / kWh and off-peak rates of 1.36 cents / kWh.[10]

On the other side of the equation, disincentives can also be a powerful tool. An increase in the State gas tax or the implementation of a carbon tax in Vermont would provide an economic disincentive for drivers to use vehicles that consume fossil fuels; conversely, a carbon tax would be a significant factor in motivating EV sales.

Aside from economic incentives and disincentives, notable other ways to overcome market barriers to EVs are the broader introduction of AWD EVs into the Vermont marketplace, particularly at a price that, when combined with economic incentives, is comparable to the purchase price of a modest conventional gasoline-powered vehicle.

Expanding EV-charging infrastructure is one way in which Vermont regulators can promote the adoption of electric vehicles. Allowing distribution utilities to assign rate base spending on EV charging stations would motivate Vermont's utilities to install charging stations and receive a guaranteed rate of return, while building their sales bases. Alternately, public-private partnerships could promote the retail sale of electricity in places like conventional gas stations if they were to offer DC fast charging, or at highway rest areas to promote tourism and long-distance travel by EV owners.

To address the lack of dealer initiative related to EV sales, additional sales commissions or spiffs (time-of-sale bonuses) could be offered for dealer sales staff. Educational outreach programs directed at dealers and sales staff could build greater familiarity with the vehicles and their benefits.

Innovative marketing strategies such as packaging together an electric vehicle with rooftop solar PV and an attractive financing option could promote vehicle-to-building technology in the future.

Electric vehicle sales continue to grow as EVs are seen as a viable alternative to fossil fuel consumption through conventional vehicles. As the EV markets continue to grow, economies of

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[10] "Electric Vehicles - Rate Options for Charging Your Plug-in Electric Vehicle (PEV)," *ConEdison*, accessed December 12, 2016, http://www.coned.com/electricvehicles/rates.asp.

scale will contribute to less expensive batteries and better technology options. This combination of declining costs and maturing technologies will be instrumental in overcoming market barriers.

Scenario Inputs

	Current account / historical data	Reference (business as usual)	Long-range target	Revised SDP
Applicable market segments	Light-duty vehicles	Light-duty vehicles	Light-duty vehicles	Light-duty vehicles
Number of units	891	10,000 by 2023	23,000 by 2023 143,000 by 2030 515,000 by 2050	23,000 by 2023 143,000 by 2030 515,000 by 2050
Total annual energy consumption	1,900 MWh	Calculated in LEAP	Calculated in LEAP	Calculated in LEAP
Type of growth	NA	Exponential	Logistic	Logistic
Changes in performance characteristics		2% increase in range annually until vehicles reach 200 miles of range		
Costs		$35,000 for 200-mile range vehicle in 2020	$25,000 for 200-mile range vehicle in 2020	$25,000 for 200-mile range vehicle in 2020

Unmet Needs

Future work on the role of EVs in the Vermont Solar Deployment Plan will need to examine how the projected vehicle fleet storage capacity can be paired with expanding solar to help with system integration and intermittency of generation.

Focus Area Brief: Heat Pumps

Introduction

Electric heating has historically not been a prudent choice for Vermont residents and businesses because electric resistance heat costs more than any other fuel. Early heat pump technology did not function well in cold winter temperatures. New cold-climate heat pumps, however, now address both issues, operating more than twice as efficiently as resistance heat, and capable of working down to extremely low temperatures.

Heat pumps can be an attractive option for buildings that already have a source of heat. They make it possible for that existing source to become a backup to the heat pump technology. If solar PV is available to the building, it can supply the electrical power needed to operate the heat pump.

These improvements mean that solar PV can be converted efficiently and cost effectively to space conditioning, as well as to water heating. This strategy is being used in net-zero-energy new construction as well as in existing home retrofits. Lower solar costs make heat pumps competitive now with equipment that uses fossil fuels and biomass.

Heat pumps also benefit solar by increasing the electric demand on the grid and creating more room for solar generation. They add water heating and space conditioning to the services that solar PV can provide. This additional electric load comes with demand response opportunity. Water heating has long been used for demand response, and heat pump water heaters can continue this tradition while being much more efficient. During the early afternoon in the summer, heat pump space heaters may be dispatched to pre-cool space when solar generation is peaking and demand has not yet risen to the afternoon peak. Heat pumps may also be controlled at other times to balance supply and demand, however, they operate most efficiently when allowed to modulate based on their own programming.

Technology and Market Description

Heat pumps use electricity to move heat. There are many variations of the technology, but the focus here is on air source heat pumps that use energy in outdoor air to provide space heating and cooling. Heat pump water heaters work similarly and are another aspect of growing electrification in Vermont.

The economics are most compelling for homes using one of the non-electricity fuels for heating, highlighted in **Table 3.** For homes with more expensive heating fuels, a heat pump could be paid off in as little as four or five years. Operating costs are nearly even as those for natural gas and wood, so people are not likely to rush to switch, but might consider heat pumps when replacing failed systems.

Table 3. Annual savings for a typical home (75 MMBtu / year), assuming 80 percent fuel offset[11]

Fuel	Cost of 75 MMBtu / Year
Natural gas	- $68
Wood	- $23
Pellets	$289
Fuel oil	$590
Kerosene	$909
Propane	$1,026
Electricity	$1,583

Heat pumps are least efficient when outdoor temperatures are very high or low, so they pose a challenge for utilities by possibly contributing to peak problems. Currently in Vermont, winter peak is not a concern, but both peaks are growing, and the summer peak is an issue in some areas. Equipment controls and solar supply can both help lower the summer peak. Winter peak issues can be addressed with controls that shift heating to existing fossil systems during peak conditions.

Market Conditions

Opportunities

Growth

Vermonters generally are enthusiastic about heat pumps for displacing fossil fuel heating, as shown in Efficiency Vermont data:

- The most common search term on www.efficiencyvermont.com is *heat pumps*
- The fourth most common search term on that site is *heat pump* (the singular form)
- In 2014-2015, VEIC's Customer Support group reported 200 customers who have contacted them are waiting for Efficiency Vermont to roll out a heat pump program
- Trade shows indicate that Vermonters associate the Efficiency Vermont brand with heat pumps
- Even roofers have expressed an interest in offering heat pumps

Green Mountain Power's (GMP's) lease program took more than 600 calls in the first few days of its announcement. The utility had to stop taking calls because it could not satisfy the high volume of requests.

As awareness of residential split systems (heat pumps whose technology offers both heating and cooling) continues to grow, so do sales:

- 2012 sales
    - Close to 35 percent growth over 2011
    - Approximately 1,720 units sold

[11] An updated version of this table is available in Volume 1.

- 2013 sales
    - Major manufacturers reported growth of 40 percent
    - 2,400 units sold

Technical Advances

Cold-climate heat pumps are advancing quickly. Initially only available as single head units, there are now multi-zone and multi-head systems. These systems come with more installation options for the indoor units that address some of the barriers listed below. Soon, heat pumps designed to connect to conventional duct and water pipe distribution systems will be available, as will be combined space and water heating systems. These improvements increase the number of homes and businesses that can use the technology.

Efficiency is also increasing. Researchers are now designing systems that can use carbon dioxide as a highly efficient and low-impact refrigerant. Solid-state heat pumps are another focus of research. In Vermont, heat from heat pumps currently costs less than all fuels except cord wood and natural gas, as shown in **Table 4**. With increasing efficiency, heat pumps might overtake these two fuel sources, again expanding their potential market.

Table 4. Relative cost-effectiveness of electric heat pumps, compared to other fuel types[12]

Fuel Type	Unit	Btu/Unit	Efficiency	$/Unit	$/MMBtu
Natural Gas	Therm	100,000	90%	$ 1.48	$ 16.44
Wood	Cord	22,000,000	60%	$ 227.00	$ 17.20
Pellets	Ton	16,400,000	80%	$ 294.00	$ 22.41
Fuel Oil	Gallon	138,200	85%	$ 3.22	$ 27.41
Kerosene	Gallon	136,600	85%	$ 3.80	$ 32.73
Propane	Gallon	91,600	90%	$ 2.86	$ 34.69
Electricity	kWh	3,412	100%	$ 0.15	$ 43.96
Electricity (Heat Pump)	kWh	3,412	250%	$ 0.15	$ **17.58**

Source: Adapted from Vermont Fuel Price Report, Vermont Public Service Department

Challenges

Barriers

- Perception that heat pumps don't work in Vermont's climate
- High upfront costs mean financing might be required; many customers are debt averse
- Many older homes need weatherization, first

[12] An updated version of this table is available in Volume 1.

- Many older homes also don't have open floor plans, so they cannot be effectively heated from a single source
- The aesthetic effects of visible units in living space are a drawback, compared to traditional heating systems hidden in basements

Overcoming barriers

- Training and good information about heat pumps' capabilities and applications
- Weatherization assistance
- Future heat pumps that connect to ducted and hydronic distribution systems

Costs

- Single-zone ductless: $4,000
- Multi-zone ductless: $6,000 to $20,000
- Ground source: $20,000+

As contractors become more familiar with the technology, costs will likely come down. There have been some group-buying efforts similar to those for solar. Contractors are combining heat pump and solar projects, gaining customers for both markets and rolling projects into attractive cash-flow-neutral loans.

Scenario Inputs

Data type	Current accounts / historical data
Applicable market segments	• Residential market: fossil fuel displacement • Commercial market uncertain • Restaurant application • LIHEAP • 40,000 - 45,000 households • Multifamily; retrofit and new construction
Number of units, and market share by type	• Low lease penetration with GMP program • 6,000 CCHPs installed in Maine • Collect information on Efficiency Vermont incentives • GMP goal of 750 heat pumps leased by end of 2015 • Home Performance
Typical load profiles, annual consumption, annual production	• Winter peak not a concern right now • Work on reworking load shape via Itron • VELCO estimates that Vermont will not see a net increase in demand from heat pumps for at least 10 years from now
Type of growth	Exponential
Changes in performance characteristics	• Higher efficiency units • CO_2 as refrigerant with higher coefficient of performance (COP) • Solid-state heat pumps

Data type	Current accounts / historical data
	• New brands in the marketplace, offering new technology and other air-to-water heat pumps, with steadily increasing performance each year
Costs	• Installation cost reduction as Heating, Ventilation, and Air Conditioning (HVAC) technicians become more familiar with the equipment • More competition in the marketplace • Equipment costs should come down with improved efficiency
Technical or market elements	• Controlling units remotely to shape loads: Is it the most cost-effective way to reduce peaks? Or are battery banks, for example, better for smoothing out loads?
Top three issues	
Peak load impacts	Forecast the possible negative impacts on peak load
Source of the energy	Movement away from dirty energy
Equipment obsolescence	New equipment outperforming existing equipment, and that equipment is being removed before the end of its useful life
Incentives	Allowing market to transform itself
Manufacturers	Service support: Recall communication

Unmet Needs

More information needed

- Utility plans for controls or rates to manage peak
- Cost projections for equipment and fuels
- Demand response control of heat pumps is likely to be an important strategy to address solar on distribution circuits. This focus group will examine items such as the potential for communications and controls to be integrated with higher solar saturation.

Focus Area Brief: High-Performance Modular Homes & Mobile Home Replacement

Introduction

High-performance modular homes are a relatively new entry in the homeowner marketplace, and they significantly reduce heating and cooling loads through air tightness, high insulation levels, and heat recovery ventilation. By lowering heating and cooling loads with those measures, loads can further be reduced by smaller and less complex HVAC systems such as point source heating and cooling devices. The most efficient and cost-effective point source approach for meeting these demands is ductless cold climate heat pumps. Combined with solar hot water or heat pump hot water heating, these homes can be all-electric with no reliance on fossil fuels. This makes them a very attractive option for people with low to moderate incomes, and those on fixed incomes.

A high saturation of solar power, when combined with the conservation strategies and all-electric approach in high-performance modular homes, can significantly reduce or eliminate energy costs for a homeowner. A solar package can be included in the homes' financing. In effect, homeowners are pre-buying their energy with the home purchase. Solar energy, either site based or available at the community level, can then be part of an affordable housing solution that protects homeowners from future energy cost escalation and reduces their carbon footprint.

Technology and Market Description

For many years, there has been a general conversation about what to do to replace older, energy-inefficient mobile homes with more efficient, durable, and comfortable models. The U.S. Department of Housing and Urban Development (HUD) created standards for mobile homes in 1976 and has updated them several times since. Although the HUD standards have contributed greatly to upgrading the quality of the homes, those standards do not approach the energy efficiency requirements of Vermont's Residential Building Energy Standards (RBES) or ENERGYSTAR® Homes for "stick-built" or modular homes.

Members of Vermont's energy efficiency community have been particularly vocal in asserting that it does not make sense to replace an older, inefficient home with something that cannot meet a high level of energy efficiency, given the price of fuel and the State's legislated commitment to reducing carbon emissions. Tropical Storm Irene added urgency to this conversation because 15 percent of the homes damaged or destroyed by Irene were mobile or manufactured homes. Replacing poor-quality, but very inexpensive, homes with homes of better quality that cost more must be considered in the context of the fact that nationally 41 percent of mobile home dwellers have incomes below 50 percent of area median. A University of Vermont survey of nine sizable mobile home parks has found similar demographics in Vermont.[13]

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[13] Daniel Baker, Kelly Hamshaw, and Corey Beach, "A Window Into Park Life: Findings From a Resident Survey of Nine Mobile Home Park Communities in Vermont," *Journal of Rural and Community Development* 6, no. 2 (December 29, 2011), http://journals.brandonu.ca/jrcd/article/view/415.

Currently, there are more than 22,000 manufactured and mobile homes in Vermont. One-third of these homes are located in mobile home parks on leased land, whereas the remaining homes are on privately owned land. Nearly 70 percent of the homes were built more than 20 years ago, and approximately 25 percent of the homes were built prior to 1976 and the HUD Code. Data from the U.S. Energy Information Administration (EIA) in 2009 showed Northeast mobile homes had average energy consumption of 79.2 MMBTUs per year.[14] By comparison, a high-performance modular home will use around 22 MMBTUs per year in energy; a PV rooftop array of 6 kW would allow the home to produce as much energy as it consumes. These comparisons are shown in **Figure 10.**

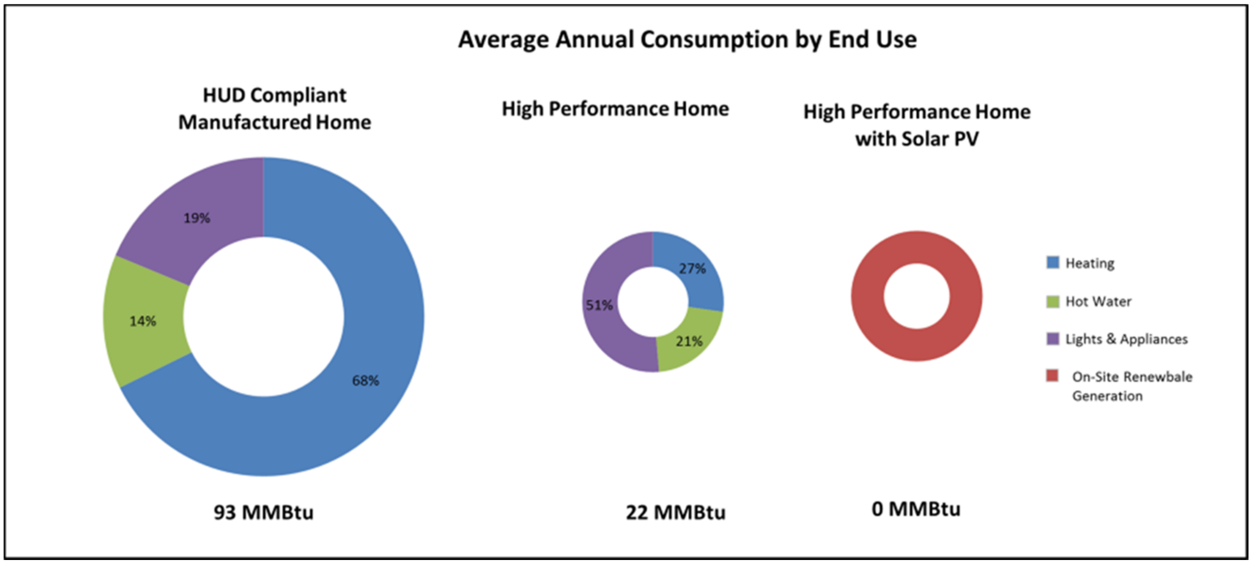

Figure 10. Modeled average annual consumption by end use in Vermont, comparing new HUD-compliant manufactured home standards with a home that meets Efficiency Vermont's High-Performance Home (HPH) tier, assuming the HPH has solar power.

The 2011 *Vermont Comprehensive Energy Plan* calls for a broader market penetration of net-zero-energy buildings, with a goal of having 30 percent built to net-zero design standards by 2020 as an interim target, on the way to 100 percent net-zero buildings by 2030. With this goal in mind, policy makers and decision makers could make net-zero-energy modular housing a priority for Vermont.

Currently, Efficiency Vermont offers a Mobile Home Replacement program and provides incentives for the purchase of high-performance modular units at $8,500 for buyers with incomes less than or equal to percent of area median income and $2,000 for those whose income is above 80 percent of area median income. Several cost breakouts are shown in **Figure 11.** The State also offers a $35,000 tax credit through its HomeOwnership Center Network, which amounts to a 0 percent interest loan with payment deferred until the home, on leased land, is sold. Partners supporting this effort have also created statewide financing terms for these homes on private and leased land, with local lenders and a USDA Rural Development program. These options are as good as or better than typical home financing packages. Currently, low-income homebuyers

[14] U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 2009*, Table CE4.7

of one manufacturer's buildings (Vermod) can access financing terms that are as low as 30 years at 1 percent, with a small down payment.

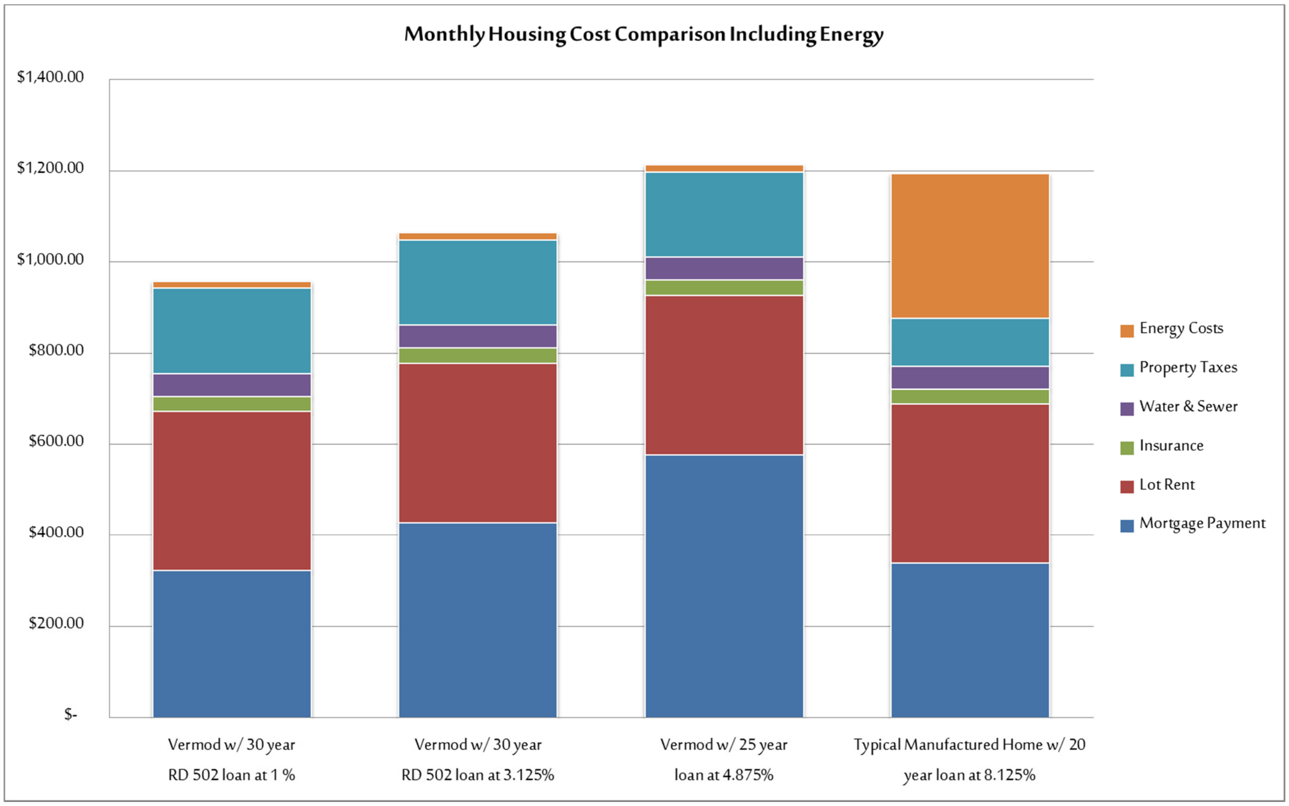

Figure 11. Housing types at available loan terms, highlighting the benefit of USDA Rural Development 502 financing in the two leftmost bars.

Figure 11 assumes a Vermont Housing Finance Agency loan and Efficiency Vermont incentives, where applicable. Note that the monthly payment for a high-performance modular home (denoted in the figure by one manufacturer's name, *Vermod*) would increase by $15 if energy costs doubled; under the same conditions, the owner of a typical manufactured home would have to pay more than $300.

Market Conditions – Opportunities and Challenges

Initial conditions:

- $145,000 for a 980-square-foot, 2-bedroom, 2-bathroom unit without incentives or subsidies
- Three factories in Vermont can construct these mobile home replacement units
- Estimated pace of replacements in 2015: 20 mobile homes
    - Anticipate more than doubling the number of units in 2016, and continuing that trend over the next five years

Opportunities

Growth

High growth for this market would be the achievement of 1 percent replacement of the mobile and manufactured housing stock per year in five years. This would represent around 200 replacement units per year by 2020. The strategies for achieving this goal are outlined below.

Low growth would be the achievement of approximately 50 units per year in five years; that pace would represent approximately 0.25 percent of Vermont's current housing stock.

This initiative and approach to affordable housing began in 2014 in Vermont and across the United States. VEIC is introducing this concept and specific product to the low-income sector for the first time. There are no data on prior mobile home replacement efforts of this type to evaluate. To inform the next phase of developing high-performance homes of modest scale, VEIC, under a grant from High Meadows Fund, conducted market research about the demographics of the potential market and psychographic characteristics of potential buyers. That high-performance home market research is available on the High Meadows Fund website.[15]

The main conclusions were:

- There is no ready-and-waiting market to be served. The market needs to be created.
- Land costs are a significant factor. Finding sites in clustered developments or parks could alleviate this challenge. Southern Vermont and Central Vermont might offer opportunities because land prices in those regions are relatively moderate.
- Even with a financing package, low-income Vermonters will not be able to afford these homes unless they can have access to significant subsidies. Such subsidies could be less than the per-home subsidy for other new affordable-housing options.
- People who are comfortable with change and taking risks are more likely to be early adopters.
- Visiting a home makes a big difference in purchase decision making. People can see and feel the difference in a way that is hard to convey with printed material.
- The terms *High-Performance Home* and *Net-Zero Home* are very weak, and are not understood in the marketplace. Most people do not associate the terms with comfort and affordability of a home.
- Early adopters valued having a "trusted advisor" to guide them in the home-buying process—someone they knew personally or to whom they had been introduced by a trusted source.

[15] Energy Futures Group et al., *Market Potential for High Performance Homes in Vermont*, https://static1.squarespace.com/static/51b0ce25e4b0e8d244de368b/t/547f1163e4b002e3c07d92c1/1417613667602/HPH+Market+Research+Report+11-12-14A.pdf.

Next Phase

Having learned to build a great home and receiving impressive results in terms of energy efficiency, the next phase of this effort will seek to fully fund and implement an overall strategy for moving the project beyond the pilot phase. The strategy for this phase will be to create a path to a sustainable business model for the small, modestly priced high-performance home industry. Specifically, VEIC will:

1. Implement a marketing plan for the high-performance home products in Vermont, identifying obstacles to sales and what appeals to potential buyers. This will involve working with other team members to overcome barriers identified both through the market research and in conversations with potential buyers.
2. Pull together a reasonable financing package for a highly energy-efficient small home. The package might contain on-bill financing or other mechanisms to convert energy savings into a long-term financing opportunity.
3. Test whether mobile home parks can be re-developed in a manner that improves overall quality of life by using the high-performance home model—either as individually owned homes or rental housing. The test would also seek information on whether the high-performance home model enhances the potential of residents to own an asset that appreciates in value.
4. Test whether there is a broader market that can be penetrated with the high-performance home in many locations inside and outside Vermont for early adopters, downsizing elders, and other buyers who meet the profile outlined in the marketing research.

Technical Advances

Efforts are under way to improve the initial cost and financing which will make this type of housing more accessible to low-income Vermonters:

- Minimal down payment
- Low fixed interest rates (less than 4 percent and down to 1 percent for homebuyers at 50 percent of area median income)
- Long terms (30 years)
- Second mortgages at 0 percent interest, with payment deferred until the home is sold
- On-bill financing, using energy savings to cover a portion of the mortgage payment through the homeowner's electric utility
- Higher incentive through Efficiency Vermont for low-income homebuyers, to support early adoption and market transformation
- Increasing the volume of high-performance home production, which should lead to a 10 percent reduction in initial cost of homes

Building science and technologies change very quickly. Further, the industry continues to introduce approaches for effectively achieving high-performance characteristics in new and more cost-effective ways. The High-performance Modular Team at VEIC regularly evaluates the new science and technologies, and incorporates new approaches that can improve the home and reduce either initial cost or life-cycle costs.

Challenges

Barriers

Broadly speaking, the goal of this effort is to transform the market to the point at which high-performance modular homes (HPMH) are affordable and accessible, and can be purchased with conventional sources of financing. Two primary challenges exist:

1. The purchase price is significantly higher than a new manufactured ENERGY STAR home of the same size. Although the ENERGY STAR standard for manufactured homes still fails to meet the Vermont residential energy code, homebuyers consider the product efficient.
2. The concept of this kind of home is very unfamiliar to most people

Overcoming Barriers

The HPMH Team seeks support in continuing to develop tools to overcome these three challenges. What is needed:

1. A financing package that overcomes initial first-cost barriers for moderate-income Vermonters who want to purchase these homes
2. Supplemental financing and funding that enables low-income residents of mobile home parks to own or rent a high-performance home
3. A marketing approach—including graphics, a name, and the necessary hand-holding—that makes the home an attractive purchase option
4. Business planning and support for a company (or companies) willing to serve this market

These elements will allow Vermont to begin to see traditional mobile home parks transformed into communities that provide higher-quality and higher-efficiency options for residents, and to see a substantial increase in market-based sales of high-performance, modest homes.

Costs

- $145,000 today for a 980 square-foot, 2-bedroom, 2-bathroom home, net-zero energy
    - A 10 percent reduction in cost is possible if the volume of sales and production increase (eventually, these should be compared to baseline to meet Code or ENERGY STAR standard, to determine the incremental cost difference).

Scenario Inputs

	Current accounts / historical data	**Reference (business as usual)**	**Long-range target**	**Revised SDP**
Applicable market segments	22,000 existing mobile and manufactured homes in Vermont			

	Current accounts / historical data	Reference (business as usual)	Long-range target	Revised SDP
Number of units (and identify the units)	~ 20 replacement units anticipated in 2015	~ 200 HPMH replacements per year by 2020	23,000 or 100% replacement of MH housing stock by 2050	23,000+ or 100% replacement of MH housing stock by 2050
Total capacity				
Total annual energy consumption	Savings estimated at ~ 70MMBTUs / unit / year			
Type of growth	NA	Linear	Interpolate	Exponential
Changes in performance characteristics	Transforming housing from below RBES to exceed Code by 75%			
Costs	High-performance unit costs twice that of a typical new manufactured home of the same size ($70,000 vs. $145,000)	Anticipate a 10% reduction in cost as demand and volume of production increases		

Unmet Needs

More information needed:

Looking forward, the economics and possible controlled integration of community scale solar versus individual unit solar might be topics for this group to consider.

Focus Area Brief: Incentives

Introduction

Tax credits and other direct incentives have been essential to the growth of solar PV markets. With declining costs and the possibility that future federal tax credits will decline, it is essential to examine whether incentives are still necessary for promoting market development. As the market continues to grow, it is also important to consider if particular market segments (for example, low-income or low-wealth segments) require ongoing incentive support.

Historically, direct incentives have provided statewide oversight of solar electric installations; they have also enabled close communication between the end user and the installer. Without the benefit of a comprehensive direct incentives program, policy makers and decision makers must consider innovative approaches for continued oversight and communication. Incentives can also affect the type of solar installation (rooftop versus ground mounted) and the technical operations (for example, western versus southern exposure) of systems that are deployed. Targeted incentives encouraging well-sited and right-sized systems should be encouraged for maximum efficiency.

Technical and Market Description

State Incentive

The Vermont Small Scale Renewable Energy Incentive Program (SSREIP) discontinued its residential solar electric incentive on December 31, 2014. An incentive structure for “special category” customers (municipalities, public schools, and low-income nonprofit housing) remains, although no funds are available for such projects. The Special Category incentive structure is based on module capacity at $1.00 / Watt, up to 10 kW, with system capacity of up to 25 kW. The incentive requires a reservation and an approved application prior to installation. Afterward, the installer must submit paperwork documenting the system and verifying completion. The program issues the payment directly to the installer, who then transfers it to the customer either through (1) a discount on the final invoice or (2) a rebate from the installer to the customer, once payment has been received from the program.

The Vermont SSREIP does not allow self-installations, and requires that customers use pre-approved Reserving Partners to access the program. The Reserving Partner must oversee system design and installation, and identify—by name and title—the person who installs each project. These Partners apply to Renewable Energy Vermont for acceptance into the program. Businesses with experienced installers committed to high-quality, safe installations may have several “open” reservations at a time. Businesses new to the solar industry are considered “Provisional Partners,” and may have only one open reservation at a time. All Partner installations are subject to inspection by Vermont SSREIP staff, to ensure the installation was completed with homeowner safety and program compliance in mind.

Other basic requirements for the State Incentive are (1) system warranties to ensure that installations remain functional for at last five years; (2) interconnection to the electric utility grid; and (3) a Certificate of Public Good pursuant to 30 V.S.A. § 248 from the Vermont Public Service Board.[16]

Federal Tax Credits

The Business Energy Investment Tax Credit offsets 30 percent of solar PV system expenditures, with no maximum credit. The credit is available for eligible systems placed in service on or before December 31, 2016. After December 31, 2016, the credit will decrease to 10 percent.[17]

The Residential Renewable Energy Tax Credit allows taxpayers to claim 30 percent of qualified expenditures for a system that serves a dwelling unit located in the United States and is owned and used as the taxpayer's residence. It does not have to be the taxpayer's principal residence. There is no maximum credit for systems placed in service after 2008. Systems must be placed in service on or before December 31, 2016.[18]

Corporate Depreciation

Businesses may use the federal Modified Accelerated Cost-Recovery System (MACRS) to recover investment in solar. Solar photovoltaic systems are classified as five-year property, which refers to the Business Energy Investment Tax Credit to define eligible property.[19]

Standard Offer Contracts

Vermont retail electricity providers are required to purchase electricity generated by eligible renewable energy facilities through the State's Sustainably Priced Energy Enterprise Development (SPEED) Program—now known as the Vermont Standard Offer. The Standard Offer uses long-term (10 to 25 years for PV technology) contracts, with fixed standard offer rates. The program provides a reasonable return on investment (ROI) to renewable energy facility developers. In turn, the existence of this reasonable ROI is intended to increase renewable energy production by facility developers. These systems may be up to 2.2 MW. Competitive RFPs are released annually on April 1; contracts are issued according to the proposed $ / kWh structure.[20]

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[16] The Public Service Board offers an expedited Certificate of Public Good process for solar electric systems 15 kW and less.

[17] NC Clean Energy Technology Center, "Business Energy Investment Tax Credit (ITC)," *DSIRE*, December 21, 2015, http://programs.dsireusa.org/system/program/detail/658.

[18] NC Clean Energy Technology Center, "Residential Renewable Energy Tax Credit," *DSIRE*, January 14, 2016, http://programs.dsireusa.org/system/program/detail/1235.

[19] NC Clean Energy Technology Center, "Modified Accelerated Cost-Recovery System (MACRS)," *DSIRE*, January 11, 2016, http://programs.dsireusa.org/system/program/detail/676.

[20] NC Clean Energy Technology Center, "Standard Offer Program," *DSIRE*, accessed December 13, 2016, http://programs.dsireusa.org/system/program/detail/5680.

Historical Trends

State Incentive

The Vermont PV market has sustained tremendous growth over the past several years. Between 2006 and 2009, solar electric installations receiving state incentives funded through the Clean Energy Development Fund (CEDF) via the SSREIP increased at approximately 40 percent per year (56 installations in 2006; 75 in 2007; 109 in 2008; and 153 in 2009). The market stagnated from 2009 to 2010, due to confusion about compliance with conditions for receiving American Recovery and Reinvestment Act incentives through the SSREIP. The market, however, quickly rebounded, increasing 183 percent in 2011 (442 PV installations).[21] The 2011 rate of installation kept pace throughout 2012, even with the sun-setting of the ARRA-funded program and declining incentive rates ($1.75 / W at the height of the period down to $0.75 / W at the close). In 2013, incentive rates continued to decline (to $0.45 / W for residential installations and $0.40 / W for commercial ones).

The PV market quickly responded with the emergence of large-scale leasing options to the public. This market force precipitated another large increase in PV installations, up another 106 percent (404 installations in 2012 to 833 in 2013[22]). By the end of 2013, customer economics for commercial PV were such that the SSREIP no longer was necessary to support that market sector, and the program retired the incentive structure for commercial PV. Under the 2014 SSREIP PV incentive structure ($0.25 / W for residential customers), 1,023 PV installations were completed. This number represented 36 percent of total PV systems receiving an incentive through the SSREIP; another 339 systems were still under reservation. The Vermont PV market remained robust in spite of a continually decreasing incentive. This trend provided strong support for ending the PV incentive altogether from the SSREIP. The CEDF subsequently removed it from the SSREIP on December 31, 2014.

Over the course of the SSREIP PV program, 3,685 PV installations were completed, representing 25.1 MW and 29.5 MWh; an additional 2.3 MW are now under reservation. These and other data are shown in **Table 5.** The trends in incentive rates as installations have increased are shown in **Figure 12**. **Figure 13** shows the comparative value of SSREIP dollars between 2004 and mid-year 2015.

Table 5. Vermont SSREIP summary of solar installations and reservations awaiting installation and incentives, January 2003 through May 7, 2015

Solar PV: For all funding sources	
Number installed	3,685
Total cost of installed systems	$125,176,209
Incentives paid for installed systems	$15,068,349

[21] SSREIP database. May 2015.
[22] Ibid.

Solar PV: For all funding sources	
Total installed capacity (W)	25,117,566
Estimated annual kWh / year	29,507,823
Leveraged economic development: $1 SSREIP investment[23] equals	$7.31
Number under reservation	339
Value of current reservations - not yet installed	$625,982
Total proposed capacity (W)	2,361,475

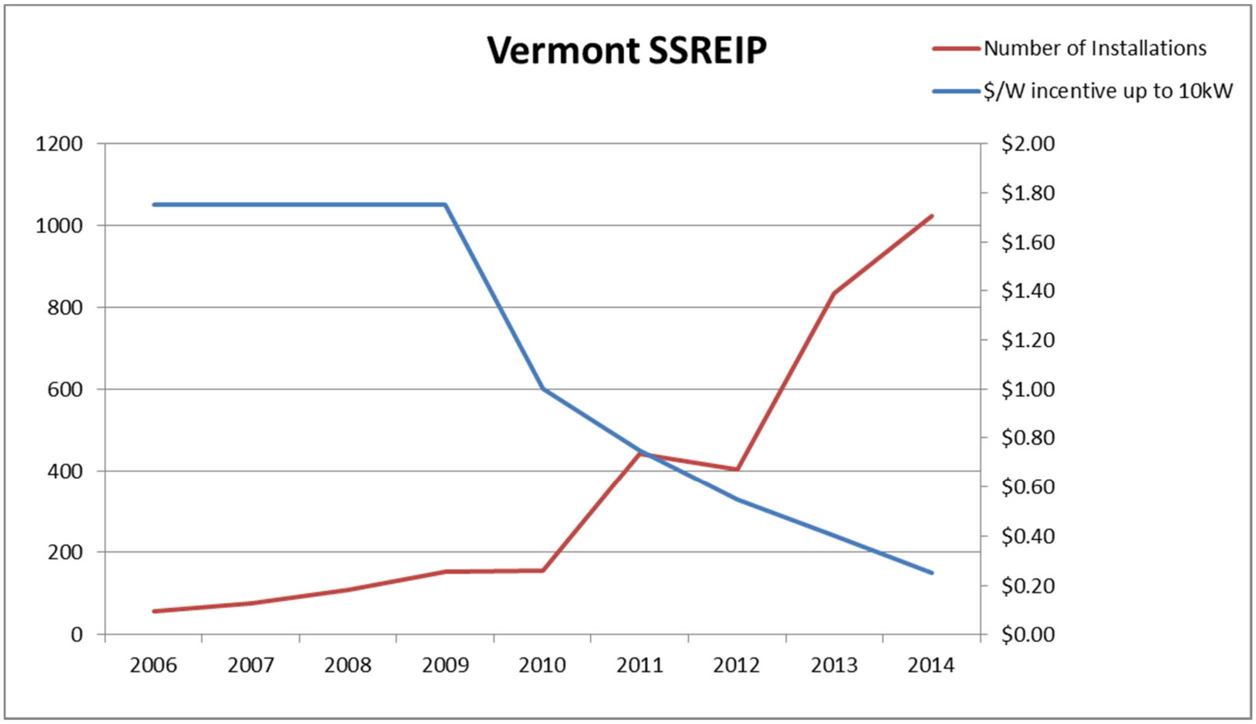

Figure 12. Vermont SSREIP incentive rate, compared to the number of program installations, 2006 – 2014.

[23] Based on reported costs of installed systems and awarded incentives.

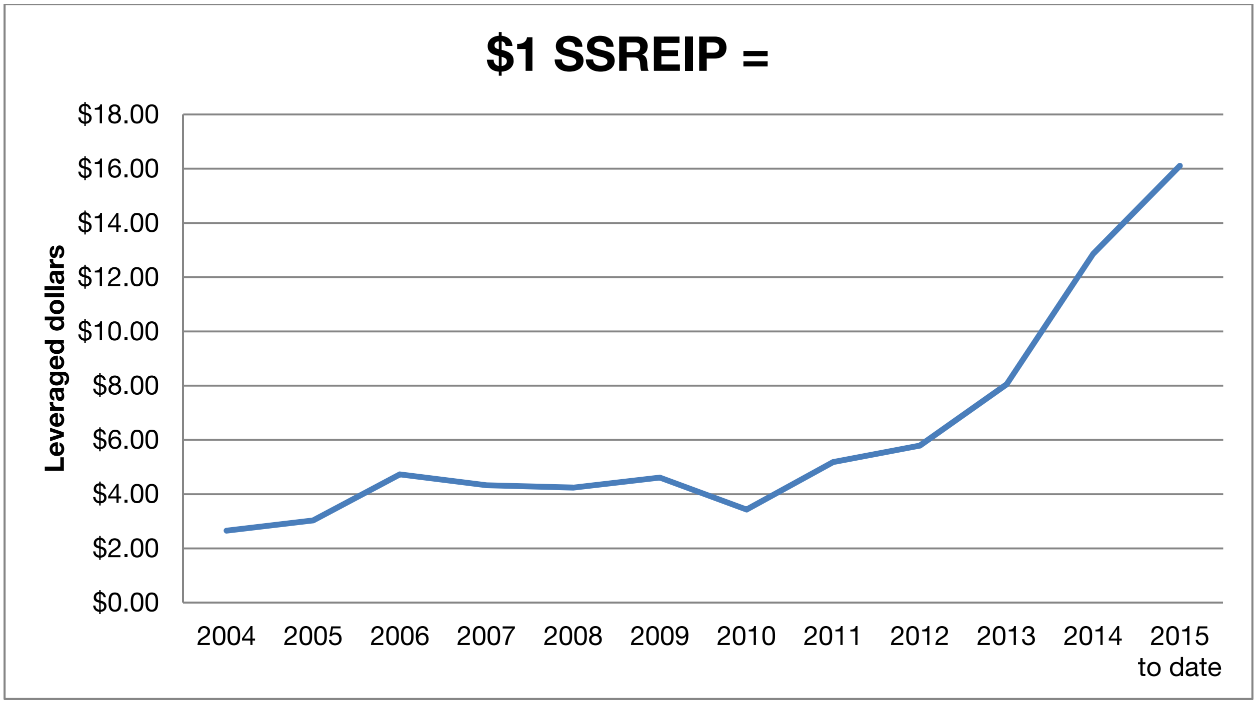

Figure 13. Trend line showing the value of leveraged SSREIP dollars.

Market Conditions

State Incentive

Between January 1, 2003, and the first quarter of 2015 (January 1 through March 30, 2015), the Vermont SSREIP has paid incentives on 3,685 solar photovoltaic systems, resulting in a total estimated annual production of over 25 MWh / year. The program expects to pay incentives on an additional 339 solar photovoltaic systems in 2015, resulting in an additional production of over 2 MWh / year. The average size of a solar photovoltaic system installed in the first quarter of 2015 is approximately 7.5 kW and costs slightly less than $32,000, before incentives (including tax credits). These systems cost an average of $4.26 / Watt before incentives. The state incentive has decreased this average cost to $4.02 / Watt.

There is continued interest in the Special Category, particularly because of the High Performance Mobile Home Replacement pilot (see **Focus Area Brief: High-Performance Modular Homes and Mobile Home Replacement**). That program has allowed end users to access the increased Special Category PV incentive rates directly. Schools, municipalities, and nonprofit low-income housing organizations continue to be interested in solar energy. However, they are now turning to alternate ownership models and to federal grant programs to provide financial opportunities, now that the SSREIP no longer provides incentives for them.

Standard Offer Contracts

Standard offer rates have remained under $0.15 / kWh, with the 2014 rate fixed at less than $0.13 / kWh.[24] As a result of standard offer contracts, Vermont has acquired an additional 5 MW of solar-produced electricity per year. This is expected to increase over the coming years due to Vermont Act 170,[25] which expanded the Standard Offer Program up to 127.5 MW for in-state renewable energy projects (including other technologies) over the next ten years.[26] Even if all of the expected increase in production and purchases takes place, Vermont will not achieve its goal of meeting 20 percent of its electricity needs through the Standard Offer program by 2017. Much of the Standard Offer capacity is solar. Facility developers argue that such projects require a lot of work, and often do not see adequate financial returns. However, with the decreasing cost of installing solar electric systems, the impact of changing rates is less traumatizing to the market.

Renewable Portfolio Standard – RESET Bill

Vermont is currently considering a Renewable Portfolio Standard (RPS) that would generate revenue to support new incentive models. The Vermont General Assembly has not yet determined the solar portion of the standard (*solar carve-out*).[27] That determination will influence the market and how it will react to the proposed incentives under the RPS. The scenario modeling for this project will need to make assumptions to address the uncertainty.

Opportunities

Currently, some tax credits will be decreasing and all direct Vermont state incentives will be expiring. National trends indicate that direct incentives are falling out of favor, not necessarily because they have ceased to be useful, but because they compete with other, more critical budgetary priorities. Taken together with lowered installation costs direct PV incentives will be increasingly less attractive to state and utility budgets.

To maintain the current momentum in the marketplace, other incentive structures must quickly and seamlessly replace reduced tax benefits and direct incentives. Different market sectors have different financial needs and abilities to take advantage of advanced incentive structures. Corporate and commercial markets will likely remain on track with tax benefits such as depreciation, the Investment Tax Credit, and third-party ownership models. Residential markets, particularly low- to-moderate income, will likely rely on innovative financing programs that offer interest rate buy-downs and on-bill financing. Credit enhancements should allow low-income

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[24] *Standard offer rates* refer to the rates an alternative energy supplier—chosen by a customer's utility—charges. In some jurisdictions, utility customers can choose their own alternative energy supplier and pay the supplier's rates, which are typically lower than the utility's chosen standard offer supplier.
[25] General Assembly of the State of Vermont, *An Act Relating to the Vermont Energy Act of 2012*, 2012, http://legislature.vermont.gov/bill/status/2012/S.214 (see act/resolve text).
[26] VEPP Inc., "Standard Offer Program," *Vermont Standard Offer*, accessed December 13, 2016, http://www.vermontstandardoffer.com/standard-offer-program-summary/.
[27] This information will be supplied in a subsequent draft, once the updated information is confirmed and available on the Vermont.gov website.

consumers and those who are unable to take advantage of the tax credit to purchase solar electric systems or buy into a community / group solar array with a cash-neutral-or-better monthly payment.

Group net metering and community solar opportunities will likely stimulate an uptick in participation from residential markets. Other approaches are:

- State support for a Solarize program[28]
- Payment for net excess from net metering
- An easy, facilitated process for donating excess net metering credits to nonprofit organizations or low-income consumers, with a charitable donation deduction
- State RPS requirement for distributed generation, or specifically PV (currently part of the State's RESET law)[29]
- Increasing the Standard Offer program, both in terms of size of systems that can participate and total number of MW. A sliding amount of MW could be put out to bid each year, based on the rate of PV deployed / installed. More MW could be bid if there is a slow rate of deployment.
- Deploy incentives—but not direct subsidies—if they guide customers toward synergistic technologies. Vermont will not reach 90 x 2050 without electric vehicles, for example. How do we create collaborative incentives that support growth in both markets simultaneously?

The Rogers Adoption Curve, shown in **Figure 9** for electric vehicles, pertains to PV, too. If customer acceptance of PV is to move beyond *Innovators,* public awareness and information campaigns will be crucial for overcoming hurdles that relate to general perception and understanding of PV technology. Financially struggling individuals and groups will likely not engage the PV marketplace without a substantial capital or other motivation to do so. Further, with the phase-out of the direct incentives for Vermont, the state lost access to a qualified installer inventory with training verification. Consumer confidence is tied directly to an installer class that is trustworthy and competent.

Highly engaged end users will likely not need further support through direct incentives. However, certain markets could benefit from programs that offer minimal direct incentives. Reducing the need for capital outlay and providing an infrastructure for information and customer support will be essential to addressing barriers for low- to moderate-income individuals and families. Even high-income consumers who can take broad advantage of ever-decreasing tax benefits / credits are in a position to deprioritize renewables in the face of competing interests. In the next 5 to 10 years, Gen Xers and Millennials will have to contend with significant financial burdens and barriers preventing engagement with the solar electric market. Some of these are student loan repayment, decreased rates of home ownership, aging and potentially ailing parents, daycare costs, and high tuition payments for their children. It essential to anticipate consumer needs in

[28] Linda Irvine et al., "The Solarize Guidebook: A Community Guide to Collective Purchasing of Residential PV Systems" (National Renewable Energy Laboratory, May 2012), http://www.nrel.gov/docs/fy12osti/54738.pdf.
[29] General Assembly of the State of Vermont, *H.40*, 2015, 40, http://legislature.vermont.gov/bill/status/2016/H.40 (see act/resolve text).

order to provide a cost-effective, prescriptive financial product that allows struggling markets engage the solar PV marketplace with ease and assurance of a reasonable return on investment.

Finally, non-traditional incentives such as increased property values for homes with solar PV should also be explored.

Incentive programs have also made it possible to track market data. Supplemental tracking programs will be important to monitor activity toward the achievement of goals, ensuring that forward movement aligns closely to projections, or indicates the need to redirect future resources.

Challenges

Costs

Costs for the programs described above can be difficult to calculate. Target deployment must be initially broken down by sector. Using market data from the SSREIP can develop a direct incentive structure for low- to moderate-income consumers. The expired $0.25 / W structure, combined with appropriate financing, would support installations for moderate-income customers, whereas broader application of the $1 / W structure—with additional administrative and financial support from nonprofit, low-income housing organizations—would continue the rise of solar PV ownership by low-income consumers.

Community solar and group net metering offer economies of scale and tax benefits to consumers who would not ordinarily be able to take advantage of financial offsets. However, developers might require further financial incentives to bring the $ / W down to levels that would engage moderate-income consumers. Direct incentives to this market could cost-effectively raise awareness; further, deployment of this financial structure could be phased out as Vermont moves closer to its targets in five years. Community solar tariffs are more thoroughly explored in the **Topic Brief: Net Metering.**

Scenario Inputs

Incentive inputs are dependent on this project's Phase I modeling of technologies and markets. Incentive inputs will likely be determined in late June or July 2015.

Unmet Needs

The following unmet needs also suggest directions for further work, if Vermont is to achieve its 90 x 2050 goals:

- Further research on costs associated with charitable donations for excess renewable energy credits needs to be conducted. However, too much emphasis on tax credits could negatively affect low- to moderate-income participation, because those taxpayers might not meet the thresholds for taking advantage of such credits.
- Further information and discussion for this group will be how incentives and other market signals' rates might be designed in a way that facilitates system integration of high levels

of solar. It is possible that there will be incentives for systems that are located on target feeders, or which can meet certain performance specifications.

- Expanding the Standard Offer program could be beneficial to commercial installations, particularly if they include community solar projects. Vermont needs further research on costs associated with an expanded program.
- Vermont needs to determine the impact of the proposed RPS.
- To increase solar deployment, the State should consider incentives for PV development within or adjacent to built-up areas that are serviced by a generation facility. This siting suggestion could reduce impacts on natural resources that support and contribute to the continued development of other industries, such as tourism, forestry, and agriculture. They might also contribute ecological services such as maintaining the clean water statewide, providing flood attenuation, and preserving wildlife habitat.

Focus Area Brief: Smart Grid, Demand Management, & Energy Storage

Introduction

The smart grid offers opportunities to integrate improved energy forecasting (with weather, load, and generation factors) with distribution system operations and management. Demand management through distributed customer-level equipment and devices can work with batteries and other forms of storage to enhance the capacity of the grid to support higher saturations of intermittent solar PV generation. The following are attributes of and future considerations for smart grid, demand management, and energy storage:

- The smart grid allows communication and coordination of loads with generation to help manage the localized and system wide variability of PV system supply.
- The smart grid allows standards-based, real-time communication with inverters and generation meters. It also allows communication with responsive loads and storage. (for example, electric vehicles, pre-heating and cooling, peak demand management)
- As battery prices drop, “grid-scale” storage and distributed storage will be part of the smart grid response and capability to coordinate and optimize site and system energy.
- The location of controllable loads and storage, relative to sources of generation, will begin to matter at a certain level of solar penetration. It is important to note that location will not be the driving factor, at first. However, the value of storage and demand response will vary by location, even in the relatively early stages. It is likely the variation in locational value will increase as saturations increase, overall.
- Providing sufficient system status, control, and forecast networks to distributed generation, controllable load, and storage will be challenging. Meeting those challenges will require compromises.
- New rates models and interconnection rules and processes will likely be needed to fully realize the public and private cost savings potential of smart grid and energy storage.
- Smart grid, demand management, and storage can collectively provide insight into costs by location and time of use, to reflect the true cost and value of solar generation.

These items set the context for understanding the current and near-future market responses to the relationship between customer and utility, in scenarios with advanced and refined system integration of solar generation.

Technology and Market Description

The electricity grid is the connections between energy supplies, transmission, and distribution to customer load end uses

- Circuits and transformers have capacity limitations that vary in response to load, supply, weather, and other effects

- Costs are related to the wholesale purchase of power at various time scales, associated investments in system maintenance, and ongoing operation

The smart grid enables communication and automation of the electricity grid

- New sensors and control points are available to utilities
- Networking everything is required
- Standards allow different systems to communicate together, for example:
  - OpenADR for demand response
  - SEP 1.1, SEP 2.0 for consumer connected devices

Sources of data that apply directly to smart grid uses and applications

- ISO-New England, Vermont's regional transmission organization
- Distribution utilities
- Other energy markets
- Weather forecasts
- Equipment and devices directly or through product and service aggregators

Controllable loads / resources

- Energy storage
  - Direct storage in energy "batteries" (electro-chemical batteries)
  - Thermal (ice-making, pre-heating and cooling of space, water, or process fluids and equipment)
  - Pumped hydro – there is little hydropower in Vermont is not run-of-river, what is dispatched is subject to tighter flow regulation, and no new storage hydropower in the state is anticipated
  - Flywheels, compressed air, etc.
- Demand response (DR)
  - Large, traditional DR loads
  - Distributed DR: smart appliances, devices, and equipment
  - Integration: direct to device or through service providers / aggregators
- Electric vehicles
  - Rate and level of charging can be configurable by time, location, and account, to moderate variability and lower costs.
  - Location of charging stations
- PV systems
  - Smart inverters can communicate with the grid to provide diagnostics and support to lower maintenance and operating costs.
  - Smart inverters could provide volt/VAR support and other grid services.
  - "Flicker" due to passing cloud cover drives rapid and significant changes in power production for large systems.

Applications that automate load /resource management

- Utility-driven demand response program management

- Grid-scale storage to manage peak and localized variability
- Customer-driven applications that respond to market prices
- New markets, energy management services that aggregate customer accounts and utility programs, etc.

Incentives / rates that motivate automated controls

- True energy cost information, rate plans, and associated configurable signals between customers and electricity system.

Historical Trends

- Advanced metering infrastructure (AMI)
  - Distribution utilities have been installing AMI networks (smart meters) in Vermont. The state has a 90 percent saturation rate (only small municipal utilities and individual opt-outs use non-AMI)
  - Much of the distribution equipment is also connected
  - Other parts of the country are not as well built out, compared to Vermont.
- Behind the meter
  - Legacy DR load controllers: water heaters, conventional thermostats
  - Smart thermostats and home energy management systems are an area of significant growth
  - Heat pumps need statewide standards, but there is a rapidly growing market for heat pump domestic hot water (DHW) and space conditioning, driven by fuel cost differences, improved equipment performance, and utility incentives and financing (see also **Focus Area Brief: Heat Pumps**)
- Batteries
  - New residential products have seen significant investment and early market traction nationally, but are still at a very low level of penetration
  - Falling cost of generation and storage are at parity with customer utility costs in some locations
  - Note: without rate structures that reflect differences in energy costs over time, the pure economic benefits of storage are negligible or negative for most customers, and market uptake will be driven solely by the benefit of backup during outages
- Section 111(d) of the U.S. Clean Air Act
  - National and regional EPA office support for state compliance with carbon emissions reductions incorporates cost considerations, and flexible approaches to implementation that will likely leverage smart grid, demand management, and other relevant existing policy preferences
  - The state-by-state approach from national leaders in the West and Northeast are likely to exert strong influence on Vermont policy actions, despite the state's relative exemption from current emissions reductions targets; this could drive grid generation and time-of-use impacts associated with supply carbon intensity economics that favor enabling rules for rate structures and storage.

Market Conditions

Opportunities

Growth

The amount of solar PV generation deployed in the high scenario modeled in this study is approximately 1 GW. Assuming a capacity factor of 13 percent, 1 GW of PV would produce approximately 3 GWh / day.[30]

Key Questions

- Depending on conditions, is it possible to imagine that the full daily capacity must be able to shift, requiring a full 3 GWh of storage?
- Would more than a day be required, to ensure capacity during multiple under-performing days?
- Or is storage required to handle only smaller and more localized fluctuations? In that case, only a fraction of the 3 GWh would be required.

If only 0.3 GWh (or 300 MWh) of storage was required, that would be equivalent to 30,000 of the larger Tesla Powerwall batteries at 10 kWh each. Assuming at-scale installed costs of $3,500 each, that capacity would cost more than $100 million. Other sources of storage will have different costs and performance characteristics. So a blended portfolio analysis might be required to consider different battery size and technologies (including electric vehicles). In addition to this analysis, various demand response and thermal storage scenarios might be required. It is possible that existing equipment such as HVAC systems, water treatment systems, and snow-making systems have a considerable amount of storage capacity that requires only advanced controls. This is a significant problem, but it scales well. The scale of demand for storage will depend on saturation levels and percent of solar on feeders. Once suitable communication and management systems are developed, the marginal cost can be quite low in comparison to battery storage.

> *What additional value propositions do distributed generation and storage provide through enabling smart grid technologies?*

Grid power quality and availability can be supported through transactive relationships with individual or aggregated customer equipment directly or through third-party services. In some localized instances, the economic benefit of this grid support role could exceed the marginal value of energy production. These opportunities need to be better understood, and the foundational principles for rates and associated marketplace mechanisms created, to allow for optimal performance of the system as a whole.

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[30] D. Steward and E. Doris, "The Effect of State Policy Suites on the Development of Solar Markets," Technical Report (Golden, CO: National Renewable Energy Laboratory, November 2014), http://www.nrel.gov/docs/fy15osti/62506.pdf.

Technical Advances

Time-of-use rates would significantly help battery technology, since under flat rates for residential and small-business customers there is no incentive to charge and discharge a battery at all, even if the communication and controls existed. The roundtrip efficiency for the Tesla batteries is 92 percent, so ratepayers lose 8 percent on any energy that they provide to the grid, and then replenish their own capacity—whether from renewable energy sources or the grid. Further, there is the amortized cost of the equipment purchase and maintenance, since batteries can withstand only a moderate number of charge cycles in their lifetime. Policy and market advances will enable the technical potential of these technical advances.

Many of the devices and systems that could provide storage and DR capabilities are starting to integrate communication and controls capabilities, as those technologies become more affordable and more mature. Integrating these features into building systems at the time of manufacture allows for both lower cost and more functionality than the add-on solutions available today (such as switching a device to low-power mode, rather than simply cutting power to it entirely).

Challenges

Barriers

Besides the need for dynamic or time-of-use rates, Vermont needs a technology marketplace for the control systems, robust and well-adopted communication standards, and market mechanisms that allow fair prices and efficient transactions. This is potentially a chicken-or-egg challenge, since incentives for the development of both dynamic rates and rate-responsive devices are dependent each on the presence of the other.

Overcoming Barriers

Utilities and regulators can address these in many different ways.

Costs

We will continue to gather estimates for current and future prices of customer sited as well as circuit-level storage and control technologies.

Reducing Costs

Pilots could help determine appropriate models for dynamic rates and could also help build the case with regulators and other stakeholders. Proof-of-concept demonstration projects and incentives might help to build public adoption for storage and DR devices.

Scenario Inputs

	Current accounts / historical data	Reference (business as usual)	Long-range target	Revised SDP
Applicable market segments (add rows as necessary)	Very small (< 1%) of customer behind-the-meter storage and DR controls at residential and commercial scales	Need base case definition for rate models that drive uptake of DR and storage	TBD	TBD
Number of units (and identify the units)				
Total capacity			Economic optima?	
Total annual energy consumption				
Type of growth	NA	Linear		Exponential
Changes in performance characteristics	Not currently cost competitive with very low market presence and grid impact. Existing storage products have become only recently “productized” to enable mass-manufacturing reductions in hard and soft costs.	Coupled to financing packages of residential PV systems, backup and daily-cycle storage systems might grow rapidly; but without changes to rate structure, they will be constrained to backup systems, and to a smaller number of larger commercial customers.		

	Current accounts / historical data	Reference (business as usual)	Long-range target	Revised SDP
Costs	Breakeven capital cost for a reserves-only storage device ($ / kW) 100 MW mid-ranges between $1,800 - $3,000 $ / kW[31]	Need projections	Need projections	

Unmet Needs

More Information Needed

Critical:

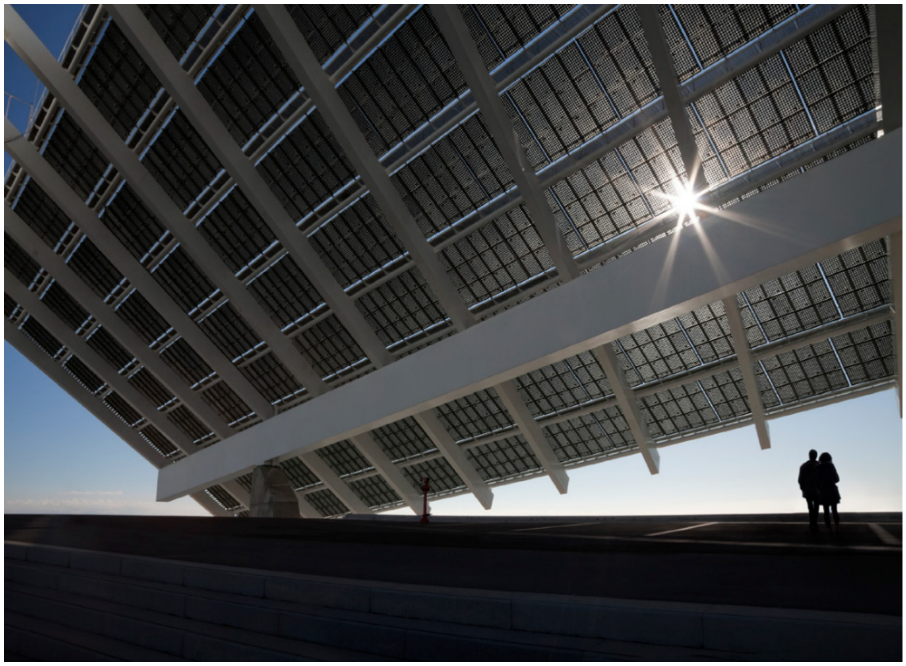
- Characteristics of existing system costs and constraints related to business-as-usual scenarios.
- Likely range of values for associated grid support services provided by distributed generation, storage, and load management that are enabled by advanced solar deployment.

More information is needed on:

- Grid circuit constraints: Hundreds of distinct parts of the grid have associated costs that could be modeled with a simplified collection of circuit types, possibly reflecting the characteristics of the overall network.
- PV grid interactive effects: Some of the costs and benefits of solar power can be recognized only at spatial and granular scales. To reflect these contributions in the model, these interactions must be better understood through simplifying estimates and analyses.
- Rate structure changes are likely responses to greater system information capabilities and market forces (such as those highlighted by concerns over a "utility death spiral"); ultimately, these rates might drive adoption curves for demand management and energy storage systems at the customer level.

[31] Denholm et al. Table 5-4, p. 32. "The Value of Energy Storage for Grid Applications" NREL & US DOE Technical Report NREL/TP-6A20-58465, May 2013. http://www.nrel.gov/docs/fy13osti/58465.pdf.

Vermont Solar Market Pathways



Volume 3

Barriers and Integration Brief

December 2016

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Preface

The growth of solar markets is part of an emerging trend toward a decentralized and well-networked energy system. Historically, electricity has been generated at large central power plants, with a one-way delivery of electricity to end users via transmission and distribution lines. Advances in solar energy, communications, and end use equipment are now contributing to the steady growth of distributed energy resources (DERs) and a more networked energy system.

Today, energy production and storage are more likely than before to occur at a customer's site. It is also increasingly possible to monitor, manage, and control customer energy in new ways that can help provide greater convenience, enhance energy performance, and lower costs. For example, new technology can sense when you or your visitors are approaching your home, and turns on your lights for you; and there are thermostats that "learn" your behavior patterns and adjust heating and cooling to match.

Volume 3 of the Solar Market Pathways Report looks in detail at issues with the integration of high levels of solar and other intermittent renewable resources into the electric distribution and transmission system. The majority of **Volume 3** material is based on research and on market and regulatory conditions existing in 2015 and reported in September of that year. These all continue to evolve rapidly. This preface to **Volume 3** offers an update on the September 2015 materials, to illustrate the several emerging trends in the past year.

Volume 1 (Summary Report) provides an overview of the project and recent results. **Volume 2** (Focus Area Briefs) is the initial research on the state-of-the-art of growing and high levels of solar generation. **Volume 3** (Barriers and Integration) documents potential problems with high solar generation. The discussions and research in the project were supported by scenario analysis. The team built a model of Vermont's total energy system with scenarios that vary the levels of efficiency, fuel switching, and renewables. The model quantifies demand, supply options, costs, and emissions. **Volume 4** (Methods) provides sources for inputs and more comprehensive results than provided elsewhere in the report.

As of late 2016, solar provides roughly 2.8 percent of Vermont's electricity generation.[1] The Vermont Solar Market Pathways Report and project assume that this value increases more than seven times, so that by 2025, solar resources account for 20 percent of Vermont's total electric generation supply. **Volume 3** examines the technical, regulatory, and business model issues and opportunities with this level of solar generation.

Highlights from **Volume 3:**

- **How much solar can be integrated into the electric distribution system** is an important and complicated question relevant with today's level of solar market saturation and more so in the future. There are locations on the distribution system where it will be expensive and / or difficult to host new solar capacity. However, other areas in the system can host new capacity without upgrades. The issues are complex and depends on interdependent factors such as the design and age of existing equipment, the amount of solar that is already present in a given area, the distance between customers), and the types of size, shape, and location of loads.

[1] With ~150 MW installed capacity, 167,000 MWh per year annual solar generation and ~6,000 GWh of annual electricity consumption (167,000 MWh / 6,000 GWh = 2.8%). Note that Certificate of Public Good (CPG) applications have been filed with the Vermont Public Service Board for more than 250 MW of solar capacity; with net metering rule changes taking place at the end of 2016, an increase in CPG filings before the end of 2016 is expected.

- Improved information is increasing—for example, through Green Mountain Power's (GMP's) Solar Map[2]—on **where the distribution system is most and least likely to be able host new solar capacity** without distribution system upgrades. This type of information, updated weekly, helps developers and customers understand where new applications could face additional costs and / or delays because of system constraints. Rapid market growth increases the need for this type of information.

- The range of **solutions to address potential system constraints** on hosting capacity for new solar is growing, and new solutions and strategies are likely to continue as areas of rapid innovation. For example, in addition to "traditional" upgrades to distribution system poles and wires, there are new options such as on-site storage, load building, and shaping or shifting aggregated load. Smart inverters and detailed forecasting of demand and renewable supply will also help. Physically, solar can be easily curtailed to deal with over generation, but that is bad for the project economics unless a few hours per year of curtailment allow a project to be installed where it otherwise could not. All of these strategies can be used to maintain or increase distribution system hosting capacity.

- Vermont's **revised net metering rules**[3] do not have caps limiting the amount of net metered solar capacity a utility can host. The new rules will lower the credit paid for net metering projects, and creates categories with different rates for projects of different types and sizes. As a result, the pace of net metered capacity is expected to slow somewhat, and to be directed toward more favorable sites. Sites with higher credits include pre-existing structures, disturbed land, or land adjacent to the customers who are consuming the power.

- Processing the quickening permit and interconnection applications, and keeping up with necessary system upgrades for them are expected, even with the new lower credit amount, to put some upward pressure on electric rates. The rate premiums offered for net metered systems will also contribute to additional costs for ratepayers. On balance, however, the Vermont Public Service Board anticipates that **the economic benefits of diversified and distributed solar justify the additional costs** associated with the revised net metering rules. Ongoing monitoring of the costs and market development will continue.

- **Distributed resource planning**—to identify preferred sites, technologies, and integrated solutions—can reduce costs, spur innovation, and provide better certainty for developers and technology and solution providers. Distributed resource planning is a complicated and involved process that will require investments and active participation and resources from several stakeholders. Striking an appropriate balance between strictly letting the market determine where, when, and what type of distributed resources are deployed, and using planning to shape the market, is an emerging regulatory and policy question in Vermont and other jurisdictions.

- The bulk power system provides the interconnection between Vermont's distribution utilities and the rest of the New England power grid. The impacts of Vermont's increasing solar generation are already visible to the Vermont Electric Power Company (VELCO), which owns and operates Vermont's

[2] "Solar Map," *Green Mountain Power*, accessed September 21, 2016, http://www.greenmountainpower.com/innovative/solar/solar-map/.
[3] Vermont Public Service Board, *Revised Rule 5.100 Pursuant to Act 99*, 2016, http://psb.vermont.gov/statutesrulesandguidelines/proposedrules/rule5100.

transmission system. The reduction of loads and / or the export of power during periods of high sunshine and low demand add a new dimension to system operations and planning. **Bulk power system planning** is considering increasing levels of solar and wind, and other distributed resources such as storage and load shaping, in forecasting and resource planning efforts.

- The amount of potential import and export required to support 20 percent of electric supply from solar by 2025 will result in **changes to the timing, scale, direction, and volatility of bulk power flows and market interactions.** Broadly speaking, they are not out of step with what is currently handled by the market and system infrastructure. Vermont is a small component of the regional market and does not have a strong effect on its operation. If solar markets in other states grow at the same pace as Vermont, the implications for bulk power system operations and markets will increase.

- The production of 20 percent of Vermont's electricity with in state solar by 2025 **reduces the amount of imported electricity**. This outcome meets the state's goals of increasing the share of total energy coming from renewable resources. It also makes Vermont more reliant on its own energy resources and encourages in-state economic development.

- Solar markets are part of a rapidly expanding field of distributed energy resources. Along with the evolution of technology in communications, sensors, and interconnection is a vibrant and rapid expansion of research and reports on how markets, regulations, and policies reflect the new opportunities. **Relevant additional research and reports** that have been issued, or were not referenced in the original draft of the September 2015 Market Barriers and Integration brief, are:

    - ***Distributed Energy Resources Rate Design and Compensation***: A Manual Prepared by the National Association of Regulatory Utility Commissioners (NARUC) Staff Subcommittee on Rate Design, November 2016. This document examines issues and strategies for rate design for net metered solar and other distributed energy resources.

    - ***Smart Electric Power Alliance, The 51st State: Mapping the Dynamics of Energy Transformation***, Conversations about the Evolution of the Electricity Marketplace from SEPA's 51st State Phase II Summit, Denver Colorado, April 2016.[4] Phase II of the 51st State Initiative draws on a wide range of stakeholder perspectives ("roadmaps"), on how regulatory and markets might evolve. Vermont Solar Market Pathways was presented at the Summit as one of the Phase II Roadmaps.

    - ***Pacific Gas and Electric Company Electric Distribution Resources Plan,*** July 2015. This report is representative of how utilities in some markets, most significantly New York and California, have begun to create distributed energy resource plans that integrate solar, storage, demand response, electric vehicles, and other resources to meet future distribution and bulk power system needs. Appendix C of the Plan presents details on DER growth scenario methods and results, in a fashion that complements and informs the scenario modeling and regional applications of the total energy scenario modeling that has been conducted using LEAP software by the Vermont Solar Market Pathways project.

[4] "The 51st State: Mapping the Dynamics of Energy Transformation" (Denver, CO: Smart Electric Power Alliance, April 2016), http://www.sepa51.org/phaseII/51stState_PhaseII_SummitReport.pdf.

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Executive Summary

Originally released September 2015; copy edited December 2016 for consistency with subsequent work on the project

Vermont has state energy goals, codified in law and described in detail in the 2011 Vermont *Comprehensive Energy Plan*—essentially, to meet 90 percent of all energy needs via renewable sources by 2050. To meet these goals, the state must address the extent to which the various forms of renewable energy can be deployed.

Vermont Solar Market Pathways, the primary document to be produced by and for stakeholders of a U.S. Department of Energy SunShot Initiative award,[5] maps the steps for developing solar energy generation with sufficient scope to maximize the role of solar energy in meeting the state's goals.

Vermont Solar Market Pathways is based on detailed scenario analyses of future energy and supply mixes in Vermont. The first scenarios were completed during the first six months of the project. They provided the foundation for the next phase of the project, to examine the issues and barriers associated with obtaining 20 percent of Vermont's total projected electric generation supply from solar by 2025.

Developing comprehensive solar pathways, similar to the one being created for Vermont by this project, is expected to contribute to lower solar costs through specific mechanisms. By taking a long-term planning perspective and integrating the growth of the solar market into the state's overall energy economy, the approach of *Vermont Solar Market Pathways* will help policy makers, local planning commissions, and the market understand both the potential for, and the potential barriers to, an advanced solar market. This understanding will improve the chances for sustained market growth and investment.

This brief is a critical element of that mapping exercise, because it identifies and discusses the major technical, policy, regulatory, and market barriers to solar's ability to provide this level of contribution to the state's energy mix. During the coming phases of the project, the issues and market barriers identified in this brief will be prioritized for in-depth analysis, and will inform scenario revisions and the final *Vermont Solar Market Pathways.*

Three initial policy and market scenarios provide the basis for examining solar energy's potential to meet the goals:

1. Business as usual (Reference scenario);
2. A "90 x 2050_{VEIC}" scenario that VEIC developed and which meets the State's *Comprehensive Energy Plan* goals of obtaining 90 percent of total energy from renewables by 2050. The VEIC subheading on this scenario should be understood to indicate that it has been developed by VEIC, but with significant input from project stakeholders.
3. The Solar Development Pathways (SDP) scenario meets the 90 x 2050 target and increases solar development so that 20 percent of electric generation supply comes from solar by 2025.

The 90 x 2050_{VEIC} and SDP scenarios assume the anticipated increase in the installations of cold-climate heat pumps and sales of electric vehicles, along with continuing improvements in energy efficiency across all sectors.

The SDP scenario initially allocates solar into three types of project classes. Rooftop or ground-mounted systems at individual customer sites are expected to account for roughly 300 MW of capacity by 2025. Community solar, which will be primarily ground mounted, but will also occupy some rooftops, is expected

[5] Award DE-EE-0006911, to the Vermont Energy Investment Corporation; David Hill, Ph.D., Principal Investigator.

to account for 300 MW. Utility scale ground-mounted systems with wholesale power purchase contracts are expected to account for 400 MW of new capacity.

The level of solar growth in the SDP scenario reflects approximately 10 times more solar than is currently connected or in project development. This level of growth raises technical, regulatory, policy, and market issues and barriers. The initial analysis of the net demand resulting from 1 GW of installed solar capacity shows negative net demand in times of high solar output, and lower demand for 3 percent of the hours in the year. This analysis is by nature very highly aggregated. The nature of net demand is very specific according to the loads, and according to the distribution system infrastructure, equipment, and controls for each feeder, substation, and region.

This project is not designed or intended to replace detailed system impact reviews and planning, but rather to provide a framework for coordinating and prioritizing methods for addressing the technical issues raised by this level of solar market development. During subsequent phases of research, the Project Team undertook several more detailed analysis related to the technical issues. Results can be found in **Volume 1**.

This brief also addresses the expected regulatory and policy issues that will be priorities for further investigation in the next research phase. Finally, this brief discusses potential business model and market-related barriers. In all cases, the Project Team's objectives in this brief are to provide solid information and analysis to support further discussion and research with partners and stakeholders, to enhance the final *Vermont Solar Market Pathways* report, scheduled to be completed in 2016.

Introduction

This brief presents the findings and recommendations on how to address barriers and issues related to high levels of solar integration in Vermont's energy economy. The brief is a deliverable in the comprehensive scope of work and project objectives for the Vermont Solar Market Pathways Project supported by Department of Energy's SunShot Initiative.

VEIC, along with our partners—the Vermont Public Service Department and the Regulatory Assistance Project (RAP)—are working with a broad range of stakeholders to develop a comprehensive plan to address how Vermont can obtain 20 percent or more of its total electric energy requirements from solar energy by the year 2025. During the first 9 months of the project, the Project Team has held three large meetings, attended by more than 85 stakeholders representing Vermont's energy, planning, legislative, and regulatory communities.

The project has a 3-year work plan, and the market barriers and integration brief is a deliverable at the end of the third quarter.

Objectives

Vermont has recently experienced rapid growth in solar energy installations. There is increasing public interest, investment in—and in some cases, opposition to—examining the potential for solar to make more significant contributions to meeting Vermont's *Comprehensive Energy Plan* targets.

Our objectives are to identify issues and barriers that will arise as solar energy significantly increases its presence in the state. The scenarios developed in early phases of the project have been designed to provide an analytic framework that includes both supply and demand resources, for what is required to get 20 percent of Vermont's electric energy supply from solar by 2025.

This is an increase of more than 10 times what is currently installed. Before policy makers, utilities, consumers, ratepayers, businesses, and other stakeholders in Vermont can be expected to support or oppose this level of solar development, it is important to provide accurate and up-to-date information about what the barriers, issues, benefits and costs of this level of development entail. This Barriers and Integration Brief identifies and provides recommended methods for examining the issues and barriers. Later work in the project will quantify the costs and benefits with the Solar Development Pathways scenario, in comparison to reference cases.

Methods

Vermont Solar Market Pathways will be based on comprehensive scenario modeling of the supply and demand sectors of Vermont's energy economy. The Project Team is including transportation and thermal fuel use, as well as electricity use, within the scenario planning so that the full impacts of higher levels of renewables and of reaching Vermont's *Comprehensive Energy Plan* targets can be fully understood.

The energy scenario modeling in the project is being conducted with the Long Range Energy Alternatives Planning (LEAP), a planning system developed by the Stockholm Environment Institute.[6] The LEAP system provides a structured accounting framework for developing and comparing internally consistent energy future scenarios. It offers excellent visual reporting and graphics to help stakeholders understand the implications of various options.

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[6] Heaps, C.G., *Long-Range Energy Alternatives Planning (LEAP) System*, version 2015.0.24 (Somerville, MA, USA: Stockholm Environment Institute, 2016), https://www.energycommunity.org/default.asp?action=introduction.

VEIC analysts have worked with Team Partners and stakeholders to develop initial scenarios during the first nine months of the project. These reflect current and recent historic energy use, and project future demand and supply based on state and utility plans. The scenarios will continue to be reviewed and refined as the project continues, and they are now providing the basis for additional complementary analyses and discussions such as the work conducted for this integration and market barriers brief.

Document Overview

This brief provides guidance to stakeholders of Vermont Solar Market Pathways, a project funded by the U.S. Department of Energy within the SunShot Solar Market Pathways Program.

The project itself coordinates and facilitates a broad stakeholder process and develops a stakeholder-informed—and where possible, an agreement-based—solar development plan for the State of Vermont. The resulting document, *Vermont Solar Market Pathways,* will play an important role in putting Vermont on target to meet its ambitious *Comprehensive Energy Plan* (CEP) goal of obtaining 90 percent of total energy supply from renewable resources by 2050. *Vermont Solar Market Pathways* will specify the necessary policy, regulatory, and market conditions in 2020 (5 years ahead) and 2025 (10 years ahead) for allowing distributed and central solar generation to fulfill this role. Informed by this broad objective, VEIC expects *Vermont Solar Market Pathways* to examine the requirements and constraints with 1+ GW of PV deployed in Vermont by 2025.

In this brief, the Project Team addresses Vermont's long-term economic realities under several key scenarios for a high-saturation solar future that is also consistent with and contributes to the overall energy supply goals of the CEP. This brief looks at the barriers of integrating this level of solar energy into the electric generation mix, and recommends specific steps for the stakeholders and Project Team to take during the next phases of research to address these issues.

Project Context

The Program advances solar deployment across the United States, while concurrently addressing ways to reduce the non-hardware ("soft") costs of solar energy deployment. *Vermont Solar Market Pathways* is one of 15 awarded projects under the Program, which seeks effective approaches for strategic plans to expand solar electricity use for residential, community, and commercial properties.

The lessons learned from these projects will offer replicable examples for deployment throughout the United States. This is considered "an important step towards making solar deployment faster, easier, and cheaper across the country," a major goal of the SunShot Initiative.

In general, comprehensive solar development pathways strategies and plans are expected to provide greater certainty to the development, planning, and investment communities. This certainty is expected to help lower the soft costs associated with solar energy. Also by sharing experience and approaches to identifying and addressing barriers to high levels of solar, plans such as that being undertaken by this project will also help lower the costs of addressing these barriers.

Vermont Energy Future Scenarios

Initial Supply and Demand Scenarios through 2050

Three scenarios of Vermont's energy future have been developed to support the stakeholder discussions and process under the project:

Reference scenario: "Business as usual" (BAU), similar to today, but it assumes more efficient cars due to Corporate Average Fuel Economy (CAFE) standards and expanded use of natural gas. It is based on the BAU scenario of the Vermont *Total Energy Study* (TES).[7] The Project Team revised the model to slow the growth of natural gas after the cancellation of a second phase of a pipeline project. State regulators have since held hearings to decide whether to reopen and possibly revoke the Phase 1 permit, because of new cost estimates that are nearly double the ones made available during the initial permit application review.[8]

90 x 2050_{VEIC} scenario: Stronger efficiency and accelerated renewable energy adoption to achieve the State's goal of meeting 90 percent of total energy needs with renewable sources by 2050. This scenario is based on the TES Total Renewable Energy and Efficiency Standard (TREES; local energy) scenario.[9] The efficiency gains include electrification of space and water heating, and transportation. This scenario greatly lowers the total energy demand, while increasing the amount of electricity consumption.

Solar Development Pathways (SDP) scenario: Very similar to 90 x 2050_{VEIC} but with more solar, accounting for more than 20 percent of electricity by 2025 and over 30 percent by 2050.

End Use Efficiency

Efficiency is widely recognized as the most cost-effective and lowest-impact way to reduce greenhouse gas (GHG) emissions. Vermont has a strong history of effective electrical efficiency programs and is moving toward a total energy perspective that can expand those results to the thermal and transportation sectors. The effectiveness of these programs causes a downward trend over time in the Reference scenario, shown by the dashed line in **Figure 1.** The demand in the SDP scenario drops more dramatically, shown by the colored areas in **Figure 1,** particularly in the residential and transportation sectors. The total demand falls by about 35 percent from 2010 to 2050, assuming the State's continued progress on improving efficiency across time.

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[7] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals" (Montpelier, VT: Vermont Department of Public Service, December 8, 2014), http://publicservice.vermont.gov/publications-resources/publications/total_energy_study.

[8] Pat Bradley, "Vermont Public Service Board Holds Hearings On Pipeline Project" (Albany, NY: Northeast Public Radio (WAMC), June 24, 2015), http://wamc.org/post/vermont-public-service-board-holds-hearings-pipeline-project.

[9] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals."

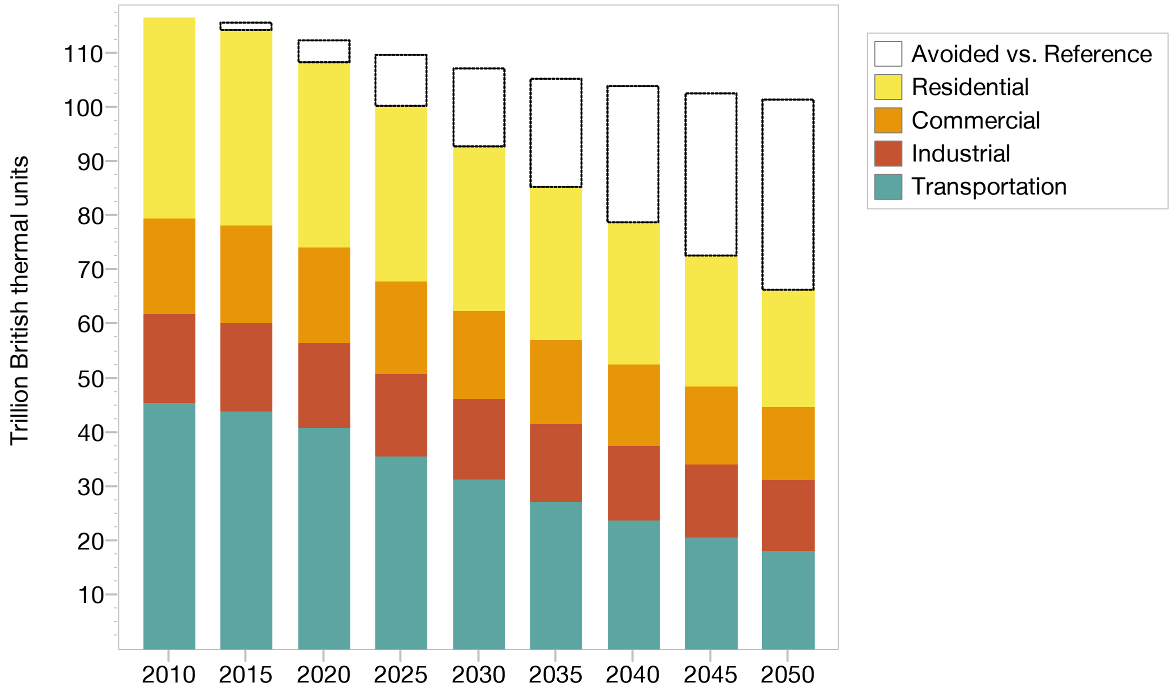

Figure 1. Energy demand by sector, 2010 through 2050, by energy use sector in Vermont.

Electric Supply

In the Reference scenario, electricity supply is determined by the contracts that the distribution utilities held at the end of 2013. **Figure 2** shows the largely flat contracts for hydropower, solar, wind, farm methane, and wood. Nuclear drops off sharply by mid-2015 with the closure of Vermont's only nuclear power plant. The remaining nuclear is imported from regional plants. With no significant new renewables or contracts, the state would rely increasingly on importing electricity from the New England grid, the supply of which is primarily generated with natural gas. As the timeline extends closer to 2050, more gas is required as electric demand rises with projected increasing population and economic activity, and because of a small shift toward electrification of buildings' thermal needs and transportation.

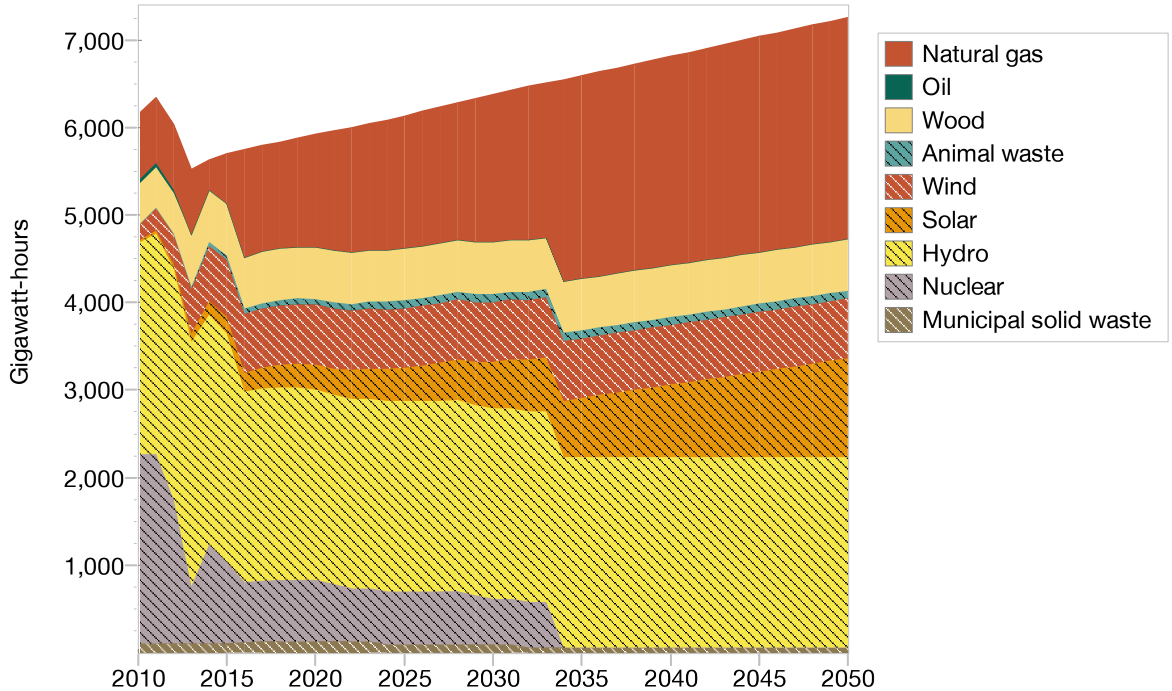

Figure 2. Electric supply allocations in the Reference scenario, through 2050.

The 90 x 2050VEIC and SDP scenarios assume quicker adoption of heat pumps and electric vehicles, both of which are expected to result in twice as much growth in electricity consumption. Sources of electricity in these scenarios are shown in **Figure 3** and **Figure 4.** Both assume additional wind, hydro, and solar in the electricity supply. Some of the hydropower is assumed to be imported from Hydro-Québec; all other renewables are within Vermont. These assumptions diverge from the TES, which assumes more wind generation from turbines sited mostly outside Vermont, and less hydropower.

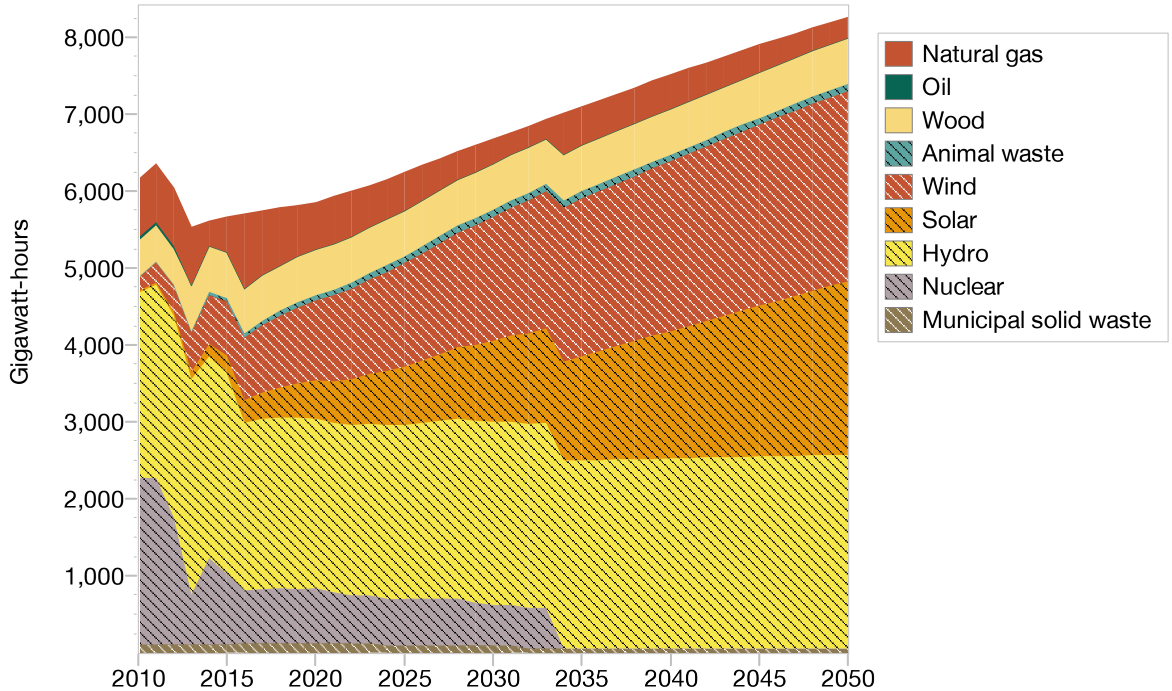

Figure 3. Electric supply in the 90 x 2050VEIC scenario, through 2050.

The SDP differs from the 90 x 2050VEIC by assuming solar exceeds 20 percent of generation by 2025, and 30 percent by 2050. The dispatch model correspondingly reduces wind and hydro.

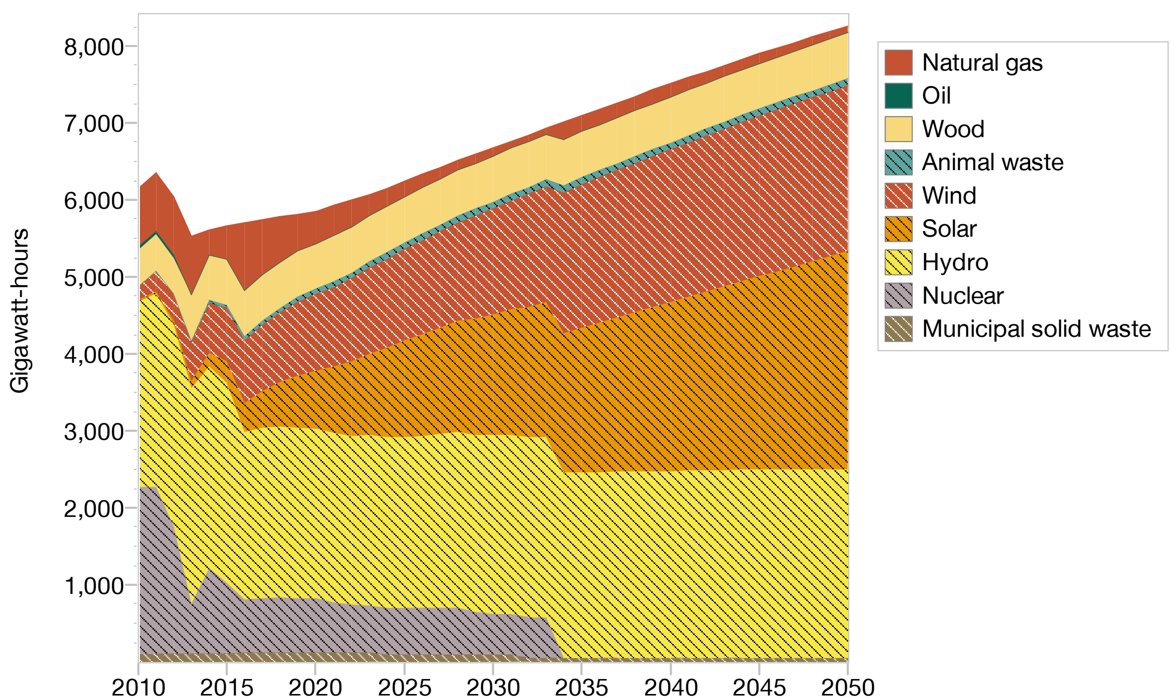

Figure 4. Electric supply in the SDP scenario

Figure 5 shows the difference between the SDP and Reference scenarios. The clear difference is the proportion of solar, wind, and hydro, instead of natural gas.

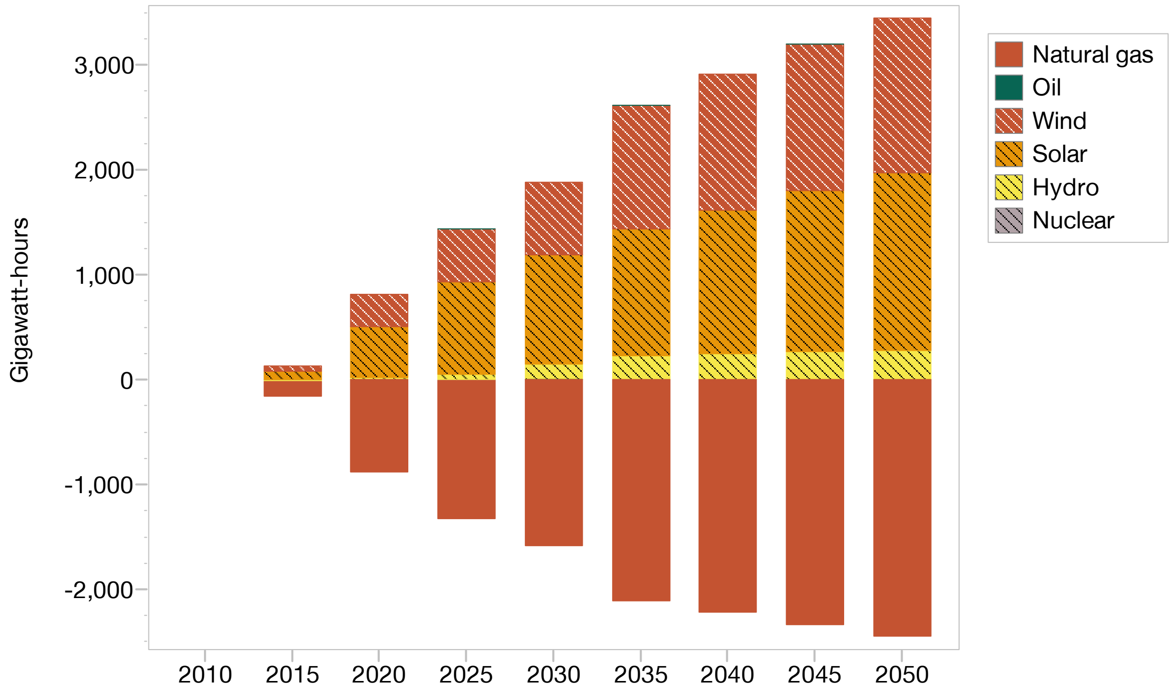

Figure 5. Difference in electric supply between the SDP and Reference scenarios.

Solar and Other Key Metrics

The quick growth of solar and other renewable forms of electricity generation is partially driven by and drives the electrification of end uses traditionally served by fossil fuels. Vermont is experiencing quick growth of electric cold-climate heat pumps for heating and cooling, and of electric vehicles (EVs). Anecdotal evidence suggests that people who adopt these technologies do so to rely on clean electricity, or they adopt solar to cleanly fuel their new heater or car. A local weekly newspaper, *Seven Days,* ran an article last January about a VEIC employee who installed a heat pump and solar panels in an existing home, with the intention to achieving a zero energy home.[10] Further, several Vermont companies—such as King Arthur Flour[11] and Green Mountain Power, as shown in **Figure 6** and **Figure 7**, respectively—are offering their employees solar charging for electric vehicles.

[10] Amy Lilly, "Retrofitting: Saving Energy (and Environment) in a 1950s House," *Seven Days*, January 7, 2015, http://www.sevendaysvt.com/vermont/retrofitting-saving-energy-in-a-1950s-house/Content?oid=2500132.
[11] "King Arthur Flour Charging Station," *Green Energy Times*, December 15, 2013, http://www.greenenergytimes.net/2013/12/15/king-arthur-flour-charging-station/.

Figure 6. A Tesla charging at King Arthur Flour Company, in Norwich, Vermont.[12]

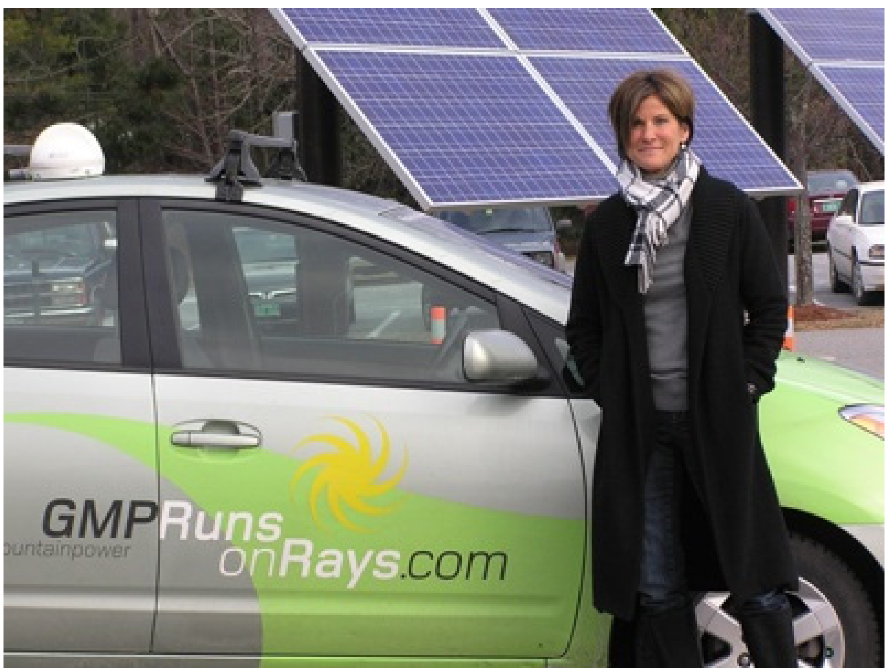

Figure 7. Green Mountain Power CEO Mary Powell with a company EV, charging with solar.[13]

Table 1 shows the expected growth of solar, EVs, and heat pumps through 2025. Each of these technologies is currently seeing exponential growth. It is noteworthy that there is nearly as much solar in permitting now, as the current installed capacity.

12 "King Arthur Flour Charging Station."
13 James Ayre, "Green Mountain Power Is Perfect Example Of How Utilities Can Embrace Distributed Renewables," *CleanTechnica*, July 16, 2014, https://cleantechnica.com/2014/07/16/green-mountain-power-perfect-example-utilities-can-embrace-distributed-renewables/.

Table 1. Increasing use of solar energy and electrification

Type of application	Units	2010	2025
Behind-the-meter PV	MW	13	300
Community solar	MW	0	300
Utility scale PV	MW	5	400
Electric vehicles	Vehicles	10	33,000
Heat pumps	Households	0	54,000

This growth is strong. Concurrently, there is strong support for clean energy among Vermonters and in the Statehouse. During the 2014-2015 session, the Vermont General Assembly passed Act 56, which includes Renewable Portfolio Standards (RPS; referred to in the law as a Renewable Energy Standard) requirements of 55 percent in 2017 and 75 percent in 2032.[14] The Project Team's supply model shown in **Figure 4** would meet those targets. The Act includes transportation and heating fuels within the RPS. Because electric utilities bear the responsibility of meeting the targets, they may support electrification as a path that brings additional end uses into their business models. The State and VEIC support electrification, instead of imported combustion fuels, for the emissions, safety, and local economic benefits.

[14] Anthony Klein and Rebecca Ellis, *H.40*, 2015, 40, http://legislature.vermont.gov/assets/Documents/2016/Docs/BILLS/H-0040/H-0040%20As%20Passed%20by%20Both%20House%20and%20Senate%20Official.pdf

Barriers and Integration

This study investigates the requirements and possibilities of transitioning to an advanced solar economy, where 20 percent of Vermont's total electric energy requirements are met by solar. As prices for solar installation have continued to decline, and policy objectives such as the targets set by Vermont's *Comprehensive Energy Plan* are codified, it is necessary to examine the extent to which solar and other renewable resources can be safely and reliably connected. It is also important to determine if this can be done economically.

Space Required for Solar

Vermonters appreciate the "working landscape" of the state. Open agricultural land in valleys offers wide views of the mountains and lush greenery that attract visitors and those who want to move to the state. There is strong opposition to energy projects that encroach on wooded or agricultural land. Solar can affect agricultural land and thus may be sited near populated areas. In Vermont, solar projects are primarily subject to State regulation, with sometimes limited reference to local zoning rules or review. To address concerns about quick solar development with sometimes-limited local input, the Legislature created the Solar Siting Task Force in Summer 2015. The *Vermont Solar Market Pathways* project defers to the Task Force for leadership on siting, but the Team is cognizant of the concerns and seeks to minimize the impact of solar on agricultural land, open space, or forests.

Rooftop systems do not require any open space, and most systems on commercial roofs are not visible from the ground. The Team's Policy Brief on net metering estimated the rooftop potential at 375 MW. The Team assumes that not all viable roofs—those that have little to no shade and can carry the weight of PV panels—will receive solar installations. Therefore, the Team has assumed a lower value: 300 MW for rooftop solar by 2025. Reaching such a high proportion of the potential might require innovative models such as an extension of the community solar concept, where interested people lease space on the roofs of uninterested businesses and homeowners.

A carefully refined version of the rooftop potential would benefit the project and help allay concerns about the land impact of solar. The National Renewable Energy Laboratory (NREL) has a method using LiDAR data to find suitable rooftop space. The Project Team submitted a request to NREL's Technical Assistance Center to map all of the Vermont LiDAR data available to them. The response to the request offered information on 12,000 buildings near Montpelier, the state capital. The analysis showed the percentage of buildings and areas large enough to support a solar system at various module efficiencies. For example, 100 percent of large buildings, 52 percent of medium buildings, and 37 percent of small buildings have sufficient south-facing, unshaded roof space for solar.

Although these data are useful, Montpelier is just one of Vermont's 255 municipalities, and has only 8,000 residents, ranking 13th in the state for population. By comparison, the state's biggest city, Burlington, is approximately 5 times larger. A much greater portion of the state is covered by some type of LiDAR than what NREL used. The Team is considering either processing those data to make it possible for NREL's method to be applied statewide, or extrapolating the Montpelier results to other hilly and wooded parts of the state.

Vermont's group or virtual net metering legislation allows anyone within a utility service territory to benefit from a shared renewable energy system in that territory. These types of system are growing quickly, given the combination of economy of scale and retail credit for the energy generated. The Project Team's model assumes 255 MW of ground-mounted community solar and 45 MW mounted on structures or over parking lots. An example of this type of installation that takes up virtually no usable space is at the Unitarian Universalist Society in Burlington, as shown in **Figure 8**.

Figure 8. Solar panels installed over parking spaces at the Unitarian Universalist Society in Burlington.

The Team expects the largest amount of capacity will be utility scale ground-mounted systems. By 2025, the Team anticipates 400 MW of this type of installed solar, with the energy sold wholesale to the utilities. Although most of the utility scale solar that has been installed to date has been 2.2 MW systems under Vermont's Standard Offer Feed-in Tariff (FIT) program, the Team expects larger systems in the future. Project stakeholders initially decided on 5 MW as a likely maximum, so that projects could go through state permitting without additional requirements from the regional transmission organization, ISO New England. However, the transmission operator, Vermont Electric Power Company (VELCO), is aware of three 20 MW projects considering applications.[15]

Overall, the total anticipated level of utility scale systems in the SDP scenario would cover approximately 3,200 acres. Combined with the ground-mount community systems, 655 MW of ground-mounted solar could require over 5,000 acres of land, or 0.09 percent of the state's land surface. It is important to recognize that this amount of land requirement is very small in comparison to other land uses in Vermont, and to acknowledge the State and all stakeholders have a clear interest in the proper siting and permitting of solar in order to minimize adverse impacts.

[15] Personal communication, August 27, 2015.

Negative Net Load and Ramp Rates

The California "duck curve" brought the issues of low daytime net load and high evening ramp rates to the attention of the solar industry, utilities, and regulators. Shawn Enterline, Power Supply Project Manager at Green Mountain Power and an active stakeholder on this project, used hourly forecasts and simulations to create the Vermont "Champ" Curve shown in **Figure 9**. "Champ" is a mythical creature residing in Lake Champlain, the state's major body of water. The creature is rumored to have the body of an Elasmosaurus.[16] Champ's belly goes below zero between 2025 and 2030 as the installed capacity increases beyond 1 GW.

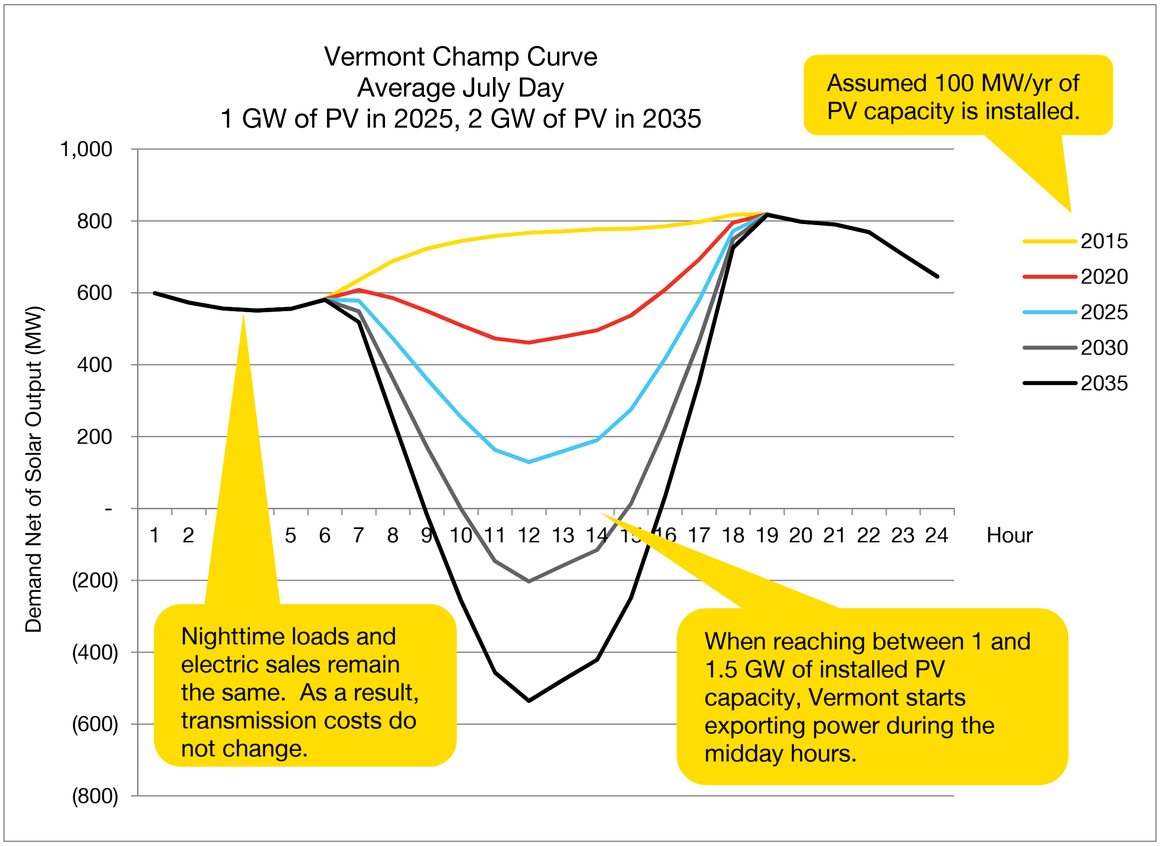

Figure 9. Vermont Champ curve, showing the net load on a July day.

The potential for over-generation is a challenge. **Figure 9** considers only solar generation, so other generation would also need to be off during those hours of negative load. Ramping down hydro generation has ecological impacts from rising water in the reservoirs. Curtailing wind or solar has economic impacts. Must-take contracts would need to be re-negotiated before this event, or else utilities will pay for power they do not use. Demand response / load shifting and storage might mitigate this likely problem. These data raise many issues that can be addressed with several possible strategies.

To determine how much energy needs to be shifted, stored, or exported—and how often—we used Shawn Enterline's data to look at the entire year of 2025. **Figure 10** shows the hourly load, net of solar, in Vermont. It shows 259 hours of negative net load.

[16] Robert E. Bartholomew, *Untold Story of Champ, The: A Social History of America's Loch Ness Monster* (SUNY Press, 2012).

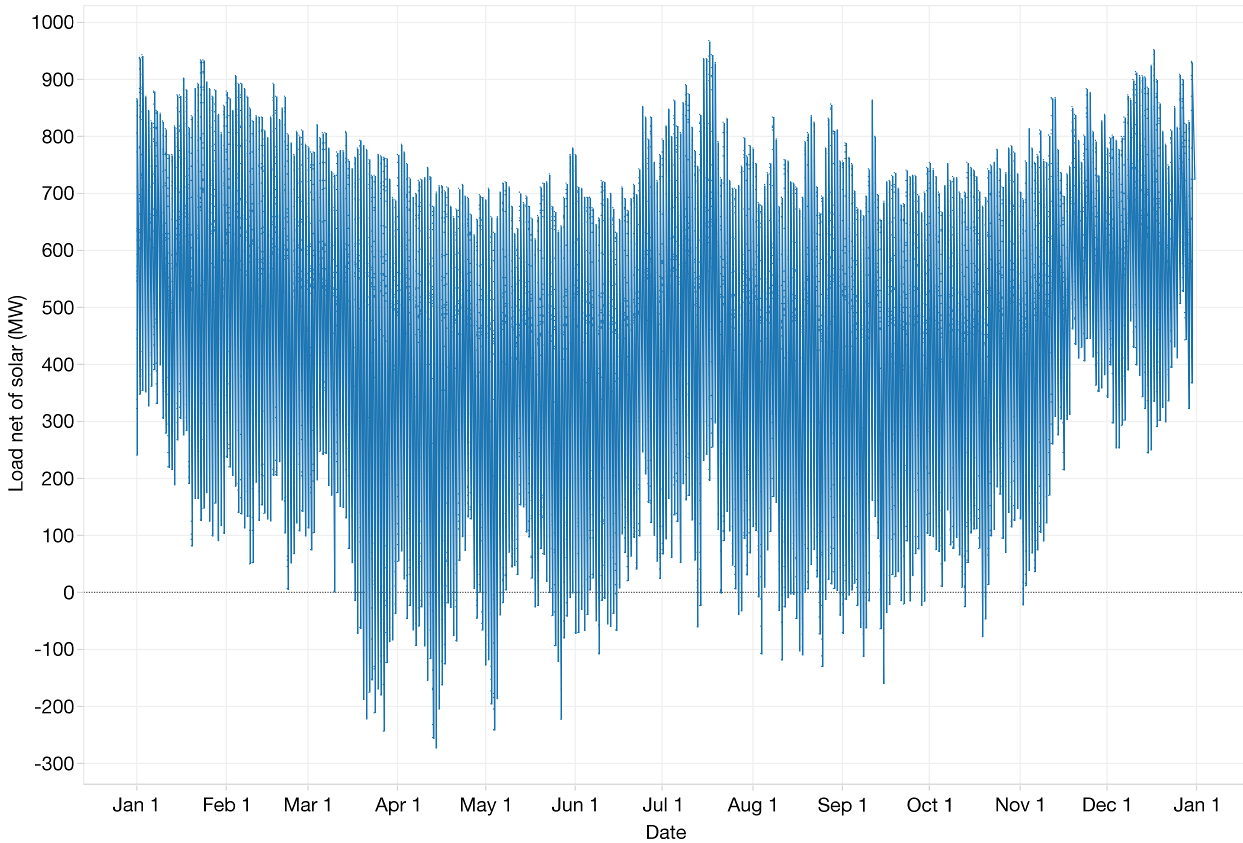

Figure 10. Hourly load, net of solar, across 2025.

The storage and demand response teams now have these data. They are conducting quantitative analysis to determine how much of what type of storage or load shifting could occur, based on the storage capacity (MWh), time (minutes to hours), and power (MW). Shorter time scales such as frequency regulation are considered as well, but require finer data.

Why Might High Levels of Solar Generation Cause Problems?

The following section reviews the literature, and recommends key questions to help shape the next stages of scenario development and analysis for the Vermont Solar Market Pathways project. The inter-relatedness is significant; however, we use three categories to structure the review: (1) technical considerations, (2) policy and regulatory considerations, and (3) business model.

Innovation, research, and creativity are rapidly emerging and co-evolving in each of these areas, amid the backdrop of an existing century-old system for the generation and delivery of electric power services. This brief provides a condensed literature review, and makes initial recommendations on how to analyze and address the high-priority topics that are considered tractable within the scope and resources of the Vermont Solar Market Pathways project.

When we look at how high levels of solar can be integrated into the existing, or historical, electric system, two fundamental elements should be considered. Solar is variable and a distributed energy resource (DER). Most integration issues arise in relation to one or both of these characteristics of solar as an electric generation resource.

First, solar is variable and intermittent. It does not generate power at all hours of the day; the amount of solar generation varies throughout the year; and when a cloud passes over an array, the amount of generation can be highly variable over the course of minutes and even seconds. Because electric systems need to maintain balance between supply and demand, the variability and intermittency of solar create challenges that are not present with steadily operated and dispatched generation sources that can more easily maintain a constant output level. Wind also shares this variability, to the extent that it has the same seasonal, daily, and short-term fluctuations from weather.

Second, solar is typically a distributed resource. Thus, the location of solar generation on the electric grid and the flow of power from a solar generation source or other "distributed energy resources" are more complex than the historical pattern of centralized generation. That is, centralized generation is delivered via one-way power flows from distribution substations to loads.

Many specific issues and barriers to high solar integration arise from these two fundamental drivers. Advancing technologies, and market and regulatory solutions exist (or are being developed) that reduce or eliminate most of these issues. In the following sections, the Project Team highlights the barriers that are most commonly identified, and through a condensed literature review, examines ways in which these issues might be addressed in Vermont.

Technical Considerations: Distribution System Impacts

In February 2015, the Electric Power Research Institute (EPRI) released *The Integrated Grid: A Benefit Cost Framework*.[17] The report acknowledges that the electric system is "evolving to accommodate changes in the way that electricity is produced, delivered, and used." Technical and market advances now enable distributed energy resources—primarily photovoltaic generation, storage, and demand response—that promise to have profound impacts on the operation of the electric system. These resources also promise to have strong effects on the scale and direction of future system growth and investment. In theory, a transformed electric system that takes advantage of the potential for highly networked aspects of distributed energy resources can enhance value, offer greater flexibility, lower costs, and increase resilience.[18]

Similar to this brief, the EPRI report has sought to create a comprehensive framework for assessing the costs and benefits of a system that safely and reliably integrates a high level of distributed energy resources. That is to say, the EPRI report discusses the frame, method, and elements for such assessments. It does not actually conduct a quantified cost-benefit analysis of a specific, or even a generalized, example.

This stage of the Vermont Solar Market Pathways work plan is similar. The Project Team is in the process of developing a framework for assessing the costs and benefits of integrating a high level of solar and other DERs into Vermont's energy economy in the coming decade. This framework will be the basis for the cost-benefit analysis of Vermont Solar Market Pathways scenarios as the study progresses. If successful, the framework will also offer a helpful structure for further, more detailed studies in the future.

[17] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework" (Electric Power Research Institute, February 2015), http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004878.

[18] Paul De Martini and Jeffrey Taft, PhD., "Value Creation through Integrated Networks and Convergence" (Caltech Resnick Institute and Pacific Northwest National Laboratory, February 2015), http://smart.caltech.edu/papers/ElectricNetworksConvergence_final_022315.pdf.

The EPRI report considers the impacts and solutions for distributed energy resources on the grid. The assessment has two parts, the first of which is the ability of the distribution and sub-transmission systems[19] to host distributed energy resources in a reliable and safe fashion.

The hosting capacity of individual distribution circuits depends on several factors. Further, there are industry-specific tools for conducting distribution circuit analyses. As distributed energy resources are added to a system, an ongoing assessment of the capacity of the distribution system and individual feeders to host additions needs to be conducted. The EPRI report defines *hosting capacity* as the amount of distributed energy resources that a feeder can support under its existing topology, configuration, and physical characteristics.[20] As distributed energy resources are added to a feeder, the most common constraints that arise are related to four categories of root cause: impacts on voltage, protection schemes, energy, and thermal capacity.[21] The increased saturation of DERs on a feeder can provide benefits and create situations that require mitigation costs or changes to operational procedures.

The outcomes of well-designed and executed distribution study analyses will provide the following findings for substations and individual feeders:[22]

1. **Feeder-specific hosting capacity.** Individual feeders and locations along an individual feeder will have varying ability to host DER without violating voltage and protection scheme thresholds. On any given feeder, there are often additional segments in which the hosting capacity is higher than on other portions of the feeder. Generally, locations that are closer to a substation on a radial feeder will have a higher hosting capacity than locations at the end of a feeder line. The presence of DER does not always result in negative impacts. For example, if the end of a radial feeder line is challenged to maintain adequate voltage, the development of DER with appropriate controls can be used to alleviate the situation.
2. **Substation-level hosting capacity.** A substation serving individual feeders offers collective impacts that in turn help to inform analysis of the bulk power system and analysis of overall supply adequacy and system reliability.
3. **Energy consumption and loss impacts.** The levels of DER on a feeder affect the loading of the feeder. This, in turn, translates into changes in overall energy consumption and distribution system losses. For example, the high end of voltage operating windows results in higher line losses. The operations of equipment along a feeder, such as the frequency of changes in voltage tap regulators, can also be affected by additional DER. Sometimes relatively simple solutions to such situations are available, whereas in other cases more expensive changes in the system are required.
4. **Asset deferral.** The development of well-integrated DER can help to alleviate the need for distribution and substation capacity upgrades.

Examples of assessments of distribution system hosting capacities and analyses of distribution system impacts are becoming more common. In California[23] and New York,[24] distribution utilities are now required

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[19] The sub-transmission system consists of the substations, lines, transformers, controls, and communications that operate <=115kV transmission voltage. The transmission system in Vermont is owned and operated by VELCO, the distribution and sub-transmission systems are owned and operated by the distribution utilities.
[20] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework."
[21] Ibid.
[22] Ibid.
[23] "Distribution Resources Plan," *California Public Utilities Commission*, July 1, 2015, http://www.cpuc.ca.gov/General.aspx?id=5071.
[24] "Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision," *New York State Department of Public Service*, accessed December 10, 2016,

to submit plans for investment and operation of the distribution system that explicitly considers how greater levels of distributed energy resources can be integrated.

Southern California Edison and the other major California investor-owned utilities now have online distribution mapping tools that indicate the hosting capacity for segments of the distribution feeder network.[25] In Vermont, Green Mountain Power has a system map that identifies areas of the network where three-phase power is available.[26] The California hosting capacity maps are examples of distribution system "heat maps" that identify areas in which interconnection problems are not likely. These maps also identify areas in which problems are probable, and where hosting capacity has been reached. The distribution hosting capacity mapping and analysis are replacing "rule of thumb" metrics, such as capping the DER on a circuit to a certain percent of the minimum circuit load.

NREL has conducted case studies of specific sub-transmission distribution feeders, where the size of a distributed photovoltaic system represents a high share of the feeder capacity.[27] These cases show where a simple rule of thumb for saturation on a feeder might have prevented or limited the size of new distributed generation. With solutions that involve staged energizing after an outage, dedicated express feeder lines to a substation, and the changing of settings on voltage regulators, the hosting capacities of the feeders in the case studies ranged from approximately 50 percent to over 90 percent of maximum feeder loads.

Depending on the situation, solutions that enable the integration of higher levels of DER are available. These range from modifications to existing operational practices and equipment settings, to the upgrading and installation of new distribution system infrastructure such as conductors, transformers, or substation equipment. Further, changes to protection systems and the use of advanced inverters that can provide active and reactive power control can help alleviate potential problems. They can even be used to improve system efficiency and power quality. Standards for advanced inverters are under development through the process described in the IEEE 1547 Interconnection Standard for Distributed Generation.

The EPRI Integrated Grid Report documents the technology options for supporting greater levels of DER on the distribution system. These range from upgrades to conductors, feeders, substations, control equipment, and improved control and communications.[28] In Vermont, the utilities, the transmission system operator VELCO, and various working groups, are actively exploring the issues and potential solutions. Examples are the Rutland Grid Innovation project, Green Mountain Power's Solar Mapping and Rutland Grid Innovation Projects, the Vermont System Planning Committee, and the GMP Integrated Resource Plan (for example, annual peak load reviews for substations, and plans for voltage conversions).

Technical Considerations: Bulk Power System Impacts

The EPRI Integrated Grid report also addresses how to account for the costs and benefits of increased DER on the bulk power system, which comprises the transmission system above 69 kV,[29] and the

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http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=14-m-0101&submit=Search+by+Case+Number.

[25] Southern California Edison, "Southern California Edison's Distributed Energy Resource Interconnection Map," November 16, 2016, http://www.arcgis.com/home/webmap/viewer.html?webmap=e62dfa24128b4329bfc8b27c4526f6b7.

[26] "3 Phase Service in Vermont" (Green Mountain Power), accessed December 10, 2016, http://www.greenmountainpower.com/innovative/solar_capital/3-phase-service-in-vermont/.

[27] J. Bank et al., "High Penetration Photovoltaic Case Study Report," Technical Paper (Golden, CO: National Renewable Energy Laboratory, January 2013), http://www.nrel.gov/docs/fy13osti/54742.pdf.

[28] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework."

[29] IEEE medium voltage is 69kV, the distribution and sub-transmission system in Vermont operate below 115kV.

generators that provide both the bulk power and ancillary services required to keep the system operating safely and reliably.

A growing number of bulk power and transmission level studies have been and are being conducted to assess the extent to which higher levels of renewable energy (primarily wind and solar) can be integrated on the grid. These are studies at the national level,[30] for the eastern[31] and western[32] interconnection regions, and for individual regional transmission operators.[33]

These assessments consider the impacts of increased variable (renewable) and distributed energy resources on the bulk power system, with respect to current and future planning needs. The EPRI report, which looks at the cost-benefit framework for an integrated grid, identifies the following categories of bulk power system impacts:[34]

- **Resource adequacy.** Are the existing and planned generating capacity levels sufficient to meet demand? For renewable resources, the daily and seasonal variability in output and the matching of generation to demand load shapes need to be considered. The National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS) system[35] provides a national-level visualization of scenario modeling illustrating the mapping of generation loads and transmission in a high renewable energy future.
- **Flexibility assessment.** The intermittent nature of solar and wind resources increases the need for resources on the system that are sufficiently flexible to adapt to increased ramping up and down.
- **Operational scheduling and balancing.** Operational processes and market structures to allow for adequate balancing of supply and demand, given the reliability, safety, and power quality standards and requirements.
- **Transmission system performance, deliverability, and planning.** Analysis and planning that considers constraints and congestion on the delivery of power on the transmission system. Increased renewable generation might result in generation that is both closer to load (in the case of DERs) and more distant from it (for example, large wind resources).

As levels of DERs increase, impacts from the distribution and sub-transmission levels can be reflected up to the transmission level. Therefore, iterative and repetitive analyses and planning processes are often required for an integrated and comprehensive assessment.

In Vermont, distribution and transmission planning is coordinated among the transmission system owner, distribution utilities, efficiency utility, and other stakeholders via the Vermont System Planning Committee (VSPC). The Vermont System Planning Committee is a statewide collaborative process for addressing electric grid reliability planning.[36] The planning process and cycles used by the VSPC and its members reflect the interactive and iterative process of planning at the transmission level. This planning is informed

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[30] Hand, M.M. et al., "Renewable Electricity Futures Study" (Golden, CO: National Renewable Energy Laboratory, 2012), http://www.nrel.gov/analysis/re_futures/.
[31] Aaron Bloom et al., "Eastern Renewable Generation Integration Study," Technical Report (Golden, CO: National Renewable Energy Laboratory, August 2016), http://www.nrel.gov/grid/ergis.html.
[32] General Electric International, Inc., "Western Wind and Solar Integration Study" (Schenectady, NY: National Renewable Energy Laboratory, May 2010), http://www.nrel.gov/grid/wwsis.html.
[33] General Electric International, Inc., "PJM Renewable Integration Study" (Schenectady, NY: PJM Interconnection, LLC., March 31, 2014), http://www.pjm.com/committees-and-groups/subcommittees/irs/pris.aspx.
[34] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework."
[35] Hand, M.M. et al., "Renewable Electricity Futures Study."
[36] "Planning for the Future of Vermont's Electric System," *Vermont System Planning Committee*, accessed December 10, 2016, http://www.vermontspc.com/.

by the assessment of non-transmission alternatives and distributed resources at the distribution and sub-transmission levels. It primarily involves efficiency, demand response, projected load growth associated with emerging electricity applications such as electric vehicles and plug-in hybrids, and cold-climate heat pumps. The work of the VSPC and VELCO are then reflected through market participation in ISO New England, the regional transmission operator.

Exploring Technical Solutions via this SunShot Solar Market Pathways Study

The range of technical issues and potential solutions is broad, and is fortunately accompanied by a similarly wide range of solutions. It is beyond the scope of the Solar Market Pathways Initiative and this project to comprehensively address the full span of these issues and solutions. However, it *is* possible to make concrete contributions, particularly by presenting some case studies and by helping to catalyze and coordinate discussion around the highest value and most critical opportunities and issues.

One way to delineate and prioritize technical issues is to categorize them according to scale. At one end, we have individual system components (single PV modules, circuit inverters, and controls); at the other end of the scale is the trans-regional interconnection. For Vermont, the latter is the Eastern Interconnection, which consists of more than 60,000 transmission level nodes. In between these two ends, we have micro-grids, distribution feeders, distribution substations, a sub-transmission network, the transmission network, bulk power balancing areas, and regional transmission pools.

For the Vermont Solar Market Pathways project, the Team anticipates exploring the extent to which individual systems affect the distribution feeder, up to the transmission level. The Team will place less emphasis on the scales of regional or trans-regional bulk system impacts. Given the relatively small size of Vermont's presence in ISO New England and the Eastern Interconnection, this allocation of emphases makes sense.

Strategically, approaches to technical impacts can be placed into three categories:

1. **Limited deployment,** or placing caps on specific or general deployment—for example, the legislated 15 percent net metering limit.
2. **Strategic deployment.** Controlling deployment through market or command mechanisms, to add capacity where it has the lowest costs or the highest values.
3. **Enhanced / upgraded distribution or transmission systems or both.** This might involve active load management and storage, as well as modifying the nature of the other power-generating sources or contracts. Within this category are the following subcategories:
    a. Enhancing or upgrading the inverter (via system-based controls)
    b. Load shaping, demand response, and energy storage
    c. Forecasting
    d. Contract or operational shaping of other supply sources to adjust the other balancing mechanisms

To reach the SDP goals and to contribute to the *Comprehensive Energy Plan* goals, we expect that strategies 2 and 3 will be required, and that there might be locations and regions in which only limited deployment associated with Strategy 1 will be applicable.

Next Steps

For the next phase of Vermont Solar Market Pathways, the SDP Team recommends to stakeholders the following next steps related to technical issues and barriers:

1. **Document and characterize the current state of distribution system information and hosting capacity analyses** across the participating utilities. The level of current mapping and how much has been, or is being, developed, to provide segment level hosting capacity for distribution systems should be compared and contrasted. It will be important to discuss areas in which efforts can be beneficially coordinated, and to explore the needs and possibilities for funding. A collaborative e-mail exchange of information, and one or two working group phone calls or short meetings should be adequate to address this task.

2. **Identify and document candidates for consideration as possible case studies**. The SDP Team will identify planned or possible activities related to distribution system operations, upgrades or analyses, demand response, integration of storage, and use of active inverter capacities. The Team will articulate options that represent the varying level of activity and resources across utilities of various sizes, and also seek examples of customer-side demand response resources (active control of water heaters would be one such example), and solutions implemented on the distribution and transmission systems and operations.

3. **Create work plans for detailed case studies**. Steps 1 and 2 will provide the information needed to compare and contrast priority issues and analyses to be selected for deeper analysis in the second year of this Solar Market Pathways study. The Team will discuss recommendations for case studies, with the stakeholder group. The Team will also identify priority issues that are likely to make substantive contributions, and that will enhance the scenario modeling and cost-benefit comparisons that are also scheduled for the first half of 2016. Case study recommendations will consider the need and potential for additional technical assistance or funding to support the identified research.

The most efficient processes for moving forward with these activities will be to seek opportunities to collaborate with other working groups and committees (for example, VSPC), and to coordinate some activities through the Vermont Solar Market Pathways Focus Area leaders.

After this Barriers and Integration Brief was published VEIC sought Technical Assistance for further distribution system analysis. The request was declined in part because of work being planned by the Department of Energy's Grid Modernization Laboratory Consortium. In Vermont, Sandia National Lab is leading this work under the Grid Modernization Initiative. The Vermont Solar Market Pathways team is participating in that project and is providing the results of our analyses, and reports to the grid modernization team.

Policy & Regulatory

In addition to the technical issues and barriers already discussed, *Vermont Solar Market Pathways* must also consider today's policy and regulatory issues and barriers, as much as it must consider issues that could arise as the market saturation of solar increases to meet this SDP scenario objective of providing 20 percent of electric energy generation by 2025. This section provides a brief literature review. It also discusses some key questions for Vermont and recommendations on how to address these issues in the next round of scenario development and analysis.

Policy & Regulatory Literature Review

Increasingly dynamic policy and regulatory discussions reflect the rapid pace of technology and market change in solar and other distributed energy resources. The consequent initiatives and debates vary widely. Some states have adopted or are considering initiatives to reverse, roll back, or put a moratorium on renewable portfolio standards, net metering, and the development of distributed resources.[37] Other jurisdictions are examining how new policies and regulations can be an important driver of and catalyst for transformation. California's distribution resource plans[38] and New York's "Reforming the Energy Vision" proceedings are examples of policy and proceedings taking the more transformational view of distributed resources.

Expanded renewable energy generation, at both the distributed and transmission levels, is also a well-recognized, primary strategy or building block for states and regions that are now designing plans to comply with the Clean Power Plan requirements issued by the Environmental Protection Agency.[39] The National Association of Clean Air Agencies commissioned a study from the Regulatory Assistance Project, which compiled options for implementing the Clean Power Plan.[40] The options involved improved integration of renewables into the grid; optimizing distribution and transmission system operations; and taking greater advantage of distributed resources such as storage, demand response, and customer-sited generation. These are all elements that regulators, planners, and policy makers should consider as they evaluate, design, and implement compliance plans.

New market structures, such as the energy imbalance market now operating in the California ISO, have begun to emerge. They are driven by current and future expectations or requirements for increasing the mix of variable renewable resources in the supply mix. The energy imbalance market provides a platform for generators or load sinks that can ameliorate differences between day-ahead and real-time forecasts of renewable energy generation, by providing the ability to source or sink power that results from the energy imbalance.[41]

[37] Ohio and Arizona are examples of where recent policy and regulatory discussions have tended toward consideration of how it may be necessary to restrict contributions from renewable energy and distributed resources.
[38] California Assembly Bill 327 directed utilities to submit a distribution resources plan to the California Public Utilities Commission by July 1, 2015. Stakeholder working groups and comments on these plans are underway as this brief is being drafted. The filed plans provide insight into the utilities broad DER strategies and recommend specific pilots for Commission review and approval. According the statute Distributed Energy Resources include: Distributed renewable generation, energy storage, energy efficiency, demand response and electric vehicles.
[39] "Clean Power Plan for Existing Power Plants," Policies and Guidance, *US Environmental Protection Agency*, (August 3, 2015), https://www.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants.
[40] "Implementing EPA's Clean Power Plan: A Menu of Options" (National Association of Clean Air Agencies, May 2015), http://www.eesi.org/files/NACAA_Menu_of_Options_LR.pdf.
[41] Mike Hogan et al., "What Lies 'Beyond Capacity Markets'? Delivering Least-Cost Reliability Under the New Resource Paradigm" (The Regulatory Assistance Project, August 14, 2012), http://www.raponline.org/wp-content/uploads/2016/05/rap-hogan-whatliesbeyondcapacitymarkets-2012-aug-14.pdf.

Taking a "blank slate" approach to how distributed energy resources and renewables can most effectively contribute to reliable, safe, clean energy systems that maximize consumer choice, the Solar Electric Power Association has initiated the 51st State project.[42] A call for ideas for how new energy markets could be created in a hypothetical "51st State" resulted in submissions that addressed the emergence of a transactive energy economy, where the transmission and distribution systems provide a platform for an innovative, market-based exchange of energy services.[43]

Regulatory and Policy Issues Vermont Context

Vermont has recently issued a draft for public comment of the update to the *2011 Comprehensive Energy Plan* (known now as the 2016 *Comprehensive Energy Plan)*.[44] The 2016 update builds from planning undertaken in 2008 and 2011. The Project Team has designed the SDP scenario within Vermont Solar Market Pathways to be consistent with reaching the long-term CEP targets, and to illuminate how accelerated solar market development can contribute to meeting these targets.

Stakeholder workshops are also under way to review potential changes to net metering and interconnection requirements in Vermont. These will lead to recommendations from the Vermont Public Service Board on new rules and requirements, with a target date of 2017 for implementation. The Legislature also directed the Public Service Department to convene a solar siting task force, which is reviewing and investigating issues and potential modifications for solar siting criteria.[45]

The working group and task force do not directly address the levels of solar market development being investigated as part of this study. They do, however, provide an indication of the overall direction of policy and regulatory discussions in Vermont, pointing toward initiatives and other planning that expand the use of solar resources. At the same time, they acknowledge that careful consideration must be given to developing siting criteria and processes.

Critical Questions

The next phases of Vermont's Solar Market Pathways project will address several critical questions related to policy and regulatory issues.

1. **Market forces versus targets.** The SDP Team's scenario modeling indicates that 10-fold solar market growth is required to achieve the objective of meeting 20 percent of Vermont's electric generation supply by 2025. As the Team refines scenarios, and begins to conduct priority analyses in the next phase of this project, it will be important to consider if the projected level of growth is catalyzed and guided solely by market forces. For example, how much solar is developed? Where and when? Or are there specific targets set by policy or regulatory decisions that set targets—for example, by project type (rooftop, community solar, utility scale grid connected), or location by region, or with respect to existing infrastructure? Market or policy directions might also play a critical role in determining to what extent the grid evolves toward stand-alone micro-grids with customer defection from the grid, versus a more networked system.

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[42] Smart Electric Power Alliance, "The 51st State Initiative," accessed December 11, 2016, http://sepa51.org/about.php.
[43] Jon Wellinghoff, James Tong, and Jenny Hu, "The 51st State: Market Structures for a Smarter, More Efficient Grid" (Smart Electric Power Alliance, February 27, 2015), http://sepa51.org/submissions/submissions/Tong_Wellinghoff_Hu_51st_State.pdf.
[44] "2016 Comprehensive Energy Plan" (Montpelier, VT: Vermont Department of Public Service, December 2015), http://publicservice.vermont.gov/publications-resources/publications/energy_plan/2015_plan.
[45] "Vermont Solar Siting Task Force," *State of Vermont*, June 11, 2015, http://solartaskforce.vermont.gov/.

2. **Cost projections.** Cost declines for solar have continued, and recently large utility scale projects have been announced with long-term power purchase agreements at or less than 4 cents per kilowatt hour.[46] As part of this Solar Market Pathways project, the SDP Team will project forward prices for solar at various scales, and will conduct price-driven sensitivity analyses. The potential reduction of the federal Solar Investment Tax Credit (ITC) at the end of 2016 will have important implications for cost projections. The Project Team expects to conduct a sensitivity analysis of the implications for an extension of the ITC, with a base case assumption that the credits will be reduced at the end of 2016.

3. **Energy "stance" of the state and regions.** In designing and evaluating scenarios that meet both the *Comprehensive Energy Plan* and Solar Market Pathways targets, the SDP Team recognizes important questions regarding the extent to which Vermont wants to rely on imported energy, and how much Vermont wants to develop in-state resources. The same questions apply to regions within the state. For example, some regions might want to develop renewable or other energy resources and seek to export energy. Other regions or the state might not want to host energy development, and might prefer to import energy resources.

4. **Rate impacts and opportunity to participate.** The revised scenarios to be developed by the end of the year will become the basis for estimating the costs and benefits associated with attaining the high-saturation solar goals. It will be important to address the allocation of the costs and benefits, and the mechanisms by which the utilities or other market actors will be able to fairly and equitably recover costs. It will also be important to ask whether incentives or other mechanisms will be required to assure that low- and moderate-income households, smaller utilities, or other market segments can participate in the growing market. Vermont's potential transition to an advanced solar market might face a lower level of "stranded assets" than other U.S. regions, where changes in the power market might result in the early retirement of resources for which prior approved costs have not been fully recovered.

Next Steps

In the next phase of the study, the Project Team recommends the following steps related to regulatory and policy issues:

1. **Review scenario results with stakeholders and examine them with respect to the 2015 *Comprehensive Energy Plan* and current net metering, interconnection, and siting proceedings.** The Project Team will solicit feedback via individual outreach and through the Focus Area working groups in October and early November 2015.

2. **Examine if there are "gaps" between the emerging regulatory and policy initiatives and the scale and nature of solar development under the solar pathways scenarios.** Based on the feedback from stakeholders, the Project Team will determine if there are significant policy and regulatory gaps that need to be addressed in the revised scenarios. The SDP Team will review findings from this analysis with stakeholders in early December 2015.

[46] Stephen Lacey, "Cheapest Solar Ever: Austin Energy Gets 1.2 Gigawatts of Solar Bids for Less Than 4 Cents," *Greentech Media*, June 30, 2015, https://www.greentechmedia.com/articles/read/cheapest-solar-ever-austin-energy-gets-1.2-gigawatts-of-solar-bids-for-less.

3. **Prioritize regulatory and policy issues and analysis to be conducted in Year 2.** Once the revised scenarios are completed, and in Year 2 of the study, the Project Team will work with stakeholders to prioritize and investigate potential policy and regulatory issues for further analysis, research, and inclusion in the final report. Experience from other states, such as further progress or problems with the approval and early-stage implementation of the distributed energy resource plans in California will provide valuable information as this work proceeds during the first half of 2016.

Markets / Business Models

The sustained and orderly development of solar markets in Vermont will create and require innovative market structures and business models. Existing and new firms will develop, test, and offer expanded services to consumers and utilities. The new services and business structures will help unlock the increased value from a well-networked system. Technologies that enable the interconnectivity of energy-producing and energy-consuming devices create a new landscape of consumer choice, consumer aggregation, and control / operations of the utility system.

The technical and policy issues discussed in the prior sections of this brief will influence the evolution of business models, but the inverse is also true. The development of new business models will help to shape and drive changes in technology and policy. This section provides an overview of the types of business models and services that might emerge as Vermont makes progress on the path toward becoming an advanced solar economy.

Solar Business Models

The scenario analyses indicate that a mix of business approaches to solar projects will be required to accomplish the Solar Development Pathways target**. Individually and third-party-owned rooftop and ground-mounted systems** will provide consumers with the opportunity to host or own solar generation on their properties. In the Solar Development Pathways scenario, the share of solar expected to be located on site, in ground, and / or as rooftop systems is roughly 300 MW by 2025.

Community solar is enabled by Vermont's virtual net metering regulations, and is one of the more rapidly developing and evolving markets. Community solar permits a single system to provide credits for solar generation to a group of virtually net metered customers who reside in the same utility service territory. Innovation, research, and market testing for community solar business models, including those offered by third parties and those offered directly by utilities, is under way in Vermont. This is also true of other parts of the country. Several of the other national Solar Market Pathways projects have community solar as integral to their awards,[47] and a community solar affinity group has been established to share information. The U.S. Department of Energy has also launched a national community solar partnership with a specific emphasis on serving moderate- and low-income households. The White House announced this initiative on July 7, 2015.[48] In the SDP scenario, the share of solar expected to be allocated to community solar is roughly 300 MW by 2025, with the majority of this being ground mounted.

The rooftop and community solar installations are based on principles of both direct and virtual net metering, and therefore offset consumption at retail electric rates. **Projects that have direct power purchase agreements with utilities** are also expected to play an important role in the growing market.

[47] "Solar Market Pathways," *Department of Energy: Office of Energy Efficiency & Renewable Energy*, accessed September 22, 2016, http://energy.gov/eere/sunshot/solar-market-pathways.
[48] "National Community Solar Partnership," *Department of Energy*, accessed September 22, 2016, http://energy.gov/eere/solarpoweringamerica/national-community-solar-partnership.

Under Vermont's Standard Offer Program, projects of up to 2.2 MW are eligible for long-term contracts.[49] Another option for larger projects is to apply for long-term contracts under Rule 4.100, which is Vermont's structure for implementing the Public Utility Regulatory Policies Act (PURPA). Recently the Vermont Public Service Board and VELCO have received applications for several projects that are much larger (20 MW each) than what has currently been built in Vermont.[50] The process for review and interconnection of projects at this scale is not yet clear, but it indicates how evolving market strategies and business models will likely influence the technical and regulatory issues, and vice versa. In the Solar Development Pathways scenario, the share of solar expected to be based on direct connection to the transmission or distribution utilities with wholesale contracts are expected to be 400 MW by 2025.

Complementary Distributed Resource Business Models

Several distributed energy resources will enable, help to drive, and also be driven by increasing solar saturation. The primary resources are storage (customer on-site, and storage located on the utility distribution system); electric vehicles with smart charging and vehicle-to-grid enabled capacities; controllable customer loads such as heat pumps, hot water heaters; and high-performance zero energy buildings, including high-performance modular housing. This project explicitly recognizes the importance of these markets and technologies through its Focus Area working groups. The project scenarios are examining the potential scale of development and potential barriers to progress in each.

The scenario results presented in **Volume 4** illustrate the net demand and ramp rate impacts associated with the SDP scenario. The Focus Area briefs drafted in May 2015 provided initial inputs for the scenario development. In the next phase of the work, based on the net demand and ramp rate analyses, the Project Team will assign high and low levels of development to each of the complementary DERs. This will provide insights to the levels of investment and market developments for each market. The analysis will be similar in approach to the allocation of the total 1 GW of solar capacity to categories of size and project type.

The importance of integrating other DER resources as part of the advanced solar scenarios is illustrated by findings from research conducted in Europe for the Power Perspective 2030 study. These findings indicate that a shift of 10 percent of aggregate demand in a day results in a 20 percent reduction of investment required in the supply side infrastructure over a 15- to 20-year horizon.[51]

The distributed and networked attributes of the technologies contributing to an advanced solar economy increase the need and opportunities for aggregation of energy services. Community solar is one example. Another is aggregation of electric vehicles for coordinating charging or vehicle-to-grid services. The scale of service and value from an individual vehicle or other DER, such as an electric water heater, is not large enough to justify individuals' participating in a market. However, through aggregation, the coordination and value from a larger number of devices can be captured. Innovative approaches to aggregation can be combined. For example, through the coordination and aggregation of electric water heaters, a community solar power project in West Virginia was able to generate revenues sufficient to fund the investment required for installation of a community solar array on the local church.[52]

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[49] Vermont Electric Power Producers, Inc., "SPEED Solar Online Projects - Comparison DC/AC" (Vermont Standard Offer, April 24, 2015), http://static1.1.sqspcdn.com/static/f/424754/26167074/1429817055967/SOLAR+AC-DC+ON+LINE+PROJECTS+4-24-15.pdf?token=1Yt%2FAygme2klyXP2dW2SjliFs2M%3D.
[50] Erin Mansfield, "State Concerned about Proposal for Giant Solar Project," *VTDigger*, September 8, 2015, http://vtdigger.org/2015/09/08/state-concerned-about-proposal-for-giant-solar-project/.
[51] Christian Hewicker, Michael Hogan, and Arne Mogren, "Power Perspectives 2030: On the Road to a Decarbonised Power Sector," accessed September 22, 2016, http://www.roadmap2050.eu/reports.
[52] "Shepherdstown Presbyterian Church," *Solar Holler, Inc.*, accessed September 22, 2016, http://www.solarholler.com/shepherdstown-presbyterian-church-project-gallery/.

Utility Business Models

The solar and other DER technologies create business model opportunities for non-utility market participants, but they also open the door to a wider range of customer service offerings for utilities, and expand the potential portfolio of investments on the supply and demand side of the customer's meter.

The current proceedings in California and New York, requiring the distribution utilities to develop and submit distributed energy resource plans, are an example of regulatory expansion of the scope of resources conventionally considered in distribution planning. In other cases, including examples from Vermont, utilities are offering incentives, financing, and leasing for equipment such as on-site storage, heat pumps, and solar generating equipment. These technologies have the potential for coordinated control and operations.

The distribution utilities also have business opportunities related to the investments required to support higher levels of saturation on the distribution system, whether these entail upgrades to distribution operation, communication and control schemes—or direct investment in solar generation that is strategically sited on the distribution network.

The procurement of solar and other DER resources and their inclusion in a utility's portfolio will affect the requirements for the balance of the portfolio. For example, they might require that other power supply contracts provide a higher level of flexibility.

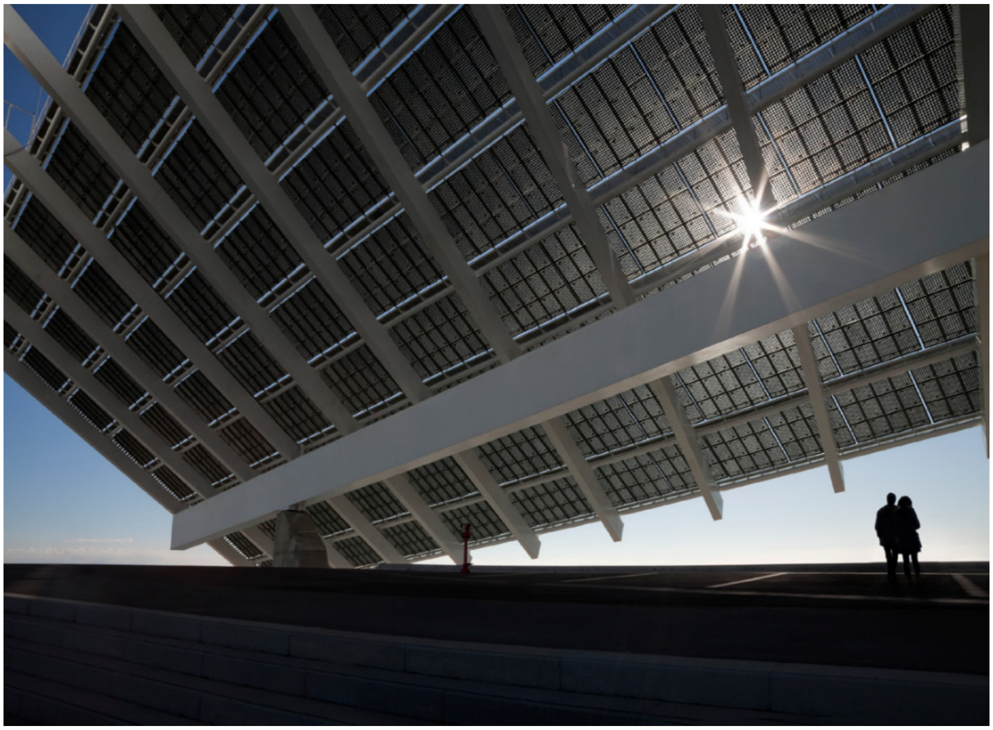
Integrating and controlling a large number of DERs and solar will require greater visibility, communications, and control of resources. The required services might be provided by third-party providers, or directly by distribution and transmission system operators. A study conducted for the California ISO estimated that the benefits from enhanced visibility and control of DERs far exceed the costs associated with the required costs for the communications and other required infrastructure.[53]

Business Models Recommendations for Next Steps

The net demand and ramp requirements associated with the SDP scenarios will be used to allocate the nature of resource flexibility and response to DER resources. The initial allocations will be presented and reviewed with stakeholders, and will be used to examine and prioritize potential case studies that can be conducted as priority analyses during the first quarter of 2016. The characteristics of the DER control and response that is required will inform consideration of the possible business models, and / or cost recovery required to support needed investments.

[53] KEMA, Inc., National Renewable Energy Laboratory, and Energy Exemplar, LLC, "Final Report for Assessment of Visibility and Control Options for Distributed Energy Resources" (California Independent Systems Operator Corporation, June 21, 2012), https://www.caiso.com/Documents/FinalReport-Assessment-Visibility-ControlOptions-DistributedEnergyResources.pdf.

Vermont Solar Market Pathways



Volume 4

Methods and Detail Tables

December 2016

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Introduction

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

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

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

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

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[1] [1] Heaps, C.G., *Long-Range Energy Alternatives Planning (LEAP) System*, version 2015.0.24 (Somerville, MA, USA: Stockholm Environment Institute, 2016).
[2] Vermont Department of Public Service, "Act 174 Recommendations and Determination Standards," Accessed 11/10/2016, http://publicservice.vermont.gov/content/act-174-recommendations-and-determination-standards
[3] Guidelines for Satisfying the Analysis and Targets Section of the Department of Public Service's Determination Standards, Department of Public Service, November 9, 2016.

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

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

Approach

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

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

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

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

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

Residential

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

Historical Data

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

Space Heating

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

Additional information came from the following data sources:

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

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[7] Vermont Energy Investment Company, "Recommended Electric Energy Efficiency Scenario for Vermont's 20-Year Demand Resources Plan Comparative Analysis and Findings," April 16, 2014 http://psb.vermont.gov/sites/psb/files/projects/EEU/drp2013/1.%20VEIC%20DRP%20Scenario%20Recommendation.pdf.
[8] Vermont Housing and Finance Agency, "2010 Vermont Housing Needs Assessment," December 2009, http://accd.vermont.gov/sites/accd/files/Documents/strongcommunities/housing/complete%20final%20report.pdf.
[9] U.S. Energy Information Administration, "Vermont Energy Consumption Estimates, 2004," https://www.eia.gov/state/print.cfm?sid=VT

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

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

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

Space Cooling

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

Lighting

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

Water Heating

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

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[10] Frederick P. Vermont Residential Fuel Assessment: for the 2007-2008 heating season. Vermont Department of Forest, Parks and Recreation. 2011.
[11] U.S. Energy Information Administration, "Adjusted Distillate Fuel Oil and Kerosene Sales by End Use," December 2015, https://www.eia.gov/dnav/pet/pet_cons_821usea_dcu_nus_a.htm.
[12] U.S. Energy Information Administration, "Residential Energy Consumption Survey," 2009, https://www.eia.gov/consumption/residential/data/2009.
[13] Efficiency Vermont, "Technical Reference User Manual (TRM): Measure Savings Algorithms and Cost Assumptions, No. 2014-87," March 2015,

Appliances and Other Household Energy Use

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

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

Reference Scenario: 2050

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

Space Heating

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

The Reference scenario also reflects some trends increasing home sizes.

Space Cooling

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

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

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

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

Lighting

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

Water Heating

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

Appliances and Other Household Energy Use:

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

90 x 50_{VEIC} Scenario: 2050

Space Heating

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

Space Cooling

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

Lighting

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

Water Heating

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

Appliances and Other Household Energy Use

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

Commercial

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

Historical Data

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

Reference Scenario: 2050

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

[16] Vermont Energy Investment Company, "Recommended Electric Energy Efficiency Scenario for Vermont's 20-Year Demand Resources Plan Comparative Analysis and Findings," April 16, 2014 http://psb.vermont.gov/sites/psb/files/projects/EEU/drp2013/1.%20VEIC%20DRP%20Scenario%20Recommendation.pdf.
[17] U.S. Energy Information Administration, "Annual Energy Review 2010", 2010.
[18] U.S. Energy Information Administration, "Commercial Buildings Energy Consumption Survey," 2003. https://www.eia.gov/consumption/commercial/data/2003/.

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

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

Industrial

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

Historical Data

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

Reference Scenario: 2050

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

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

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

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

90 x 50_{VEIC} Scenario: 2050

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

Transportation

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

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

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

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

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

Historical Data

Light Duty Vehicles

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

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

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

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

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

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

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

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

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

Heavy Duty Vehicles

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

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

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

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

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

Rail

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

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32 Jonathan Dowds et al., “Vermont Transportation Energy Profile.”

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

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

35 US Energy Information Administration (EIA), “Freight Transportation Energy Use, Reference Case.”

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

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

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

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

Air

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

Reference Scenario: 2050

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

Light Duty Vehicles

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

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

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

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

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[39] National Association of Railroad Passengers, "Fact Sheet: Amtrak in Vermont," 2016, https://www.narprail.org/site/assets/files/1038/states_2015.pdf.
[40] U.S. Environmental Protection Agency: Office of Transportation & Air Quality, "Biodiesel."
[41] U.S. Energy Information Administration, "Light-Duty Vehicle Miles per Gallon by Technology Type," *Annual Energy Outlook 2015*, 2015, https://www.eia.gov/forecasts/aeo/data/browser/#/?id=50-AEO2016&cases=ref2016~ref_no_cpp&sourcekey=0.

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

Heavy Duty Vehicles

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

Rail

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

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

Air

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

90 x 50_{VEIC} Scenario: 2050

Light Duty Vehicles

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

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

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

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

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

Heavy Duty Vehicles

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

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

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[46] Vermont Energy Investment Corporation, "Solar Market Pathways Stakeholder Meeting #7 Meeting Notes."
[47] Oregon Department of Transportation and U.S. Department of Transportation Federal Highway Administration, "Primer on Renewable Diesel," accessed August 29, 2016, http://altfueltoolkit.org/wp-content/uploads/2004/05/Renewable-Diesel-Fact-Sheet.pdf.
[48] California Environmental Protection Agency Air Resources Board, "Draft Technology Assessment: Medium- and Heavy-Duty Battery Electric Trucks and Buses," October 2015, https://www.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf.
[49] Elon Musk, "Master Plan, Part Deux," *Tesla*, July 20, 2016, https://www.tesla.com/blog/master-plan-part-deux.
[50] Electrification Coalition, "Fleet Electrification Roadmap," November 2010, http://www.rmi.org/Content/Files/Fleet%20Electrification%20Roadmap.pdf.
[51] Noel, Lance and McCormack, Regina, "A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus," *Applied Energy* 126 (2014): 246–55.

Rail

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

Air

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

Supply

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

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

Table 1. New Capacity Added 2015-2050

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

[52] Joseph Barr, AICP et al., "Vermont State Rail Plan: Regional Passenger Rail Forecasts."
[53] U.S. Department of Transportation: Office of the Assistant Secretary for Research and Technology Bureau of Transportation Statistics, "Table 4-26: Energy Intensity of Amtrak Services."
[54] Vermont Public Service Department, *Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals.* December 8, 2014. http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/TES/TES%20FINAL%20Report%2020141208.pdf.
[55] Vermont Public Service Department provided the data behind the graph on the bottom half of page E.7 in *Utility Facts 2013.* It is compiled from utility Integrated Resource Plans

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

Table 2. Capacity Factor and Hourly Profile

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Detailed Tables

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

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

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

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

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

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

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

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

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

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

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

Table 8. Fuel costs

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

Table 9. Capacity cost $ per Megawatt of production capacity

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

Table 10. Transmission and distribution costs by scenario

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

Table 11. Overhead and maintenance costs by generation type

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

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

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

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

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