VERMONT BIOENERGY INITIATIVE

A program of the Vermont Sustainable Jobs Fund

Final Report to the U.S. Department of Energy

U.S. DOE Award #DE-FG36-08GO88182

September 2016

ACKNOWLEDGEMENTS

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The Vermont Bioenergy Initiative spanned eight years of activity, from 2008 to 2016. Over that time, the Vermont Sustainable Jobs Fund had the pleasure of collaborating with a number of bioenergy innovators and early adopters, talented consultants, and thought partners. We'd like to acknowledge and thank the following individuals and their organizations for being part of this ambitious and first of its kind initiative in the United States.

Staff and Key Consultants: Netaka White, Chris Callahan (Callahan Engineering and UVM Extension), Scott Sawyer, Ellen Kahler, Sarah Galbraith, Anthony Mennona, Mike Brouillette (Vermont Center for Geographic Information), Heather Pipino, Greg (River) Strong (Spring Hill Solutions), Gretchen Stern.

VSJF Biofuels Grants Committee: Ed Kiniry, Nancy Wood, Kelly Launder, David Lane, Bill Murray.

Sub-Recipients: John Williamson – Stateline Biofuels; Roger Rainville – Borderview Farm; Larry Scott and Peggy Hewes – Ekolott Farm; Nick and Taylor Meyers – North Hardwick Dairy; Mark and Bill Mordasky – Rainbow Valley Farm; Jon Satz and Brad Lawes – Otter Creek Biofuels (Woods Market Garden and Lawes Ag); Andrew Knafel – Clearbrook Farm; Dr. Heather Darby and her team at the Northwest Crop & Soils program at University of Vermont Extension; Dr. Sid Bosworth – UVM Extension; John Bootle and Adam Dantzscher – Renewable Energy Resource; Greg Cox – Vermont Farmers Food Center; Dr. Anju Dahiya Krivov – GSR Solutions; Josh Wilkenfeld – Carbon Harvest Energy; Dr. Alexander (Sandy) Wurthmann and Bryan Holmes – Green Mountain Spark; Dr. Jeffrey Marshall – UVM School of Engineering; Gail Busch – Algepower; Peter Bourne – Bournes Energy; Scott Oeschger – D&C Transportation; Winston Sadoo – Nava Bioenergy; Dr. John Todd – University of Vermont; Dr. John Kidder – Vermont Technical College; Renewable Energy Vermont; and Vermont Businesses for Social Responsibility.

Research Consultants: Vermont Law School's Institute for Energy and the Environment; Eric Garza – UVM Rubenstein School; Eleanor Campbell; Dwayne Martin – Shearwater Energy Partners; Biomass Commodities Corp.; Wilson Engineering; Energy Co-op of Vermont; ACORN Renewable Energy Co-op, Sunwood Biomass; VT Wood Pellet Company; Chris Davis - Meach Cove Trust; Mike Dolce - UVM Extension; Emily Stebbins.

Other Key Project Partners: Biomass Energy Resource Center, KSE Partners, Vermont Center for Geographic Information, Fountains Spatial, Renewable Energy Vermont Biofuels Working Group, Vermont Fuel Dealers Association.

Funding Partners: U.S. Department of Energy, High Meadows Fund, Vermont Agency of Agriculture, Food and Markets, Vermont Department of Public Service.

This final report to the US DOE was written by Chris Callahan, Scott Sawyer and Ellen Kahler.

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ABOUT THE VERMONT BIOENERGY INITIATIVE

The purpose of the **Vermont Bioenergy Initiative** (VBI) was to foster the development of sustainable, distributed, small-scale biodiesel and grass/mixed fiber industries in Vermont in order to produce bioenergy for local transportation, agricultural, and thermal applications, as a replacement for fossil fuel based energy.

The VBI marked the first strategic effort to reduce Vermont's dependency on petroleum through the development of homegrown alternatives. With billions of gallons of ethanol produced and blended with gasoline each year in the United States—and very little possibility of corn-based ethanol development in Vermont—we focused on a specific subset of bioenergy alternatives:

- We worked with interested farmers to develop **on-farm oilseed production, processing, and biodiesel production capacity for farm and local community use**, and we worked with researchers to develop the agronomics and economics of oilseed crop and biodiesel production in Vermont.

- We worked with interested farmers, entrepreneurs, and researchers to augment Vermont's woody biomass supply with **grass and mixed fiber pellets for thermal applications**.

- We worked with interested researchers, entrepreneurs, and farmers to develop **cold climate algae** that could eventually be available for biodiesel production.

- We developed **many tools** for understanding Vermont's bioenergy alternatives, including:
    - the Renewable Energy Atlas of Vermont (relaunched in 2016 as the Community Energy Dashboard), a map-based website for visualizing existing and potential renewable energy sites;
    - an Oilseed and Biodiesel Production Calculator (downloaded more than 200 times from people in the U.S. and around the world);

- a nine-part video series, Bioenergy Now!— **collectively viewed over 89,000 times—**that highlights oilseed crop and biodiesel production, grass energy production, and algae research;
- the VBI website, a repository for all materials developed by the Initiative; and
- content for biomass-to-bioenergy courses offered at the University of Vermont and Vermont Technical College.

At the beginning of this project, Vermont had very limited experience with the research, feedstocks, production processes, industry networks, and many other factors necessary to develop biodiesel and grass/mixed fiber pellet industries. **Our investments in feasibility analyses, research and development, technology and demonstration projects, and education and outreach resources for various bioenergy feedstocks have created a solid foundation for future efforts to build from.**

The Vermont Landscape

Vermont is a very small New England state with a population of 626,000 and a land area of 9,623 square miles. Forests make up about 78% of Vermont's iconic working landscape, while nearly 8,000 farms—including about 810 dairy farms milking 134,000 cows—are highly visible reminders of the rural character of the state. Not surprisingly, an estimated 37% of Vermont households get some portion of their space and water heat from firewood or wood pellets—and more than 100 institutions such as schools use woody biomass for heating. The waste from Vermont's dairy herd powers 19 anaerobic digesters. Wood bioenergy and methane biogas, then, are readily in use in Vermont's energy system.

Forests make up about 78% of Vermont's landscape.

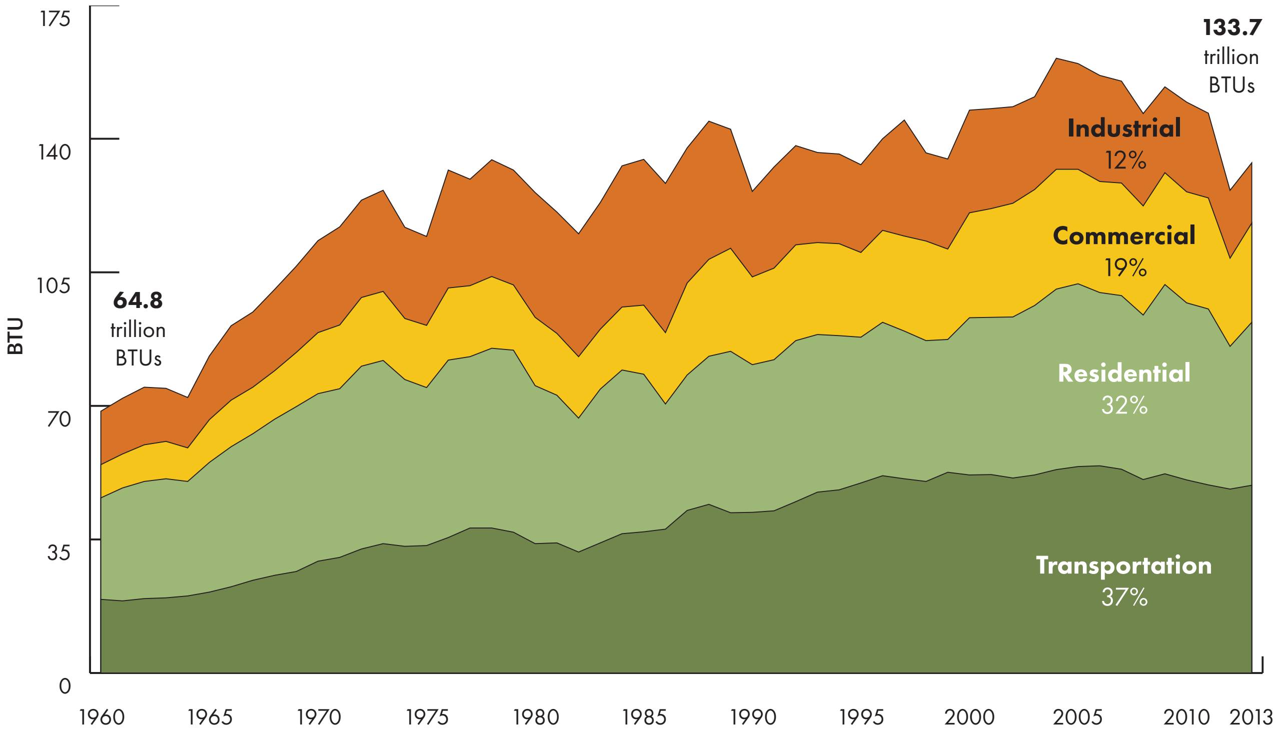
Vermont's hydropower resources have largely been tapped (equal to about 67% of total installed renewable electrical capacity), while four large wind sites have an installed capacity of about 120 megawatts (equal to about 12% of installed renewable electrical capacity), and thousands of solar photovoltaic installations have bloomed across the state. **Liquid bioenergy production and consumption, on the other hand, was virtually nonexistent in Vermont at the start of the VBI.**

Dairy farms and rolling hills are a familiar sight in Vermont.

Vermont Energy Production and Consumption

Vermont produces and consumes a relatively small amount of energy: Vermont ranks 46th in energy production in the United States (84.2 trillion BTUs in 2013), equal to 0.1% of total national energy production. Vermont consumes the least amount of energy of any state (134 trillion BTUs in 2013, Figure 1)—in fact, less than the District of Columbia—equal to 0.15% of total national consumption (Vermont ranks 44th in energy consumption on a per capita basis). Over the past 50 years, energy consumption in Vermont has increased over 100%, from about 65 trillion BTUs to 134 trillion BTUs. Transportation accounted for 36.8% (49.2 trillion BTUs) of total energy consumption in Vermont in 2013, and nonrenewable gasoline makes up 77% of energy consumption in the transportation sector. Homes in Vermont accounted for about 31.9% (42.7 trillion BTUs) of total energy consumption, and over 50% of that amount is for space and water heating from nonrenewable (e.g., distillates) and renewable (e.g., wood) sources. Vermont's commercial sector accounted for about 19.4% (26.0 trillion BTUs) of total energy consumption, and consumption is about evenly split between electricity sales and different fuels for space and water heating. Finally, Vermont's industrial sector consumed about 11.8% (15.8 trillion BTUs) of Vermont's energy from electricity sales and other mostly nonrenewable fuels for space and water heating and transportation.

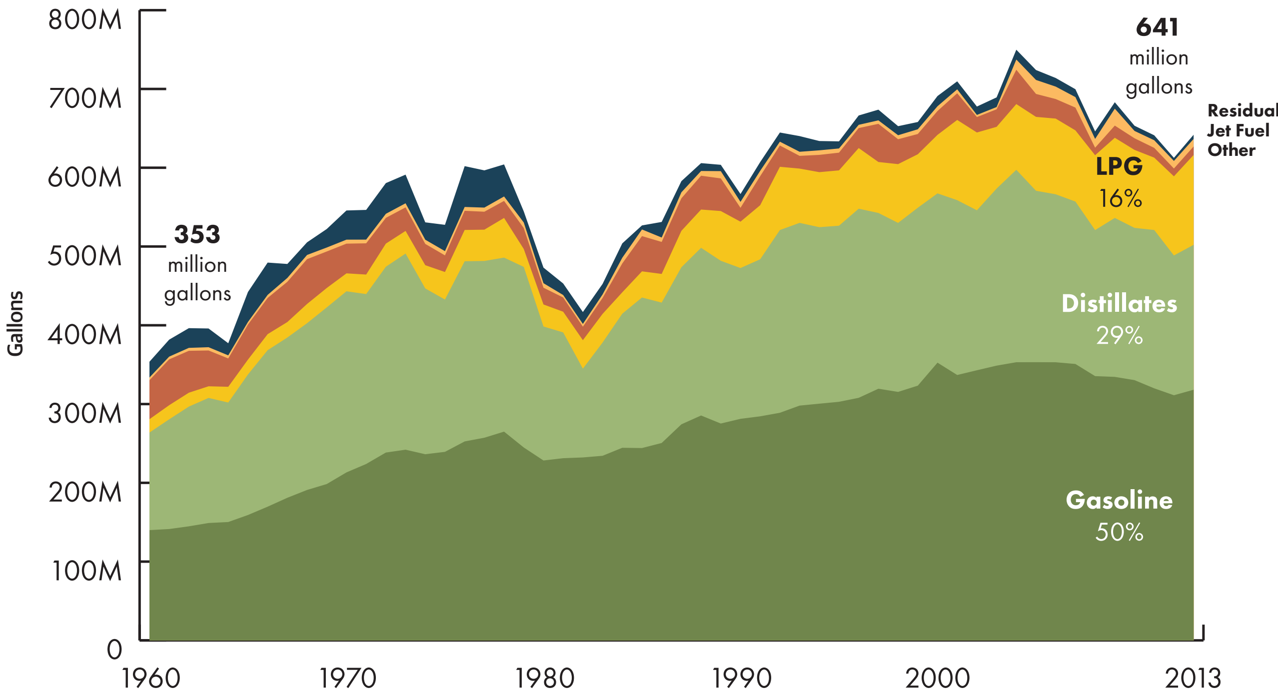
Figure 1: Vermont Energy Consumption by End Sector, 1960-2013



Source: U.S. Energy Information Administration, 2013, www.eia.gov/state/?sid=VT.

Vermont consumes the least amount of petroleum of any state in America, but ranks 15th in petroleum consumption on a per capita basis. Liquid fuel consumption in Vermont increased by about 74% from 1960 to 2013 (Figure 2). However, Vermonters have reduced total petroleum consumption by about 108 million gallons from the highest year of consumption on record, 2004 (749,868,000 gallons), to 2013 (641,886,000 gallons). Gasoline consumption increased 127% from 1960 to 2013 and is equal to 50% of total petroleum consumption. The majority of the gasoline consumed in Vermont is for transportation (98%). Billions of gallons of ethanol are produced in the U.S. and the Energy Information Administration reports that almost all U.S. gasoline is now blended with 10% ethanol. Distillate consumption in Vermont increased 48% from 1960 to 2013 and is equal to 29% of petroleum consumption. About 28% of distillate consumption in Vermont is for transportation, with the rest used for heating.

Figure 2: Vermont Liquid Fuel Consumption, 1960-2013



Source: Energy Information Administration, www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/tx/use_tx_VT.html&sid=Vermont

Energy Use and Climate Change

The extraction of energy resources, their conversion into fuel, and their use creates a wide variety of environmental and health problems. With the combustion of fossil fuels to power societal development over the past 100 years, atmospheric concentrations of carbon dioxide have now surpassed 400 parts per million. From 1990 to 2014, U.S. greenhouse gas emissions generally increased in the electricity, transportation, agricultural, and residential sectors (with a decrease during the Great Recession), while decreasing in the industry and commercial sectors. However, a recent study estimates that methane leaks from fracking and the nation's natural gas infrastructure may have increased 30% from 2002 to 2014. In other words, the replacement of coal power plants with natural gas power plants may have increased America's greenhouse gas emisssions. This increase in greenhouse gases is changing the Earth's climate, resulting in melting glaciers and ice sheets, rising ocean levels, altered weather patterns (e.g., increasing the frequency and severity of hurricanes), and changes in the composition of local plants, animals, and insects.

Vermont's emissions are equal to 0.1% of total U.S. emissions. From 1990 to 2012, Vermont's greenhouse gas emissions essentially stayed the same—a little over 8 million metric tons per year. Vermont statute called for a 25% reduction of 1990 emissions by 2012. This mark was clearly not met. Transportation and residential/commercial/industrial activities account for 72% of Vermont's greenhouse gas emissions. When substituted for their petroleum counterparts, bioenergy products like biodiesel and grass pellets can theoretically lead to a reduction in greenhouse gas emissions through the sequestration of carbon during the feedstock growth process as well as the avoidance of fossil fuel-related emissions. In 2009, Eleanor Campbell, a graduate student at the University of Vermont, assessed the carbon equivalent impact of small-scale sunflower and canola crops grown with organic and conventional methods at Borderview Farm (Alburgh, Vermont). **Campbell found that sunflower and canola crops produced with organic and conventional methods can lead to net greenhouse gas reductions when the resulting biodiesel is used in place of diesel, with organic sunflower production resulting in the largest reduction of emissions.**

Agriculture in Vermont

Vermont's small size, relatively short growing season, and hilly topography (which is more suited to small-scales of production) are generally considered to be barriers to generating large volumes of crops. According to the 2012 Census of Agriculture, 92% of Vermont's cropland is devoted to hay and corn production (428,984 acres), while oilseed crops like soybeans (4,500 acres, up from 2,011 acres in 2007) and sunflowers (68 acres) make up less than 1% of cropland. Soybean production in Vermont is mainly for animal feed.

LAND IN AGRICULTURE (2012)

Land	Acres
Vermont Land Area:	6,154,240
Land in Forest	4,591,281
Land in Agriculture:	1,251,713
Woodland	498,975
Cropland	470,403
Forage	337,694
Corn for silage	80,231
Corn for grain	11,059
Soybeans	4,478
Sunflowers	68
Pastureland	195,000

The VBI drew a connection between diversified agriculture and local renewable energy production for on-farm and community use. Namely, oilseed crops could be grown in rotation with grains (i.e., corn) and grasses and can yield high quantities of oil. At the height of VBI activities in 2010, about 320 acres were specifically devoted to oilseed crops for biodiesel production. Additionally, thousands of acres of former farmland is either unused or underutilized and this could potentially be used for growing herbaceous biomass crops such as perennial grasses. The use of grass biomass buffer strips at field edges and near waterways could help to improve water quality. **The VBI aimed to supply farm inputs (e.g., fuel and animal feed) and reduce fossil fuel consumption through research, technical assistance, infrastructure development, and education and outreach.**

Looking west from Mt. Philo across Addison County and Lake Champlain, with New York state in the background. Vermont's landscape is covered in forests, hills, mountains, and many small farms.

ABOUT THE VERMONT SUSTAINABLE JOBS FUND

As a grant-making entity, project manager, and technical assistance provider, the **Vermont Sustainable Jobs Fund (VSJF)** selected the best sub-recipient proposals for bioenergy projects through a competitive Request for Proposal (RFP) process.

Netaka White was the VBI Program Director from 2008 to 2013.

VSJF provided all grant management and administration over the course of the award period (FY08-FY16). Sub-recipients were required to provide the requisite statutory cost share as determined by the DOE and comply with all pertinent state and federal regulations and/or conditions.

VSJF also conducted a number of staff directed investigations, all designed to support the four key priorities of the U.S. Department of Energy's Multi-year Biomass Plan:

1.) Dramatically reduce dependence on foreign oil;
2.) Promote the use of diverse, domestic and sustainable energy resources;
3.) Reduce carbon emissions from energy production and consumption;
4.) Establish a domestic bio-industry.

Vermont Sustainable Jobs Fund

WWW.VSJF.ORG

The Vermont Sustainable Jobs Fund is a 501(c)(3) nonprofit based in Montpelier, Vermont. VSJF was created by the Vermont Legislature in 1995 to nurture the sustainable development of Vermont's economy.

VSJF provides business assistance, network development, research, and financing in food system, forest product, waste management, renewable energy, and environmental technology sectors.

STATEMENT OF PROJECT OBJECTIVES

VSJF developed objectives in six areas to nurture the development of Vermont's bioenergy sector, with the goal of reaching early stage commercialization of these oilseed, grass, and algae feedstocks over 7 years. We utilized U.S. DOE funds to deploy grants and administer projects intended to:

- Provide ongoing education, networking, outreach and technical assistance to farmers, entrepreneurs, municipalities, and others interested in expanding the production and use of bioenergy (Task A)
- Create and fund updates to the Renewable Energy Atlas of Vermont—later dubbed the Community Energy Dashboard—a GIS-based website for identifying, analyzing, and visualizing renewable energy sites (Task C)
- Support early-stage research and development in algal biodiesel (Task D)
- Support early-stage research and development for grass/mixed fiber pellet feedstocks and equipment (Task E)
- Expand the physical infrastructure, knowledge, outreach, and technical assistance available for on-farm biodiesel production using oilseed feedstocks (Task F)
- Develop the commercial availability of biodiesel in Vermont (Task G)

Task A: Education, Outreach, Network Development, Technical Assistance

Sub-Task A.1: Analysis, Education & Outreach

The objective of this sub-task was to organize conferences, workshops, peer learning, and networking opportunities for bioenergy entrepreneurs, farmers, academics, state officials, service providers, and consumers to share knowledge and experience. This sub-task also supported the development of educational curriculum at Vermont Technical College and the University of Vermont in bioenergy related research, technology, and production application.

Sub-Task A.2: Technical Assistance

The objective of this sub-task was to provide technical assistance to entrepreneurs and farmers for feedstock development, agronomic species and biological analysis, business planning and business model development, systems optimization, economic analysis, greenhouse gas assessments, and energy returned on energy invested calculations.

Task B: Project Management & Solicitation Administration

VSJF managed all aspects of DOE pre-award paperwork; conducted sub-award solicitations; coordinated and managed grant making; identified and secured co-funding opportunities; monitored funded projects; submitted quarterly reports to the U.S. DOE; and tracked outcomes.

Task C: Community Energy Dashboard (formerly Renewable Energy Atlas of Vermont)

The objective of Task C was to develop a GIS-based website of existing and potential bioenergy and other renewable energy locations that could spur future development statewide.

Task D: Algae Feedstock Analysis and Production Techniques

Sub-Task D.1: Research

The objective of this sub-task was to provide sub-recipient award funding to researchers, entrepreneurs, and others to experiment with the development of algae feedstocks that are adaptable to nutrient-rich waste streams and suitable for Vermont's colder climate. Research included how algae could interface with other Vermont-scale agricultural activities (e.g., anaerobic digesters, nutrient management).

Sub-Task D.2: Logistics / Production

The objective of this sub-task was to provide sub-recipient award funding for algae feedstock logistics and new methods for optimizing production processes that fit the scale of Vermont farms and communities. Funding supported lipid optimization, harvest, dewatering, oil extraction, and refined oil and algal biomass research.

Sub-Task D.3: Processing / Demonstration

The objective of this sub-task was to provide sub-recipient award funding for demonstration projects (e.g., analysis of prototype for algal biodiesel production facility.)

Task E: Biomass – Feedstock Analysis and Production Techniques

Sub-Task E.1: Agronomics / Research

The objective of this sub-task was to provide sub-recipient award funding to researchers, entrepreneurs, and farmers to experiment with the development of perennial grass and biomass feedstocks that are suitable for Vermont soils and climate. Agronomic research for biomass crops involved replicated field trials and analysis on appropriate varieties (e.g., yield, vigor, ash content), soil impacts, seeding rates, nutrient management, weed, disease, and pest control. Research included grass varieties that can be pelletized or potentially be used for cellulosic ethanol production. Research evaluated cost and reliability of supply, potential volume available, and distribution considerations.

Sub-Task E.2: Logistics / Production

The objective of this sub-task was to provide sub-recipient award funding to find new methods for optimizing production processes, including harvesting and drying techniques, optimal storage moisture, and managing ash content. Logistics trials included fiber processing and pellet production testing (i.e., grass and grass-wood combinations) using stationary and/or mobile equipment; identification of appropriate fiber processing and pelletizing machinery to meet the needs of a single farm, group of farms, or a surrounding community.

Sub-Task E.3: Processing / Demonstration

The objective of this sub-task was to provide sub-recipient award funding for demonstration projects (e.g., analysis of grass pellet heating plant in a small commercial business).

Task F: Oilseed Crops – Feedstock Analysis & Production Techniques

Sub-Task F.1: Agronomics / Research

The objective of this sub-task was to provide sub-recipient award funding to researchers, entrepreneurs, and farmers to experiment with the development of oilseed feedstocks and companion crops, such as sweet sorghum, that are suitable for Vermont soils and climate. Agronomic research involved replicated field trials and analysis of appropriate varieties (e.g., oil content, sugar content, and meal quality), seeding rates, nutrient management, weed, disease, and pest control.

Sub-Task F.2: Logistics / Production

The objective of this sub-task was to provide sub-recipient award funding for oilseed crop and sweet sorghum feedstock logistics and production techniques that fit the scale of Vermont farms and communities, including harvesting and drying techniques, pressing, optimal storage, expelling (to optimize oil extraction) and/or pelletization of co-products (oilseed meal).

Sub-Task F.3: Processing / Conversion / Demonstration

The objective of this sub-task was to provide sub-recipient award funding for biodiesel conversion, processing, and demonstration projects (e.g., developing small-scale or on-farm facilities for biodiesel and potentially ethanol production as a methanol replacement for biodiesel production).

Task G: Expansion of Commercial Biofuels Availability

Sub-Task G.1: Research and Development

The objective of this sub-task was to provide sub-recipient award funding to Vermont fuel dealers to complete land use and/or engineering feasibility studies and/or analyze financing options for new or improved capacity (e.g., to comply with new EPA rules, to provide biodiesel and bioheat in underserved areas of the state) or to expand into other renewable fuels.

Sub-Task G.2: Demonstration / Biodiesel

The objective of this sub-task was to provide sub-recipient award funding to enhance biodiesel blending capacity in the state.

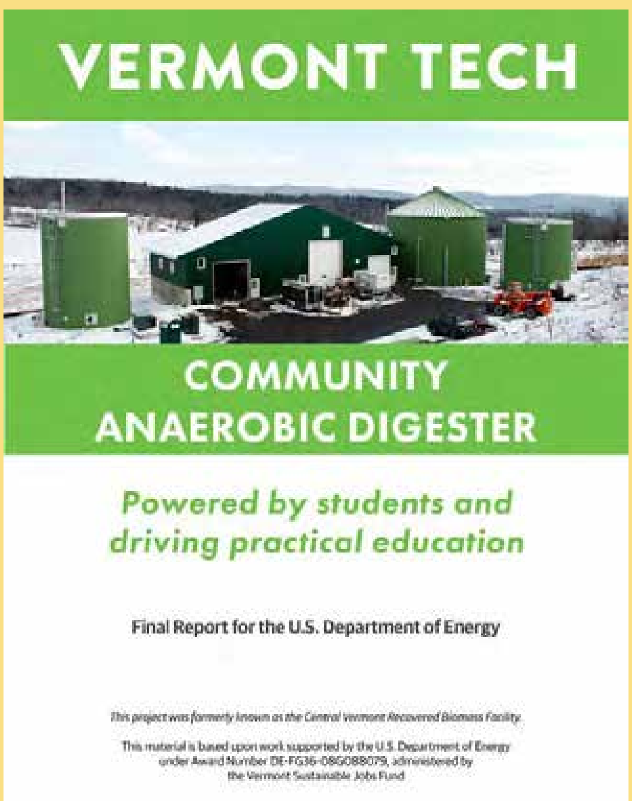
Sub-Task G.3: Demonstration / Biomass fuel

The objective of this sub-task was to provide sub-recipient award funding to enhance bulk distribution of biomass heating fuel in the state.

Report Outline

The rest of this overview provides a summary of VBI tasks. It starts by describing the market development approach that VSJF used to deploy sub-recipient funding and staff-directed projects. It then summarizes tasks based on the stage of development of each bioenergy topic (e.g., number of participants, level of sub-recipient readiness, availability of technical assistance and research expertise), starting with oilseed crops and biodiesel (Task F), grass energy (Task E), algae research (Task D), and commercial biodiesel (Task G). The overview ends by describing the Renewable Energy Atlas of Vermont—renamed the Community Energy Dashboard in 2016—(Task C), and VBI education and outreach activities (Task A).

RELATED PROJECT


VERMONT TECH

COMMUNITY ANAEROBIC DIGESTER

Powered by students and driving practical education

Final Report for the U.S. Department of Energy

This project was formerly known as the Central Vermont Recovered Biomass Facility

This material is based upon work supported by the U.S. Department of Energy under Award Number DE-FG36-08GO88079, administered by the Vermont Sustainable Jobs Fund

"Big Bertha," the anaerobic digester at Vermont Technical College, is operating at full capacity and successfully putting electricity onto the grid. With a carefully formulated diet of cow manure and organic matter from Vermont farms and brewery waste from the Alchemist and Long Trail Brewing Co., at full power Big Bertha transforms 16,000 gallons of waste to 8,800 kilowatt hours of electricity daily—equivalent to about 200 gallons of heating oil, or the amount of electricity consumed by about 70 houses on a cold day.

VSJF acted as fiscal sponsor for this project (DOE Award Number DE-FG36-08GO88079).

VSJF'S MARKET DEVELOPMENT APPROACH

The components of Vermont's bioenergy supply chain for oilseed crops. grasses, and algae were virtually nonexistent in Vermont when the VBI started. VSJF uses a market development approach to nurture the sustainable development of Vermont's economy for food systems, forest products, and, through the VBI, energy systems. We ask several questions: Where is a particular market in its development trajectory? What does a particular market's supply chain currently look like? By meeting a set of ten market development needs across a supply chain—from feedstock production, feedstock logistics, and biomass conversion, to bioenergy distribution and end use—the intention is to highlight and address specific market development needs that could strengthen Vermont's renewable energy system.

Market Development Needs

- **Research** (e.g., oilseed and perennial grass agronomics)
- **Natural Resource, Physical Infrastructure, and Technology** (e.g., land use issues, using new equipment, infrastructure development and optimization)
- **Sales and Distribution** (e.g., matching bioenergy supply and demand, gaining familiarity with bioenergy products and distribution methods)
- **Marketing and Public Outreach** (e.g., building consumer awareness about bioenergy products)
- **Business Planning and Technical Assistance** (e.g., agronomic advice to farmers for oilseed production, engineering advice for biodiesel processing facilities)
- **Financing** (e.g., identifying additional sources of funding for businesses at different stages of development)
- **Network Development** (e.g., support for existing networks and trade associations, creation of peer learning opportunities)
- **Education** (e.g., technical exposure to bioenergy topics at institutions of higher education)

- **Workforce Development** (e.g., identifying workforce needs)
- **Regulation and Public Policy** (e.g., identifying state or federal regulations that impact bioenergy production in Vermont).

Matrix Key:

- Oilseed and/or biodiesel production projects (yellow)
- Grass energy projects (light green)
- Algae projects (dark green)
- Cross-cutting projects (e.g., education and technical assistance) (orange)

VBI MARKET DEVELOPMENT MATRIX

<table>
<tr><th>Market Development Needs</th><th>Feedstock Production</th><th>Feedstock Logistics</th><th>Bioenergy Conversion</th><th>Bioenergy Distribution</th><th>Bioenergy End Use</th></tr>
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<tr><td colspan="2">UVM Extension: perennial grass production and processing research</td><td></td><td></td><td>Biomass Commodities Corp and VSJF: Air Emission Profile Testing</td></tr>
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<tr><td colspan="2">GSR Solutions: algae feedstock development</td><td>Green Mountain Spark: photochemical reactor</td><td></td><td></td></tr>
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<tr><td colspan="5">Dr. Sid Bosworth (UVM Extension): perennial grass technical assistance</td></tr>
<tr><td colspan="5">Chris Callahan (UVM Extension): engineering technical assistance; project management</td></tr>
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<tr><td colspan="5">Grass Energy Symposium</td></tr>
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<tr><td>Community Energy Dashboard: energy analysis and mapping</td><td></td><td></td><td></td><td>Community Energy Dashboard: energy analysis and mapping</td></tr>
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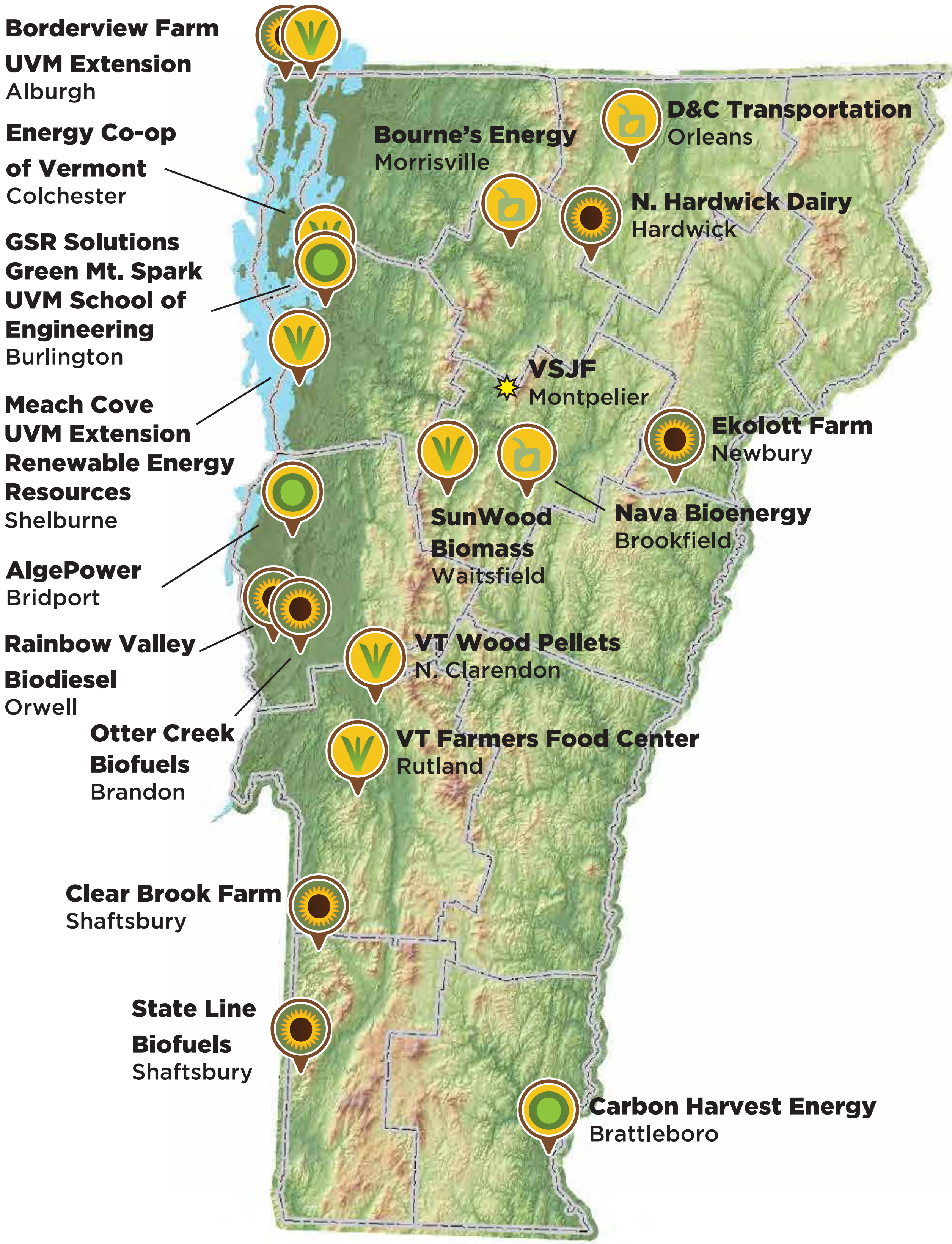
MAP OF VBI RESEARCH AND DEMONSTRATION SITES



TASK F: OILSEED CROPS AND BIODIESEL

Jon Satz runs Wood's Market Garden (Otter Creek Biofuels), an organic fruit and vegetable farm in Brandon. He explored oilseeds as a rotational crop with vegetables that can also provide fuel (oil) and fertilizer (meal).

Although the Northeast region of the United States has a history of growing a variety of crops, including oilseeds, much of the experience and equipment once used for this purpose is long-gone. The farmer and agronomic researcher sub-recipients supported by the VBI needed to study-up and tool-up in order to become acquainted with the reintroduced crops. For example, planters and seed drills needed to be modified and small combines needed to be purchased. It was necessary to establish combine capacity for oilseeds and developing an understanding of how to use that capacity effectively. Postharvest handling also required investment in learning and additional infrastructure. Seed dryers and bins were built and installed. Conveyance equipment such as augers and elevators were required.

The work funded by the VBI in the area of oilseeds has included agronomic research and development, crop processing research and development, fuel production research and development, technical assistance, and education and outreach. These activities have been in pursuit of objectives outlined in multiple Statement of Project Objectives among a variety of sub-recipients.

Our original intention was to develop sufficient on-farm capacity to replace at least 12.5% (750,000 gallons) of the 6 million gallons of imported diesel and at least 12,500 tons of the over 100,000 tons of livestock meal consumed each year on Vermont farms with homegrown biodiesel and feed. This was informed by actions taken by farmers and researchers responding to high prices for diesel—$5 a gallon—at the pump in 2008. At the height of the VBI in 2010, about 320 acres were specifically devoted to oilseed crops in Vermont. While biodiesel production in Vermont is relatively low, the vision of producing a percentage of our liquid fuel needs with local alternatives remains relevant, and the agronomic and technical knowledge now exists to do so.

OILSEEDS AND BIODIESEL PROJECTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08-FY10	**University of Vermont Extension:** Crop Production, Agronomic Research, Education and Outreach	$233,512	$77,188	$310,700
FY08-FY10	**Borderview Farm:** Crop Production and Processing, Biodiesel Production	$108,103	$31,998	$140,101
FY08-FY10	**Stateline Biofuels:** Crop Production and Processing, Biodiesel Production	$64,861	$60,340	$125,201
FY08-FY10	**Otter Creek Biofuels:** Crop Production and Processing	$80,000	$107,684	$187,684
FY08-FY09	**Ekolott Farm:** Crop Production and Processing	$49,200	$18,641	$67,841
FY08	**North Hardwick Dairy:** Crop Production and Processing	$13,000	$32,396	$45,396
FY08	**Clearbrook Farm:** Crop Production and Processing	$20,000	$3,700	$23,700
FY08	**Rainbow Valley Biodiesel:** Crop Production and Processing, Biodiesel Production	$65,000	$98,819	$163,819
	SUB-RECIPIENT SUBTOTAL	**$633,676**	**$430,766**	**$1,064,442**
Fiscal Year(s)	**Staff Directed Projects**	**DOE Funds**	**Total Cost Share**	**Total Project Cost**
FY08-FY10	**Chris Callahan:** Technical Assistance/Project Management	$171,694	$36,295	$207,989
FY08	**Chris Callahan:** Mobile Oilseed Unit Cost / Benefit		$20,549	$20,549
FY08	**Eleanor Campbell:** Oilseed to Biodiesel Greenhouse Gas Calculator		$28,050	$28,050
FY08	**Eric Garza:** On-Farm Biodiesel EROEI analysis	$5,063		$5,063
FY08	**Shearwater Energy Partners:** On-Farm Biodiesel RINS analysis	$4,850		$4,850
FY10	**Vermont Law School:** On-Farm Biodiesel Regulatory Review	$25,000		$25,000
	STAFF DIRECTED PROJECTS SUBTOTAL	**$206,607**	**$84,894**	**$291,501**
	TASK TOTAL	**$840,283**	**$515,660**	**$1,355,943**

These efforts have produced the following findings:

Crop Production and Agronomic Research

- Oilseed crops can be successfully grown in the Vermont and the Northeast US. Researchers and growers in Vermont have successfully produced sunflower, canola, winter rapeseed, flax, safflower, and camelina.
- Production guidance from other, high-volume production regions is generally not well-aligned with Vermont's growing region due to soil fertility, pest management and weather differences.
- Researchers in Vermont have compiled and published regionally-specific production guidance based on the crop research done locally.
- Crop production costs are generally stable on a per-acre basis, varying mainly based on management practice.
- Yields are highly variable from year to year with the main depressive pressure being from pests and disease.
- As a result of variable yields, crop production costs on a unit output basis are highly variable.

Crop Processing Research and Development

- Harvester (combine), drying, cleaning, and storing capacity are critical barriers to entry in adoption of oilseeds as a revitalized crop in the Northeast.
- Oilseed presses, though commercially available, are not well specified by manufacturers and require nuanced expertise to operate.
- Researchers in Vermont and Pennsylvania compiled and published oilseed press best practices and reviews to assist with more expedient adoption of the practice.

Biodiesel Production Research and Development

- Multiple scales of biodiesel production from seed oil have been demonstrated on farms in Vermont including self-built and commercially available systems.

- The feasibility of mobile seed processing and biodiesel production was explored and summarized in a report.
- Alcohol recovery from the production process has been demonstrated using post-process distillation.
- The use of glycerin as a heating fuel for the biodiesel production process has been demonstrated using a waste oil boiler to make hot water.

Integrated Economic, Energy and Environmental Analysis

- Researchers have documented the financial cost of production for various oilseed crops and associated co-products. An associated calculator was developed to allow others to perform early-stage enterprise budgeting and forecasting. A fuel cost of $2.30—2.50 per gallon was estimated based on current practice.
- Researchers have documented the Energy Return on Energy Investment associated with biodiesel production from oilseeds grown on the farm. A net energy return ratio of between 3.6 and 5.9 to 1 was estimated.
- Researchers have documented the net carbon benefit of oilseed-based biodiesel produced on the farm. Net carbon avoidance of 1,984 to 3,227 pounds per acre per year was estimated for sunflowers.
- Renewable Fuel Identification Numbers (RINS) were explored for relevance to on-farm production and deemed difficult to advance due to the scale of production and necessary consolidated record keeping of production and sale.
- A regulatory review of on-farm biodiesel production was conducted by researchers at Vermont Law School which explored a wide range of regulatory hurdles and requirements that farm-based fuel enterprises would face.

Education and Outreach Programming

- A mix of large-group field days, focused grower meetings, and one-on-on direct consulting enabled a diverse set of early adopters to grow and process oilseed crops.

- The Vermont Bioenergy website serves as a clearinghouse of VBI related information and publications.
- The Bioenergy Now! Video series captures the above work and findings in a viewer-friendly and accessible manner enabling outreach to a broader audience.
- Outputs from research and development efforts have been integrated into undergraduate education programs at the University of Vermont and Vermont Technical College.
- Outputs from research and development efforts have been published as part of the new textbook, "Bioenergy: Biomass to Biofuels."
- Interest in oilseed-based biodiesel is highly dependent upon the cost of petroleum based fuels.
- Although there is interest in oilseed-based biodiesel among larger, institutional and fleet customers, the cost of fuel and variability of quality is a limiting factor for near-term adoption.

Lessons Learned

1.) Oilseed crops such as sunflower, canola, winter rapeseed, flax, safflower and camelina can be successfully grown in the Vermont and the Northeast with relatively stable annual per-acre cost of production, albeit with lower and more variable yields than traditional production regions. VBI supported research helped to provide regionally specific crop production guidance to address the regional differences noted in these crops.

2.) System-wide infrastructure is a barrier to entry for farms in the Northeast to grow and process oilseed crops. VBI funded projects have helped to demonstrate equipment, practice and technologies that are appropriate for small to medium sized farms. Research and Extension work has helped to collect and develop best practices for this infrastructure to make further adoption and replication easier.

3.) Farm-scale biodiesel production has been demonstrated with several different systems and at several different scales and various models of shared infrastructure. This work focused on self-built, farm systems and integrated safety as a key design element.

4.) Based on an integrated economic and environmental assessment, the projects have demonstrated local crop-based, fuel production at a cost of $2.30-2.50 per gallon, with a positive energy return on investment ranging from 3.6 to 5.9 to 1, and with a net carbon avoidance of 1,984 to 3,277 pounds per acre.

"The VBI arrived at the right time to help diversified farm and energy pioneers with the tools they needed to break the cycle of fossil fuel dependence."

— Netaka White, Vermont Sustainable Jobs Fund

Larry Scott and Peggy Hewes, Ekolott Farm (Newbury, Vermont) were VBI sub-recipients for oilseed crop production.

TASK E: GRASS AND MIXED FIBER BIOENERGY

Almost a third of Vermont's total energy demand is for heating purposes. Nearly 60% of the heating fuel used in the state is No. 2 heating oil, while propane makes up 14%. Both of these are nonrenewable sources of energy, prone to extreme price fluctuations, and they contribute to carbon dioxide emissions.

Grass pucks being fed into an EvoWorld HC100 Eco boiler at Meach Cove Trust in Shelburne, VT.

Prior to the VBI's research and demonstration investigations, there had been little information on grass production for biomass purposes in Vermont, including suitable species and cultivars, agronomic practices, and economic viability. The goal of this task was to assess potential grasses and evaluate potential economic viability of direct combustion grass energy systems for Vermont and the Northeast region.

These efforts have produced the following findings:

Crop Production and Agronomic Research

- Grass biomass crops trials have demonstrated 3 to 6 tons per acre yields with annual production costs averaged over 10 years—including prorated establishment costs of $250 to $300 per acre per year—resulting in farm gate biomass costs of $50 to $80 per ton depending on annual biomass yield.
- The key factors supporting success of grass biomass crops in the region are species and variety selection, soil fertility, successful establishment including weed management, and soil productivity class.

- Grass biomass crops are aligned with the region's historical production and use of hay and other grass forages.

- Grass biomass crops can be harvested using equipment that already exists in the region.

GRASS AND MIXED FIBER BIOENERGY PROJECTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08-FY10	**University of Vermont Extension:** Crop Production, Agronomic Research, Education and Outreach	$151,080	$40,933	$192,013
FY09-FY10	**Renewable Energy Resources:** Densification and Transportation	$117,104	$120,606	$237,710
FY10	**Vermont Farmers Food Center:** Thermal Conversion and Economic Feasibility Research	$41,000	$78,481	$119,481
	SUB-RECIPIENT SUBTOTAL	**$309,184**	**$240,020**	**$549,204**
Fiscal Year(s)	**Staff Directed Projects**	**DOE Funds**	**Total Cost Share**	**Total Project Cost**
FY10	**Wilson Engineering:** Grass Energy in Vermont and the Northeast report	$17,640		$17,640
FY08	**Biomass Commodities Corp and VSJF:** Air Emission Profile Testing	$22,468		$22,468
FY08	**VSJF and Partners:** Grass Energy Symposium	$3,738	$4,612	$8,350
FY08-FY10	**Chris Callahan:** Technical Assistance/Project Management	$1,458		$1,458
FY09	Bulk Wood Pellet Delivery Investigation	$50,000	$29,194	$79,194
	STAFF DIRECTED PROJECTS SUBTOTAL	**$95,304**	**$33,8060**	**$129,110**
	TASK TOTAL	**$404,488**	**$273,826**	**$678,314**

Densification and Transportation Research and Development

- Grass biomass crops can be densified in forms more suitable for storage, transportation, delivery and combustion in appropriately-sized heating appliances for on-farm heating at a conversion cost of $49 to $148 per ton.
- Grass biomass fuels can be delivered with production cost of $85 to $228 per ton ($5.2 to $14.4 per million BTU.).

Thermal Conversion and Economic Feasibility Research

- Grass biomass fuels can be combusted in small commercial boilers intended for wood chips with a 3 to 5 year simple payback period and emissions comparable to wood pellets.
- Recent advances in boiler design such as improved combustion air controls and automated ash removal have helped address earlier issues with the use of these newer, high-ash fuels.

Educational and Outreach

Education and outreach was a continual theme throughout the project. Several specific "Grass Energy" field days were held to provide focused, hands-on review of the developing practice. This work was integrated into other farmer "field days." The results of our research and demonstration projects have also been highlighted in undergraduate bioenergy survey courses at the University of Vermont (UVM) and Vermont Technical College. Project outputs have been posted on a variety of websites for longer-term use, including the Vermont Bioenergy Initiative website, the UVM Grass Biomass Energy website, and the UVM Extension Ag Engineering website.

Lessons Learned

1.) Grass biomass crops aligned with the region's historical production and use of hay and other grass forages and VBI supported trials have demonstrated 3 to 6 tons per acre yields with annual production costs averaged over 10 years—including prorated establishment costs of $250 to $300 per acre per year—resulting in farm gate biomass costs of $50 to $80 per ton depending on annual biomass yield. The key factors supporting success of grass biomass crops in the region are species and variety selection, soil fertility, successful establishment including weed management, and soil productivity class.

2.) Grass biomass crops can be densified in forms more suitable for storage, transportation, delivery and combustion in appropriately-sized heating appliances for on-farm heating at a conversion cost of $49 to $148 per ton leading to fuels with total production costs of $85 to $228 per ton ($5.2 to $14.4 per million BTU.)

3.) Recent advances in biomass boiler design such as improved combustion air controls and automated ash removal have helped address earlier issues with the use of these newer, high-ash fuels. Grass biomass fuels can be combusted in small commercial boilers intended for wood chips with a 3 to 5 year simple payback period and emissions comparable to wood pellets.

4.) An analysis conducted for the VBI found several barriers that make it unlikely that grass pellets will gain widespread acceptance in the residential pellet fuel market without a significant price advantage over wood, which does not currently exist. These barriers are: significantly higher ash content compared to wood, clinkering (i.e., the fusion of ash into hard chunks) caused by lower ash fusion temperatures, lower heat energy content of grass compared to wood, and increased processing costs in producing a grass pellet compared to wood pellets due to increased wear on processing equipment. Ash content and composition can be controlled by managing soils, nutrients applied, and harvest practices. There are pellet stoves, furnaces and boilers available that can burn grass pellets but the high ash content compared to wood requires more robust ash handling equipment.

5.) Larger boilers and equipment are commercially available that can burn grass from bale form to briquettes, cubes and pellets however; there are very few biomass-burning appliances of this large size currently installed in Vermont or the Northeast.

TASK D: ALGAE

As described in the National Algal Biofuels Technology Roadmap, algal biofuel production is attractive due to the possibility of 1) high per-acre productivity, 2) non-food based feedstock resources, 3) use of otherwise non-productive, non-arable land, 4) utilization of a wide variety of water sources (fresh, brackish, saline, marine, produced, and wastewater), 5) production of both biofuels and valuable co-products, and 6) potential recycling of CO_2 and other nutrient waste streams.

A view of the Carbon Harvest Energy prototype algae raceway.

The development of algal bioenergy feedstocks was pursued with VBI funding due to the potentially high yields of this approach and the possible nutrient and carbon conversion opportunities present when co-located with anaerobic digesters or landfills.

The early stage results of this body of work include:

Feedstock Development

- A curated collection of one hundred (100) oil-rich native Vermont algal strains for commercial oil production and nutrient recovery were isolated and are being maintained in a purpose-built facility with ten (10) of these strains being classified as best performers.
- Several Vermont strains that were isolated were transferred to pilot research demonstrations at a closed landfill and at a dairy farm with an anaerobic digester.
- Isolated, regional algae strains will be leveraged in projects aimed to scale up production through integration with waste streams such as new community biodigesters.

ALGAE PROJECTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08	**Algepower:** Production Systems	$20,000	$5,606	$25,606
FY08-FY10	**Carbon Harvest Energy:** Production Systems	$233,349	$66,225	$299,574
FY08-FY10	**GSR Solutions:** Feedstock Development	$133,833	$106,244	$240,077
FY09	**Green Mountain Spark:** Conversion Technologies	$65,000	$33,651	$98,651
FY09	**University of Vermont School of Engineering:** Production Systems	$44,828	$24,673	$69,501
	TASK TOTAL	**$497,010**	**$236,399**	**$733,409**

Production Systems

- The integration of a pilot-scale algal biomass production system with an anaerobic digester demonstrated the use of waste CO_2 and nutrient (N and P) rich digester effluent.
- The integration of a pilot-scale algal biomass production system with a landfill power plant demonstrated the use of waste CO_2 sources and tolerance of algae production to potential exhaust contamination (i.e., flue gas).
- An experimental platform was established to study the fluid dynamics of mixing and flow related to optimal algal biomass production systems at the University of Vermont School of Engineering.

Harvest and Conversion Technology

- A bench-scale photochemical algal fuel processing system was developed that is capable of producing biofuel more cost effectively and with less energy investment compared to standard oil extraction and transesterification.

- A bench-scale photochemical algal fuel processing system was developed that demonstrated production of a fuel with superior cloud point, pour point, cold filter plugging point, and heat of combustion when compared to fuel produced using transesterification.
- With the granting of a U.S. Patent for their system, Green Mountain Spark intends to pursue commercialization and scaling activities to further develop their photoreactor.

Educational and Outreach Programming

- Educational materials related to algal bioenergy production specific to Vermont have been developed and published.
- A conference focused on algal bioenergy production in the Northeast was held to share research findings and strengthen the research network.
- A Vermont network of stakeholders with interest in algal bioenergy has been established.

Lessons Learned

1.) A collection of regionally specific algae strains with high potential for oil production have been evaluated, selected and curated to provide for future development.

2.) Algal biofuels systems that are integrated with existing agricultural and food system infrastructure have been explored and demonstrated indicating potential for symbiotic solutions of waste management, carbon emission reduction and fuel production.

TASK G: COMMERCIAL BIODIESEL

The VBI provided funding support to two commercial fuel dealers for the development of blending infrastructure. Blending systems enable the proper mixing of 100% biodiesel (B100) with petroleum diesel that provides important technical and economic benefits for the early adoption of biodiesel. At the time of these projects, a blending tax credit was being provided to distributors of fuel to incentivize biodiesel purchase and use while also not exposing the market to increased risk from a complete switch. The use of a blended fuel helps to minimize technical risk that comes along with the use of 100% biodiesel (e.g., engine fuel system issues, suspension of sediment in old tanks, cold-weather performance challenges).

Bourne's Energy biodiesel blending facility.

COMMERCIAL BIODIESEL PROJECTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08	Bourne's Energy	$45,000	$49,077	$94,077
FY08	D&C Transportation	$32,500	$98,370	$143,370
FY08-09	Nava Bioenergy	$45,000	$126,911	$159,411
	TASK TOTAL	**$122,500**	**$274,358**	**$396,858**

These efforts have produced the following findings:

- The commercial biodiesel infrastructure supported by the VBI has helped to orient two large fuel dealers in Vermont to the handling and mixing of this biofuel. This improved integration of a new fuel into the distribution channel—about 1 million gallons over five years—sets the stage for future growth in the use of biodiesel.

Lessons Learned

- A federal tax credit was important to early adopters of biodiesel, but was removed too quickly to maintain stable use.
- There is a market for bioheat among consumers but more, and consistent, education is needed by fuel dealers to market the environmental benefits of the fuel.
- Housing biodiesel in a temperature controlled building mitigates cold weather issues likely to occur in Vermont and New England.

Further work is needed to increase production of biodiesel in the state and region to supply these enterprises with high quality fuel from sustainable sources with a reliable volume of production.

TASK C: RENEWABLE ENERGY ATLAS OF VERMONT

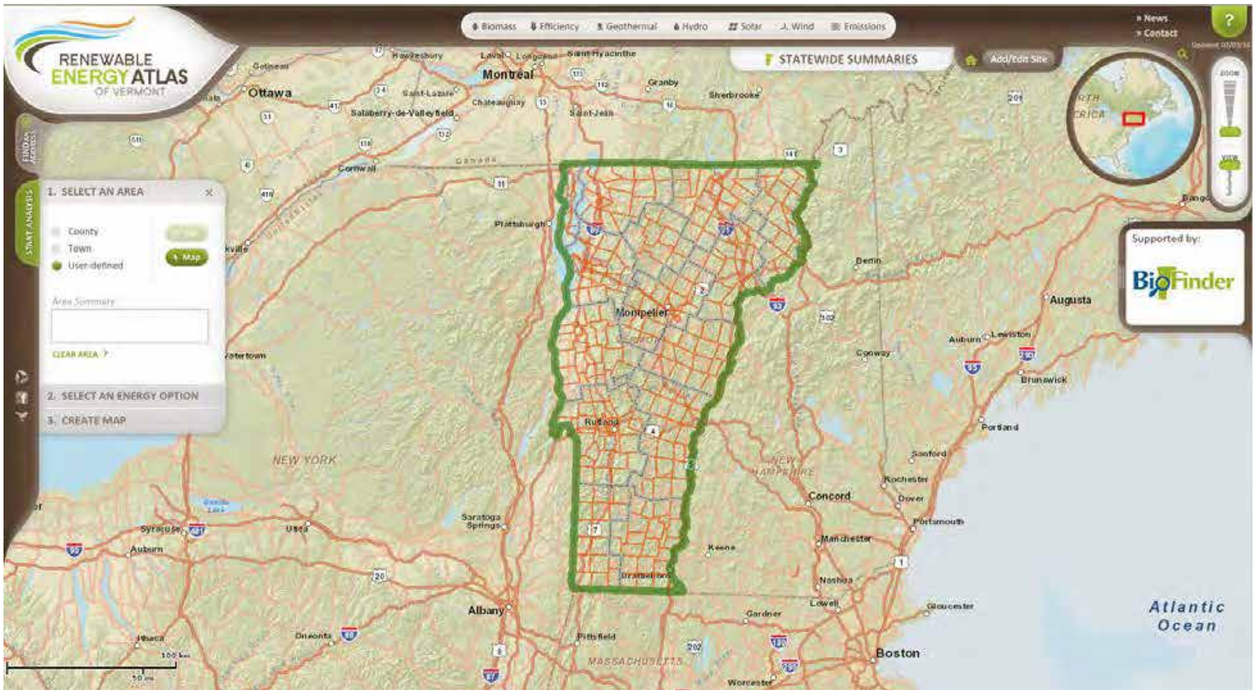
The Renewable Energy Atlas of Vermont was developed as a GIS-based website for identifying, analyzing, and visualizing existing and promising locations for renewable energy projects. The Atlas was created to assist town energy committees, Vermont's Clean Energy Development Fund and other funders, farmers, educators, planners, policy-makers, and businesses in making informed decisions about the planning and implementation of renewable energy in their communities—decisions that ultimately lead to successful projects, greater energy security, a cleaner and healthier environment. The state-of-the-art Atlas was the first tool of its kind in the United States that enabled end users to click on their town (or several towns or county/counties) and select from a thorough suite of renewable energy options: biomass, efficiency, geothermal, hydroelectric, solar, and wind.

RENEWABLE ENERGY ATLAS AND COMMUNITY ENERGY DASHBOARD

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Project Cost
FY08-10	**VSJF:** project management	$82,214	$82,214
FY08-10	**Vermont Center for Geographic Information:** Energy data layer creation	$116,667	$116,667
FY08-10	**Fountains Spatial:** website development and hosting	$114,067	$114,067
FY08-10	**Vermont Design Works:** Community Energy Dashboard data conversion	$32,129	$32,129
	TASK TOTAL	**$345,077**	**$345,077**

The results of this body of work include:

- First of its kind resource assisted Regional Planning Commissions, Vermont Department of Public Service, Vermont Energy and Climate Action Network, and other stakeholders in analyzing renewable energy potential and reporting results.



The Atlas homepage allowed users to select communities and energy layers to create maps.

- ▶ Creation of renewable energy GIS data layers available for download at the Vermont Center for Geographic Information website.

- ▶ Creation of database of all renewable energy installations in Vermont.

Working with the Energy Action Network, VSJF evolved the Energy Atlas into the Community Energy Dashboard released in May 2016. The Dashboard has many more features, including:

- ▶ **Energy Atlas:** The Energy Atlas remains a tool for mapping town, county, and Regional Planning Commission boundaries for existing and potential renewable energy sites. With the tool, users can turn on additional “constraints” (e.g., endangered species habitat) in order to identify new potential sites that take environmental resources into account. Users can also crowdsource their own information.

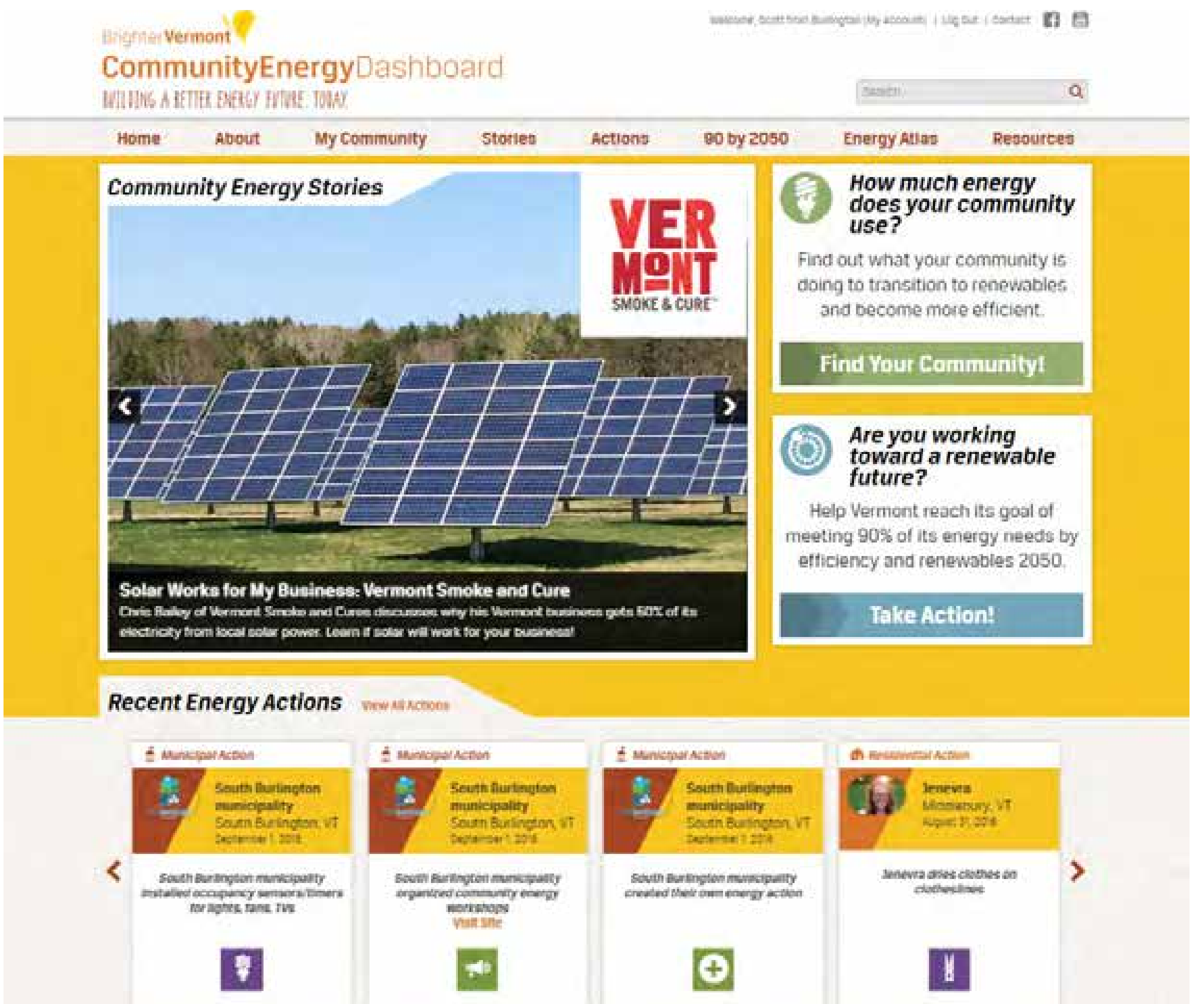
- ▶ **Statistics:** Energy installations included in the Atlas database aggregate into real-time renewable energy installations, installed capacity, and electrical generation statistics for every town, county, and Regional Planning Commission in Vermont (e.g., Burlington, Franklin County, and Northeastern Vermont Development Association). Statistics allow users to see how their community ranks compared to other communities.

- **Analysis:** Statistics compiled by the Atlas and other official sources can then be turned into data visualizations (e.g., [Renewable Electricity Sites]) that showcase long-term trends.

- **Stories:** The Dashboard is also a central repository for a growing list of Vermont [energy stories], including Bioenergy Now! videos and bioenergy stories.

- **Progress Timeline:** A Progress Timeline for every community in Vermont allows Dashboard users to track community progress towards meeting 90% of local energy needs through efficiency and renewables by 2050. Each Progress Timeline includes heat and transportation calculations.

- **Actions:** [Action "tiles"] provide an interactive way for Dashboard users to add individual, business, municipal, school and farm actions in order to showcase the collective impact of their community.



The Dashboard includes a searchable database of Vermont renewable energy stories, including bioenergy stories.

Lessons Learned

- Use of proprietary programming software (i.e., ESRI's ArcGIS) increasingly constrained our ability to make updates to the Atlas (e.g., bulk upload of renewable energy sites was desired but not possible). Staff changes at website developer also reduced our ability to make Atlas changes. Consequently, when we transitioned from the Renewable Energy Atlas to the [Community Energy Dashboard] we used open source software.
- The user interface of the Atlas proved to be overly complicated for some users. When we transitioned to the Dashboard we tested all features extensively and made the user interface more intuitive.
- Bioenergy site development using the Atlas was of low interest to users compared to solar energy and wind siting.

TASK A: EDUCATION AND OUTREACH

The objectives of Task A were to develop the network of farmers and entrepreneurs involved in growing and processing oilseed crops and other bioenergy feedstocks (e.g., algae, perennial grasses) and provide peer learning opportunities. Actions included organizing conferences, workshops, and networking sessions for biofuel entrepreneurs, farmers, academics, state officials, service providers, and consumers to share knowledge and experience. VBI funding supported the development of educational curriculum at the University of Vermont and Vermont Technical College in bioenergy related research, technology and production application.

EDUCATION AND OUTREACH PROJECTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08	**Vermont Technical College:** College course development	$20,000	$14,600	$34,600
FY08	**University of Vermont:** College course development	$19,994	$9,600	$29,594
FY08	**Renewable Energy Vermont:** Biofuels Working Group	$13,800	$2,555	$16,355
FY09-10	**Vermont Businesses for Social Responsibility**: Business Energy Action	$54,406	$11,939	$66,345
	SUB-RECIPIENT SUBTOTAL	**$108,200**	**$38,694**	**$146,894**
Fiscal Year(s)	**Staff Directed Projects**	**DOE Funds**	**Total Cost Share**	**Total Project Cost**
FY08-09	**KSE Partners and VSJF:** Bioenergy Now! Video Production	$80,037		$80,037
FY08-10	**VSJF:** Technical assistance	$64,286	$30,677	$94,964
FY08-10	**Chris Callahan:** Oilseed technical assistance	$171,694	$36,295	$207,989
	STAFF DIRECTED PROJECTS SUBTOTAL	**$316,017**	**$66,972**	**$382,990**
	TASK TOTAL	**$424,217**	**$105,666**	**$529,884**

- **UVM Biomass to Biofuels Course:** This course provided hands-on experience with various types of bioenergy, including liquid biofuels, solid biomass, and biogas to students at the University of Vermont (Burlington, Vermont). The course provided the participants—including students, farmers, entrepreneurs, and others—with technical exposure to bioenergy topics. The course involved a) on campus classes; b) field work involving tours to farms/bioenergy facilities; c) presentations by bioenergy experts; d) bioenergy equipment demonstrations by professionals; e) online supplementary classes/information including video clips; and f) service learning projects. The course has been offered 3 times.

- **Vermont Technical College Biomass to Biofuels Course:** This project developed biomass to biofuels course modules at Vermont Technical College that provided hands-on experience and technical exposure to various feedstocks, technologies, production processes, policies, regulations, along the biomass-to-biofuels supply chain. The course was designed as separate modules to be comprised of informational slides for presentation in a classroom or discussion forum, as well as basic plans for activities that demonstrate and engage participants in the subject. The five modules addressed the following topics:
    - Introduction to Biomass and Biofuels
    - Biodiesel: Feedstock and Byproducts
    - Biodiesel: Fuel Production, Standards, and Regulations
    - Solid Biomass Fuel: Resources, Material Handling and Processing
    - Solid Biomass Fuel: Combustion, Emissions, and Byproducts

- **Renewable Energy Vermont Biofuels Working Group:** Renewable Energy Vermont is a trade association of renewable energy businesses. The Renewable Energy Vermont Biofuels Working Group— comprised of a cross-section of key bioenergy players—met regularly to promote the biofuels sector in the state. The goal of the Biofuels Working Group was to address the strategic growth of the Vermont biofuels industry with an emphasis on identifying gaps in marketing, public relations, and public policy. REV served Vermont's biofuels industry—and the renewable energy community at large—by increasing educational activities through their newsletter, conference, newspaper and public awareness efforts, industry support, and their website.

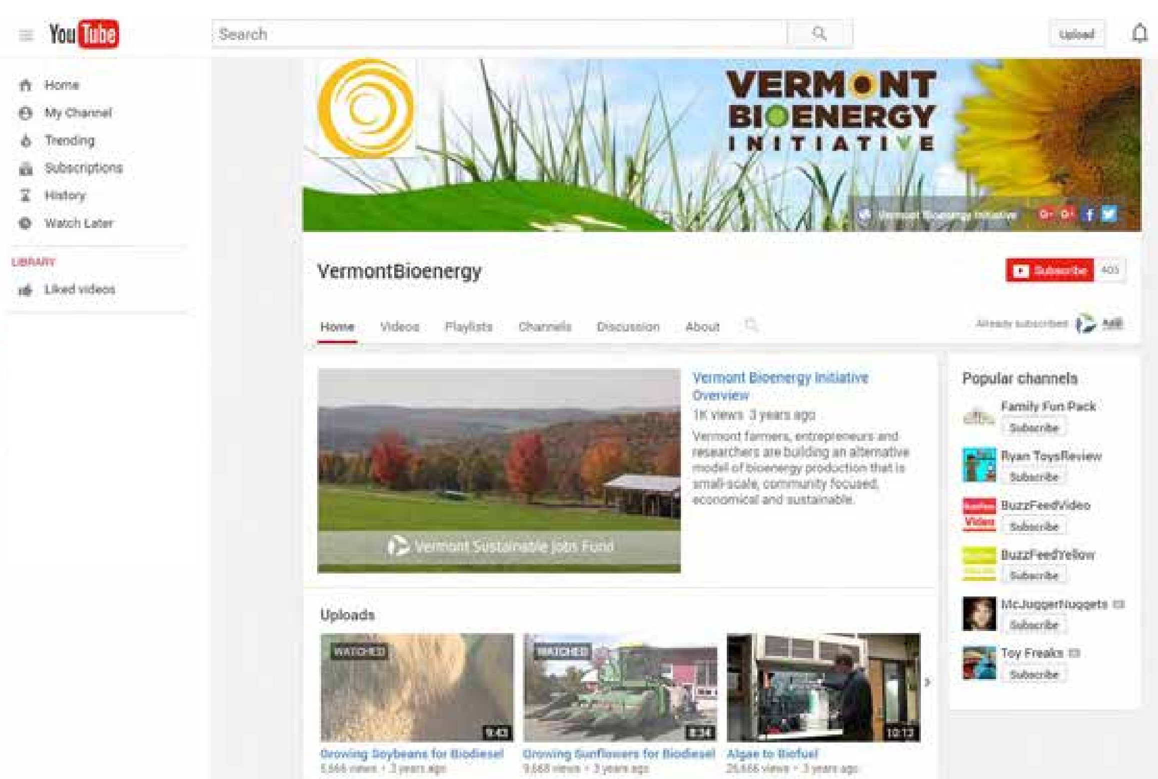
- **Vertical Businesses for Social Responsibility:** In 2012, VBSR created the Business Energy Action demonstration project to help Vermont businesses reduce consumption of electricity and heating fuel by 5% a year for 5 years. Eighty-five (85) businesses signed up to participate. They were required to make a public 5-year commitment to the project. Each business established a baseline level of energy consumption for electricity and heating fuel. Increases or decreases against the baseline were tracked for 2013 and 2014. At the end of the first project implementation year, participants exceeded the 5% savings goal.

B|E|A
Business Energy Action

- **Conferences:** VSJF staff organized numerous conferences and sub-recipient gatherings related to oilseeds, grass, and algae. For example, oilseed farmer meetings were held each spring in advance of planting season.

Question and answer session at the 2008 Grass Energy Symposium, Shelburne Farms, Vermont.

- **Bioenergy Now! Video Series:** The projects and results of the Vermont Bioenergy Initiative were documented in a 10-part video series titled Bioenergy Now! under the direction of Netaka White in 2013. **The 2 to 10 minute videos are hosted on a VBI YouTube channel have collectively been viewed over 89,000 times and are promoted via the VBI website, associated social media channels, and through project partners' outreach activities.** The video segments include:
    - The Vermont Bioenergy Initiative Overview
    - Homegrown Fuel and Feed
    - Growing Canola for Biodiesel
    - Growing Soybeans for Biodiesel
    - Growing Sunflowers for Biodiesel
    - Oil Crop Pest Pressures
    - Oil and Meal Extraction
    - Making On-Farm Biodiesel
    - Grass Fuel
    - Algae to Biofuel



Tasks E and F also led to education and outreach components that we summarize here. That is, technical assistance provided through Tasks E and F frequently led to products such as reports with education and outreach relevance. VSJF helped spread these products through various communications channels.

University of Vermont Extension Northwest Crops and Soil Team

As part of her sub-recipient grant awards, Dr. Heather Darby provided extensive agronomic related technical assistance to a large number of oilseed farmers from 2008 to 2015.

On-Farm Field Days (Multiple per Year)

A key component of oilseed outreach and education has been UVM Extension led field days at partner farms. Beginning in 2010, oilseeds were a highlight of the UVM Extension Northwest Crops and Soils Team annual field day at Borderview Farm in Alburgh. Additional field days were hosted at State Line Biofuels (Shaftsbury), Wood's Market Garden (Brandon) and Ekolott Farm (Newbury) to demonstrate specific aspects of those site's operations. These field days allowed for hands-on, direct experience with crops, practices, equipment, and products for those showing interest in the emerging industry. They also served as an important networking and outreach mechanism that helped to expand the reach of the VBI funded research and technical assistance in this area.

Oilseed Growers Meetings (Annual)

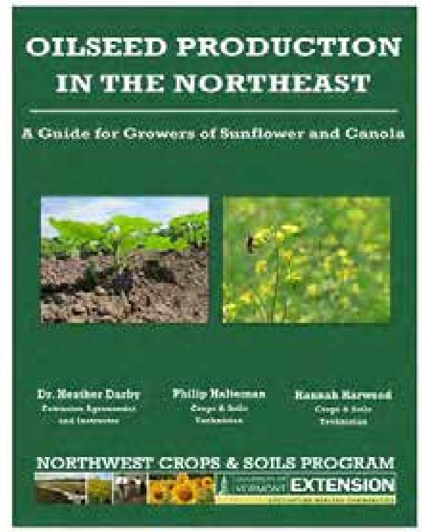
In addition to the annual field days, the UVM Extension Northwest Crops and Soils Team facilitated annual meetings of growers actively involved in oilseed crop production. These late winter meetings were held centrally in Berlin or White River Junction (Vermont) each year beginning in 2010. The gatherings served as a chance to share lessons learned from the past year, express challenges and research questions, and to sort out the seed order for the coming year.

Farmer to Farmer Education

A somewhat unintended result of investing in on-farm oilseed and biodiesel facilities has been the development of these farms as peer resources for other interested farmers. State Line Biofuels (Shaftsbury), Borderview Farm (Alburgh) and Ekolott Farm (Newbury) all field inquiries from around the nation and the world related to the work they are doing in this area. These farms host school groups, professional tours, and field days each year that help to educate farmers and the general public about the potential for this unique production model.

Oilseed Production in the Northeast

VBI funding, combined with USDA SARE funding, supported the University of Vermont Extension Northwest Crops and Soil Program in the production of a guide that focuses on sunflowers and canola. (Darby et al., 2013). The guide covers crop growth, development, establishment, and production; pest management; harvesting practices; and seed processing and storage.



The University of Vermont Extension Northwest Crops and Soil Program website has become a major resource for all aspects of oilseed crop production and processing. Research results from the past six years are posted on the website.

University of Vermont Department of Plant and Soil Science

As part of his sub-recipient grant awards, Dr. Sid Bosworth from UVM provided extensive agronomic related technical assistance to grass farmers between 2008 – 2015.

On-Farm Field Days

- Two major field days were held at the Meach Cove and Vermont Tech locations in 2010 and 2011, respectively.
- The Borderview Farm research trials conducted by Dr. Sid Bosworth (UVM Extension) were highlighted at four consecutive Crop Field Days held there from 2009 to 2012.

Grass Energy Symposium

- A Grass Energy Symposium was held in November, 2008 and featured many speakers on topics such as growing and harvesting, processing and pelletizing, and the state of combustion technology.

Perennial Grass Production in the Northeast

- A website dedicated to highlighting Dr. Bosworth's research results was launched (http://pss.uvm.edu/grassenergy).

Chris Callahan, Callahan Engineering PLLC and University of Vermont Extension Ag Engineering

Chris Callahan Engineering (2005-2012) provided engineering assistance (e.g., systems optimization, FMEA safety protocols, economic analysis) as an independent contractor and then through UVM Extension after Callahan joined this organization as their Agricultural Engineer (2012-present). With VSJF's Bioenergy Director, Netaka White, and, later, Sarah Galbraith, Callahan provided guidance in the development of these reports.

- **Oilseeds and Biodiesel Cost of Production Calculator:** Early in the life of the VBI, a need was noted for an easy, concise calculation of seed, meal, oil and fuel costs based on the unique characteristics of the farm enterprise. A cost of production model was developed and packaged in an easy-to-use Excel format by Chris Callahan: http://vermontbioenergy.com/oilseed-cost-profit-calculator. This tool—downloaded more than 300 times across the U.S. and other countries, including the Philippines, Germany, and Zambia—enables the the calculation of actual unit costs for the primary outputs of the on-farm oilseed enterprises that exist and allow others to assess pro-forma economics using "typical" cost factors included in the input entry page or using parametric sweeps of these parameters.

- **A Feasibility Study of a Mobile Unit for Processing Oilseed Crops and Producing Biodiesel in Vermont:** A feasibility study completed by Chris Callahan (and funded by the High Meadows Fund) reviewed the feasibility of a mobile oilseed processing unit in Vermont. A mobile oilseed processing unit was predicted to be a feasible and profitable opportunity. It is technically feasible to transport appropriately sized equipment with a truck and small trailer to remote locations to provide processing services. It was also estimated that the cost of processing is below the market value of certain outputs (biodiesel and organic meal). A key challenge to such an operation will be establishing a sufficient initial market to breakeven at a reasonable price while also planning on future growth to capitalize on economies of higher volume production. As production volume increases, the breakeven price will decrease and higher profit can be realized at the same market price. A processor charging a price between breakeven and market value can realize a profit while providing some savings to the farmers they serve.

- **An Update on Solid Grass Biomass Fuels in Vermont:** This report documented densification and combustion testing of solid grass biomass fuels from switchgrass, miscanthus, reed canary grass, mulch hay, and "Ag Biomass"/field residue in the fall of 2015. Research identified finished fuel costs for grass and ag biomass solid fuels in Vermont, combustion efficiency of these fuels in an EvoWorld HC100 Eco commercial boiler, and determined the payback period for both the boiler and the delivered fuel.

Additional Research Projects

- **Energy Return on Energy Invested Research:** Research was conducted by Eric Garza, lecturer at the Rubenstein School for Environment and Natural Resources at the University of Vermont which examined the EROEI of small-scale locally produced biodiesel compared to large industrial scale production systems. Garza reviewed the VBI's farm-based oilseed operations using a life cycle assessment and determined returns of 2.6 to 5.9 with projections to 3.9 to 8.1 based on increases in production.

- **Greenhouse Gas Emissions Research:** Research conducted by Eleanor Campbell examined the GHG impacts of small-scale locally produced biodiesel compared to large industrial-scale production systems. Campbell assessed the carbon equivalent impact of these practices and found that, on average, they achieved net carbon avoidance of 1,984 to 3,227 pounds per acre per year.

- **Renewable Identification Number Research:** An analysis was conducted by Shearwater Energy Partners to explore the feasibility of generating RINs from on-farm biofuels. This investigation explored the economic and practical constraints, and compliance issues associated with small scale biodiesel production and the RINS market. It was determined that this was not an opportunity for Vermont small scale biodiesel producers to explore further at the time. VSJF staff prepared comments that were submitted in April 2013 on Proposed Rulemaking for USEPA 40 CFR Part 80, EPA-HQ-

OAR-2012-0621; FRL-9758-7, RIN 2060-AR72, RFS Renewable Identification Number (RIN) Quality Assurance Program.

- **Legal and Regulatory Overview of On-Farm Biodiesel Production:** This report informs farmers interested in producing biodiesel on their own farm about the potential laws and regulations that may be triggered when adding biodiesel production to their farming activities. While several of the federal regulations are only triggered by high levels of production, there are a number of state laws and regulations that may be triggered by small-scale biodiesel production, such as state air emission provisions that establish lower thresholds when compared to the federal Clean Air Act. In addition, it is critical to understand the role biodiesel production plays in the definition of "farm" and "farming activities" for the purpose of states laws, such as Act 250 and Vermont's Use Value Appraisal Program.

- **Grass Energy in Vermont and the Northeast:** The purpose of this report was to explore whether grass thermal energy can be a viable industry in Vermont. The task included reviewing publications, interviewing people involved in developing aspects of the industry, summarizing the current state of the industry, identifying models for successful projects, and recommending the next steps for moving the industry forward.

LESSONS LEARNED

The VBI pursued a set of ten market development needs for the conversion of oilseed crops, perennial grasses, and algae into bioenergy via sub-recipient awards and staff-directed projects. Over eight years, the VBI yielded many positive results, including new infrastructure and equipment, the steady development of agronomic expertise and technical know-how, and many bioenergy resources used throughout the world, as well as some disappointments.

> **"While the approach supported by VBI funding is somewhat unique to Vermont, the basic fundamentals are applicable anywhere. We focused on the resources we had and the methods that were reasonable for the scale and type of farms in our region, allowed the process to be farmer and user driven, and allocated technical and research resources to support that progress. I think, in a nutshell, that was the project approach and it has resulted in a lasting example of progress in sustainable fuels that will support greater production in the future."**
> **— Chris Callahan, University of Vermont**

The oilseed and biodiesel infrastructure investments of the VBI has supported the development of an overall capacity of 605,000 gallons per year. For a variety of reasons, actual production volumes have remained well below that with each facility generally producing less than 5,000 gallons per year. Crop production challenges such as disease, weather and pest pressure have prevented more wide-spread adoption of crops and ultimately acceptable yields that would support higher volume production.

In 2016, the Vermont Department of Public Service released the Vermont Comprehensive Energy Plan, which calls for obtaining 90% of the state's energy from renewable sources by 2050 and reducing greenhouse gas emissions 50% from a 1990 baseline. The plan calls for major decreases in petroleum use through the electrification of vehicle fleets, wider use of heat pumps, and increased use of bioenergy. The VBI set the stage for increasing the production and consumption of biodiesel and grass/mixed fiber bioheat, but Vermont will have to overcome several obstacles to accomplish that state's long-term energy goals:

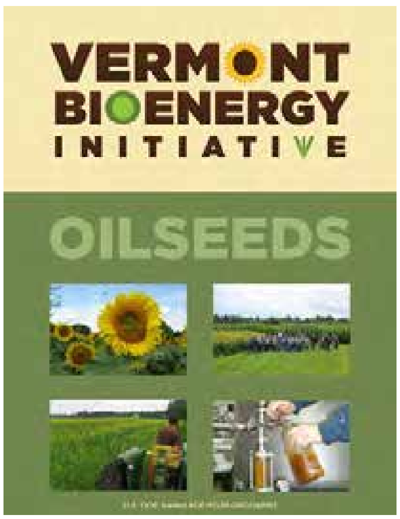
1.) Early adopters are unlikely to be the ones to make the transition to commercialization of new methods and technologies. The skills and attributes necessary for research and development are rarely combined with the necessity of standardization and marketing and a range of risk tolerance is required at different stages of this process. A sustained focus on recruitment, development, and support of new entrants at different stages of commercialization is important to ensure a continuous development trajectory.

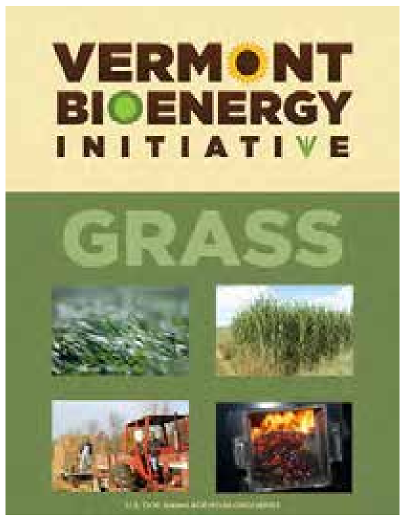
2.) Externalities are significant in the area of bioenergy development. A strong interest in these technologies against a backdrop of high fuel prices is unlikely to be sustained when and if prices drop. A continued focus on future scenario planning may help provide a foundation for planning and adaption that softens the programmatic impact of external factors such as fuel price volatility.

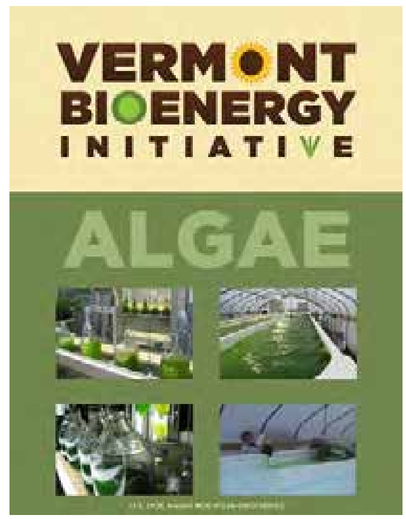
3.) The funding for this project was made possible at a time of Congressionally-Directed Awards. This funding mechanism was instrumental in demonstrating a novel approach to bioenergy systems in Vermont with relevance to rural communities throughout the nation.

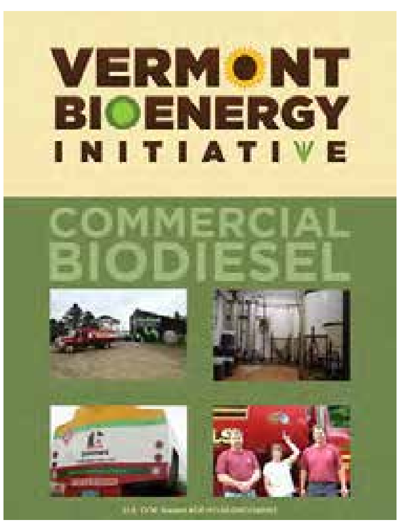
VBI REPORT SECTIONS

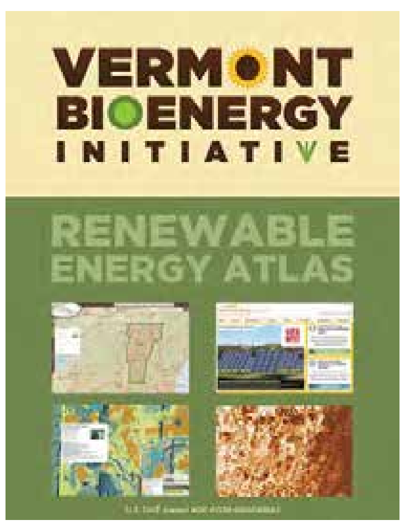
Five subsequent sections of the VBI report summarize in greater detail tasks related to oilseed crop production and conversion into biodiesel; perennial grass production and conversion into heating fuel; algae research; commercial biodiesel blending facilities; and the Renewable Energy Atlas of Vermont (renamed the Community Energy Dashboard in 2016).











VERMONT BIOENERGY INITIATIVE

A program of the Vermont Sustainable Jobs Fund

OILSEEDS

U.S. DOE Award #DE-FG36-08GO88182

ABOUT THE VERMONT BIOENERGY INITIATIVE

The purpose of the **Vermont Bioenergy Initiative** (VBI) was to foster the development of sustainable, distributed, small-scale biodiesel from oilseeds and algae and grass/mixed fiber industries in Vermont that would enable the production and use of bioenergy for local transportation, agricultural, and thermal applications. Our investments in feasibility analyses, research and development, and demonstration projects for various bioenergy feedstocks were intended to lead to their commercialization over 7 year time horizon. This initiative was a statewide market building approach to sustainable development that may be replicated in other rural states around the country.

As a grant-making entity, project manager, and technical assistance provider, the Vermont Sustainable Jobs Fund (VSJF) solicited and selected the best sub-recipient proposals for bioenergy related projects through a competitive Request for Proposal process and conducted a number of staff directed investigations, all designed to support the four key priorities of the U.S. Department of Energy's EERE Strategic Plan:

1.) Dramatically reduce dependence on foreign oil;
2.) Promote the use of diverse, domestic and sustainable energy resources;
3.) Reduce carbon emissions from energy production and consumption;
4.) Establish a domestic bio-industry.

Thank you to the office of U.S. Senator Patrick Leahy for securing three U.S. Department of Energy congressionally directed awards (FY08, FY09, FY10) to financially support the Vermont Bioenergy Initiative.

Learn more at

VERMONT BIOENERGY INITIATIVE

http://vermontbioenergy.com

U.S. DOE Award #DE-FG36-08GO88182

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OILSEEDS SUMMARY

Energy costs are often one of the most significant farm expenses. On farms—where tractors and other engine-powered equipment are common—diesel fuel costs dominate total energy costs. From 1997 to 2012, the amount of money Vermont farmers spent on fuel increased 132%, from $19.7 million to $45.8 million. Fuel expenses increased from 3.5% of total expenses in 1997 to 6.4% of total purchases in 2012.

With support from the Vermont Bioenergy Initiative, Vermont farmers have experimented with producing their own biodiesel made from vegetable oil as a replacement or blended supplement for diesel fuel. **The intent was to replace imported fuel on farms with home-grown fuel.** Although ASTM D6751 quality certification was a goal, since farm use is generally off-road use, this was not an absolute requirement.

The oilseed biodiesel work was accomplished through five main activities:

1) Crop Production and Agronomic Research
2) Crop Processing Research and Development
3) Biodiesel Production Research and Development
4) Integrated Economic, Energy and Environmental Analysis
5) Education and Outreach

These efforts have produced the following results:

Crop Production and Agronomic Research

- Oilseed crops can be successfully grown in the Vermont and the Northeast US. Researchers and growers in Vermont have successfully grown sunflower, canola, winter rapeseed, flax, safflower and camelina. At the height of VBI activities in 2010, about 320 acres were specifically devoted to oilseed crops for biodiesel production.

Sunflowers in bloom at Ekolott Farm in Newbury, Vermont.

- Production guidance from other, high-volume production areas is generally not well-aligned with Vermont's growing region due to soil fertility, pest management and weather differences.
- Researchers in Vermont have compiled and published regionally-specific production guidance based on the crop research done locally.
- Crop production costs are generally stable on a per-acre basis, varying mainly based on management practice.
- Yields are highly variable from year to year with the main depressive pressure being from pests and disease.
- As a result of variable yields, crop production costs on a unit output basis are highly variable.

Crop Processing Research and Development

- Harvester (combine), drying, cleaning, and storing capacity are critical barriers to entry and adoption of oilseeds as a revitalized crop in the Northeast.
- Oilseed presses, though commercially available, are not well specified by manufacturers and require nuanced expertise to operate.
- Researchers in Vermont and Pennsylvania compiled and published oilseed press best practices and reviews to assist with more expedient adoption of the practice.

Bill Mordasky runs Rainbow Valley Farm with his son, Mark, in Orwell, Vermont.

Biodiesel Production Research and Development

- Multiple scales of biodiesel production from seed oil have been demonstrated on farms in Vermont including self-built and commercially available systems.
- The feasibility of mobile seed processing and biodiesel production was explored and summarized in a report.
- Alcohol recovery from the production process has been demonstrated using post-process distillation.
- The use of glycerin as a heating fuel for the biodiesel production process has been demonstrated using a waste oil boiler to make hot water.

John Williamson (Shaftsbury) draws a sample of fuel from a 300-gallon batch of biodiesel made in his self-built processor.

Roger Rainville (Alburgh) uses a 50-gallon Springboard Biodiesel BioPro 190 to make fuel at Borderview Farm.

Integrated Economic, Energy and Environmental Analysis

- Researchers have documented the financial cost of production for various oilseed crops and associated co-products. An associated calculator was developed to allow others to perform early-stage enterprise budgeting and forecasting. A fuel cost of $2.30—2.50 per gallon was estimated based on current practice.
- Researchers have documented the Energy Return on Energy Investment associated with biodiesel production from oilseeds grown on the farm. A net energy return ratio of between 3.6 and 5.9 to 1 was estimated.
- Researchers have documented the net carbon benefit of oilseed-based biodiesel produced on the farm. Net carbon avoidance of 1,984 to 3,227 pounds per acre per year was estimated for sunflowers.
- Renewable Fuel Identification Numbers (RINS) were explored for relevance to on-farm production and deemed difficult to advance due to the scale of production and necessary consolidated record keeping of production and sale.
- A regulatory review of on-farm biodiesel production was conducted by researchers at Vermont Law School which explored a wide range of regulatory hurdles and requirements that farm-based fuel enterprises can face.

Education and Outreach Programming

- A mix of large-group field days, focused grower meetings, and one-on-on direct consulting enabled a diverse set of early adopters to grow and process oilseed crops. **Over 1,300 people attended field days and producer meetings.**
- The Vermont Bioenergy Initiative website serves as a clearinghouse of VBI related information and publications.
- The Bioenergy Now! Video series captures the above work and findings in a viewer-friendly and accessible manner enabling outreach to a broader audience.
- Outputs from research and development efforts have been integrated into undergraduate education programs at the University of Vermont and Vermont Technical College.

- Outputs from research and development efforts have been published as part of the new college textbook, "Bioenergy: Biomass to Biofuels."
- Interest in oilseed-based biodiesel is highly dependent upon the cost of petroleum based fuels.
- Although there is interest in oilseed-based biodiesel among larger, institutional and fleet customers, the cost of fuel and variability of quality is a limiting factor for near-term adoption.

Dr. Heather Darby led crop trials and agronomic studies throughout Vermont. Here, she hosts over 200 farmers at a field day at Borderview Farm in Alburgh.

In summary, oilseed crops can be produced and processed in the region. Even at relatively moderate yields and at small scales of production, farm-based biodiesel enterprises can produce fuel from these crops:

- At a cost of $2.30-2.50 per gallon
- With a net energy return ratio of between 3.6 and 5.9 to 1, and
- With net carbon avoidance of 1,984 to 3,227 pounds per acre per year.

U.S.Senator Patrick Leahy speaks at a gathering of VBI sub-recipients at North Hardwick Dairy.

THE OPPORTUNITY

Vermont consumes the least amount of petroleum of any state in America, but ranks 15th in petroleum consumption on a per capita basis. Liquid fuel consumption in Vermont increased by about 74% from 1960 to 2013. However, Vermonters have reduced total petroleum consumption by about 108 million gallons from the highest year of consumption on record, 2004 (749,868,000 gallons), to 2013 (641,886,000 gallons). Gasoline consumption increased 127% from 1960 to 2013 and is equal to 50% of total petroleum consumption. The majority of the gasoline consumed in Vermont is for transportation (98%). Billions of gallons of ethanol are produced in the U.S. and the **Energy Information Administration reports** that almost all U.S. gasoline is now blended with 10% ethanol. Distillate consumption in Vermont increased 48% from 1960 to 2013 and is equal to 29% of petroleum consumption. About 28% of distillate consumption in Vermont is for transportation, with the rest used for heating.

Energy costs are often one of the most significant farm expenses. On farms—where tractors and other engine-powered equipment are common—diesel fuel costs dominate total energy costs. Vermont farms consume about 6 million gallons of diesel fuel per year. From 1997 to 2012, the amount of money Vermont farmers spent on fuel increased 132%, from $19.7 million to $45.8 million. Fuel expenses increased from 3.5% of total expenses in 1997 to 6.4% of total purchases in 2012.

The VBI marked the first strategic effort to reduce Vermont's dependency on petroleum through the development of homegrown alternatives. With billions of gallons of ethanol produced and blended with gasoline each year—and very little possibility of corn-based ethanol development in Vermont—we focused on a specific subset of bioenergy alternatives. We worked with interested farmers to develop **on-farm oilseed production, processing, and biodiesel production capacity for farm and local community use**, and we worked with researchers to develop the agronomics and economics of oilseed crop and biodiesel production in Vermont.

The model can be summarized as **"local production for local use."** In this case, "local" is really about being local to the farm. The crops, practices, equipment and overall production and processing models were always selected to favor on-farm feasibility. This approach manifests

"When my grandfather came to our farm back in the 1930s he came with horses and he grew oats to feed those horses. Those horses were his power that took him to town and pulled his plow. And now we're growing an oil crop, which is our power. It's just a different time, a different technology, but it's the same thing all over again."

— **John Williamson, State Line Biofuels**

itself in two key ways. First, the scale of the production and processing methods is generally small compared to national-level production plants, but larger than do-it-yourself "home brewers." Secondly, the model supported farm ownership and control of the biomass and bioenergy from planting and harvest of the seed to combustion in the tractor engine. Lastly, the work also sought to fully capitalize on the co-products of the overall process, the meal and glycerin, by demonstrating their on-farm use and value.

Oilseed crops are grown in rotation with grains and grasses and can yield high quantities of oil. These replacement fuels can be produced at lower cost than diesel fuel, depending on crop yield and market price of diesel fuel. Since replacement fuels can be sourced from crops grown on the farm in rotation with other existing crops, biodiesel produced on the farm can result in greater energy security and more predictable costs. Vegetable oil and biodiesel can also be produced with a positive net energy return (meaning more fuel is produced than is used in its manufacture).

Along with high diesel fuel costs, farms also experience high feed and fertilizer costs. The costs of these three inputs are highly correlative. Farms supported by the VBI explored the use of oilseed meal to displace imported feed. Oilseed meal was also trialed as a combustion fuel in pelletized form and as a soil amendment or fertilizer. Use of meal as a fertilizer was especially attractive to organic vegetable growers due to the high nitrogen content.

Oilseed crops provide an alternative means of producing feed, fuel and food in a more local model which can minimize cost and maximize benefit.

Taylor (left) and Nick (right) Meyer in a field of sunflowers at North Hardwick Dairy.

STATEMENT OF PROJECT OBJECTIVES

The Vermont Bioenergy Initiative made a series of grants to sub-recipients for oilseed-based biodiesel that were focused on research and development, systems feasibility, and education and outreach (Task F). The work funded by the VBI in the area of oilseeds has included agronomic research and development, crop processing research and development, fuel production research and development, technical assistance, and education and outreach.

Task F: Oilseed Crops — Feedstock Analysis & Production Techniques

SUB-TASK F.1 AGRONOMICS / RESEARCH

The objective of this sub-task was to provide funding to researchers, entrepreneurs, and farmers to experiment with the development of oilseed feedstocks and companion crops, such as sweet sorghum, that are suitable for Vermont soils and climate. Agronomic research involved replicated field trials and analysis on appropriate varieties (e.g., oil content, sugar content and meal quality), seeding rates, nutrient management, weed, disease, and pest control.

- **University of Vermont Extension's Northwest Crops and Soils Team (Dr. Heather Darby):** The objective of the NWCS Team project was to develop regionally appropriate oilseed crop production guidance for farmer adoption (e.g., crops and varieties, plant density, fertilization, harvesting maturity).
- **Borderview Farm:** The objective of the Borderview farm project was to explore oilseed drying, cleaning and pressing options along with commercially available biodiesel production options for small scale operations. Borderview also hosted farm-level variety trials in addition to the agronomic trials done by UVM Extension NWCS.
- **State Line Biofuels:** The objective of this State Line Biofuels project was to improve operational capacity and efficiency in order to expand the scale of oilseed and biodiesel processing in the Bennington County area.
- **Otter Creek Biodiesel:** The objective of the Otter Creek Biofuels project was to gather comparative agronomic and economic data on organic and conventional methods of oilseed crop production and processing on two Vermont farms at the

partner's farms (Lawes Ag and Wood's Market Garden). In this project the team purchased a new combine, combine head, no-till grain drill, cover crop roller, and an oilseed press.

- **Clear Brook Farm:** The objective of the Clear Brook Farm project was to explore organic production methods for oilseeds and to host farm-level variety trials.
- **Ekolott Farm:** The objective of the Ekolott Farm project was to gather comparative agronomic and economic data on organic and conventional methods of oilseed crop production and processing.
- **North Hardwick Dairy:** The objective of the North Hardwick Dairy project was to research the production and processing of oilseed crops for the dual benefit of making fuel and dairy feed.

SUB-TASK F.2 LOGISTICS / PRODUCTION

The objective of this sub-task was to provide sub-recipient award funding for oilseed crop and sweet sorghum feedstock logistics and production techniques that fit the scale of Vermont farms and communities, including harvesting and drying techniques, pressing, optimal storage, expelling (to optimize oil extraction) and/or pelletization of co-products (oilseed meal).

- **Farm Fresh Fuel:** The objective of the Farm Fresh Fuel project—managed by UVM NWCS and Borderview Farm—was to improve oilseed crop yields through targeted efforts within one Vermont County to increase farmer adoption of oilseed and farm-scale biodiesel production.

SUB-TASK F.3 PROCESSING / CONVERSION / DEMONSTRATION

The objective of this sub-task was to provide sub-recipient award funding for biodiesel conversion, processing, and demonstration projects (e.g., developing small-scale or on-farm facilities for biodiesel and ethanol production).

- **Rainbow Valley Biodiesel:** The objective of the Rainbow Valley Biodiesel project was to increase grain storage and oilseed pressing capacity in order to expand the scale of oilseed production in Addison and Rutland counties.

- **State Line Biofuels:** The objective of the State Line Biofuels project was to explore the feasibility of using a waste oil boiler to burn glycerin as a biodiesel byproduct and heat the production process.

Chris Callahan provides an overview of the biodiesel production process during a field day at Borderview Farm in Alburgh.

TABLE 1: VBI OILSEEDS AND BIODIESEL PROJECTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08-FY10	**University of Vermont Extension:** Crop Production, Agronomic Research, Education and Outreach	$233,512	$77,188	$310,700
FY08-FY10	**Borderview Farm:** Crop Production and Processing, Biodiesel Production	$108,103	$31,998	$140,101
FY08-FY10	**Stateline Biofuels:** Crop Production and Processing, Biodiesel Production	$64,861	$60,340	$125,201
FY08-FY10	**Otter Creek Biofuels:** Crop Production and Processing, Biodiesel Production	$80,000	$107,684	$187,684
FY08-FY09	**Ekolott Farm:** Crop Production and Processing	$49,200	$18,641	$67,841
FY08	**North Hardwick Dairy:** Crop Production and Processing	$13,000	$32,396	$45,396
FY08	**Clearbrook Farm:** Crop Production and Processing	$20,000	$3,700	$23,700
FY08	**Rainbow Valley Biodiesel:** Crop Production and Processing, Biodiesel Production	$65,000	$98,819	$163,819
	SUB-RECIPIENT SUBTOTAL	**$633,676**	**$430,766**	**$1,064,442**
Fiscal Year(s)	**Staff Directed Projects**	**DOE Funds**	**Total Cost Share**	**Total Project Cost**
FY08-FY10	**Chris Callahan:** Technical Assistance/Project Management	$171,694	$36,295	$207,984
FY08	**Chris Callahan:** Mobile Oilseed Unit Cost / Benefit		$20,549	$20,549
FY08	**Eleanor Campbell:** Oilseed to Biodiesel Greenhouse Gas Calculator		$28,050	$28,050
FY08	**Eric Garza:** On-Farm Biodiesel EROEI analysis	$5,063		$5,063
FY08	**Shearwater Energy Partners:** On-Farm Biodiesel RINS analysis	$4,850		$4,850
FY10	**Vermont Law School:** On-Farm Biodiesel Regulatory Review	$25,000		$25,000
	STAFF DIRECTED PROJECTS SUBTOTAL	**$206,607**	**$84,894**	**$291,501**
	TOTAL OILSEED BIOENERGY PROGRAM	**$840,283**	**$515,660**	**$1,355,943**

LOCAL PRODUCTION FOR LOCAL USE

The work of the VBI related to oilseed-based biodiesel was focused on a replacement model for farm diesel. The model can be summarized as "local production for local use." In this case, "local" is really about being local to the farm. The crops, practices, equipment and overall production and processing models were always selected to favor on-farm feasibility. This approach manifests itself in two key ways. First, the scale of the production and processing methods is generally small compared to national-level production plants, but larger than do-it-yourself "home brewers." Secondly, the model supported farm ownership and control of the biomass and bioenergy from planting and harvest of the seed to combustion in the tractor engine. Lastly, the work also sought to fully capitalize on the co-products of the overall process, the meal and glycerin, by demonstrating their on-farm use and value.

Parts of the System

-Seed -Soil Prep. -Fertilizer -Planting -Cultivation -Harvesting -Hauling	-Grain -Cleaning -Grain -Drying -Grain -Storage	-Pressing oil -Primary filtration & settling	-Raw oil storage -Meal storage -Secondary filtration	-Catalyst & alcohol produce biodiesel	-Glycerin settling -Fuel washing -Biodiesel storage & filtration

Equipment Needed

-Tractors -Seed drill -Planter -Cultivator -Sprayer -Combine -Wagons	-Seed cleaner -Grain bin -Drying fan	-Trailer -Truck -Press & filter -Receiving tank -Pump	-Oil storage tanks -Meal bins -Pelletizer -Filters	-Trailer -Truck -Receiving tank -Catalyst tank -Proc. tank	-Settling tank -Proc. tank -Fuel washing equip. -Fuel tank

Crop Production and Agronomic Research

Although the Northeast region of the United States has a history of growing a variety of crops including oilseeds, much of the experience and equipment once used for this purpose is long-gone. The farmer sub-recipients supported by the VBI, and even the agronomic researchers, needed to study-up and tool-up early on to become acquainted with the reintroduced crops. For example, planters and seed drills needed to be modified and small combines needed to be purchased.

Crop production and agronomic research improved current practices for producing oilseed crops in Vermont and New England for use as high protein livestock feed (i.e., oilseed meal), and biodiesel for running farm equipment and heating greenhouses. Currently, oilseeds are primarily produced in the northern and western plains of the country. Most production information available for oilseeds is based on research from these areas, where conditions differ markedly from New England. The climate of New England has more precipitation and humidity,

Jon Satz runs Wood's Market Garden (Otter Creek Biofuels), an organic fruit and vegetable farm in Brandon. He explored oilseeds as a rotational crop with vegetables that can also provide fuel (oil) and fertilizer (meal).

soils are generally more acidic and existing cropping systems are based on hay or corn silage production. Researchers found that standard oilseed agronomic practices needed to be modified for New England. There was a need for more specific agronomic data for oilseeds in New England, specifically with regard to varieties, fertility requirements, plant populations and weed control. At the height of VBI activities in 2010, about 320 acres were specifically devoted to oilseed crops for biodiesel production.

Dr. Heather Darby is an agronomist with UVM Extension where she leads crop production trials each year. She and her team helped to develop regionally appropriate guidance for these crops based on work supported by the VBI.

Variety Trials

Each oilseed crop presents variety options to farmers at the time of seed purchase. While agronomic data generally exists for different varieties of oilseeds, none of it existed for production in the Northeast. In response to this need, University of Vermont Extension Northwest Crops and Soils Team (NWCS) led by Dr. Heather Darby performed multi-year, multi-treatment variety trials at the Borderview Research Farm (Alburgh) along with field locations in other parts of the state. These trials were conducted both at small-scale plot level and at farms growing the crops on a demonstration basis such as State Line Biofuels (Shaftsbury), Rainbow Valley Farm (Orwell), North Hardwick Dairy (North Hardwick), Wood's Market Garden (Brandon), Clear Brook Farm (Shaftsbury), Lawe's Ag (Brandon) and Ekolott Farm (Newbury). Each year, an annual Oilseed Growers Meeting was held to share research and farm production findings and plan for the coming season. Farmers shared challenges they faced and worked with researchers to plan for additional trials.

Organic and Conventional Production Comparison

Several partner farms were interested in exploring organic oilseed production and carried out related farm-based trials with support of UVM Extension. North Hardwick Dairy, Wood's Market Garden, Ekolott Farm, and Clear Brook Farm all explored organic production methods in their sponsored activities.

Fertility Requirements

Another area of difference between the Northeast and other common oilseed production regions turned out to be fertility. The soils in the Northeast are relatively fertile and early crop trials demonstrated "lodging" of sunflower attributed to over fertilizing when following standard fertilizer application guidance from other areas. Lodging results from plants growing very tall and thin and being blown down by wind or simply toppling due to gravity. This impacts the consistency of the crop stand and can result in increased challenges in harvesting. This finding resulted in more focused crop research trials aimed at understanding the impact of fertilizer type and amount on the crops and varieties in question.

Plant Populations

Canola field at Borderview Farm (Alburgh).

Another key agronomic decision related to plant population or density of planting. A higher plant density generally will result in a greater number of smaller plants, while a lower plant density generally will result in a smaller number of larger plants. This is especially evident in sunflowers and can be seen in the size of the sunflower heads which can have a harvesting impact. Plant population studies helped to optimize planting density for Northeast growers and aided in harvest efficiencies as well.

Weed Control

As with most crops, oilseeds benefit from strong control of competitive weeds. Some of the growers supported by the VBI desired organic production and even those not seeking certified organic production aimed to minimize inputs and operations for other reasons (e.g., environmental, philosophical, and economic). As a result, weed control in these crops that

Cover cropping at Wood's Market Garden (Brandon).

were new to the region required research and education as well as some fortunate weather. Generally, a combination of herbicide application and mechanical cultivation (e.g., tine weeding) led to adequate weed control. Cultivation requires cooperative weather leading to proper soil conditions which can be hard to find in the Northeast in the spring. Alternative practices such as tine weeding, cover crop rolling, and no-till planting were explored by partner farms such as Woods' Market Garden and Lawes Ag.

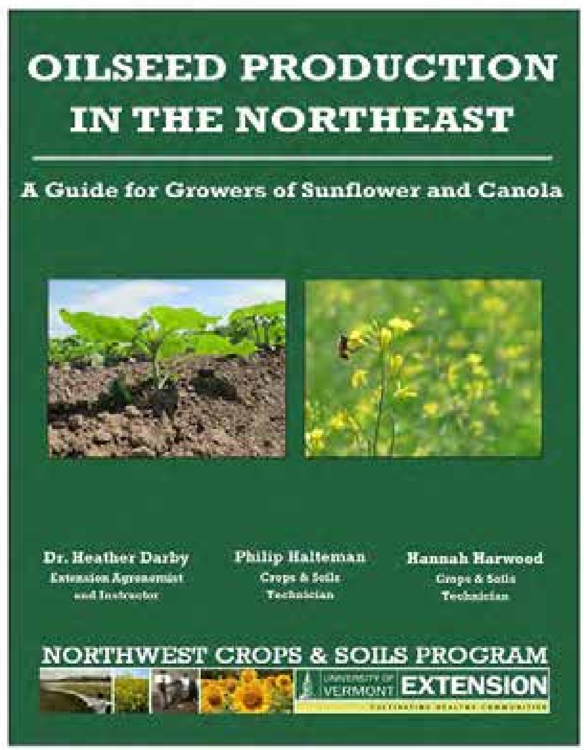
Pest Control

Deer, birds, and bears were continually identified as the main challenges in producing a predictable yield of oilseeds. Deer were to blame for early season loses as seedlings emerged from fall-sown winter canola, or spring sown canola or sunflowers. Crops that survived predation in spring and matured in the fall often faced bird and bear damage. Birds were especially troubling for sunflowers. Some mitigations were trialed including distress calls, visual deterrents, and electric fencing.

Birds in field of sunflowers.

John Williamson surveys a field of sunflowers. On-farm trials were a large part of the VBI funded research into oilseeds. An insect trap is visible in the foreground which helped to quantify the pest pressure in this crop and plan for mitigations.

The overall work of the agronomic production research and development activity has been documented on the [UVM Extension Northwest Crops and Soils Team website](). Additionally, research findings were published in a regionally specific handbook (Darby, Halteman, & Harwood, 2013).



Research findings from the UVM Extension Northwest Crops and Soils Team were published in a regionally specific handbook.

Crop Processing Research and Development

VBI sub-recipient activity also focused on harvesting, handling, and processing of oilseed crops to value-added products. Harvesting small grains is a practice that has history in the region, but not recent history. It was necessary to establish combine capacity for oilseeds and developing an understanding of how to use that capacity effectively. Postharvest handling also required investment in learning and additional infrastructure. Seed dryers and bins were built and installed. Conveyance equipment such as augers and elevators were required.

Harvesting

The harvesting of oilseeds involves combining (combined reaping and threshing) using purpose built machines. These machines were once common in the region when farms harvested seeds for food, feed, or future sowing. However, at the start of the VBI, combines were rare in the region and early effort was needed to procure scale-appropriate machines for use at

A small Massey Harris SP35 combine was resurrected from the hedge row for use by John WIlliamson at State Line Biofuels in Shaftsbury. Jim Williamson (foreground) handles the grain cart while John Williamson combines sunflowers (background).

John Williamson using a "classic" Massey Harris SP35 combine to harvest sunflowers (top) and canola (bottom) early in the days of growing oilseeds at State Line Biofuels.

The VBI supported the joint purchase of a larger scale (and newer) John Deere combine used at State Line Biofuels and Clear Brook Farm in Shaftsbury.

participating farms. Early trials were done using very old and very small machines with the scale and sophistication improving over the years of the project. Additionally, a research scale "plot combine" was purchased by UVM NWCS and used to support their crop trials.

The VBI funded the purchase of three larger scale used combines, one each at Otter Creek Biofuels (Brandon), Ekolott Farm (Newbury) and Clear Brook Farm (Shaftsbury).

Drying, Cleaning, and Storing

Oilseeds benefit from high stability in storage once harvested at maturity and dried to stable storage conditions. The infrastructure required for drying and storing oilseeds was generally lacking in a region most familiar with storing other feeds (e.g., corn silage, haylage, and dry-bailed hay). Early adopters were instrumental in researching, purchasing and demonstrating small grain cleaning, drying and storage systems. Grain bins with false floors were commonly employed, making use of ambient air for low-temperature drying of the oilseeds. Corn driers are not well-suited to this task due to oilseeds being damaged by the high heat their burners generate. Some grantees repurposed existing grain bins while others purchased new bins, allowing for documenting differences in costs and experiences of each practice. One grantee also trialed a solar hot water heated grain dryer funded externally by USDA-REAP (Williamson, Williamson, & Callahan, 2008).

John Williamson checks the performance of a Clipper seed cleaner.

The "Bio Barn" at State Line Biofuels (Shaftsbury) was built "into the hill" to receive oilseeds on the uphill portion and allow the use of gravity as much as possible to flow the seed through the processing. The solar panels in this image were funded separately, but augment the grain drying with low-grade heat.

The VBI supported the construction of a "Bio Building" and a grain drying and storage bin at Borderview Research Farm in Alburgh.

The radiator from a Ford F250 pickup truck was salvaged and attached to the grain drying fan at State Line Biofuels (Shaftsbury) to speed up the drying time of the oilseeds.

The VBI supported the purchase of additional drying bin capacity at Ekolott Farm. Here the bin is shown in mid-winter keeping the harvested and dried crop of sunflower seeds dry and stable.

Pressing

The conversion of oilseeds to meal and oil (as a precursor to biodiesel) requires pressing. This is a mechanical process that applies heat and pressure to burst the seed and split the liquid oil from the solid meal. Generally speaking, there are two categories of oilseed presses with relevance to farm-scale operations; less-expensive ones made for attended operation and more expensive ones made for automated operation. At the start of the VBI there was very little domestic experience with farm-scale presses. Sub-recipients were supported in purchasing different kinds of presses to better understand the pros and cons of each. Borderview Farm purchased a large, attended press from China, while State Line Biofuels purchased an automated press from Sweden, while North Hardwick Dairy purchased a Kern Kraft press from Germany. These early experiences helped to inform future adoption of practices at Rainbow Valley Farm, Ekolott Farm, and Otter Creek Biofuels. Borderview eventually abandoned the attended press for two automated presses used both for fuel production and for research trials.

Borderview Farm originally purchased a large, attended press from China.

Borderview eventually abandoned the attended press for two automated presses used both for fuel production and for research trials.

Oil presses are used to crush the seed and separate oil from the meal. In this picture the oil is seen coming through the wall of the press barrel, seed is coming in from the right via a screw impeller and meal leaves to the left.

Jerrod LaValley demonstrates the Kern Kraft press at Borderview Farm (Alburgh).

Changing screw impellers on the Kern Kraft press at Borderview Farm (Alburgh). Different screws are used for different seeds based on size and hardness.

The positive experiences of John Williamson at State Line Biofuels with this Taby oilseed press informed Larry Scott's decision to install one at Ekolott Farm.

John Williamson cleans up his Taby oilseed press following a day of operation.

An overall evaluation of oilseed presses was conducted in parallel with VBI activity funded by USDA-SARE. A report on this evaluation was published and includes summaries of each press in use and general guidance from operators of those presses to help others accelerate their learning process (Callahan & Harwood, 2013).

Meal Utilization

Uses for oil meal include livestock feed, fertilizer, and as a solid fuel. Oilseed meal, as produced on farms in VBI funded projects remained high in residual fat that made it difficult to use in rumen nutrition (e.g., dairies). Monogastric species such as chickens and pigs are better aligned with oilseed meal as a feed than ruminants such as dairy cows and some sub-recipients have marketed their meal co-product to these other farm customers. In general, the fluctuation of volume and quality of the oilseed meal has limited the access to traditional market channels. Feed dealers need a consistent volume and quality in order to commit to buying the meal. As a result, they

Canola meal as it comes off the oilseed press at Otter Creek Biofuels (Brandon).

tend to depend on regional and national suppliers for their sourcing. Some preliminary work was done to explore the use of oilseed meal as a fertilizer and also as a pelletized fuel for on-farm use. Both Clear Brook Farm (Shaftsbury) and Wood's Market Garden (Brandon) explored the use of meal for fertilizer when other listed organic fertilizers were becoming scare and expensive. Generally, given the nascent nature of these enterprises, the closer to the farm the use was, the more likely it was to be economically feasible. As a result, on-farm uses tended to be favored.

Biodiesel Production Research and Development

Biodiesel Processing Equipment

The conversion of vegetable oil to biodiesel requires heat and chemical inputs (i.e., lye and alcohol). This process is performed in a heated and generally insulated tank. While there are many small-scale options to performing this task, the VBI supported a more rigorous design and evaluation approach to the process. Sub-recipients that had made fuel with less refined designs prior to the VBI were eager to explore improved approaches and systems. State Line Biofuels (Shaftsbury) constructed a 300,000 gal/yr processor using salvaged brewing tanks, dairy piping and an explosion proof pump. Borderview Farm (Alburgh) purchased a "turn-key" processor from SpringBoard Biodiesel called the "BioPro 190" that is capable of producing 14,000 gal/yr.

Roger Rainville (Alburgh) purchased a BioPro 190 biodiesel processor after careful consideration of building his own system. He liked the fact that the machine came all in one piece, "ready to go." Roger also bought a fuel finishing unit (background) that attaches to the BioPro to filter fuel and remove water and glycerin.

Quality Improvement

In addition to fuel processing equipment to enable the primary conversion process, on-farm enterprises also needed post-processing equipment to clean the fuel. This step is often done with water washing in small-scale production, but results in waste water that can have methanol and other contaminants present. The idea of adding water to fuel was also never fully embraced by the farmers in the project. As a result, some VBI sub-recipients received funding support to invest in flow-through cleaning systems that use drying media and ion-exchange media to clean the fuel. These media are replaceable and can be packaged and shipped back to the supplier for proper recharging and disposal.

Chris Callahan and John Williamson explain the nuance of a self-built biodiesel processor at a farmer field day held at State Line Biofuels in Shaftsbury.

John Williamson gives the thumbs-up after checking the settling tank filled with the results of his first "large" batch of fuel (300 gallons) at State Line Biofuels.

Biodiesel storage tanks at State Line Biofuels.

Roger Rainville shows off his methanol recovery system. Removing residual alcohol from the final fuel batch is an important quality hurdle that VBI funding helped to address.

Jerrod LaValley performs a test for water in feedstock oil at Borderview Farm prior to making a batch of fuel. The VBI supported the purchase of simple lab equipment like this to improve fuel quality at the partner farms.

Use of Waste Streams & Co-Products

A guiding principle of VBI oilseed sub-recipients has been to make the most use of the products produced. In the case of oilseed meal, although it is a commodity and is sold in large volumes nationally, local production was of varied quality and volume and its sale into that traditional distribution channel was limited. More often the meal was used on-farm directly to displace imported feed. It was also trialed as a combustion fuel in pelletized form and as a soil amendment or fertilizer. Use of meal as a fertilizer was especially attractive to organic vegetable growers due to the high nitrogen content.

Glycerin from the biodiesel process was trialed as a combustion fuel at State Line Biofuels using a waste oil boiler from EnergyLogic. The boiler was designed to burn waste motor oil, but was shown to be able to burn a mixture of glycerin and biodiesel or 100% glycerin to produce heat for the biodiesel process. Glycerin is separated from biodiesel during the biodiesel production process and accumulates. Again, although it is a commodity valued in some other industries such as soap making and pharmaceuticals, small-scale producers do not produce enough of it at high enough quality to reach those markets.

State Line Biofuels demonstrated a waste oil boiler to heat the biodiesel processor and enable methanol recovery. The waste oil boiler was selected due to the potential to use glycerin, a co-product of the biodiesel process, as a fuel source.

Table 2 summarizes the oilseed processing capacities of VBI sub-recipients.

"There is probably no way I would have built out our BioBarn to the point that it is today, had it not been for the help of the VBI and U.S. DOE. The engineering guidance we received from Chris Callahan in order to make a safe and high quality product and the help from Dr. Heather Darby in growing the best oilseed crop possible was priceless. The collaborations we had with other farmers involved with this same program was also a great help. What I learned mostly through this whole process was the sustainability and fuel independence that we can achieve as farmers. My hope is that the knowledge that I have learned will be carried forward for generations to come." — **Roger Rainville, Borderview Farm**

TABLE 2: OILSEED PROCESSING CAPACITIES

	Storage Bins		Pressing Capacity		Biodiesel Capacity
Site	**Bushel**	**Tons**	**Gallons / Yr**	**Tons / Yr**	**Gallons / Yr**
State Line Biofuels (sunflower)	1,363	22	26,280	183	312,857
Borderview Farm (sunflower)	2,130	34	179,093	1,679	13,036
Ekolott Farm (sunflower)	9,500	152	26,280	183	N/A
North Hardwick Dairy (sunflower)	1,643	26	23,360	219	13,036
Rainbow Valley Farm (soybean)	30,000	900	155,733	2,920	417,133
TOTALS	**44,636**	**1,134**	**371,813**	**5,183**	**756,071**
Totals with 80% uptime	N/A	N/A	297,451	4,146	604,857

Note: The calculations assume 15% oil content for soybeans and 38% for sunflower as well as an oil density of 7.5 pounds per gallon. In most cases the farms would need to purchase additional oil extraction and storage equipment to match their biodiesel production capabilities. These components are modular and can be added in the future as dedicated acreage is secured.

Integrated Economic, Energy and Environmental Analysis

Crop Production Assistance

Crop production assistance was provided through VBI grant-funded support of seed purchases, on-farm consultation, on-farm research and engagement in farmer-to-farmer educational programming. This technical assistance followed the growing and processing cycle each year. In early spring, a grower's meeting was held to share growers' lessons and researchers' findings from the prior year. Often this served as a workshop or seminar where technical assistance providers could deliver formalized content to a larger group followed by a group discussion. Crop and variety selection, as well as production practices, were commonly discussed in an open, sharing environment which allowed reflection on both successes and failures. In-field educational and consulting support was supported by VBI funding through partnership with UVM Extension Northwest Crops and Soils Team. **The Crops and Soils team planned, organized and facilitated the growers' meeting, coordinated a consolidated seed order, led both research trials and on-farm trials, and provided in-field consultation related to disease and pest management as well as production practices.**

Harvest and Postharvest Engineering Support

Technical assistance and facilitated farmer-to-farmer peer support was commonly used to help with adoption of improved harvesting and postharvest process systems. Some of this coordinated support was arranged at the spring grower's meeting. Often it was coordinated directly among growers who lived nearby each other. Sharing of combines, drying bins and grain wagons was common. Agronomic and engineering support was provided with VBI funding through partnership with UVM Extension Northwest Crops and Soils Team and Chris Callahan. The Crops and Soils team provided direct educational and consultation support related to pest and disease management and harvest timing. Callahan provided sizing, design and operational planning support for on-farm infrastructure such as conveyors, driers, cleaners, and storage bins.

Hannah Harwood (University of Vermont Extension) explains the results of crop trials at an annual farmer field day in Alburgh.

Biodiesel Processing Support

Engineering support was a significant part of the technical assistance provided to the farm-based biodiesel operations. Chris Callahan, a consulting engineer (and later as faculty at University of Vermont Extension), was contracted for this support with VBI funds. He provided direct consultation with VBI sub-recipient farms to help them size, design, build and commission processing infrastructure. This support included process design support and equipment selection, failure mode, and effects analyses (FMEA), development of standard operating procedures (SOP's) and general processing support (Callahan & Williamson, 2009). The FMEA and SOPs, in particular, were noted by the farm processors as being particularly helpful. The value of the FMEA was to allow a methodical "walk-through" of the processing system with an eye towards potential component failures. This enabled consideration of mitigations ahead of the first production batch, and helped to establish safety-related best practices that could be transferred from one

Chris Callahan provided technical assistance to VBI sub-recipients.

"The VBI support I received to support grantees with engineering services helped me develop a strong portfolio of work in the field and led to greater engagement in related projects through-out Vermont and the Northeast. The work of the VBI took place in a very dynamic period of fuel prices and still demonstrated strong technical and economic feasibility for the model. UVM Extension programs will continue to pursue research and education activities in these areas due to continued interest from stakeholders."

— Chris Callahan, University of Vermont

farm to the next even when they had very different looking systems. The SOP's were found to be helpful for the growers since they often have many different daily tasks and might make fuel once per month. The SOP's provided an easy reminder of the process and specific steps to take when making a batch and also provided important safety reminders. One grower printed a copy of their SOP's in poster format and mounted it on the wall above their processor. Schematics of the processors were also developed in support of the FMEA and SOP drafting process, and these have been made available on the VBI website along with the other engineering documents.

Mobile Oilseed Processor

The feasibility of a mobile oilseed processor was studied early in the course of VBI with funding support from the High Meadows Fund (Callahan, 2008). This model was explored as an alternative to centralized, stationary processing infrastructure given the geographic distribution of relatively small-volume producers expected in the buildout phase of the initiative. The study demonstrated a path to economic break-even and profitability and supported the feasibility of mobile oilseed processing (cleaning, drying and pressing) as well as mobile biodiesel processing. Since the completion of the study, several mobile biodiesel processors have been developed, though mainly as educational tools.

Community Scale Models and Farm Fresh Fuel

Given the nascent nature of oilseed enterprises, the risk associated with the new ventures and the capital investment required, farmer discussions continually returned to the concept of shared infrastructure and equipment. At several times during the VBI funding period joint ventures of various forms were explored and attempted.

The first consideration of this model was centered around State Line Biofuels in Shaftsbury. State Line Biofuels already had a biodiesel processor in place along with significant seed handling systems (i.e., dryer, bins, cleaner, press). Several farms within a 20 mile radius had expressed interest in growing oilseeds in order to secure their own fuel and meal. This interest was primarily motivated by historically high fuel prices in 2009. The group met several times, facilitated by Chris Callahan with VBI funding support. These meetings helped to clarify what each grower's expectations, capabilities and capacity were. The oilseed cost and profit calculator was used to estimate fuel and meal costs for each participant. General principles of an operational agreement were drafted that would have allowed increased combine capacity as a result of shared investment. In the end, however, fuel prices eased and the real logistical challenges of shared equipment resulted in reduced interest among the group. State Line continued to process seed for the interested farms, but it was done with existing equipment and on a "fee for service" basis. A larger, used combine was also purchased with VBI funds to improve the harvest capacity and efficiency of both State Line Biofuels and Clear Brook farm.

In 2012, another cooperative initiative was explored on the other end of the state. With funding assistance from the VBI, the UVM Extension Northwest Crops and Soils team instituted a pilot program in order to increase the acreage and visibility of oilseed production in a Grand Isle County (Harwood & Darby, 2012). There were existing farms with sunflower production experience and cropping equipment, a biodiesel processing facility at Borderview Farm, and the technical assistance to provide guidance throughout the season. In fact, the Crops and Soils Team conducts the bulk of their research trials at Borderview Farm in Alburgh. Ten growers participated and over 69 acres of land were planted with oilseed sunflowers. Fields were distributed throughout the county, with at least one grower in each town in the county. Growers received seed and technical assistance and were responsible for all of the crop production, record-keeping, and all other

The Farm Fresh Fuel Project explored collective production and processing in Grand Isle County. Ten farms and 69 acres were involved in sunflower production. Farmers received their fuel and meal after processing at Borderview Farm (Alburgh).

Dr. Heather Darby hosts a farmers' meeting for the Farm Fresh Fuel partners at Borderview Farm.

Oil pressed from Farm Fresh Fuel seeds waits to be made into biodiesel at Borderview Farm. Each farm's seed, oil, meal, and fuel were measured and kept separate to ensure they received their correct share in return.

costs associated with growing and harvesting the sunflowers. Some of the 2012 participants were experienced dairy farmers and crop growers; some were homesteaders who had the means to borrow or hire equipment and arrange the logistics of planting and maintaining the crop.

Results in this pilot year were varied. Due in part to the experimental nature of the project, there were some early obstacles and learning curves to overcome. It was difficult to properly time the termination of a previous crop and the establishment of sunflowers, since many farmers and custom operators were busy getting their first cut of hay in and their corn planted at the same time. Operators' planters and sprayers had to be cleaned and calibrated specifically for sunflowers, and the minimal acreage of the Farm Fresh Fuel project made logistics difficult. Fields that were sprayed, adequately fertilized, and planted properly and at the right time yielded much better than others. In addition, fields with wet soil conditions and poor drainage saw yield drags. There were also issues with pest management; deer and birds wreaked havoc in a number of fields.

Overall, the Farm Fresh Fuel Project's first year was a success. Most growers said they wanted to try again the following year, and maybe attempt winter canola as well. However, challenging growing conditions in the second year resulted in a total crop failure.

The key lesson learned from both of these VBI projects was that cooperative initiatives require strong leadership and a central champion who will also ensure necessary actions are taken at the right times. The coordination of crop production on distributed property using a mix of shared and owned equipment in the context of distributed production and centralized processing requires significant organization, oversight and expertise. Successful maturation of such an endeavor also requires supportive external economics. **Even with funding support from the VBI, dramatically reduced petroleum fuel prices led many participants to lose interest. It is likely, however, that fuel prices will rise again and farm-based biodiesel using a shared production model will once again be competitive. The structural learning and capital investment resulting from the VBI in this area will likely be put to use again.**

Education and Outreach

Education and outreach was a continual theme of the VBI. This work was integrated into farmer "field days" and several specific "Oilseed" and "Biodiesel" field days were held to provide focused, hands-on review of the developing practice. The work has also been highlighted in both of the formal undergraduate educational projects delivered by the University of Vermont (UVM) and Vermont Technical College. Project outputs have been posted on a variety of websites for long-term use, including the Vermont Bioenergy Initiative website, the UVM Extension Northwest Crops and Soils Program, and the UVM Extension Ag Engineering website.

Vermont Bioenergy Website

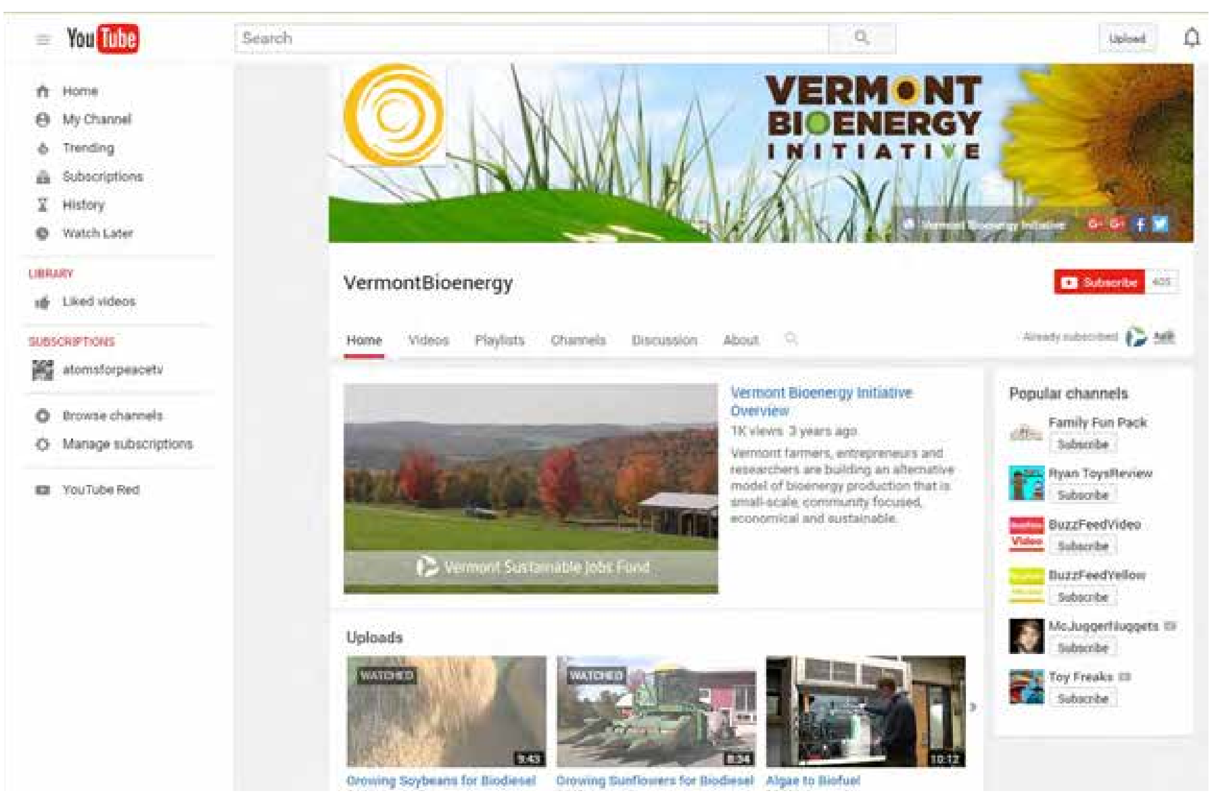
The [Vermont Bioenergy website] was established to serve as a clearinghouse of VBI videos, publications, photos, news items, and resources. It also links reports, calculators, and profiles of projects and grantees.

The Vermont Bioenergy Initiative website is a repository of all materials and resources developed by VSJF and subrecipients.

BioenergyNOW Video Series

The projects and results of the Vermont Bioenergy Initiative were documented in a 10-part video series titled Bioenergy Now! under the direction of Netaka White in 2013. The 2 to 10 minute videos are hosted on a VBI YouTube channel have collectively been viewed over 89,000 times and are promoted via the VBI website, associated social media channels, and through project partners' outreach activities. The video segments include:

- The Vermont Bioenergy Initiative Overview
- Homegrown Fuel and Feed
- Growing Canola for Biodiesel
- Growing Soybeans for Biodiesel
- Growing Sunflowers for Biodiesel
- Oil Crop Pest Pressures
- Oil and Meal Extraction
- Making On-Farm Biodiesel
- Grass Fuel, and
- Algae to Biofuel



One of the annual oilseed producer meetings held at Cedar Circle Farm, Thetford, VT.

On-Farm Field Days (Multiple per Year)

A key component of oilseed outreach and education has been UVM Extension led field days at partner farms. Beginning in 2010, oilseeds were a highlight of the UVM Extension Northwest Crops and Soils Team annual field day at Borderview Farm in Alburgh. Additional field days were hosted at State Line Biofuels (Shaftsbury), Wood's Market Garden (Brandon) and Ekolott Farm (Newbury) to demonstrate specific aspects of those site's operations. These field days allowed for hands-on, direct experience with crops, practices, equipment, and products for those showing interest in the emerging industry. They also served as an important networking and outreach mechanism that helped to expand the reach of the VBI funded research and technical assistance in this area. **Over 1,300 people attended these events.**

Oilseed Growers Meetings (Annual)

In addition to the annual field days, the UVM Extension Northwest Crops and Soils Team facilitated annual meetings of growers actively involved in oilseed crop production. These late winter meetings were held centrally in Berlin or White River Junction each year beginning in 2010. The gatherings served as a chance to share lessons learned from the past year, express challenges and research questions, and to sort out the seed order for the coming year.

Farmer to Farmer Education

A somewhat unintended result of investing in on-farm oilseed and biodiesel facilities has been the development of these farms as peer resources for other interested farmers. State Line Biofuels (Shaftsbury), Borderview Farm (Alburgh) and Ekolott Farm (Newbury) all field inquiries from around the nation and the world related to the work they are doing in this area. These farms host school groups, professional tours, and field days each year that help to educate farmers and the general public about the potential for this unique production model.

Bioenergy Class at UVM & Vermont Tech

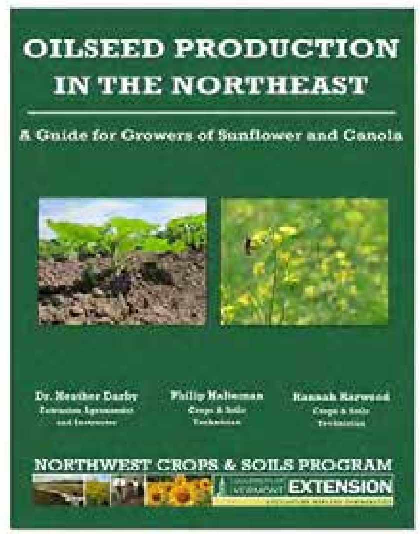
In addition to farmer meetings, field days and direct technical assistance, two other formal educational programs were supported by the VBI to expand availability of bioenergy curricula. Two separate courses were developed by John Todd and Anju Dahiya Krivov at the University of Vermont (UVM) and John Kidder at Vermont Technical College.

This course provided hands-on experience with various types of bioenergy, including liquid biofuels, solid biomass, and biogas. The course provided the participants—including students, farmers, entrepreneurs, and others—with technical exposure to bioenergy topics. The course involved a) on campus classes; b) field work involving tours to farms/bioenergy facilities; c) presentations by bioeenergy experts; d) bioenergy equipment demonstrations by professionals; e) online supplementary classes/information including video clips; f) service learning projects. The course has been offered 3 times. The development of this course, and increased leadership from Anju Dahiya Krivov led to the development and publication of a textbook, ***Bioenergy: Biomass to Biofuels*** (Krivov, 2014).

The Vermont Technical College course, "Biomass to Biofuels" included course material that was introductory and targeted towards individuals who would benefit from knowledge of how biomass resources (wood, grass, crops, etc.) can be converted and used as fuels for heat and power. The target audience was relatively broad and included educators, managers, farmers, public administrators, community groups, workers, or any others who were interested in producing and/or using biomass for energy. The content was technical in nature and highlighted the opportunities and constraints associated with adopting biomass energy technology. The information drew from several existing resources, including reports produced by the Biomass Energy Resource Center, UVM Extension, the U.S. Department of Energy, and other resources.

Publications

Oilseed Production in the Northeast

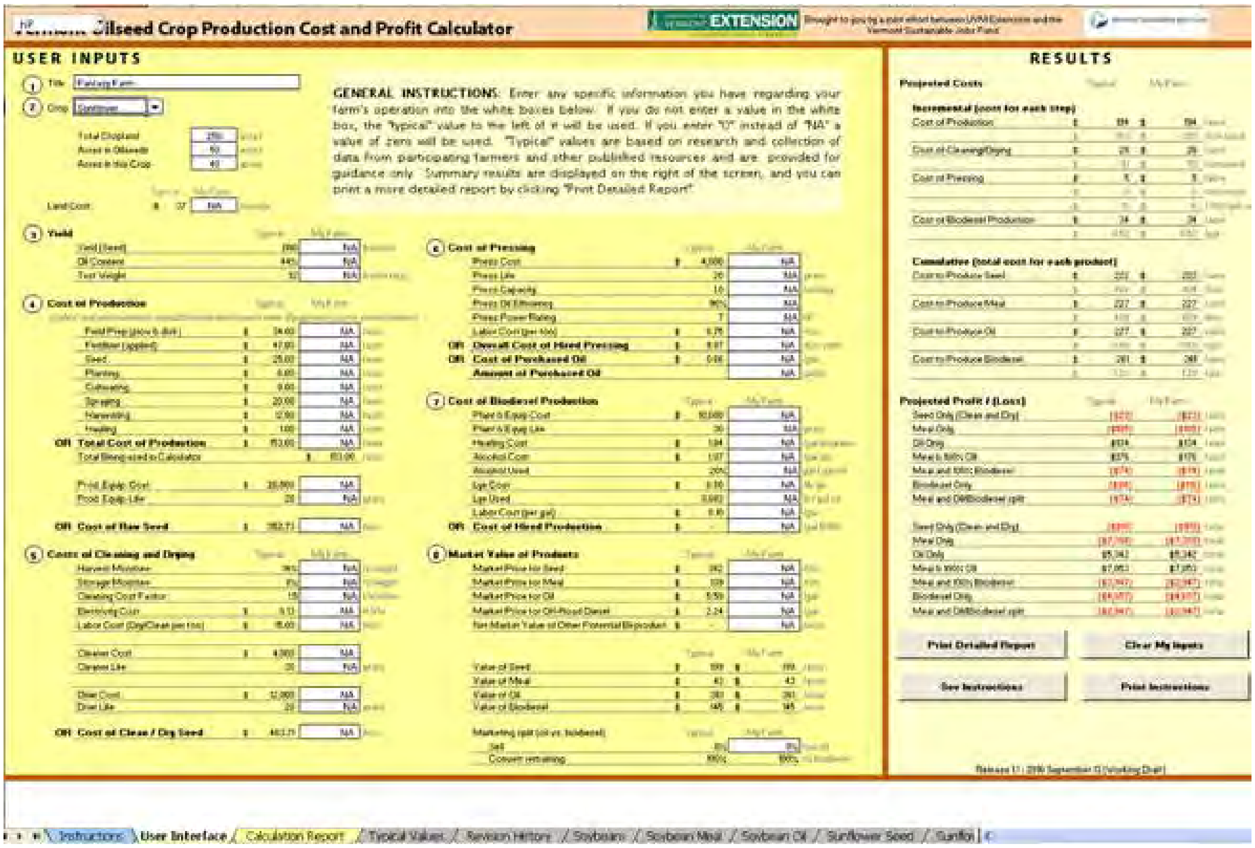


The production of oilseed crops in the region is a relatively new practice and required significant agronomic research. The findings of this research have been delivered through a series of annual meetings and field days and also in the form of a concise production manual. VBI funding, combined with USDA SARE funding, supported the University of Vermont Extension Northwest Crops and Soil Program in the production of a guide that focuses on sunflowers and canola. (Darby et al., 2013). The guide covers crop growth, development, establishment, and production; pest management; harvesting practices; and seed processing and storage.

The University of Vermont Extension Northwest Crops and Soil Program website has become a major resource for all aspects of oilseed crop production and processing. Research results from 2010 to the present are posted on the website.

Oilseed Cost and Profit Calculator

Early in the life of the VBI, a need was noted for an easy, concise calculation of seed, meal, oil and fuel costs based on the unique characteristics of the farm enterprise. A cost of production model was developed and packaged in an easy-to-use Excel format: http://vermontbioenergy.com/oilseed-cost-profit-calculator. This tool—downloaded more than 300 times across the U.S. and other countries, including the Philippines, Germany, and Zambia—enables the

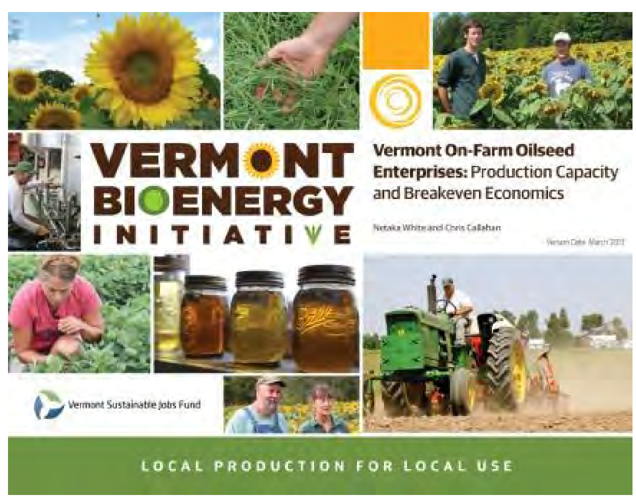


The VBI Oilseed Calculator spreadsheet has been used by people around the world.

calculation of actual unit costs for the primary outputs of the on-farm oilseed enterprises that exist and allows others to assess pro-forma economics using "typical" cost factors included in the input entry page or using parametric sweeps of these parameters (Callahan, 2010).

Oilseed Breakeven Economics Report

To summarize established capacity, document enterprise case studies and demonstrate economic fuel product progress, Netaka White and Chris Callahan prepared a report on VBI associated production capacity and break-even economics in 2012, and updated it in 2013. The findings of this report served as a common message and foundation for outreach and education during the later portion of the funding period. The key



findings noted that even at relatively moderate yields and at small scales of production, farm-based biodiesel enterprises are producing fuel:

- At a cost of $2.30-2.50 per gallon,
- With a net energy return ratio of between 3.6 and 5.9 to 1, and
- With net carbon avoidance of 1,984 to 3,227 pounds per acre per year.

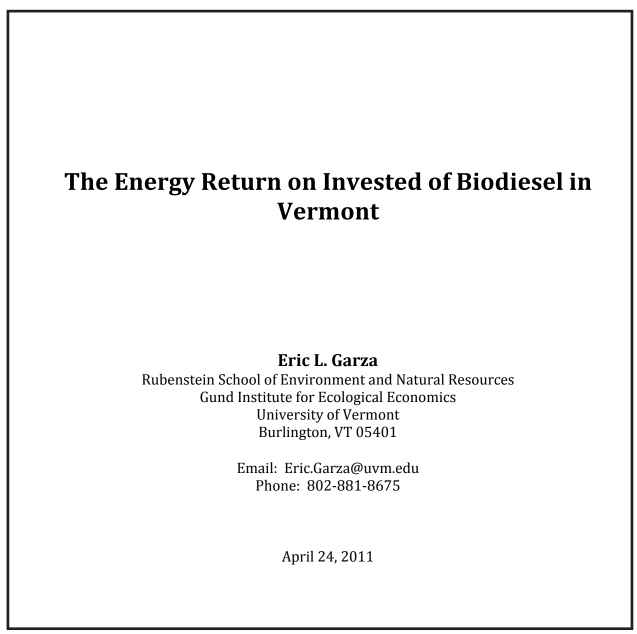
The report explored two scales of production and considered cost of outputs relative to a parametric review of two key parameters: cost per acre of production and yield. (Callahan & White, 2013).

Oilseed Greenhouse Gas Calculator and Report

In addition to financial costs of production and energy return assessments, it was important to determine the net carbon impact of the on-farm oilseed model. Campbell (2009) assessed the carbon equivalent impact of these practices as a graduate thesis and found that, on average, they achieved net carbon avoidance of 1,984 to 3,227 pounds per acre per year (Campbell, 2009).

Oilseed Energy Return on Investment Report

A key question related to the production of biofuels is whether and how well individual pathways deliver net positive energy. The extraction and/or harvesting of feedstocks, their processing and the equipment used in the process all require energy inputs which must be considered when evaluating the fuels. Supported by the VBI, UVM Rubenstein School's Eric Garza reviewed the initiative's farm-based oilseed operations using a life cycle assessment and determined returns of 2.6 to 5.9 with projections to 3.9 to 8.1 based on increases in production (Garza, 2011).



The Energy Return on Invested of Biodiesel in Vermont

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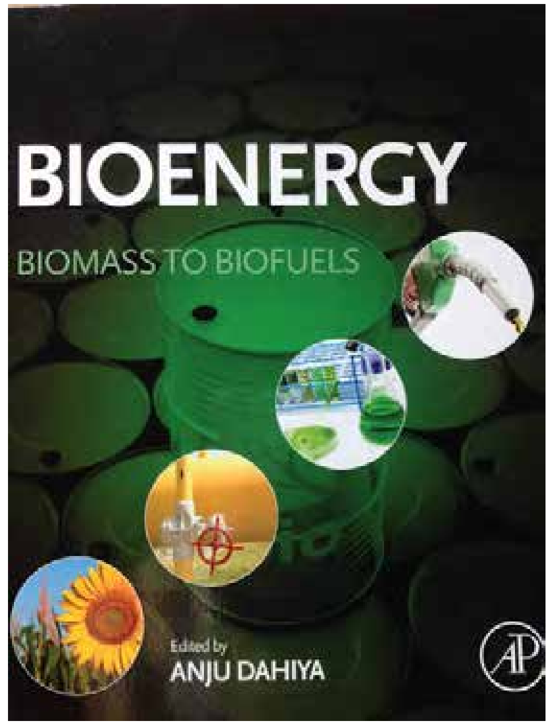
April 24, 2011

Bioenergy Textbook

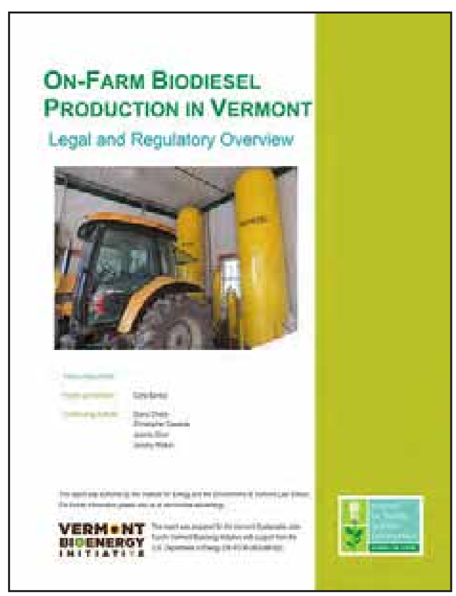
Several VBI supported researchers and educators contributed to the development of a bioenergy textbook led by Anju Dahiya Krivov and resulting in the publication of ***Bioenergy: Biomass to Biofuels*** (Krivov, 2014). The textbook examines current and emerging feedstocks and advanced processes and technologies enabling the development of all possible alternative energy sources: solid (wood energy, grass energy, and other biomass), liquid (biodiesel, algae biofuel, ethanol), and gaseous/electric (biogas, syngas, bioelectricity). Divided into seven parts, Bioenergy gives thorough consideration to topics such as feedstocks, biomass production and utilization, life cycle analysis, Energy Return on Invested (EROI), integrated sustainability assessments, conversions technologies, biofuels economics and policy. In addition, contributions from leading industry professionals and academics, augmented by related service-learning case studies and quizzes, provide readers with a comprehensive resource that connect theory to real-world implementation.



Dr. Krivov edited a Bioenergy textbook.

VT Biofuels Regulatory Review

The development of on-farm biodiesel systems among VBI sub-recipients helped to better articulate regulatory concerns across a number of areas (e.g., siting, environmental, land use, taxation.) In 2015, the VBI initiated a regulatory review by the Vermont Law School Institute for Energy and the Environment (Santos, Chace, Cavaiola, Oliver, & Walker, 2016).



NEXT STEPS

The oilseed and biodiesel infrastructure investments of the VBI has supported the development of an overall capacity of 605,000 gallons per year. For a variety of reasons, actual production volumes have remained well below that with each facility generally producing less than 5,000 gallons per year. Crop production challenges such as disease, weather and pest pressure have prevented more wide-spread adoption of crops and ultimately acceptable yields that would support higher volume production.

Although dips in petroleum prices have made the economics of biodiesel production in Vermont less attractive, the state still has the opportunity to expand the production and use of agriculturally derived bioenergy products to heat homes, offices, and commercial spaces, and for use in transportation and on farms. During the past 15 years, many Vermonters have worked to introduce liquid bioenergy products and develop viable production systems that foster the emergence of new bioenergy technologies and markets. Many of these projects remain active because farmers are interested in environmental sustainability, energy independence, and building capacity for a time when diesel prices may rise.

New private sector oilseed and bioenergy developments have benefited from the work of the VBI. Full Sun Oil Company is a startup venture in Middlebury that is producing high quality culinary oils centered around regionally and locally sourced oilseeds. The company also has long-range plans related to biofuel production via a closed loop supply chain model. Additionally, Green Mountain Power, the state's largest utility, has expressed interest in increasingly fueling their truck fleet with sustainably sourced liquid fuels. They contracted with two VBI grantees to grow sunflowers for making biodiesel in 2015 as a small pilot project and remain interested in the longer term potential of this model.

"Who knew?! That in Vermont you could power up your 180 HP tractor, feed the animals, dress your salad, reduce CO_2 emissions and save money with just a couple small fields of sunflowers?"

— Netaka White, Vermont Sustainable Jobs Fund

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VERMONT BIOENERGY INITIATIVE

A program of the Vermont Sustainable Jobs Fund

GRASS

U.S. DOE Award #DE-FG36-08GO88182

ABOUT THE VERMONT BIOENERGY INITIATIVE

The purpose of the **Vermont Bioenergy Initiative** (VBI) was to foster the development of sustainable, distributed, small-scale biodiesel and grass/mixed fiber industries in Vermont that would enable the production and use of bioenergy for local transportation, agricultural, and thermal applications. Our investments in feasibility analyses, research and development, and demonstration projects for various bioenergy feedstocks were intended to lead to their commercialization over 7 year time horizon. This initiative was a statewide market building approach to sustainable development that may be replicable in other rural states around the country.

As a grant-making entity, project manager, and technical assistance provider, the Vermont Sustainable Jobs Fund (VSJF) solicited and selected the best sub-recipient proposals for bioenergy related projects through a competitive Request for Proposal process and conducted a number of staff directed investigations, all designed to support the four key priorities of the U.S. Department of Energy's EERE Strategic Plan:

1.) Dramatically reduce dependence on foreign oil;
2.) Promote the use of diverse, domestic and sustainable energy resources;
3.) Reduce carbon emissions from energy production and consumption;
4.) Establish a domestic bio-industry.

Thank you to the office of U.S. Senator Patrick Leahy for securing three U.S. Department of Energy congressionally directed awards (FY08, FY09, FY10) to financially support the Vermont Bioenergy Initiative.

Learn more at

VERMONT BIOENERGY INITIATIVE

http://vermontbioenergy.com

U.S. DOE Award #DE-FG36-08GO88182

TABLE OF CONTENTS

GRASS SUMMARY

Vermont's long winters have meant that about 75% of all households use fossil fuels for heating and energy costs are often one of the most significant expenses for farms. Motivated by high heating fuel costs and the opportunity to replace fossil fuels with bioenergy, Vermont researchers and farmers have experimented with solid combustion fuels made from densified grass and agricultural residue with support from the Vermont Bioenergy Initiative (VBI).

A guiding principle of the VBI has been, "local production for local use." The intent was to put control of energy sources in the hands of producers and consumers within the region. In the case of grass biomass, this meant focusing on how to produce the crops, how to process them into a form appropriate for current commercial boilers and furnaces, and assessing the model against other alternatives such as wood pellets and chips.

This grass bioenergy development effort was accomplished through four main activities:

1) Crop Production and Agronomic Research
2) Densification and Transportation Research and Development
3) Thermal Conversion and Economic Feasibility Research
4) Education and Outreach

These efforts have produced the following findings:

Crop Production and Agronomic Research

- Grass biomass crops trials have demonstrated 3 to 6 tons per acre yields with annual production costs averaged over 10 years—including prorated establishment costs of $250 to $300 per acre per year—resulting in farm gate biomass costs of $50 to $80 per ton depending on annual biomass yield.
- The key factors supporting success of grass biomass crops in the region are species and variety selection, soil fertility, and successful establishment including weed management, and soil productivity class.
- Grass biomass crops are aligned with the region's historical production and use of hay and other grass forages.
- Grass biomass crops can be harvested using equipment that already exists in the region.

Switchgrass at harvest, Meach Cove Farm (Shelburne, Vermont), 2012.

Densification and Transportation Research and Development

- Grass biomass crops can be densified in forms more suitable for storage, transportation, delivery and combustion in appropriately-sized heating appliances for on-farm heating at a conversion cost of $49 to $148 per ton.

- Grass biomass fuels can be delivered with production cost of $85 to $228 per ton ($5.2 to $14.4 per million BTU inclusive of crop production and densification costs).

Renewable Energy Resources grass puck.

Thermal Conversion and Economic Feasibility Research

- Grass biomass fuels can be combusted in small commercial boilers intended for wood chips with a 3 to 5 year simple payback period and emissions comparable to wood pellets.

- Recent advances in boiler design such as improved combustion air controls and automated ash removal have helped address earlier issues with the use of these newer, high-ash fuels.

Heating with grass pellets in a Bio-Burner, (Brandon, Vermont) 2011.

Educational and Outreach

- A **Grass Energy Symposium** held in 2008 featured many industry experts on topics such as growing and harvesting, processing and pelletizing, and the state of combustion technology.
- Several specific "Grass Energy" field days were held to provide focused, hands-on review of the developing practice. This work was also integrated into other farmer "field days."
- The results of our research and demonstration projects have also been highlighted in undergraduate bioenergy survey courses at the University of Vermont (UVM) and Vermont Technical College.
- Project outputs have been posted on a variety of websites for longer-term use, including the **Vermont Bioenergy Initiative website**, the **UVM Grass Biomass Energy website**, and the **UVM Extension Ag Engineering website**.

Grass energy field day at Vermont Technical College (Randolph, VT).

THE OPPORTUNITY

According to the Vermont Department of Public Service (DPS), heating fuels that are not regulated—such as fuel oil, kerosene, propane, and wood (biomass)—account for 27% of Vermont's total energy demand, 27% of the state's greenhouse gas emissions, and 82% of Vermont's space-heating and industrial process heat requirements. The residential sector accounts for 65% of unregulated fuel consumption, nearly double the combined usage of the commercial (21%) and industrial (14%) sectors. About 72% of distillate consumption in Vermont is for heating applications. The DPS reports that all uses of wood for fuel (e.g., cords, pellets) in 2009 totaled 1.5 million tons. Over the past 50 years, liquefied petroleum gas (LPG) consumption has increased over 492%, from 5% to 16% of total petroleum consumption. Natural gas consumption in Vermont has increased 822% from 1966 to 2012 (Vermont DPS).

The federal government and the state of Vermont have set goals of displacing current non-renewable energy sources with renewable sources including solar, wind, hydroelectric, and biomass energy. Bioenergy can be used anywhere space heating (e.g., greenhouses) and water heating (e.g., maple syrup evaporators) is currently done with fossil fuels. Wood is a major source of biomass energy in Vermont due to the large area of landmass covered in forest (78%). Thousands of acres of former farmland is either unused or underutilized and this could potentially be used for growing herbaceous biomass crops such as perennial grasses. Additionally, the use of grass biomass buffer strips at field edges and near waterways could help to improve water quality.

The major barriers for utilizing grass biomass have been the lack of infrastructure, combustion technology, and economic incentive for biomass production and conversion. Prior to VBI's R&D investigations, there had been little information on grass production for biomass purposes in Vermont, including suitable species and cultivars, agronomic practices, and economic viability. The goal of this part of the VBI project was to assess potential grasses and evaluate potential economic viability of direct combustion grass energy systems for Vermont and the Northeast region.

The VBI funded research, development, and demonstration of densified grass fuels for thermal conversion through a combination of experimental field trials, development of densification machinery, combustion trials, and an economic review. These activities have led to a greater understanding of this alternative fuel which has strong relevance and potential in the region. The underlying motivation for this work is the prospect of lower cost fuels for space heating and potentially for electricity production via cogeneration plants.

There are many advantages for utilizing perennial grasses for biomass feedstock, especially when utilized for direct combustion. Vermont is well-suited for growing perennial grasses that can be grown on marginal ground not suited for major crops (Bosworth, S., 2013c). In most cases, the grasses harvested for biomass use the same equipment as for making hay, which are readily available in Vermont. Direct combustion of a densified grass product is the most energy efficient utilization of grass feedstock as a biomass fuel and probably most relevant to Vermont.

Direct combustion grass biomass systems offer many environmental benefits. Firstly, the grass species of interest will grow on marginal soils not suited for crop production; therefore, they should not interfere with existing food or feed production. Secondly, the energy output per input ratio for grass biomass direct combustion systems are quite high, therefore it takes far less energy to produce a unit of energy from a direct combustion grass system than other comparable cellulosic liquid fuel systems. Thirdly, thermal uses of perennial grass biomass feedstock are nearly greenhouse gas neutral with CO_2 released during harvest, processing and combustion closely balanced with CO_2 uptake during plant growth. Fourthly, since grass biomass is only harvested once a year and late in the season, it is very compatible with wildlife enhancement efforts, particularly with grassland birds. Finally, perennial grass sod protects the soil from erosion and reduces sediment and nutrient runoff.

At the same time, there are potential negative effects that must be addressed. There is a higher risk of increased particulate matter (PM), NO_x, and SO_2 emission levels with grass pellets and pucks compared to wood pellets; therefore, crop practices that reduce nitrogen and sulfur uptake by the grass plants, as well as properly designed furnaces with enhanced combustion air control and emissions control systems, will be important to minimize these risks. Most grass fuel trials have also noted higher ash levels and higher levels of halogens (e.g., chlorine), which can accelerate corrosion of boiler or furnace parts. In addition, when evaluating potential species for biomass production, it is always critical to assess the risks of their ability to escape and spread across a wide range of environments becoming invasive species.

STATEMENT OF PROJECT OBJECTIVES

The Vermont Sustainable Jobs Fund, through its Vermont Bioenergy Initiative, made a series of grants to sub-recipients in the area of grass bioenergy focused on research and development, systems feasibility, and education and outreach. A number of staff directed projects were undertaken when needed in order to advance the research in this area (e.g., stack air emissions testing, bulk wood pellet delivery options, and a literature review of grass energy opportunities in the Northeast, and an economic and fuel comparison analysis).

To address the question of grass biomass as a viable option for Vermont, this project pursued four objectives:

1) **Crop Production and Agronomic Research:** To develop perennial grass biomass production and management recommendations through field research that addresses basic questions pertaining to species and cultivar selection, fertility management, and harvest management.

2) **Densification and Transportation Research and Development:** To demonstrate grass biomass post-harvest processing and transportation techniques on farms to evaluate the practical adaptation and economic viability of this technology.

3) **Thermal Conversion and Economic Feasibility Research:** To demonstrate technical and economic feasibility of solid grass biomass fuels for farm-scale use.

4) **Education and Outreach:** To provide education, outreach, network development, and technical assistance to farmers, land owners, agricultural service providers, and policymakers on the potential of grass bioenergy in Vermont and the New England region.

Task E: Biomass — Feedstock Analysis & Production Techniques

SUB-TASK E.1: AGRONOMICS / RESEARCH

The objective of this task was to provide sub-recipient award funding to researchers, entrepreneurs, and farmers to experiment with the development of perennial grass and biomass feedstocks that are suitable for Vermont soils and climate (Table 1). Agronomic research for biomass crops involved replicated field trials and analysis on appropriate varieties (e.g., yield, vigor, ash content), soil impacts, seeding rates, nutrient management, weed, disease, and pest control. Research reviewed grass varieties that can be pelletized or potentially used for cellulosic ethanol production. Research also evaluated cost and reliability of supply, potential volume available, and distribution considerations.

Sub-Recipients:

- **University of Vermont Extension:** The objective of this project was to develop perennial grass biomass production and management recommendations for farmers through research with the goal of expanding grass biomass production in Vermont. In addition, UVM Extension held "field days" at demonstration farms to share best practices with farmers for perennial grass crop varieties, cultivation, harvesting, drying, and processing.

Staff Directed Projects:

- **Wilson Engineering:** The objective of this contract was to review the state of the science of grass energy and provide recommendations for how best to advance grass bioenergy adoption in Vermont and the Northeast.

- **Grass Energy Symposium:** VSJF worked with many partners—the Vermont Grass Energy Partnership—to hold a Grass Energy Symposium in 2008.

- **University of Vermont Extension Agricultural Engineering—Chris Callahan:** Chris Callahan provided technical assistance to grass densification, combustion and system integration activities (Renewable Energy Resources and Meach Cove), site specific technical support forboiler installation and demonstrating project (VFFC) and integrated economic and fuel comparison analysis.

SUB-TASK E.2: LOGISTICS / PRODUCTION

The objective of this task was to provide sub-recipient award funding to find new methods for optimizing production processes, including harvesting and drying techniques, optimal storage moisture and managing ash content. Logistics trials included fiber processing and pellet production testing (e.g., grass and grass-wood combinations) using stationary and mobile equipment; and identification of appropriate fiber processing and pelletizing machinery to meet the needs of a single farm, group of farms, or a surrounding community.

Sub-Recipients:

- **Renewable Energy Resources:** The objective of this project was to purchase, build, and modify machinery to make fuel "pucks" from several biomass feedstocks.

Staff Directed Projects:

- **Biomass Commodities Corp:** The objective of this project was to perform early stage grass pellet combustion and emissions testing at Meach Cove.
- **Bulk Biomass Fuel Pellet Delivery Systems:** lead to the development of improved methods and practices for the handling, delivery, storage and use of bulk biomass fuel pellets.
- **University of Vermont Agricultural Engineering—Chris Callahan:** heating and boiler feed testing

SUB-TASK E.3 PROCESSING / DEMONSTRATION

The objective is this task was to provide sub-recipient award funding for demonstration projects (e.g., analysis of grass pellet heating plant in a small commercial business).

Sub-Recipients:

- **Vermont Farmers Food Center:** The objective of this project was to test the burning of densified grass biomass in an EvoWorld HC100 ECO, 350,000 BTU/hr biomass boiler. Boiler settings and combustion results from three fuels was documented and reported.

TABLE 1: VBI GRASS BIOENERGY SUB-RECIPIENTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08-FY10	**University of Vermont Extension:** Crop Production, Agronomic Research, Education and Outreach	$151,080	$40,933	$192,013
FY09-FY10	**Renewable Energy Resources:** Densification and Transportation	$117,104	$120,606	$237,710
FY10	**Vermont Farmers Food Center:** Thermal Conversion and Economic Feasibility Research	$41,000	$78,481	$119,481
	SUB-RECIPIENT SUBTOTAL	**$309,184**	**$240,020**	**$549,204**
Fiscal Year(s)	**Staff Directed Projects**	**DOE Funds**	**Total Cost Share**	**Total Project Cost**
FY08-FY10	**Chris Callahan:** Technical Assistance/Project Management	$1,458		$1,458
FY08	**Biomass Commodities Corp and VSJF:** Air Emission Profile Testing	$22,468		$22,468
FY08	**VSJF and Partners:** Grass Energy Symposium	$7,290	$1,086	$8,376
FY09	Bulk Wood Pellet Delivery Investigation (see page 113)	$50,000	$29,194	$79,194
FY10	**Wilson Engineering:** Grass Energy in Vermont and the Northeast report	$17,640		$17,640
	SUB-RECIPIENT SUBTOTAL	**$98,856**	**$30,280**	**$129,136**
	TASK TOTAL	**$408,040**	**$270,300**	**$678,340**

Crop Production and Agronomic Research

University of Vermont Extension Agronomist Dr. Sid Bosworth was funded to conduct perennial grass crops trials (switchgrass and reed canary grass) on numerous Vermont farms in order to gather information on the productivity and costs of establishing, growing, harvesting, transporting, pelletizing, and marketing pellets for heating applications (Bosworth, S., 2015). Because of the abundance of both grass and woody biomass in Vermont, interest is mounting in developing a process that could combine both feedstocks into a mixed-fiber pellet or "puck."

Vermont agriculture has historically focused on dairy production, so farmers have both the infrastructure and knowledge for growing grass hay. The equipment and management skills required for producing grass biomass are somewhat similar as that for producing grasses for livestock. Vermont has an estimated 150,000 to 200,000 acres of unused or underutilized agricultural land, much of which is already growing grass. Grass bioenergy production does not

Dr. Sid Bosworth, UVM Extension, led perennial grass crop trials and farm "field days."

need to divert any of the current agricultural productivity into the energy market. In addition, this potential biomass industry can be completely independent from, but complimentary to, the production of food or animal feed.

Switchgrass at Borderview Farm (Alburgh, Vermont).

Among grass species, warm season grasses such as switchgrass are considered most suitable for grass biomass because of their long-term persistence, high yields, and inherently lower ash content (which affects efficiency of energy utilization). However, the predominant grasses grown in Vermont are cool season grasses which are generally higher in feed quality than warm season grasses and are better suited to New England's traditionally long winters and cold climate. Most of the cool season species have a lower yield potential and higher ash content than warm season grasses like switchgrass. The long-term goal for grass biomass energy production in the Northeast should be to establish acres of warm season grass species.

One of the major challenges of using warm season grasses such as switchgrass is the relatively high establishment costs due to high seed costs and slow establishment rates. Under good conditions, it can take three years to obtain full and optimally producing stands. This could be an economic barrier to the adoption of these species for biomass use in Vermont until better practices are developed.

Between 2009 and 2013, Dr. Bosworth established and maintained eleven field trials and/or demonstration plots in five locations within Vermont on a diversity of soils and in different micro-climates and landscape conditions. Germination and vigor trials helped to identify cultivars with promising performance (Bosworth, S., 2013a). Replicated field trials focused on grass species and cultivar evaluation, switchgrass establishment practices, and nitrogen fertility and harvest management. These were considered the most important factors in affecting grass biomass feedstock production (Bosworth, S., 2013b). Data collected included multi-year measurements of dry matter yield, fuel quality (e.g., ash, nitrogen, potassium, sulfur, and chloride), and stand persistence. In selected years, Dr. Bosworth also collected

Switchgrass at Meach CoveFarm (Shelburne, Vermont).

data on mineral uptake, grass phenology, and disease observations. Results of the studies were published in detailed reports and posted on a dedicated website – **http://pss.uvm.edu/grassenergy**.

Bosworth also established demonstration sites with three partners. At Borderview Farm in Alburgh, VT, a quarter acre area of 'Cave N Rock' switchgrass located at a marginal edge of a crop field was established. For two years, he was able to measure yield and estimate field losses after harvest of the site. The feedstock harvested from the field was also used for an on-farm pelleting study assessing the feasibility of using small pellet mills for densifying and burning switchgrass biomass at the "farm level." At Meach Cove Farms in Shelburne, VT, Bosworth established a one-acre field of 'Cave N Rock' switchgrass to be used for a source of feedstock for a biomass burner project that the farm operated. At the Corothers site in New Haven, VT, the team conducted a harvest demonstration on a four acre switchgrass field comparing the yield and fuel quality of a fall harvest to a spring harvest. The results of these crop trials were used to develop crop budgets and a cost estimator tool (Bosworth, 2009).

After four to five years of collecting yield data on each grass species and conducting cultivar evaluation at each location, Bosworth concluded that many grasses including switchgrass, big bluestem, giant miscanthus, and reed canarygrass are suitable for biomass production in Vermont. Overall, adapted cultivars of switchgrass provided the most reliable yields across all locations. The production potential of adapted cultivars can potentially reach 4 to 6 tons per acre per year once the stand is fully established. Fuel quality (ash content and minerals) of warm season grasses can be acceptable if soil nutrients are kept at a low to moderate level and harvests are made at the proper time. Nutrient removal is relatively low for these species; however, over time, soil nutrients will need to be replaced to assure adequate yields. Giant miscanthus provided the highest yield in two of the three locations and could be a potential biomass crop in the Champlain Valley. It did not over winter well at the higher elevation site in Randolph, VT.

Soil nitrogen (N) fertility is a key factor that affects grass biomass production and stand sustainability. A three-year trial was initiated at two sites to assess the response of a mature stand of switchgrass yield, fuel quality, and nutrient removal rates to nitrogen fertilization.

Tetting switchgrass, fall harvest, Meach Cove Farm (Shelburne, Vermont).

Based on these studies, an application of 50 to 75 lbs of N per acre per year, starting when the stand is about four to five years old, could increase yields by about 1.5 to two tons per acre. Applying nitrogen to a stand three years old or younger is likely to be uneconomical. N fertility did not seem to affect ash content.

One of the major challenges of switchgrass is its slowness to establish. This can be a serious challenge for switchgrass since an important aspect for the success of introducing a new and unfamiliar grass to farmers is the ease to which the crop establishes. In this project, two studies were conducted to evaluate the effects of differences in cultivars and seed dormancy on the establishment of switchgrass and test a "vigor test" method of evaluating seed quality in order to adjust for seeding rate. Bosworth's studies found that a seeding rate of 8 to 10 pounds per acre of switchgrass (accounting for both % germination and % dormant seed found on the seed tag) seems adequate to achieve a productive stand.

The production of perennial grasses for biomass is not a high return crop. Keeping input costs to a minimum but also assuring optimum yields will be a key to a viable production system. **VBI researchers concluded that a minimum of five tons per acre was critical to achieve a breakeven on establishment, maintenance and harvest costs depending on feedstock values.**

In conclusion, establishing, growing and harvesting grasses for biomass feedstock should not be a major barrier to the adaption of this technology in Vermont; however, efficient methods of densification and the ability of boiler systems to handle a wide range of fuel characteristics need to be further evaluated.

"We now have a better understanding of which grass species are best suited for biomass production grown across a range of soil and site conditions in Vermont. We have a better understanding of the best management practices for establishing, growing and harvesting this type of feedstock when used for thermal energy. This will give us better information for developing economic models that will help land owners make decisions about land use choices."

—Dr. Sid Bosworth, University of Vermont Extension

Densification and Transportation Research and Development

The effective use of grass as a thermal conversion fuel requires not only crop production expertise, but also post-harvest handling processes. Typical biomass fuel densification follows one of two paths: baling or pelletizing. Baling is generally used when the conversion appliance (i.e., a boiler or furnace) is large with a higher output rating. These systems include specialized conveyance and combustion systems to handle the form of the fuel. On the other end of the fuel density spectrum, pellets are a small, flowable form of biomass that can be used in a wide range of appliances.

Several firms in the Northeast have successfully pelletized grass feedstocks in a form similar to wood pellets. While this fuel form is widely applicable to a broad market due to its feasible use in many appliances, the feedstock processing systems have generally been found to be costly and energetically intense leading to costs comparable with wood pellets (Cherney and Paddock, 2014). Meanwhile, the use of bulk, coarse non-densified feedstocks (i.e., chips, loose biomass) or baled fuels has generally been found to be feasible only for larger, centralized systems.

Adam Dantzscher, Renewable Energy Resources, shows Christy Sterner (Technology Manager, Bioenergy Technologies Office, U.S. Department of Energy) how ag biomass is chopped prior to being densified, with Tom Berry from U.S. Senator Patrick Leahy's office in foreground, at Meach Cove Farm (Shelburne, VT) during a US DOE site visit to VBI projects in August 2015.

Renewable Energy Resources' Compactor 5000 is housed on a 25 ft trailer and is designed to be pulled by a 5-wheel with an optional ¾ ton pick-up truck hookup. Enabling mobility makes the compactor an ideal option for growers and fuel suppliers who have multiple field locations.

The concept of a fuel "puck"—something denser than a bale or loose biomass but less dense than a pellet—provides an alternative in the mid-range that could support the use of grass feedstocks as fuel.

A variety of biomass fuels. Left to right: wood chips, grass pucks or briquettes, and wood pellets.

Renewable Energy Resources (RER) was funded under the Vermont Bioenergy Initiative to purchase, build, and modify machinery to make fuel "pucks" from several feedstocks. Early stage work resulted in the purchase of a machine capable of densifying

Fuel "pucks" made from Switchgrass by RER for combustion testing.

700 pounds per hour of feedstock while a second generation machine was designed to produce 4,000 pounds per hour. RER has successfully produced fuel pucks from feedstocks such as switchgrass, reed canary, miscanthus, mulch hay, and "ag biomass" (i.e., native weeds harvested from fallow fields). Best results were found when these feedstocks were mixed with wood and with careful attention to moisture content, production rate, and other machine settings (Dantzscher & Bootle, 2015). **Estimates of fuel densification costs are $49-$148/ ton depending on production volume** (Callahan, 2016a).

Small, performance contracts were also initiated by the Vermont Bioenergy Initiative with four wood pellet vendors to explore the logistics of bulk pellet delivery to a growing residential market in Vermont. These contracts were made in anticipation of boilers and furnaces that could effectively burn grass biomass. With increased availability, accessibility and feasibility of combustion appliances, grass pucks or grass pellets could be delivered in the same, bulk manner as wood pellets. **At the time that these contracts were awarded, there was no bulk delivery of wood pellets in the state. Work performed under these contracts helped to advance bulk pellet delivery to residences in general and set the stage for future bulk delivery of alternative biomass fuels such as grass.**

BULK WOOD PELLET DELIVERY INVESTIGATION

Contractor	DOE Funds	Cost Share	Total Project	Purpose
Energy Co-op of Vermont	$10,000	$3,775	$13,775	Testing the performance of three different styles of bulk bins
Acorn Renewable Energy Co-op	$10,000	$3,893	$13,893	Identifying and developing system components that, when linked together, will facilitate the transfer of un-bagged wood pellets from factory to residential heating units
SunWood Biomass	$10,000	$10,000	$20,000	Developing and testing a vacuum conveyance system for delivering bulk wood pellets
VT Wood Pellet Company	$20,000	$11,526	$31,526	Developing a system which can load bulk delivery trucks with wood fuel pellets containing limited fines appropriate for burning in a typical pellet stove
TOTAL	**$50,000**	**$29,194**	**$79,194**	

Thermal Conversion and Economic Feasibility Research

The use of solid, densified cellulosic biomass fuels has been well demonstrated with wood pellets in residential and light commercial systems and wood chips in larger, often centralized systems. As noted earlier, grass fuels may be produced on otherwise marginal agricultural land, sometimes in perennial production and even in buffer strips offering environmental benefits. Additionally, fuel can be made by densifying agricultural residue or biomass harvested from idle pasture or fields. Several combustion tests were supported by VBI funding.

Chris Davis explains the details of the EvoWorld HC100 Eco to visitors at Meach Cove Trust. The boiler was designed in Austria, but is made in the US under a license by Troy Boiler Works (Troy, New York). It was intended for wood chips, but has been successful at running on grass pucks.

A first set of tests were done using pellets of various feedstocks (mulch hay, reed canary grass, and switchgrass) and combinations of feedstocks (mixed with wood) (Sherman, 2011). This testing was done in a Solagen boiler (500,000 BTU/hr) designed for wood pellets at [Meach Cove Trust] (Shelburne, VT). The primary findings of this work confirmed reasonable heating value of the fuels, relatively high ash content of the grass fuels (4.3-6.7%), different combustion air and mixing requirements of the fuel with potential for fusion (i.e., clinkers), and relatively high levels of chlorine in the grass fuels which is suspected to accelerate corrosion of internal appliance surfaces. This report—[Technical Assessment of Grass Pellets as Boiler Fuel]

Grass pucks being fed into an EvoWorld HC100 Eco boiler at Meach Cove Trust in Shelburne, VT.

Switchgrass clinker from Meach Cove Trust.

in Vermont—also noted that the challenges associated with high ash content and clinker formation could be alleviated with appliance design considerations such as automated ash removal and a moving floor or cleanout cycle. Detailed emissions profiling was also conducted as part of this prior work.

A review of the potential for a grass energy industry—Grass Energy in Vermont and the Northeast—was also conducted (Wilson Engineering, 2014). This work focused on assessing several production and marketing models (i.e., Closed Loop No Processing, Small Scale On-Farm Processing, Regional Processing, Consumer Pellet Market). The model that would be the easiest to implement with minimal incentives is the *Closed Loop No Processing* model, where minimal investment is required in harvesting and processing. Standard haymaking equipment can be employed to harvest the same or similar grass for fuel. Systems are commercially available that can accept large round or square bales and automatically deliver them to the furnace. In this scenario, grass energy can compete favorably with wood on an energy content basis (cost per BTU), due to reduced hauling, processing and storage costs. The Regional Processing model, which matches specific thermal installations to processing capacity, would also make sense for Vermont. However, important considerations are the significant investment in both processing equipment and end use installations, and a high level of coordination between parties in the supply chain. It would also require a public commitment to monetizing all of the environmental benefits of grass energy, including renewable energy and watershed improvement, to be economically sustainable.

As with most new forms of fuel, the review identified the need for additional value or incentives to help overcome inherent barriers for adoption. These incentives could be in the form of portfolio standards for utilities to carve out a portion of the Renewable Energy Credits for renewable thermal projects, and incentives for planting and establishing grass energy crops. Vermont has a significant environmental problem that may provide the ideal vehicle to establish grass energy crops and incentivize the planting and use for thermal energy: managing nutrient

Greg Cox inspects the new Evoworld 100 biomass boiler installed at Vermont Farmers Food Center (Rutland, Vermont).

runoff from agricultural activities into Lake Champlain. Switchgrass and other perennial grasses are recommended crops on highly erodible soils and for riparian buffer zones around waterways. In addition to reducing runoff, these crops act as bio-filters that trap sediment and take up significant quantities of phosphorus and nitrogen. If these acres are harvested and used for thermal applications, significant quantities of nutrients will be removed and concentrated in the ash and diverted from the watershed.

Finally, a brief, **focused test** of grass densification in puck (or briquette) form and associated combustion in a boiler intended for coarse biomass was conducted in the fall of 2015 at the Vermont Farmers Food Center (Callahan, 2016b). Fuel production was variably successful. Each fuel could be densified, but the process was not able to be optimized in the time allowed for this test period. Some of the fuels included a high proportion of chaff or loose feedstock and others included very dense and large pucks that were not able to be fed into the boiler. Occasionally

“Receiving grant funding through the VBI from the U.S. DOE was instrumental in VFFC being able to afford to install a renewable energy biomass boiler in farmers’ hall. This installation, coupled with an onsite solar array, will enable VFFC to move forward on its goal to create a sustainable, resilient, and locally sourced energy footprint for our facility.

Our goal is to turn local storm-damaged trees and meadow edges into a local source of fuel for the biomass boiler.”

— Greg Cox, Vermont Farmers Food Center

smaller, denser pucks were found to block the feed mechanism and resulted in a shutdown of the boiler. Future work will focus on optimizing the fuel production process (mixing and moisture content control, densifier rate/pressure/temperature adjustment), including fuel quality control processes and even filtering or screening fuel as it enters the boiler fuel bin and feed system. Each of the fuels made were successfully combusted. There were no fuel mixes that did not combust and heat the water system successfully. While no clinkers (fused ash) were noted in this more recent testing, the high ash levels of the fuels did lead to build-up between cleanout cycles that will require adjustments in boiler tuning.

Densification and combustion testing conducted in 2015 was intended to integrate the prior research and development projects into a concise summary of economic feasibility of distributed production and processing. **By combining review of production and processing economics with combustion feasibility tests, the team was able to demonstrate the use of biomass pucks as a viable, alternative farm-based, thermal fuel.**

This testing also explored the densification and combustion of a new fuel called “Ag Biomass.” This fuel was derived by cutting idle pasture populated with native grasses and weeds, baling it, and making pucks from the material. The cost of production for this crop is minimal since it exists naturally in idle pasture and fields throughout Vermont. The densification and combustion of the fuel was successful and this provides a very low cost alternative combustion fuel ($5.2-13.2 per million BTU).

In addition to the densification and combustion testing at Meach Cove Trust, a boiler installation completed in 2015 at The Vermont Farmer's Food Center in Rutland, VT was designed to leverage the earlier project learning at Meach Cove and expand the demonstration scope and potential regional market for grass biomass fuels (Callahan, 2016b).

The conclusions of this work indicate:

- On-farm, small scale densification of grass and agricultural biomass solid fuels via pucking is feasible with a conversion (densification) cost of $49-148 per ton and a finished fuel cost in the range of $85-228 per ton ($5.2 – 14.4 per million BTU).
- Sustained, reliable combustion of densified grass and agricultural biomass solid fuels in a light commercial boiler (EvoWorld HC100 Eco) is feasible with 73-90% combustion efficiency, and with no ash fusion or clinker development. Longer, sustained overnight runs did result in some combustion chamber clogging with ash and fuel residue which may be resolved with further boiler tuning and clean out cycle adjustment.
- The test of the Ag Biomass / Field Residue fuel demonstrated feasibility at a current delivered price of $214 per ton ($13.2 per million BTU) supporting a payback period of 3.6 years on the boiler. At higher production volume, we project the feasbility of $85 per ton ($5.2 per million BTU) and a payback period of 2.4 years.

Economics — Cost of Production & Cost and Benefit Summary

The consideration of a grass biomass heating system as an alternative to fossil fuel systems generally comes down to investing greater capital in the conversion system or appliance and recouping that investment in recurring savings via less expensive fuels. Recently depressed fossil fuel prices pose a significant challenge to biomass systems demonstrating feasibility or at least economic attraction. However, work funded by the VBI has demonstrated the feasibility of grass pucks as an alternate fuel source and form in an advanced heating appliance. The cost of the fuel varied depending on the feedstock, but was in the range of $85-228 per ton ($5.2 – 14.4 per million BTU). Even at relatively low prices today, propane at $2.75 per gallon has a normalized cost of $29.85 per million BTU and fuel oil at $2.014 per gallon has a normalized cost

GROW | DENSIFY |
---|---|---
Crop Production
$ / acre
or
$ / ton | + **Cost of Conversion**
$ / ton | = **Fuel Cost**
$ / ton
or
$ / million BTU

of $14.58 per million BTU (US DOE EIA, 3/12/2016). The normalized savings possible when using densified grass biomass fuels ranges from nearly zero to $24.65 per million BTU depending on the fuels being compared and current pricing and assuming comparable appliance efficiencies, which is reasonable when considering modern designs.

The assessment of basic economic feasibility and benefit of an alternate system must consider 1) feedstock costs, 2) densification costs and 3) appliance cost premium all in the context of current standard fuel costs. These items are reviewed in the following sections.

Feedstock Costs

Prior work has helped to estimate the establishment and recurring production costs of perennial grass crops (Bosworth, 2009; Ciolkosz, 2015). The result of this previous work concludes that an average cost of $60-80/ton is a reasonable expectation for most perennial grasses. The feedstock cost of Ag Biomass has been estimated at $35-67 per ton using standard costs for harvesting and baling hay.

Densification Costs

The cost of densification as briquettes or pucks (distinct from pellets) has been estimated based on the experiences of RER operating two scales of "slugger" densifying machines. Accounting for normal work shifts, cost of labor, cost of energy for operation, maintenance, insurance and debt service the costs of densification for the small and large machine are estimated to be $148 and $49 per ton respectively, at 50% and 63% machine utilization respectively (Table 3). This cost decreases with higher utilization (i.e., higher output of tons/year as shown in Figure 1).

TABLE 3: SUMMARY OF GRASS FUEL DENSIFICATION COSTS BASED ON RER EXPERIENCE WITH TWO SCALES OF PROCESSING MACHINES.

	Small Machine	Large machine	Units
MAXIMUMS			
Max Output	700	4,000	lb/hr
Max Operation	80	80	hours/week
	50	50	weeks/year
	0.8	0.8	uptime
Max Volume	1,120	6,400	ton/year
ACTUALS			
Work Time	10	10	hr/day
Product Volume	7,000	40,000	lbs/day
	3.5	20	tons/day
Annual Volume	560	4,000	tons/yr
Utilization	50%	63%	%
LABOR			
Staff	2	4	people
Work days	160	200	days/yr
Labor cost	$15.00	$15.00	$/hr
	$300	$600	$/day
	$86	$30	$/ton
Labor Cost	$48,000	$120,000	$/yr
FUEL			
Gasoline Used	2	5	gal/hr
Unit Cost	$3	$3	$/gal
Fuel Cost	$9,600	$30,000	$/yr
	$17	$8	$/ton
Maintenance Cost	$5,000	$10,000	$/yr
Insurance Cost	$2,500	$2,500	$/yr
EQUIPMENT			
Initial Cost	$100,000	$200,000	$
Term	7	7	yrs
Interest	5.50%	5.50%	%
Equipment Cost	$17,596	$35,193	$/yr
Total Costs of Densification	$82,696	$197,693	$/yr
Unit Cost of Densification	**$148**	**$49**	**$/ton**
at volume of	560	4000	ton/year
Fixed	$25,096	$47,693	$/yr
Variable	$103	$38	$/ton

Figure 1 shows a pathway to $120 per ton on the small machine and $45 per ton on the large machine when operated at full volume of 1500 ton/year and 4000 ton/year respectively. Note, this is not full fuel cost, it is net of feedstock.

Fuel Costs

Knowing the production and densification costs of grass biomass fuels, we can make a comparison to other common fuels in order to determine potential savings in operational costs. A summary of fuel costs, in normalized terms at current pricing, is presented in Table 4.

FIGURE 1: EFFECT OF FUEL PRODUCTION VOLUME ON COST OF DENSIFICATION FOR THE TWO SCALES OF MACHINES OPERATED BY RER.

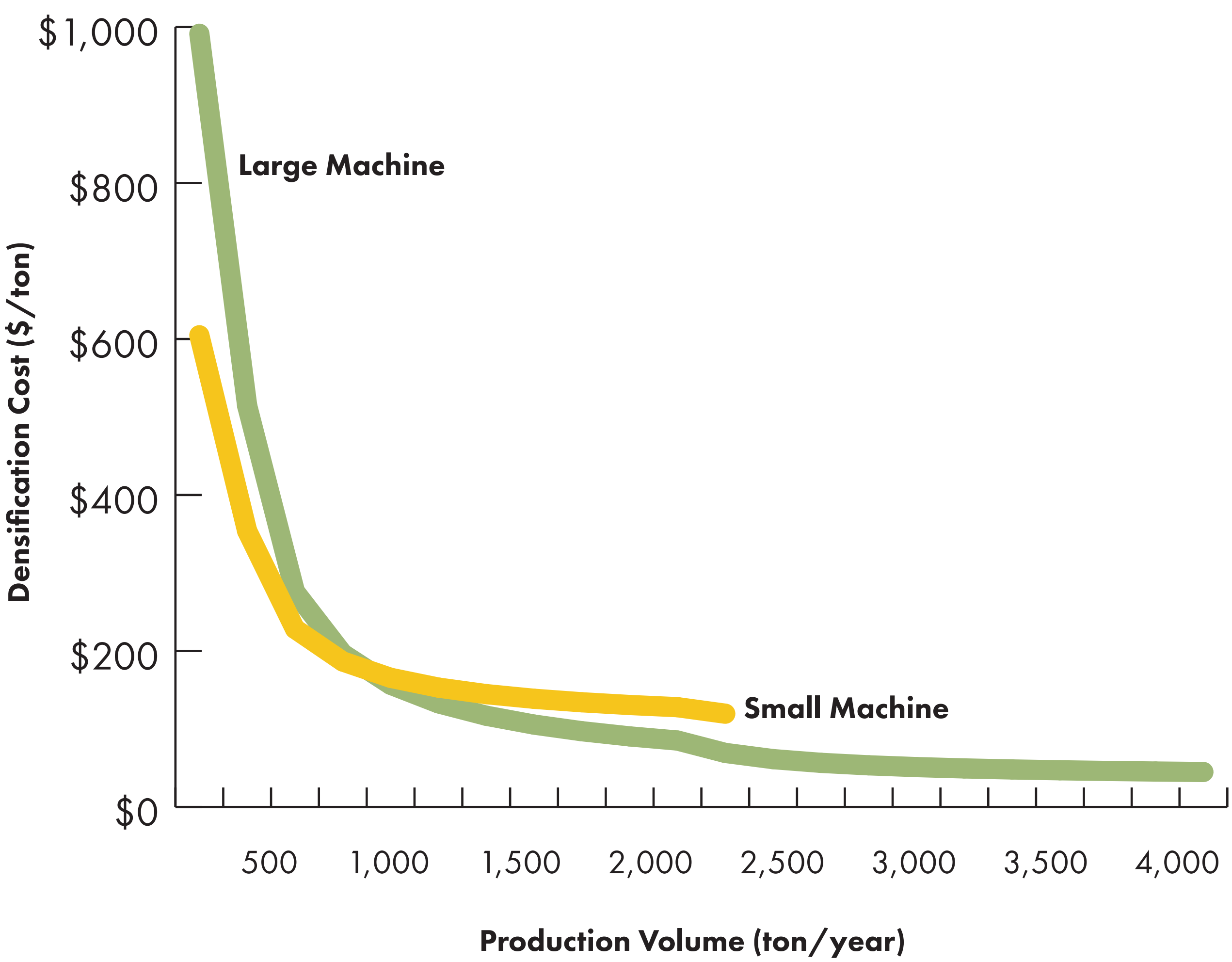


TABLE 4: COMPARISON OF FUEL COSTS IN NORMALIZED TERMS

Fuel	Cost	Cost Units	Energy Content	Energy Units	Normalized Fuel Costs
					$/million BTU
Propane	2.75	$/gal	92,000	BTU/gal	29.8
Fuel Oil	2.01	$/gal	129,500	BTU/gal	15.6
Wood Pellets	225.00	$/ton	8,600	BTU/lb	13.1
Wood Chips	56.00	$/ton (green)	9.9	mill BTU/ton	5.7
Ag Biomass	85 - 214	$/ton	8, 123	BTU/lb	5.2 - 13.2
Switchgrass	129 - 228	$/ton	8,353	BTU/lb	7.7 - 13.6
Miscanthus	129 - 228	$/ton	8, 105	BTU/lb	8.0 - 14.0
Reed Canary	129 - 228	$/ton	7,898	BTU/lb	8.2 - 14.4
Mulch Hay	129 - 228	$/ton	7,952	BTU/lb	8.1 - 14.3

Potential Fuel Savings

Given the assumed fuel costs above and the potential for modern biomass appliances to operate at efficiencies similar to standard fossil fueled appliances it is possible to achieve 7-82% savings when using densified grass biomass as a combustion fuel. This is a wide range given the variability in grass biomass production costs and fossil fuel prices. It is likely that propane will be at least $3 per gallon ($32.60 per million BTU) in the future when a mature grass biomass fuel can be produced for $130 per ton ($7.93 per million BTU). This suggests a future scenario of 75% fuel cost savings potential. The impact of that savings depends significantly on the cost premium of the appliance and the amount of heating load the site has.

Appliance Premium

The EvoWorld HC100 Eco has an output heat rating of 341,200 BTU/hr and costs approximately $53,500 (net of balance of plant and fuel bin). The cost premium of the advanced biomass boiler compared to a comparable propane or oil boiler is approximately $50,000.

Cost / Benefit

Grass biomass densified as pucks has the potential to support a minimum payback period of 2.5 years on a $50,000 appliance premium (with biomass fuel delivered at a savings of $24.6 per million BTU, that is, 82% savings, best case based on propane at $2.75 and Ag Biomass at

$85/ton in puck form). Even with a mid-range delivered fuel price of $9.8 per million BTU ($159 per ton) a payback period of 3 years is estimated. The test of the Ag Biomass / Field Residue fuel demonstrated feasibility at a current delivered price of $214 per ton supporting a payback period of 3.6 years on the boiler. Assuming a higher production volume results in a projected path to $85 per ton and a payback period of 2.4 years.

RER biomass pucks bagged and ready for shipment.

"Vermont farm and food businesses need sustainable ways to heat buildings and they are often surrounded by marginal and generally unused pasture and fields. The use of grass and weed crops as a solid, thermal fuel in advanced heating systems is a really fascinating approach to heating. The work we did integrated various projects specifically focused on, e.g., crop production, fuel densification and fuel combustion into a single complete story that points to technical and economic feasibility. This fuel is growing around us whether we use it or not. The project allowed us to combine all the pieces into an example of how to use it effectively at 20% of the cost of propane resulting in payback periods of under 3 years."

— Chris Callahan, University of Vermont

Education and Outreach

To encourage shared learning and collaboration, the Vermont Grass Energy Partnership was established and included the University of Vermont Department of Plant and Soil Science, UVM Extension, Vermont Sustainable Jobs Fund, the Biomass Energy Resource Center, Vermont Technical College, Meach Cove Trust, Borderview Farm, Lincoln Farm, and Renewable Energy Resources. Through the partnership:

- A Grass Energy Symposium was held in November, 2008 and featured many speakers on topics such as growing and harvesting, processing and pelletizing, and the state of combustion technology. Presenters at the symposium included:
    - **Keynote Address: Building a Viable Grass-Energy Economy**
      Roger Samson, Executive Director, R.E.A.P.-Canada
    - **Growing and Harvesting**
      Jerry Cherney, Cornell University
      Pamela Porter, University of Wisconsin
    - **Processing and Pelletizing**
      Daniel Arnett, Ernst Conservation Seeds
      Bryan Reggie, BHS Energy LLC
      John Arsenault, Energex Pellet Fuel
    - **State of Combustion Technology**
      Jerry Cherney, Cornell University
      Andy Boutin, Pellergy, LLC
- Two major field days were held at the Meach Cove and Vermont Tech locations in 2010 and 2011, respectively.
- The Borderview Farm research trials conducted by Dr. Sid Bosworth (UVM Extension) were highlighted at four consecutive Crop Field Days held there from 2009 to 2012.
- Three television segments about grass energy were produced by Across the Fence (a project of the UVM Extension with WCAX in Burlington, VT).

Question and answer session at the 2008 Grass Energy Symposium, Shelburne Farms, Vermont.

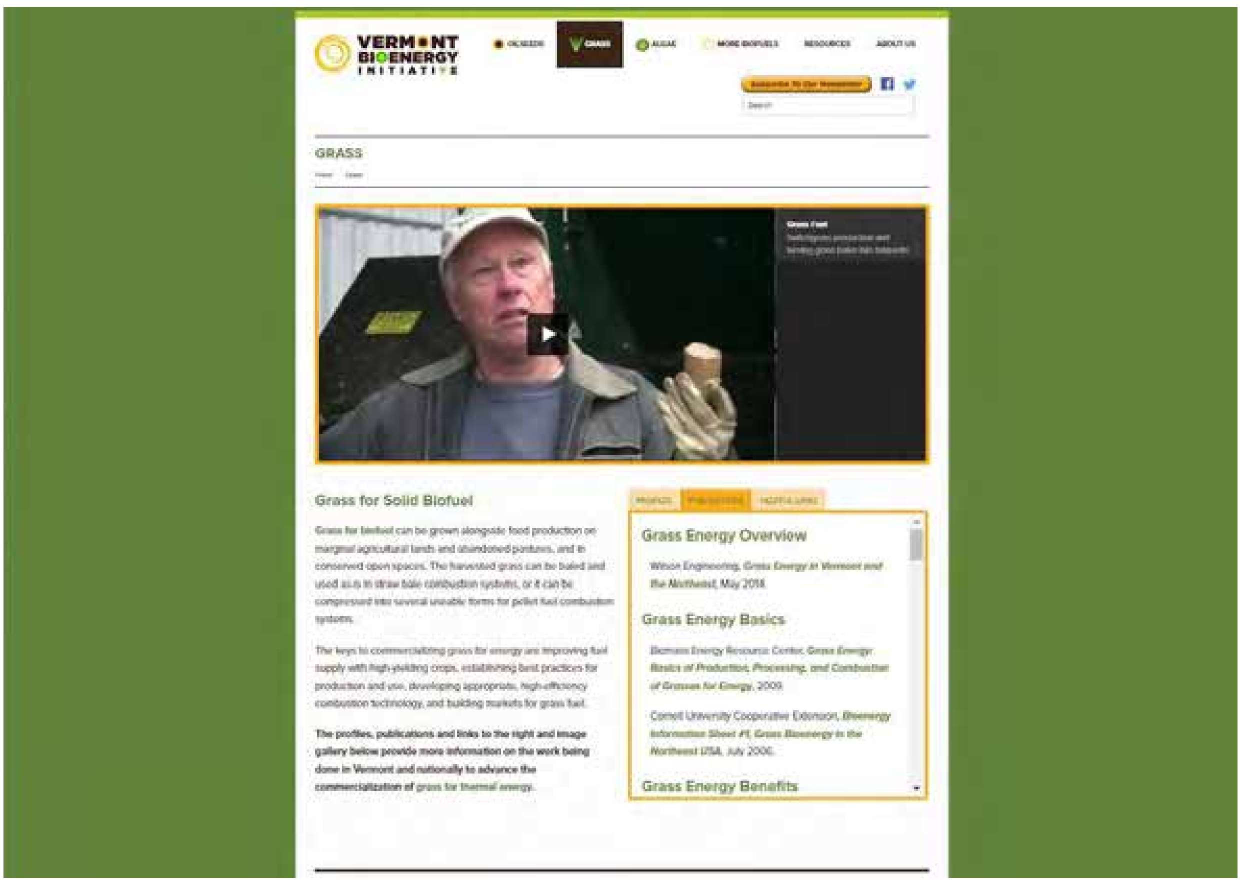
- A website dedicated to highlighting Dr. Bosworth's research results was launched (http://pss.uvm.edu/grassenergy).

- At least a dozen tours of research sites were held for University of Vermont and Vermont Technical College classes, and over a dozen presentations as lectures to undergraduate classes, faculty and graduate student seminars, civic organizations, farmer groups were made.

UVM Extension conducted several field days for grass production.

- VSJF staff worked with the [Northeast Biomass Thermal Working Group] for two consecutive years to expand panels and workshop offerings to include grass and agricultural biomass sessions in the regional Northeast Biomass Heating Expo and Conference. In 2013 there was a half-day dedicated regional conference held in Saratoga Springs, NY to explore the state of grass biomass.

- A variety of grass bioenergy resources—including reports, videos, links, and photographs—were compiled on the [Vermont Bioenergy Initiative] website. The [Grass Fuel video] made for the VBI's Bioenergy Now! series has been viewed over 12,000 times.



The Vermont Bioenergy Initiative website is a repository of all materials and resources developed by VSJF and subrecipients, including a video on grass bioenergy that has been viewed more than 12,000 times.

NEXT STEPS

VBI efforts focused on grass crop production, conversion of grass to fuel, and use of grass fuels for producing heat. This work has demonstrated the feedstock and associated pathway as both technically and economically feasible. Next steps include expanding heating appliance availability and installed base, and expanding the distribution and availability of fuel densification systems and services. Continued development is needed to produce additional small- and medium-sized boilers and furnaces that can accommodate coarse biomass with high ash content with reduced initial cost and increased operational reliability. Ideally, these systems would be better integrated into existing heating system distribution channels to ensure a high level of installer training and customer service as the new systems are adopted in greater numbers. There is an opportunity to marry the VBI efforts related to grass biomass with modern wood and wood pellet heating systems in the state and region.

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VERMONT BIOENERGY INITIATIVE

A program of the Vermont Sustainable Jobs Fund

ALGAE




U.S. DOE Award #DE-FG36-08GO88182

ABOUT THE VERMONT BIOENERGY INITIATIVE

The purpose of the **Vermont Bioenergy Initiative** (VBI) was to foster the development of sustainable, distributed, small-scale biodiesel from oilseeds and algae and grass/mixed fiber industries in Vermont that would enable the production and use of bioenergy for local transportation, agricultural, and thermal applications. Our investments in feasibility analyses, research and development, and demonstration projects for various bioenergy feedstocks were intended to lead to their commercialization over 7 year time horizon. This initiative was a statewide market building approach to sustainable development that may be replicated in other rural states around the country.

As a grant-making entity, project manager, and technical assistance provider, the Vermont Sustainable Jobs Fund (VSJF) solicited and selected the best sub-recipient proposals for bioenergy related projects through a competitive Request for Proposal process and conducted a number of staff directed investigations, all designed to support the four key priorities of the U.S. Department of Energy's EERE Strategic Plan:

1.) Dramatically reduce dependence on foreign oil;
2.) Promote the use of diverse, domestic and sustainable energy resources;
3.) Reduce carbon emissions from energy production and consumption;
4.) Establish a domestic bio-industry.

Thank you to the office of U.S. Senator Patrick Leahy for securing three U.S. Department of Energy congressionally directed awards (FY08, FY09, FY10) to financially support the Vermont Bioenergy Initiative.

Learn more at

VERMONT BIOENERGY INITIATIVE

http://vermontbioenergy.com

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ALGAE SUMMARY

As described in the National Algal Biofuels Technology Roadmap, algal biofuel production is attractive due to the possibility of 1) high per-acre productivity, 2) non-food based feedstock resources, 3) use of otherwise non-productive, non-arable land, 4) utilization of a wide variety of water sources (fresh, brackish, saline, marine, produced, and wastewater), 5) production of both biofuels and valuable co-products, and 6) potential recycling of CO_2 and other nutrient waste streams.

As a small, rural, northern climate state with significant per-capita fossil fuel use, Vermont was interested in opportunities for displacement of large volumes of liquid fuels such as diesel and heating oil. The development of algal bioenergy feedstocks was pursued with VBI funding due to the potentially high area-specific yields of this approach and the possible nutrient and carbon conversion opportunities present when co-located with anaerobic digesters or landfills. The funding was focused on the development of locally possible solutions in close partnership with university and food system stakeholders.

The specific work completed through sub-recipient projects and VBI staff-directed initiatives focused on the following areas:

1) Feedstock Development
2) Production Systems
3) Harvest and Conversion Technology
4) Education and Outreach

The early stage results of this body of work include:

Feedstock Development

- A curated collection of one hundred (100) oil-rich native Vermont algal strains for commercial oil production and nutrient recovery were isolated and are being maintained in a purpose-built facility with ten (10) of these strains being classified as best performers.
- Several Vermont strains that were isolated were transferred to pilot research demonstrations at a closed landfill and at a dairy farm with an anaerobic digester.

Production Systems

- The integration of a pilot-scale algal biomass production system with an anaerobic digester demonstrated the use of waste CO_2 and nutrient (N and P) rich digester effluent.
- The integration of a pilot-scale algal biomass production system with a landfill power plant demonstrated the use of waste CO_2 sources and tolerance of algal production potential exhaust contamination (i.e., flue gas).
- An experimental platform was established to study the fluid dynamics of mixing and flow related to optimal algal biomass production systems at the University of Vermont School of Engineering.

Harvest and Conversion Technology

- A bench-scale photochemical algal fuel processing system was developed that is capable of producing biofuel more cost effectively and with less energy investment compared to standard oil extraction and transesterification.
- A bench-scale photochemical algal fuel processing system was developed that demonstrated production of a fuel with superior cloud point, pour point, cold filter plugging point, and heat of combustion when compared to fuel produced using transesterification.

Educational and Outreach Programming

- Educational materials related to algal bioenergy production specific to Vermont have been developed and published.
- A conference focused on algal bioenergy production in the Northeast was held to share research findings and strengthen the research network.
- A Vermont network of relevant stakeholders with interest in algal bioenergy has been established.

THE OPPORTUNITY

Algae as a bioenergy feedstock provides an attractive alternative to other biomass oil sources due to its differentiation as a non-food production system with high potential yields per acre and the ability to integrate with other agricultural and food system enterprises as a nutrient sink. Previous work has shown that integration of algal biomass production with waste treatment could be a cost-effective approach. Projected yield estimates approach 3,500 gallons of oil per acre in sunny, subtropical regions (National Research Council, 2012) compared to 70-100 gallons per acre from oilseed crop feedstocks. However, algae oil production at commercial scale is not yet a reality due to the challenges in cost-effective algal biomass production, harvest and separation (Ferrell et al., 2010).

Feedstock development via strain isolation was necessary in Vermont to select those strains with local vigor that are effective oil producers. The availability of robust oleaginous (i.e., oil producing) algae strains specifically relevant to algal bioenergy production was a key challenge noted at the start of the VBI. In the National Algal Biofuels Technology Roadmap, the U.S. Department of Energy (DOE) prioritized the isolation of new, native strains directly from unique environments (Ferrell et al., 2010). **Limited work had been done in the Northeast region on strain isolation and no work had been done in this area specifically in Vermont.** Importantly, no cost-effective and robust algal bioenergy production system integrated with nutrient rich waste streams has been developed for algal biofuel production with a positive energy return on investment. Most of the research done in algal production systems has generally explored open, surface water systems in warm climates that are distinctly different from potential production systems in Vermont.

Tightening state and federal water quality guidelines support the development of effluent capture and treatment systems such as anaerobic digesters. In 2012, Vermont enacted Act 148 as the *universal recycling* law for solid waste, which may lead to an increase in the number of anaerobic digesters in the coming years in order to take advantage of an additional load of nutrients to manage on top of existing dairy manure nutrients. In 2015, Vermont enacted Act 64, the most comprehensive water quality legislation in Vermont's history, creating new regulations and devoting more resources to reduce pollution from farms, The potential synergy of algal bioenergy production with wastewater treatment is therefore of particular interest given the prioritization of needed improvements in water quality and significant reductions in excessive nutrient loading of waterways. Another opportunity involves the integration of algal bioenergy production with CO_2 sources such as landfill gas fueled power plants. Additionally, the diversion of organics from landfills to digesters would add to the digester nutrient load as described in the Biogas Opportunities Roadmap (USDA, USEPA, USDOE, 2014).

An overarching challenge to algal bioenergy development is cost effective and energy efficient production methods and mechanisms. For example, ensuring optimal mixing and exposure to light are critical for algal biomass production and these both require careful design and attention to energy use.

Harvesting algae and oil separation in order to prepare the feedstock for conversion to biodiesel fuel remains a challenge for commercialization of algae systems. While some in-situ conversion methods have been explored in the literature they remain mainly undeveloped and are seen as a potential game-changer in this area.

Based on the limited level of algal research in Vermont and other northern climates, the VBI prioritized research efforts focused on the unique challenges of these areas. In addition to specific strain isolation, the intention of our sub-recipient projects was to explore new processes and patentable approaches that could advance algae bioenergy in Vermont and in other parts of the country at a scale not possible locally.

STATEMENT OF PROJECT OBJECTIVES

The Vermont Sustainable Jobs Fund, through its Vermont Bioenergy Initiative, made a series of grants to sub-recipients in the area of algal bioenergy focused on research and development, production systems, and education and outreach (Task D).

To address the question of algal bioenergy as a viable option for Vermont, this project pursued four objectives:

1) **Feedstock Development:** To curate collections of local algal strains with commercially desirable traits.

2) **Production Systems:** To explore integration of algal production systems with existing agricultural infrastructure (e.g. anaerobic digesters on dairy farms) and landfills. In addition, researchers explored fluid dynamics related to algae production.

3) **Harvest and Conversion Technology:** To explore novel approaches to producing drop-in fuel replacements from algal feedstocks.

4) **Education and Outreach:** To integrate algae research into conferences, field day, and undergraduate educational platforms..

Task D: Algae Feedstock Analysis and Production Techniques

SUB-TASK D.1: RESEARCH

The objective of this task was to provide sub-recipient award funding to researchers, entrepreneurs, and others to experiment with the development of algae feedstocks that are adaptable to nutrient-rich waste streams and suitable for Vermont's colder climate. Research included how algae could interface with other Vermont-scale agricultural activities (e.g., anaerobic digesters and landfills).

- **Algepower:** The objective of the Algepower, a start-up business, was to quantitatively estimate increase in lipid production by the freshwater microalgae Chlorella vulgaris grown in a specially designed Algeponics™ system, and correlate with the nutrient recovery data.
- **GSR Solutions:** GSR Solutions, a research laboratory run by Dr. Anju Dahiya Krivov, investigated the use of robust high-lipid producing algae strains that could be grown in non-sterile environments (e.g., farm or industrial wastewaters) capable of capturing nitrogen and phosphorus from diverse waste streams.
- **Carbon Harvest (CHE):** The objective of Carbon Harvest, a start-up business, was to research the suitability of landfill gas combustion products as a supply of CO_2-rich flue gas for commercial algae cultivation.
- **University of Vermont, School of Engineering:** The objective of this project was to develop a testing facility that could be used by students and faculty in the School of Engineering at the University of Vermont to study novel methods for algae growth rate enhancement using different types of fluid mixing.

SUB-TASK D.2: LOGISTICS / PRODUCTION

The objective of this task was to provide sub-recipient award funding for algae feedstock logistics and new methods for optimizing production processes that fit the scale of Vermont farms and communities. Funding supported lipid optimization, harvest, dewatering, oil extraction, and refined oil and algal biomass research.

- **Green Mountain Spark:** The objective of Green Mountain Spark, a start-up business, was to investigate the feasibility of using photochemistry to create a single system for oil extraction from micro-algae and biofuel production from the separated oil.

SUB-TASK D.3: PROCESSING / DEMONSTRATION

The objective of this task was to provide sub-recipient award funding for demonstration projects (e.g., analysis of prototype for algal biodiesel production facility.)

- **No sub-recipients for this sub-task**

TABLE 1: VBI ALGAE BIOENERGY SUB-RECIPIENTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08	**Algepower:** Production Systems	$20,000	$5,606	$25,606
FY08-FY10	**Carbon Harvest Energy:** Production Systems	$233,349	$66,225	$299,574
FY08-FY10	**GSR Solutions:** Feedstock Development	$133,833	$106,244	$240,077
FY09	**Green Mountain Spark:** Conversion Technologies	$65,000	$33,651	$98,651
FY09	**University of Vermont School of Engineering:** Production Systems	$44,828	$24,673	$69,501
	TASK SUBTOTAL	**$497,010**	**$236,399**	**$733,409**

Feedstock Development

The VBI supported GSR Solutions in the isolation of oil feedstock producing regional strains. GSR Solutions investigated the use of robust high-lipid producing algae strains that could be grown in non-sterile environments (e.g., farm or industrial wastewaters) capable of capturing nitrogen and phosphorus from diverse waste streams. Cutting edge methods were used to isolate native strains and an algae culture collection facility was established. The best performing algal strains were scaled up for higher volume production in a greenhouse setting to represent the operational environment of a real world scenario such as a dairy farm or an industrial application such as a brewery.

With USDA Rural Development funding, a farm-scale pilot system was subsequently developed at Nordic Farms in Charlotte and the first large scale implementation is anticipated at the proposed Green Mountain Power community digester project in St. Albans. These projects, sited at dairy farms, could enable the demonstration and deployment of algal technologies in order to manage excess nutrients.

"The DOE support through the VBI helped GSR Solutions build cutting edge waste to energy technology utilizing the fastest growing plants on the planet, microalgae, to capture waste nutrients. By increasing our technology readiness level with supply chain and strategic partners we are gearing up to bring our technology to market for production of a range of innovative products from biofuels to fertilizer to animal feed."

—Anju Dahiya Krivov, President, GSR Solutions LLC

Dr. Anju Dahiya Krivov is a professor at the University of Vermont and principal of GSR Solutions.

Establishment of a Strain Collection Using Rapid High-Throughput Methodologies

GSR Solutions tested algal strain potential for lipid accumulation, nutrient recovery from wastewaters (nitrogen and phosphorus), carbon intake, and potential for byproducts including fertilizer manufacture. As part of this project, GSR Solutions isolated over 4,000 algal cells from different Vermont environments—ranging from farms, compost facilities, lakes, and rivers—and successfully collected over 300 strains found to have potential for lipid production. Out of these 300 strains, the 100 best performing strains were selected and are currently maintained in GSR Solutions' collection. All are capable of growing in different modes (i.e., photoautotrophic, mixotrophic, and heterotrophic).

Screenshots of the software infrastructure for algal biofuel project. Credit: GSR Solutions LLC.

GSR Solutions then screened the ten (10) best performing strains from this collection based on:

1) high growth,
2) high oil content,
3) uptake of nitrogen and phosphorus,
4) uptake of carbon, and
5) resistance to contaminants in the wastewater environment.

A statistical model of algal growth, including software infrastructure, was developed to support experimental design, data collection, and analysis. A rapid screening lipid quantification method was tested for lipids and nutrients analysis in order to obtain correlations between lipids contents and nutrients. Lipophilic dyes-based rapid screening methods using fluorescent lipophilic dye (e.g., Bodipy) were successfully implemented. This project also enabled GSR

Solutions to establish an algal culture collection facility in a laboratory setting where the isolated strains are being maintained. **One overall outcome of this activity is that a curated collection of one hundred (100) oil-rich native strains for commercial oil production and nutrient recovery were isolated and are being maintained in a purpose-built facility, with ten (10) of these being classified as highest performers.**

Development of High-performance Oleaginous Algal Growth in Vermont / Northeast

GSR Solutions undertook several algal biomass up-scaling experiments that used batch bioreactors of varying capacities (e.g., 2L to 80L), utilizing the algal strains isolated in the software noted above. The algal growth in the reactors was monitored and the biomass harvested was analyzed for lipid and nutrients (i.e., nitrogen and phosphorus) analyses. The best performing algal strains were successfully up-scaled utilizing waste nutrients.

These algal strains were cultivated for production of oil. The biomass was harvested and oil was extracted. The oil was analyzed for Fatty Acid Methyl Esters (FAME) in the form of

Native algae samples, University of Vermont, 2012. Photo credit: GSR Solutions LLC.

triacyl glycerols (TAG). Under controlled environmental conditions, the oil content ranged from 15% to 55% by dry weight with the most abundant fatty acids found to be C16:0 to C20:3. Algal biomass exceeded the benchmark production of 25 grams per square meter per day. On an acreage basis, GSR Solutions's selected proprietary strains under photoautotrophic (light-driven photosynthetic) conditions are predicted to produce over 3,800 gallons per acre per year of bio-crude (biofuel intermediate).

Algae inoculation lab, University of Vermont, 2012. Photo credit: GSR Solutions LLC.

Development of a Algal Biofuel Network

Over the project period, GSR Solutions has engaged in in-state networking efforts and brought together suppliers, processors, and potential end users of algal biofuel technology, including: Vermont Farm Bureau, National Biodiesel Board, Vermont Fuel Dealers Association, and Commercial Aviation Alternative Fuels Initiative. Nordic Farm (Charlotte, Vermont) has been engaged as host to the project.

Production Systems

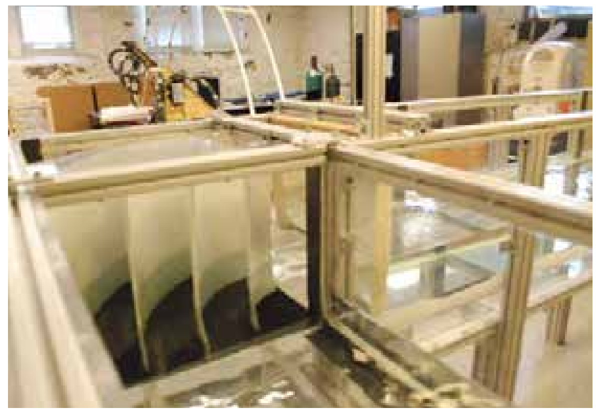
To address the need for understanding and improving production systems, several projects were funded by the VBI. The VBI supported the research and development of a flume system at University of Vermont School of Engineering, and funding was also provided for research into commercially oriented production processes by Carbon Harvest Energy and Algepower.

UVM College of Engineering and Math Sciences — School of Engineering

The objective of this VBI-funded project was to develop a testing facility that can be used by students and faculty in the School of Engineering at the University of Vermont to study novel methods for algae growth rate enhancement using different types of fluid mixing. Mixing is an important aspect of algae production systems because it enables maximum utilization of incident light throughout the production system.

The facility developed with this funding, referred to as the "algae mixing test facility" or AMTF, will enable detailed examination of different fluid mixing approaches using state-of-the-art fluid flow instrumentation. It will also allow examination of the effect of fluid mixing on the growth rate of microalgae suspended in the fluid stream.

Overview of the flume filled with water. The lighting system suspended above the flume is not shown in this photo.



View of the flume showing guide vanes placed at the corner to minimize boundary layer separation.

Carbon Harvest Energy

In 2009, Carbon Harvest Energy (CHE) initiated a project to construct and operate a highly integrated sustainable food production facility. Using established technologies from aquaculture and hydroponics, CHE incorporated an underutilized source of energy and heat in the form of landfill gas (LFG) from the retired site of the Windham Solid Waste Disposal District, located in Brattleboro, Vermont.

CHE's plan was to develop a model/prototype, beginning with the use of a highly potent greenhouse gas (GHG)—methane—as fuel for a combined heat and power (CHP) generator.

The Carbon Harvest closed loop concept.

Electricity produced by the generator would be sold to the grid, and heat from the generator would allow for the operation of an aquaponics greenhouse on a year round basis at a reduced cost.

The objective of the VBI-funded CHE project was to research the suitability of landfill gas combustion products as a supply of CO_2-rich flue gas for commercial algae cultivation. With VBI funding, CHE worked jointly with researchers at the UVM Rubenstein School Ecosystem Science Lab to explore the response of local algae strains to flue gas condensate from a landfill gas system. This project focused on three strains known to exist locally in Lake Champlain and also with potentially strong oil production characteristics. The strains were shown to tolerate a 1% concentration of flue gas condensate without significant impact to growth and production.

These preliminary benchtop results were leveraged to develop pilot trials in larger scale 2 ft x 4 ft "flat-bag" photobioreactors in order to measure the growth rates of two cultures in parallel and to explore lower cost nutrient mixes. In this second phase of work, tests were successfully conducted that introduced CO_2 rich flue gas to growth vessels with marked improvement in

Landfill gas take-off plumbing is shown in the foreground with the CHE greenhouses in the background.

Flue gas experiment shows the visual impact of differences in cell density between air plus CO_2 (white labels), air only (yellow labels), and air plus flue gas (red labels) at time of stocking (left) and 48 hours later (right).

Inoculating the CHE raceway.

growth rates and dry matter production. Importantly, these tests demonstrated that regardless of CO_2 source (flue gas or pure bottled gas) the growth rate impact was equivalent. Researchers were also able to measure reasonable fatty acid methyl ester production in the algae over time. This is a measure of the oil production in the algae. Additional work was done to quantify the heavy metal content of flue gas and the impact of it on algal biomass.

In the third and final phase of VBI-funded work, CHE produced a 9 foot x 38 foot algae raceway to demonstrate earlier work at a larger scale. The chief challenges noted in this phase had to do with structural design of the raceway, temperature control and light limitations. Biomass harvest was not conducted in this final phase due to production mass limitations.

The results of the flue gas experiments demonstrate that flue gas from combustion of LFG is quite suitable for use as a source of CO_2 for algae biomass production. The researchers concluded, however, that even in consideration of all the potential physical systems needed to maintain good environmental conditions for algae culture, and the theoretical economic value

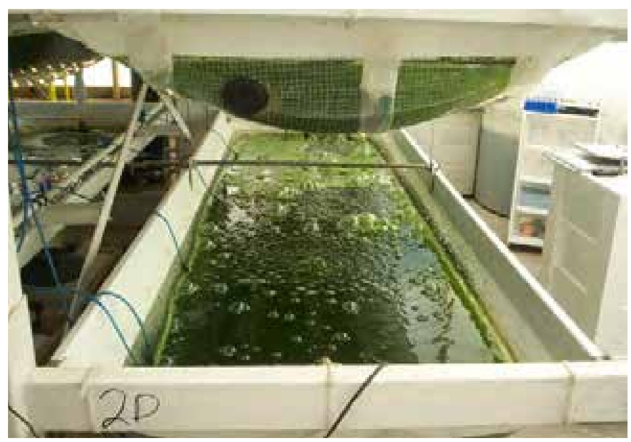
A view of the CHE prototype algae raceway and key components.

of reduced costs for power and CO_2 through use of LFG and flue gas, under current economic conditions, it is not feasible to grow algae in Vermont on a year-round basis for production of biofuel. However, given all of the specific conditions that need to be corrected, and assuming that it will eventually be possible to reasonably control problems with contamination, it could be possible to profitably produce algae biomass in Vermont for high-value bio-products such as astaxanthin, EPA, DHA, and various industrial chemicals. What will be necessary is to demonstrate that algae biomass produced for such purposes has a higher value on a $/ft^2/yr basis than competing vegetables which could be grown in the same greenhouse space.

Unfortunately, Carbon Harvest entered into Chapter 11 bankruptcy in April 2013 and the algae research they started was never completed.

Algepower

The objective of the Algepower project was to quantitatively estimate an increase in lipid production by the freshwater microalgae Chlorella vulgaris grown in especially designed Algeponics™ system, and correlate this with the nutrient recovery data. This project leveraged algal strain isolation work by GSR Solutions who provided the starting culture. The Algeponics™ system was developed to accelerate the onsite cultivation of algae in a pilot scale design, linked to an on-farm anaerobic digester at Blue Spruce Farm in Bridport, Vermont. This system was a photobioreactor designed to convert the main by-products of anaerobic digesters, CO_2, N, and P—into algal biomass and water—through photosynthesis and other biological processes. This project was not completed due to several technical challenges including difficulty with inoculation and initial growth and temperature control of the system, as well as insufficient funding to maintain the company's research and develoment.



Algepower prototype racks at Blue Spruce Farm in Bridport, Vermont.

Harvest & Conversion Technologies

The VBI funded a research project by Green Mountain Spark focused on a novel conversion process that avoids biomass separation, chemical inputs, and the time required when using traditional methods.

Green Mountain Spark

Green Mountain Spark, LLC makes green diesel in Burlington, Vermont, 2012.

The objective of the Green Mountain Spark project was to investigate the feasibility of using photochemistry to create a single system for oil extraction from micro-algae and biofuel production from the separated oil. **The outcome of this research was an algae fuel processing system capable of producing biofuel more cost effectively and with less energy investment compared to standard oil extraction and transesterification.** The system also demonstrated production of a fuel with superior cloud point, pour point, cold filter plugging point, and heat of combustion.

Green Mountain Spark, LLC holding a sample of green diesel produced by their prototype reactor.

A photochemical reactor was built to support the conversion algae feedstock and associated oil to diesel fuel, termed "green diesel." After reaction of the feedstock in the photochemical reactor, green diesel samples were collected until enough sample was available for a suite of biofuel property tests. These tests included cloud point, pour point, cold filter plug point, and heat of combustion (ASTM methods D445, D2500, D97, D6371, and D240, respectively). The results are shown in Table 2 below.

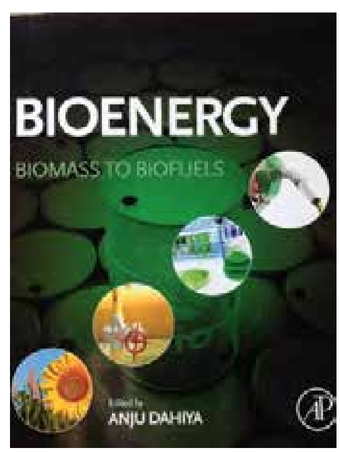
TABLE 2: COMPARISON OF GMS-1 FUEL PROPERTIES

Biofuel Type	Cloud Point (C / F)	Pour Point (C / F)	Cold Filter Plugging Point (C / F)	Heat of Combustion (BTU/lb)
GMS-1 Green Diesel	-27 / -16.6	-37 / -34.6	-22 / -7.6	18,344
Canola Biodiesel (Methyl Esters)	-4 / 24.8	-10.8 / 12.5	3.6 / 38.5	15,500
Canola Oil	0 / 32	-9 / 15.8	18 / 64.4	17,100
Diesel #2	-15 to -25 / 5 to -13	5 to -25 / 41 to -13	-6 to -12 / 21 to 10.4	19,300

The results from the GMS-1 green diesel biofuel clearly show a strong advantage in its cold flow properties compared to canola biodiesel (methyl ester), canola oil, and diesel #2. Specific highlights are the remarkable improvement in cold-weather fuel properties (i.e., lower cloud point, lower pour point, and lower cold filter plugging point), an important aspect of fuel use in the Northeast. Successful development of this technology will give microalgae oil biofuel producers a more efficient oil extraction and biofuel conversion process and lead to superior fuel properties. The work of this project resulted in a patent covering the process (Holmes & Wurthmann, 2016).

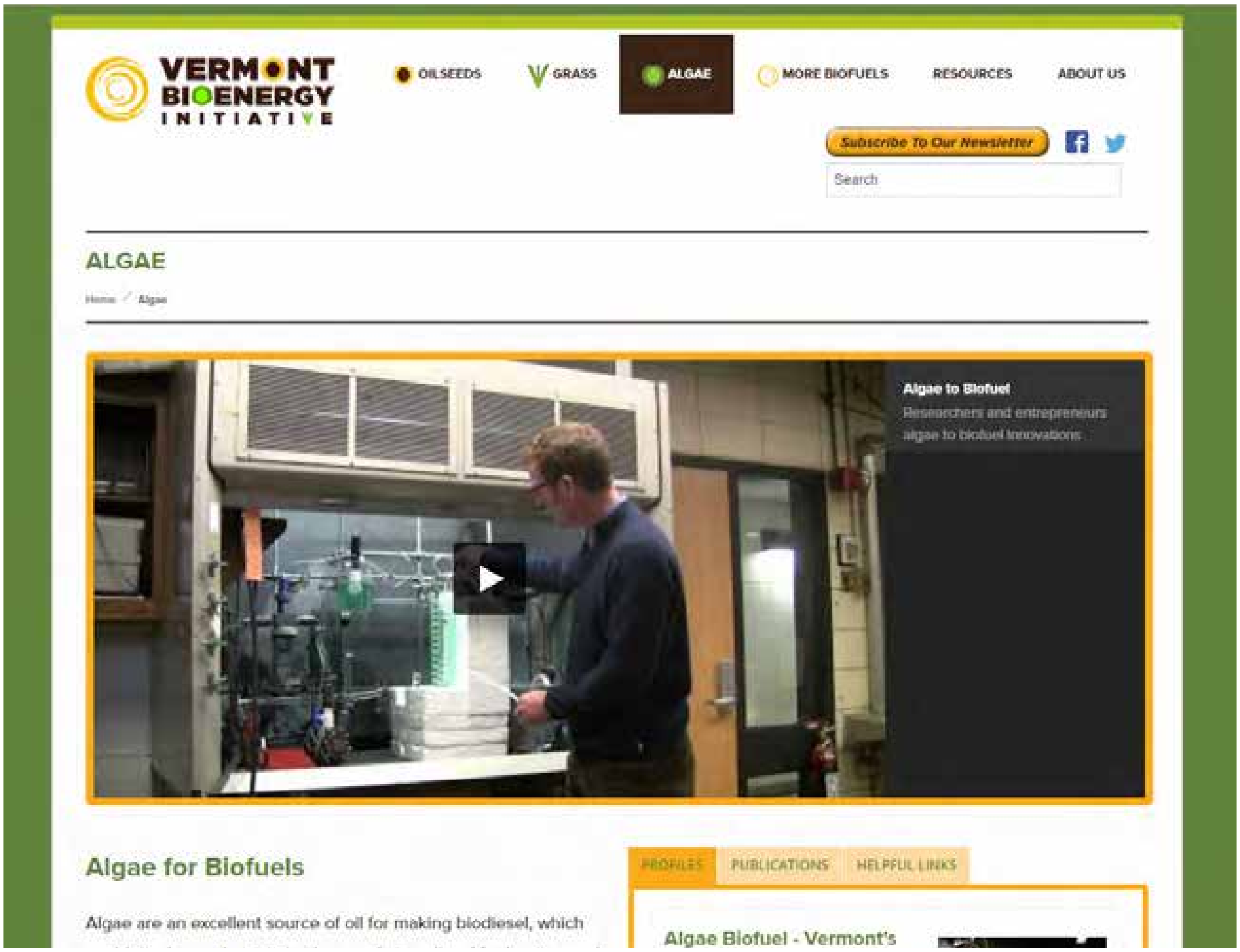
Educational and Outreach

A variety of algae bioenergy resources—including reports, videos, links, and photographs—were compiled on the Vermont Bioenergy Initiative website, including a Bioenergy Now! video—Algae to Biofuel—that continues to receive wide viewership (uploaded in 2013 with more than 27,000 views as of July 2016).



Dr. Krivov edited a Bioenergy textbook.

Several VBI-supported researchers and educators contributed to the development of a bioenergy textbook edited by Dr. Anju Dahiya Krivov, *Bioenergy: Biomass to Biofuels* (Krivov, 2014). The textbook examines current and emerging feedstocks and advanced processes and technologies enabling the development of all possible



The Vermont Bioenergy Initiative website is a repository of all materials and resources developed by VSJF and subrecipients, including a video on algae and bioenergy that has been viewed more than 27,000 times.

alternative energy sources: solid (wood energy, grass energy, and other biomass), liquid (biodiesel, algae biofuel, ethanol), and gaseous/electric (biogas, syngas, bioelectricity). Divided into seven parts, Bioenergy gives thorough consideration to topics such as feedstocks, biomass production and utilization, life cycle analysis, energy return on energy invested, integrated sustainability assessments, conversion technologies, biofuel economics and policy. In addition, contributions from leading industry professionals and academics, augmented by related service-learning case studies and quizzes, provide readers with a comprehensive resource that connect theory to real-world implementation.

The work of the algae projects was highlighted at a VBI-sponsored conference, **Algae and Energy in the Northeast**, held in August 2010 in Burlington. This event drew 123 attendees from around the region for a day focused on sharing research findings, demonstration project progress, and lesson learned from research to-date. Response to the event was very strong with evaluations highlighting interest in the area and acknowledging the work supported by the VBI.

Presentations and abstracts from the conference are available here: www.uvm.edu/~epscor/index.php?Page=events/2010_algae_for_energy_conference.php.

- **Development of Microalgal Biofuels: A National Laboratory Perspective**
  Dr. Al Darzins, Principal Group Manager, NREL
- **Pumping Algae! An Alternative Energy Future**
  Donald Redalje, University of Southern Mississippi Department of Marine Science and Cofounder of HR BioPetroleum Inc.
- **Algae Grown on Agricultural Wastewater: Algal Production, Composition and Utilization**
  Dr. Walter Mulbury, Environmental Management and Byproducts Lab, USDA Beltsville, Maryland
- **Algae Farming for Biofuel Feedstocks**
  Dr. Ron Putt, Chemical Engineering Department, Auburn University
- **Algae to Biofuel: Opportunities and Challenges**
  Vikram M Pattarkine, PhD - CEO, PEACE USA and formerly CTO/Chief Scientist, OriginOil
- **Algae for Biofeeds and Biofuels**
  Dr. Ira Levine, University of Southern Maine
- **Reflections of a Life Time of Working with Algae Towards Useful Ends**
  Dr. John Todd, University of Vermont
- **Algae Culture and Biofuels Development in Integrated Systems**
  Dr. Mary Watzin, University of Vermont
- **Microalgae Production of Biodiesel**
  Dr. Ihab H. Farag, University of New Hampshire

NEXT STEPS

VBI efforts related to algal biofuels have led to regionally relevant strain isolation with strong promise for future oil production in cold climates. The work has also explored the synergies of algal biofuel production in conjunction with waste streams high in nutrients and CO_2. Lastly, a novel photoreactor system has been developed that dramatically improves direct production of biodiesel from algal systems. The combination of these outputs points to novel, regionally appropriate technologies that have the potential to make algae a future fuel scenario for Vermont and the Northeast.

- Isolated, regional algae strains will be leveraged in projects aimed to scale up production through integration with waste streams such as new community biodigesters.
- With the granting of a U.S. Patent for their system, Green Mountain Spark intends to pursue commercialization and scaling activities to further develop their photoreactor.

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COMMERCIAL BIODIESEL

U.S. DOE Award #DE-FG36-08GO88182

ABOUT THE VERMONT BIOENERGY INITIATIVE

The purpose of the **Vermont Bioenergy Initiative** (VBI) was to foster the development of sustainable, distributed, small-scale biodiesel from oilseeds and algae and grass/mixed fiber industries in Vermont that would enable the production and use of bioenergy for local transportation, agricultural, and thermal applications. Our investments in feasibility analyses, research and development, and demonstration projects for various bioenergy feedstocks were intended to lead to their commercialization over 7 year time horizon. This initiative was a statewide market building approach to sustainable development that may be replicated in other rural states around the country.

As a grant-making entity, project manager, and technical assistance provider, the Vermont Sustainable Jobs Fund (VSJF) solicited and selected the best sub-recipient proposals for bioenergy related projects through a competitive Request for Proposal process and conducted a number of staff directed investigations, all designed to support the four key priorities of the U.S. Department of Energy's EERE Strategic Plan:

1.) Dramatically reduce dependence on foreign oil;
2.) Promote the use of diverse, domestic and sustainable energy resources;
3.) Reduce carbon emissions from energy production and consumption;
4.) Establish a domestic bio-industry.

Thank you to the office of U.S. Senator Patrick Leahy for securing three U.S. Department of Energy congressionally directed awards (FY08, FY09, FY10) to financially support the Vermont Bioenergy Initiative.

Learn more at

VERMONT BIOENERGY INITIATIVE

http://vermontbioenergy.com

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Vermont Sustainable Jobs Fund

WWW.VSJF.ORG

The Vermont Sustainable Jobs Fund (VSJF) is a 501 (c)(3) nonprofit based in Montpelier, Vermont. VSJF was created by the Vermont Legislature in 1995 to nurture the sustainable development of Vermont's economy.

VSJF provides business assistance, network development, research, and financing in food system, forest product, waste management, renewable energy, and environmental technology sectors.

COMMERCIAL BIODIESEL SUMMARY

Distillate consumption in Vermont increased 48% from 1960 to 2013 and is equal to 29% of petroleum consumption. About 28% of distillate consumption in Vermont is for transportation, with the rest used for heating. The Vermont Bioenergy Initiative marked the first strategic effort to reduce Vermont's dependency on distillate fuel—mainly used for home heating and transportation—through the development of homegrown alternatives. Biodiesel is a commercially available, renewable, low carbon diesel replacement fuel that is widely accepted in the marketplace.

The VBI worked with commercial fuel dealers to support commercialization of blended biodiesel through investment in:

1. Establishing blending infrastructure at existing fuel dealers in Vermont,
2. Development of commercial scale biodiesel production infrastructure, and
3. Facilitation and support of biofuels network development in the state and region

In particular, this task was intended to complement the research and development work in algal and oilseed biodiesel production on farms by providing for the development of commercial processing and distribution channels which could support a locally produced bioenergy market once it matured in the state.

THE OPPORTUNITY

A 2011 study commissioned by the Vermont Bioenergy Initiative explored challenges to increased biodiesel adoption by interviewing stakeholders from four key sector groups: commercial end-users, residential end-users, fuel dealers, and biodiesel producers (Spring Hill Solutions, 2011). According to these stakeholders, the primary challenges were:

- Fuel availability
- Convenience of use and delivery
- Price of biodiesel
- Technical issues

However, the fact that fuel availability, technical issues, and convenience of use were cited by users as challenges suggested that this is not just a "demand-side" problem. For their part, Vermont fuel dealers that had carried biodiesel in previous years cited four main reasons for no longer doing so:

- Infrastructure issues
- Supply issues
- Low customer demand
- Expiration of the federal biodiesel tax incentive in 2009

Given the status of commercial biodiesel distribution systems and past experiences by both dealers and customers, there was a need for support of further development.

STATEMENT OF PROJECT OBJECTIVES

The Vermont Sustainable Jobs Fund, through its Vermont Bioenergy Initiative, made a series of grants to sub-recipients (Table 1) in the area of commercial biodiesel focused on research and development, systems feasibility and demonstrations, and education and outreach ("Task G").

To address the question of biodiesel and bioheat adoption as viable options for Vermont, this project developed four objectives:

Task G: Expansion of Commercial Biofuels Availability

SUB-TASK G.1: RESEARCH AND DEVELOPMENT

The objective of this task was to provide sub-recipient award funding to Vermont fuel dealers to complete land use and/or engineering feasibility studies and/or analyze financing options for new or improved capacity (e.g., to comply with new EPA rules, to provide biodiesel and bioheat in underserved areas of the state) or to expand into other renewable fuels.

- There were no sub-recipients under this sub-task.

SUB-TASK G.2: DEMONSTRATION / BIODIESEL

The objective of this task was to provide sub-recipient award funding to enhance biodiesel blending capacity in the state.

- **Bourne's Energy:** The objective of this project was to renovate an existing facility to provide the capability of blending biodiesel for sale to end-users of on-road, off-road diesel and home heating fuel.

- **D&C Transport, Inc.:** The objective of this project was to provide B2 to B100 to customers in northern Vermont.

- **Nava Bioenergy:** The objective of this project was to improve processing technology, refine the process chain, and maximize production in order to lower production costs and profitability of biodiesel production in Central Vermont.

SUB-TASK G.3: DEMONSTRATION / BIOMASS FUEL

The objective of this task was to provide sub-recipient award funding to enhance bulk distribution of biomass heating fuel in the state.

- There were no sub-recipients under this sub-task.

TABLE 1: COMMERCIAL BIODIESEL SUB-RECIPIENTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08	Bourne's Energy	$45,000	$98,370	$143,370
FY08	D&C Transportation	$32,500	$126,911	$159,411
FY09	Nava Bioenergy	$45,000	$49,077	$94,077
	TASK TOTAL	**$122,500**	**$274,358**	**$396,858**

Establishing Blending Infrastructure

The VBI provided funding support to two commercial fuel dealers for the development of blending infrastructure. Blending systems enable the proper mixing of 100% biodiesel (B100) with petroleum diesel that provides important technical and economic benefits for the early adoption of biodiesel. At the time of these projects, a blending tax credit was being provided to distributors of fuel to incentivize biodiesel purchase and use while also not exposing the market to increased risk from a complete switch. The use of a blended fuel helps to minimize technical risk that comes along with the use of 100% biodiesel (e.g., engine fuel system issues, suspension of sediment in old tanks, cold-weather performance challenges).

Bourne's Energy

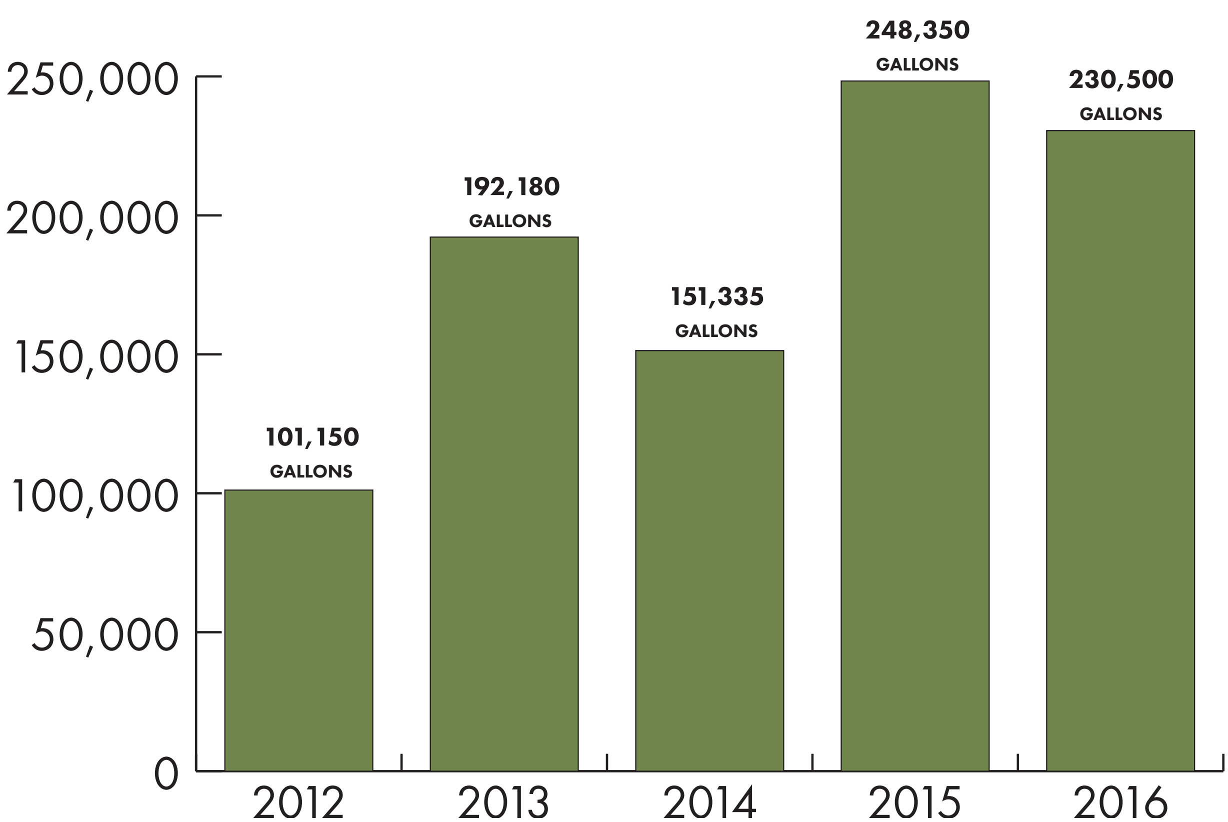
The goal of this project was to renovate an existing facility to give **Bourne's Energy** the capability of blending biodiesel for sale to end-users of on-road and off-road diesel and home heating fuel. In 2011, a 36'x 30' heated steel building was constructed in Morrisville around a 20,000 gallon tank moved from Bourne's Waterbury facility. Biodiesel injection blending equipment was purchased and installed with necessary valves and controls to allow proper

Ribbon cutting at Bourne's Energy's biodiesel blending facility. Left to Right: Elizabeth Miller (then the Commissioner of Vermont Department of Public Service), Netaka White (VBI), Tom Berry (U.S. Senator Leahy's Office), Peter Bourne (owner of Bourne's Energy) blending for heating fuel and diesel in the desired percentage. This developed the firm's capability of increasing their customer base by providing a desired blend and increasing the use of biodiesel for transportation and heating oil, thereby reducing CO_2 emissions. Bourne's biofuel has replaced about 1,000,000 gallons of fossil fuel oil with clean, high-quality, certified ASTM D6751 low sulfur biodiesel for home heating, vehicles, and equipment since 2012 (Figure 1).

Bourne's Energy biodiesel blending facility.

The grant gave us the ability, to what will be in 2016, a million gallons of totally renewable products to our customers and prove that traditional oil heat can easily be replaced with a better product while using existing infrastructures. — Peter Bourne, Bourne's Energy

FIGURE 1: BOURNE'S ENERGY BIODIESEL SUPPLY



Bourne's credits the VBI funding with expediting the project; the facility was operational after a short seven-month time frame enabling Bourne's to provide product to end-users. The construction and installation of equipment was completed at a total cost of $143,370 and was completed in May 2011.

D&C Transport

D&C Transportation's objective was to provide B2 to B100 to an existing customer base in northern and north central Vermont. Biofuel products were neither offered nor readily available in this area of Vermont at the time of this VBI supported project. The project objective was to install a 12,000 gallon above ground tank (AGT) to store B100 product. In order to facilitate the need for keeping the B100 heated in the colder months, the AGT was housed inside an existing heated storage building. The tank was piped underground to the loading rack through a computerized blending/control valve bank.

By modifying existing equipment and installing ratio blending controls at their Newport facility, D&C Transportation expanded and diversified their product line by providing blended biodiesel to retail customers, state and municipal customers and other vendors. The VBI funds were used to offset the costs of the purchase of the Junge Controls Inc. Fuel Manager system that provides the blending function.

D&C found the Junge Controls Fuel Manager system to be user friendly. The biggest challenge was to overcome the effect of the colder ambient temperatures on the B100. Early on, the firm blended fuel only in the warmer months when the ambient air temperatures were above 48 degrees. They applied heat tape and insulated the exposed B100 piping to assist with this need.

Development of Commercial Scale Biodiesel Production

The VBI provided grant support to a small-scale commercial biodiesel production facility during its start-up phase. This was done in parallel with investments in farm-based, oilseed production systems to foster market development at multiple scales and along multiple channels. The work done at the farm scale was considered relatively novel and higher risk, whereas the work done at the commercial scale was well-established at the time in other parts of the country and offered a higher chance of success and volume impact.

__Nava Bioenergy, LTD__

The purpose of this project was to improve processing technology, refine the process chain, and maximize production in order to lower production costs and profitability of biodiesel production in Central Vermont. Nava Bioenergy purchased processing equipment to improve the separation of the biodiesel and glycerin, and a methanol recovery unit to improve fuel quality, lower its environmental footprint and reduce expenses. *Note: this sub-recipient was originally reviewed by US DOE and NEPA as a Task F – Oilseed Program project.*

Nava's primary business was to process used vegetable oil and oils produced from locally grown crops for conversion into biodiesel using the transesterification method. They also focused on the use of machinery and process equipment that would be economical, energy efficient and that would enhance the production process and improve the quality of final product.

Interior of Nava Bioenergy facility.

The VBI grant enabled Nava to purchase process equipment that was needed to meet and surpass the firm's goals and objectives and to produce a high quality product that exceeds the U.S. Standard for Biodiesel, ASTM D6751. Nava also improved the filtering system and quality control using batch glycerin testing. They also designed and built an easy, convenient and practical used oil collection system that was tested and approved by New England Culinary Institute.

A biodiesel hose, new gear pump and custody transfer metering system were added to the customer delivery system. Additionally, Nava purchased two double wall insulated/heated stainless steel tanks; 400 gallons for pre-mixing and 1,000 gallons for final product storage.

While Nava's customer base was starting to grow, feedstock supply did not parallel this growth. Locally produced vegetable oils were not available at volumes necessary for high volume biodiesel production and used oil from restaurants likewise became scarce due to commoditization. While there is sufficient used oil for biodiesel production in Vermont, competition from out of state companies developed (White Mountain Biodiesel opened in 2008 in Haverill, NH) and used oil started to command much higher prices.

Although Nava anticipated moving into a new, larger building in mid- 2012, it never materialized. This sub-recipient has since closed its doors.

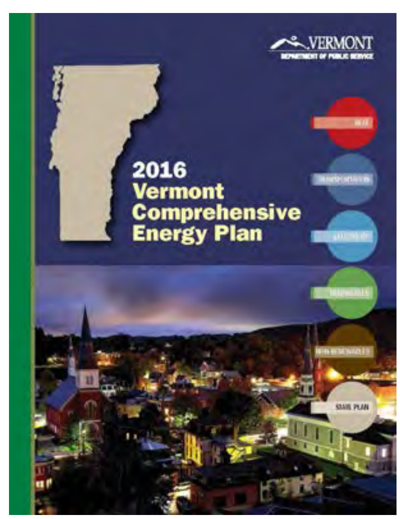
Education and Outreach

Renewable Energy Vermont

The purpose of this project (2009-2010) was to improve communication and networking opportunities within the emerging commercial biofuels sector. Renewable Energy Vermont (REV) convened a Biofuels Working Group comprised of a cross-section of key biofuels players from the following local businesses: Green Technologies and Biocardel (biodiesel producers), Bourne's Energy (fuel distributers), Green Mountain Coffee Roasters (biodiesel fleet operators), a biofuels consultant, Vermont Sustainable Jobs Fund, the Vermont Fuel Dealers Association (VFDA), REV (fuel and renewable energy industry trade groups), and AgRefresh (private sector business involved in biofuels and carbon policy work). The goal of the Biofuels Working Group was to address the strategic growth of the Vermont biofuels industry with an emphasis on identifying gaps in marketing, public relations, and public policy, and to initiate activities to fill identified gaps.

In addition, REV staff provided biofuels education to its members and the community at large through its website, newsletter, and annual conference, and by representing the biofuels industry at other renewable energy-advocacy meeting and ensuring bioenergy was included in reports, energy planning and projections, legislative strategizing, and so on. REV also assisted the VSJF in conducting a survey of biofuel producers and consumers to help determine ways of increasing demand and supply (Spring Hill Solutions, 2011). The project was not sustained after the grant period ended.

Vermont's Comprehensive Energy Plan input (2011 and 2016)



The VSJF Bioenergy Program Director worked closely with Vermont bioenergy stakeholders in the public, private and nonprofit sectors to prepare recommendations for the Vermont Department of Public Service' (DPS) twenty year Comprehensive Energy Plan (released in December 2011). Responsibilities included participation in a number of meetings and forums with the public, DPS staff, and state government officials, convening a VSJF led agricultural biomass stakeholder group forum, and completing several policy papers to DPS with crosscutting recommendations for bioenergy market development. Comprehensive Energy Plan pages 205 – 217 were written by VSJF staff.

For the 2016 update to **Vermont's Comprehensive Energy Plan**, VBI consultant Chris Callahan and VSJF staff member Scott Sawyer, contributed important bioenergy industry updates, graphics, and maps to what became the final plan document (pp. 352-366).

NEXT STEPS

In 2016, the Vermont Department of Public Service released the Vermont Comprehensive Energy Plan, which calls for obtaining 90% of the state's energy from renewable sources by 2050 and reducing greenhouse gas emissions 50% from a 1990 baseline. The plan calls for major decreases in petroleum use through the electrification of vehicle fleets, wider use of heat pumps, and increased use of bioenergy. The VBI set the stage for increasing the production and consumption of biodiesel— the commercial biodiesel infrastructure supported by the VBI has helped to orient two large fuel dealers in Vermont to the handling and mixing of this biofuel. This improved integration of a new fuel into the distribution channel sets the stage for future growth in the use of biodiesel. but Vermont will have to overcome several obstacles to accomplish that state's long-term energy goals. Despite all of its benefits as a renewable, low-emission fuel with strong potential local economic development, biodiesel remains an underutilized resource with low market penetration in Vermont. Vermont biodiesel consumption peaked in 2008 at 5,632,000 gallons and fell in 2009 to 1,885,500 gallons. In addition, the number of fuel dealers carrying biodiesel fell from 18 in 2008, to eight currently.

REFERENCES

Spring Hill Solutions. (April 2011). *Vermont Biodiesel Supply Chain Survey*. Retrieved from: http://vermontbioenergy.com/wp-content/uploads/2013/09/VSJF-Vermont-Biodiesel-Supply-Chain-Survey-Final-Report.pdf.

VERMONT BIOENERGY INITIATIVE

A program of the Vermont Sustainable Jobs Fund

RENEWABLE ENERGY ATLAS

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ATLAS SUMMARY

The Renewable Energy Atlas of Vermont was developed as a GIS-based website for identifying, analyzing, and visualizing existing and promising locations for renewable energy projects. The Atlas was devised to fulfill basic research and education needs for bioenergy market development for the Vermont Bioenergy Initiative, but was expanded to include a wider range of renewable energy products.

The Atlas was created to assist town energy committees, Vermont's Clean Energy Development Fund and other funders, farmers, educators, planners, policy-makers, and businesses in making informed decisions about the planning and implementation of renewable energy in their communities—decisions that ultimately lead to successful projects, greater energy security, a cleaner and healthier environment.

The state-of-the-art Atlas was the first tool of its kind in the United States that enabled end users to *click* on their town (or several towns or county/counties) and select from a suite of renewable energy options: biomass, efficiency, geothermal, hydroelectric, solar, and wind. In 2016, the Atlas was merged into the Energy Action Network's **Community Energy Dashboard** a powerful suite of interactive tools to set goals, track progress, map actions, share stories, and hear from trusted neighbors. The Dashboard helps translate Vermont's goal of 90% by 2050 into achievable action.

The results of this body of work include:

- First of its kind resource assisted Regional Planning Commissions, Vermont Department of Public Service, **Vermont Energy and Climate Action Network**, and other stakeholders in analyzing renewable energy potential and reporting results.
- Creation of renewable energy GIS data layers available for download at the **Vermont Center for Geographic Information** website.
- Creation of database of all renewable energy installations in Vermont.

THE OPPORTUNITY

Throughout America, concerns about economic security, dependence on foreign oil supplies, and the realities of oil depletion and climate change are leading public officials, research laboratories, educational institutions, investors, and entrepreneurs to accelerate the rate of research and capital deployment for renewable energy sources and increased energy efficiency. When the VBI began in 2008, for example, the State of Indiana initiated a comprehensive project called BioTown USA, and discovered that it was thermodynamically possible to convert a small, 'test' town from reliance on fossil fuels to biomass-derived fuels and electricity (Jenner, 2006). At the national-scale, the Department of Energy and the Department of Agriculture (2005) sponsored a study that determined that America could replace 30% of imported petroleum with one billion tons of biomass. At a global-scale, in 2007 REN21 calculated that over $100 billion was invested in new renewable energy capacity, manufacturing plants, and research and development, which they called "a true global milestone" (2008: 6).

Growing interest in energy issues and climate change set the stage for Vermont to accelerate its transition toward a renewable energy and energy efficiency based economy. A series of studies and collaborative processes completed just as development of the Renewable Energy Atlas was underway identified pathways for developing diversified, community-scale renewable energy and energy efficiency projects that can increasingly replace our dependence on non-renewable electric and liquid fuel supplies.

For example, a public engagement process and deliberative polling exercise conducted by the Vermont Department of Public Service demonstrated a strongly voiced desire for locally produced, renewable energy and energy efficiency (Wark, 2008). In 2007, the Vermont Council on Rural Development convened a Rural Energy Council to answer the question: "What combination of conservation, efficiency, in-state electric generation and alternative fuel development will effectively provide the leverage to support the prosperity and sustainability of Vermont communities?" The Rural Energy Council issued two reports, The Vermont Energy Digest and Strengthening Vermont's Energy Economy, that identified a number of recommendations for policy-makers, as well as a series of energy development scenarios that would create jobs, reduce emissions, and provide for between 3.95 to 9.26 percent of Vermont's energy consumption.

In 2008, Vermont's (now defunct) 25 by '25 Initiative Steering Committee published preliminary findings and conclusions for consideration by policy-makers (Spring Hill Solutions, 2008). The Steering Committee calculated that Vermont could generate 25.71% of its energy needs from renewable sources by 2025, with about 79% of that total coming from agricultural and forest resources.

In 2007, the Biomass Energy Resource Center (BERC) completed The Vermont Wood Fuel Supply Study for the Vermont Department of Forests, Parks & Recreation and the Vermont Department of Buildings & General Services. This study attempted to answer the question: "How much wood is out there?" It analyzed the potential supply of low-grade wood from the net annual growth on accessible timberland in all of Vermont's counties and 10 adjacent counties in New York, Massachusetts, and New Hampshire. Depending on the scenario, BERC estimated that there are between 387,491 and 2,342,053 green tons of wood available from Vermont counties, with Windham County having the highest concentration of net available low-grade wood.

In 2003, Vermont Environmental Research Associates (VERA) completed a study for the Vermont Department of Public Service that estimated the wind power potential on public lands in Vermont. The study determined that nearly 3,830 square miles, or 41%, of Vermont's land area falls under a wind class of 1 to 3. The U.S. Department of Energy (DOE) estimates that Vermont has useful solar resources—3,500 to 4,000 Whr per square mile per day—for flat plate collectors; vast low-temperature resources suitable for geothermal heat pumps; and good hydro resources.

In 2015, the Vermont legislature passed the second strongest renewable portfolio standard in the country—H.40 (Act 56) - RESET, which requires utilities to purchase 55% of electricity from renewable sources (or renewable energy credits) by 2017 and 75% by 2032. Vermont's Comprehensive Energy Plan calls for 90% of the state's energy consumption to be derived from renewable sources by 2050 (up from 20% today—mostly renewable electricity from hydropower, biomass, and wind, followed by wood for heating and ethanol).

As these studies suggest, the cumulative impact of a combination of demand-side and supply-side projects can make a substantial impact on Vermont's energy future by reducing energy demand and increasing the supply of renewable energy.

With so many valuable pieces of information gathered, Vermont has effectively answered the "why" and "what" questions. Why focus on renewable energy and energy efficiency? Because they provide plausible avenues for Vermont to 1) create jobs, 2) prepare for, mitigate against, and adapt to peak oil and climate change, 3) and Vermont has the human, technological, and natural resources to accomplish the goal of replacing 25% of its energy demand with renewable, locally produced energy by 2025. What types of renewable energy sources and technologies, as well as energy efficiency opportunities, are available and feasible in Vermont? Except for ocean tidal power, Vermont has access to the full suite of renewable energy and energy efficiency options.

The Atlas tried to answer "where" and "how" questions. Where will Vermont's bioenergy, wind, solar, geothermal, small-scale hydro, and efficiency technologies be located? Vermont is an ideal location to explore the creation of distributed renewable liquid fuel production and electricity generation in strategically identified locations around the state. The precedent for the Renewable Energy Atlas of Vermont was set by the **Renewable Energy Atlas of the West** and the **Renewable Energy Atlas of Alaska**. Both efforts used Geographic Information System (GIS) technology to develop renewable resource maps for policy-makers and others. However, the Atlas of the West and the Atlas of Alaska were state-level printed snapshots, while the Renewable Energy Atlas of Vermont provided Town and County level data via a dynamic website.

STATEMENT OF PROJECT OBJECTIVES

The purpose of this project was to create the Renewable Energy Atlas of Vermont, a GIS-based mapping website that analyzed potential biomass resources that could be sustainably used for bioenergy production. The scope of the project was expanded to include all renewable energy resources in Vermont. VSJF worked with Mike Brouillette, Senior Project Manager at the Vermont Center for Geographic Information, to develop data "layers" to depict renewable energy potential. We worked with Fountains Spatial (now VHB) and Overit Media to program and develop the website, and we later worked with Vermont Design Works to design, program, and merge the Atlas into the Energy Action Network's Community Energy Dashboard.

RENEWABLE ENERGY ATLAS AND COMMUNITY ENERGY DASHBOARD

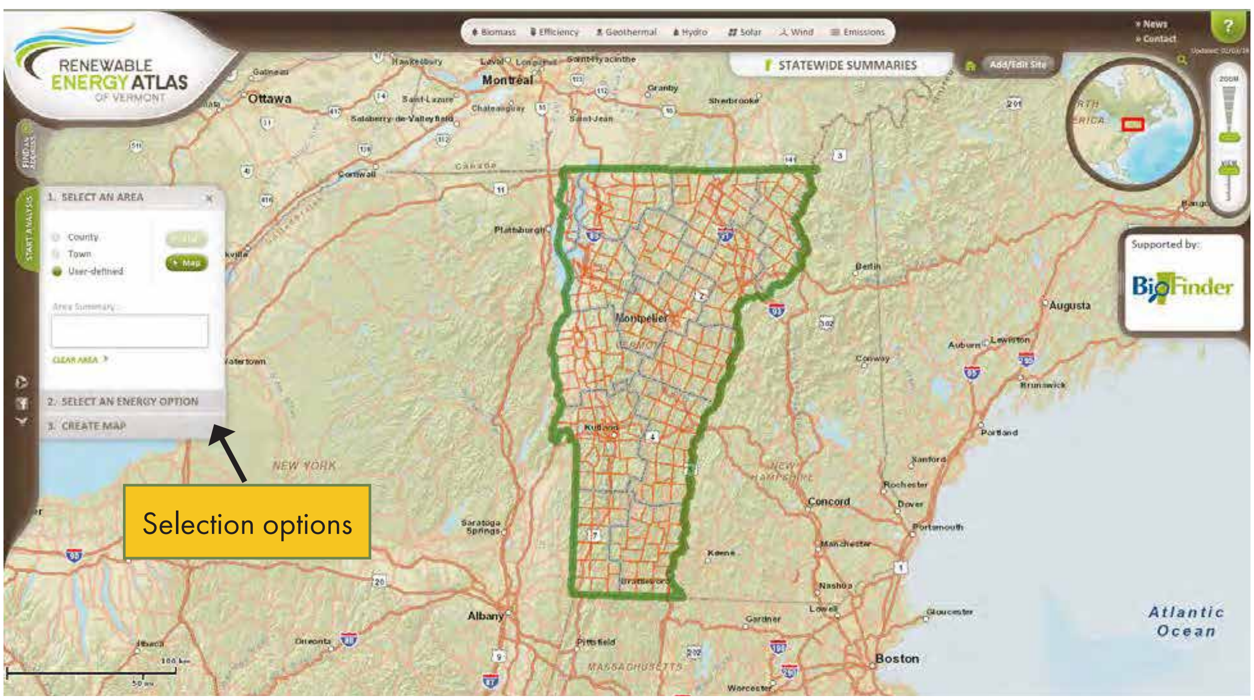
Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Project Cost
FY08-10	**VSJF:** project management	$82,214	$82,214
FY08-10	**Vermont Center for Geographic Information:** Energy data layer creation	$116,667	$116,667
FY08-10	**Fountains Spatial:** website development and hosting	$114,067	$114,067
FY08-10	**Vermont Design Works:** Community Energy Dashboard data conversion	$32,129	$32,129
	TASK TOTAL	**$345,077**	**$345,077**

RENEWABLE ENERGY ATLAS OF VERMONT

To develop the Atlas, VSJF interviewed the organizations responsible for the creating the BioTown, USA report, the Renewable Energy Atlas of the West, and the Renewable Energy Atlas of Alaska. In March 2008, we began working with the Vermont Center for Geographic Information (VCGI) to discuss data sources, technical assistance, scope of work, budget, and recommendations for a technical working group. We sought guidance from the now defunct Vermont 25 by '25 steering committee, developed a technical work group, prepared a request for proposals for website development firms, and successfully hired Fountains Spatial (now VHB) to build the website. Along the way VSJF identified and engaged partner organizations to increase buy-in and to utilize all available expertise.

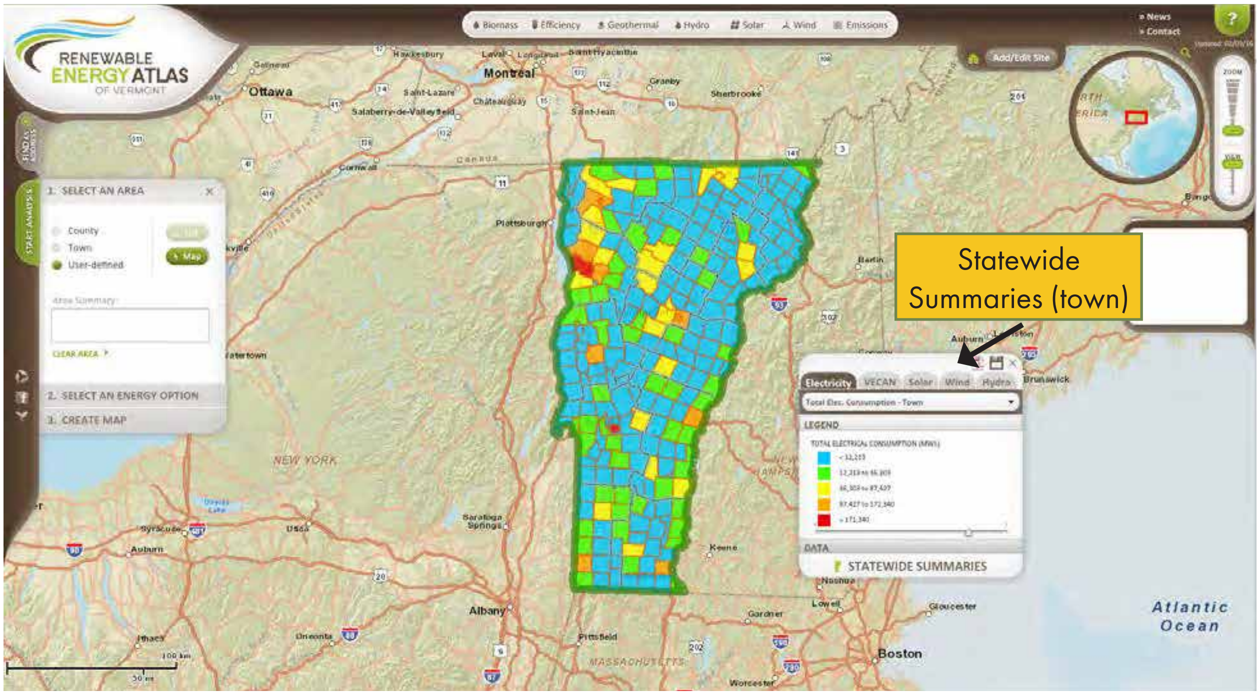
The Renewable Energy Atlas of Vermont went live on April 22, 2010— Earth Day.

RENEWABLE ENERGY ATLAS — HOMEPAGE

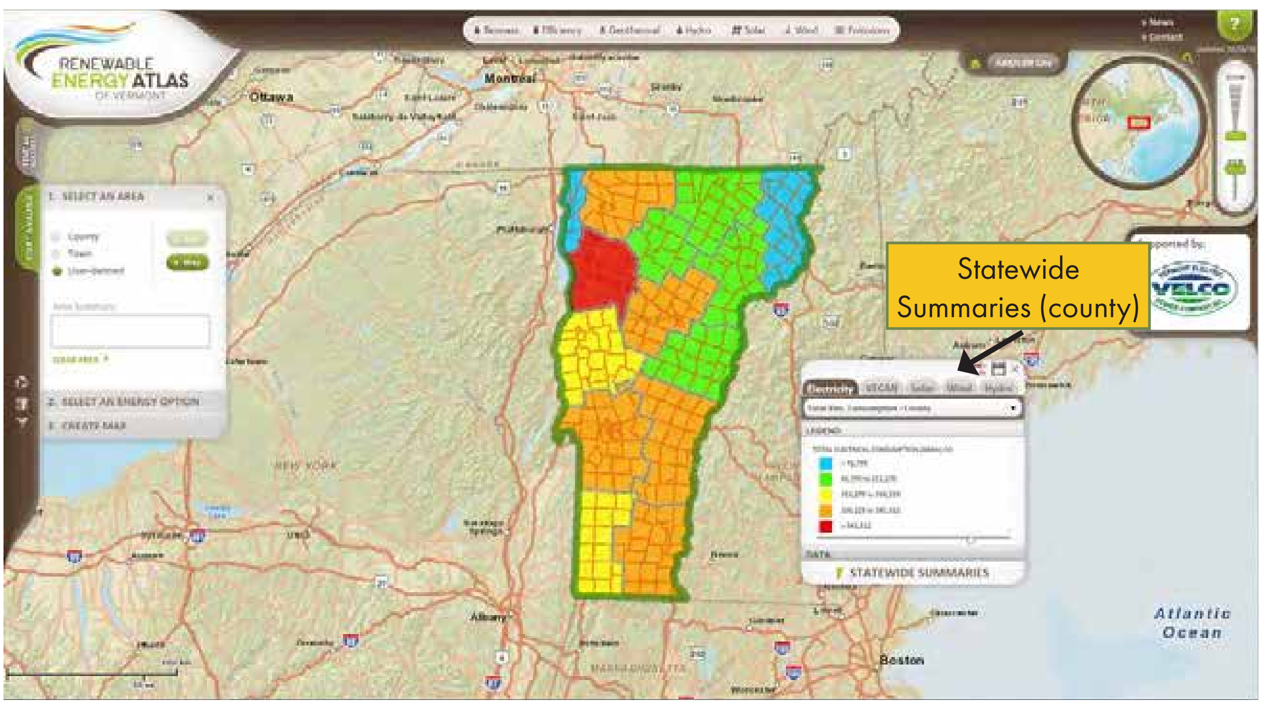


The Renewable Energy Atlas of Vermont homepage featured selection options for Areas (e.g., Town, County, Draw Your Own), Energy (e.g., Biomass, Geothermal, Hydro, Solar, Wind), and Creating a Map on the left side of the screen. Users could find their own address on the map, zoom in and out, and change their View from street maps and satellite maps. A button at the top of the screen ("Add/Edit Site) allowed users to enter their own energy sites or make edits to existing sites.

RENEWABLE ENERGY ATLAS — STATEWIDE SUMMARIES

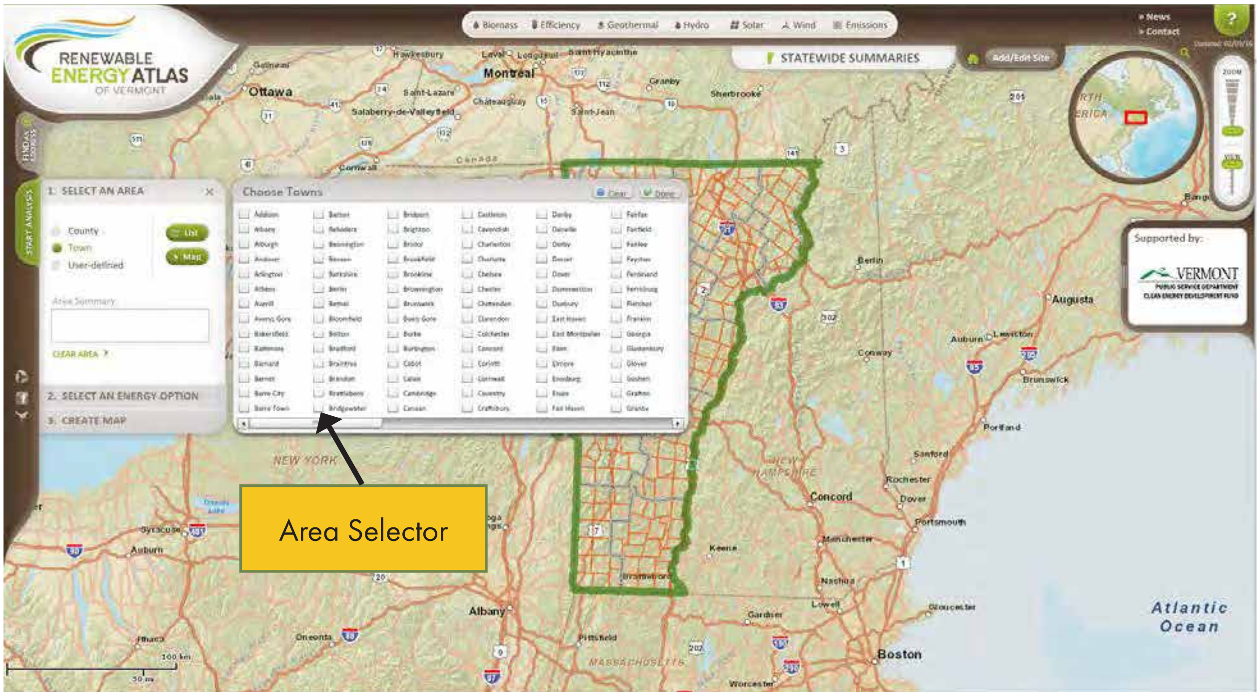


Atlas users could click on a button at the top of the screen called "Statewide Summaries" to view Town level summaries of solar, wind, and hydro installations and installed capacities, as well as electricity consumption and savings data.



Atlas users could click on a button at the top of the screen called "Statewide Summaries" to view County level summaries of solar, wind, and hydro installations and installed capacities, as well as electricity consumption and savings data. Statewide Summaries allowed for at-a-glance comparisons of communities in Vermont.

RENEWABLE ENERGY ATLAS — AREA SELECTOR

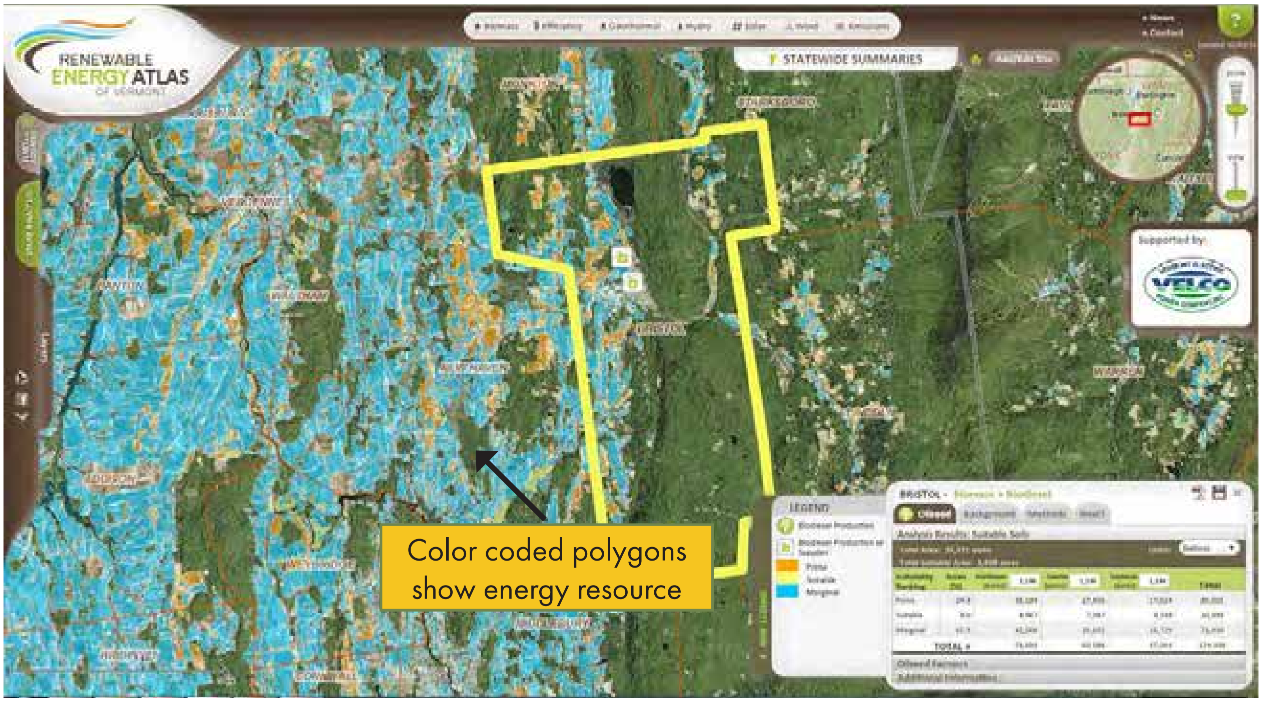


Atlas users could select their town or county from a list of towns and counties, or by clicking directly on the map.

RENEWABLE ENERGY ATLAS WITH TOWN SELECTED

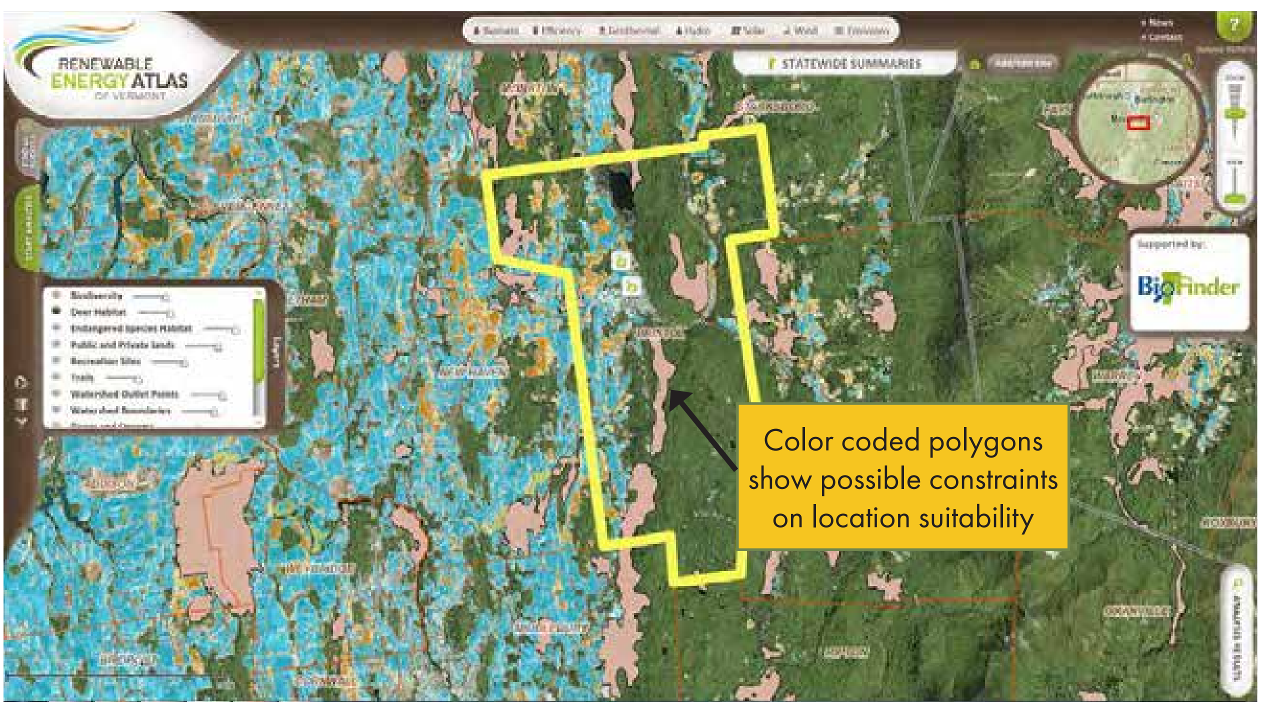
Once an Area was selected, the map would zoom into that location. Atlas users could then select an Energy option.

RENEWABLE ENERGY ATLAS WITH ENERGY LAYER SELECTED

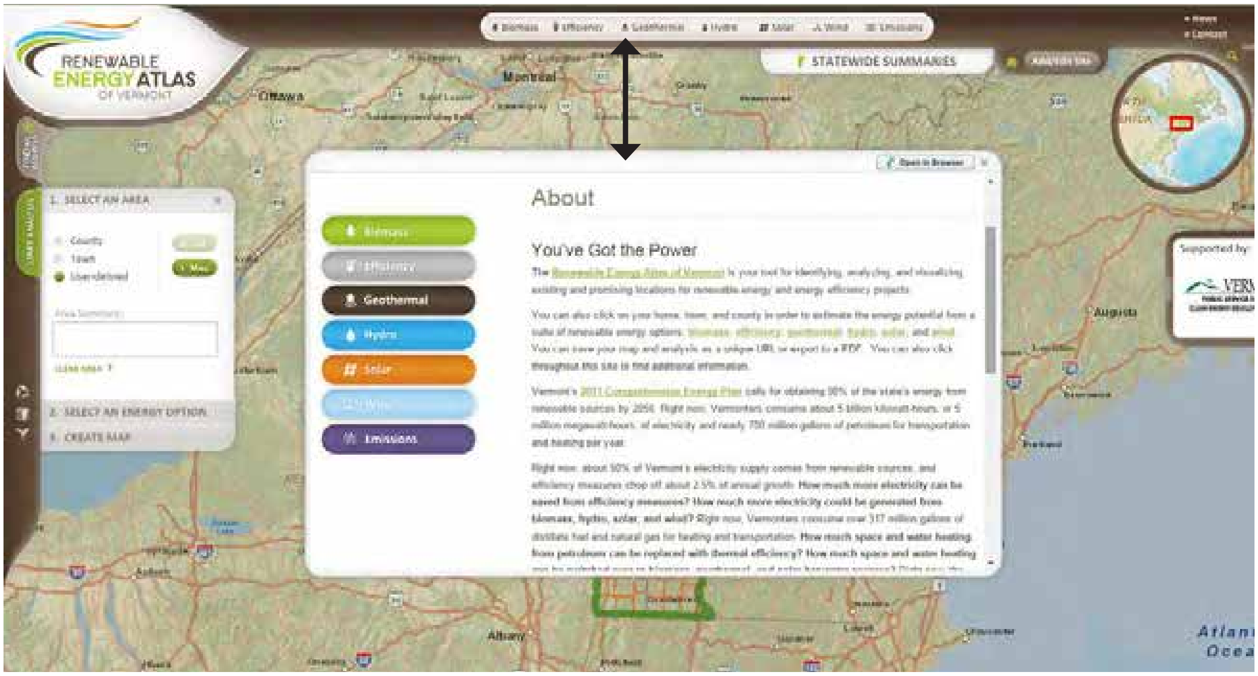


After an Area was selected, Atlas users could choose a variety of energy options. In this example, Oilseed Crop Biodiesel was selected. The map shows soil polygons deemed suitable for growing sunflowers, canola, and soybeans. An Analysis Results panel appeared in the lower right corner of the screen, containing a Legend, and calculation tools for crop and biodiesel production.

RENEWABLE ENERGY ATLAS WITH DEER HABITAT LAYER SELECTED



Atlas users could turn on additional "suitability" layers. In this case, the Deer Habitat layer is turned on.



A set of resources across the top of the screen provided additional information about Biomass, Effiency, Geothermal, Hydro, Solar, and Wind energy, as well as data about Vermont's greenhouse gas emissions. These resources opened into a separate WordPress website that contained funding sources, data sources, and resources by energy category.

Data Layers and Analysis

VCGI used the ESRI Spatial Analysis Model Builder tool to develop and process renewable energy data layers. Model Builder is a series of process wizards and diagramming tools that aid in the construction of spatial models represented as process flow diagrams. These flow diagrams aid in the visualization of the process being modeled, their quality control review, and they can be saved, documented, shared and easily rerun when variables are modified for model calibration. Individual metrics are treated as building blocks that can be combined in a variety of ways in the ESRI Model Builder environment. This approach is flexible and allows for customization of individual metrics as needed.

VSJF built the "sites" database that includes renewable energy installations, installed capacity, and additional relevant information about these sites (e.g., residential, farm, business). Data for all of the sites that appear as pins on the map are collected from "certificates of public good" issued by the Vermont Public Service Board, the Vermont Dam Inventory, AgSTAR, and crowdsourcing. The sites database later became a major engine for the functionality and data displays on the Community Energy Dashboard.

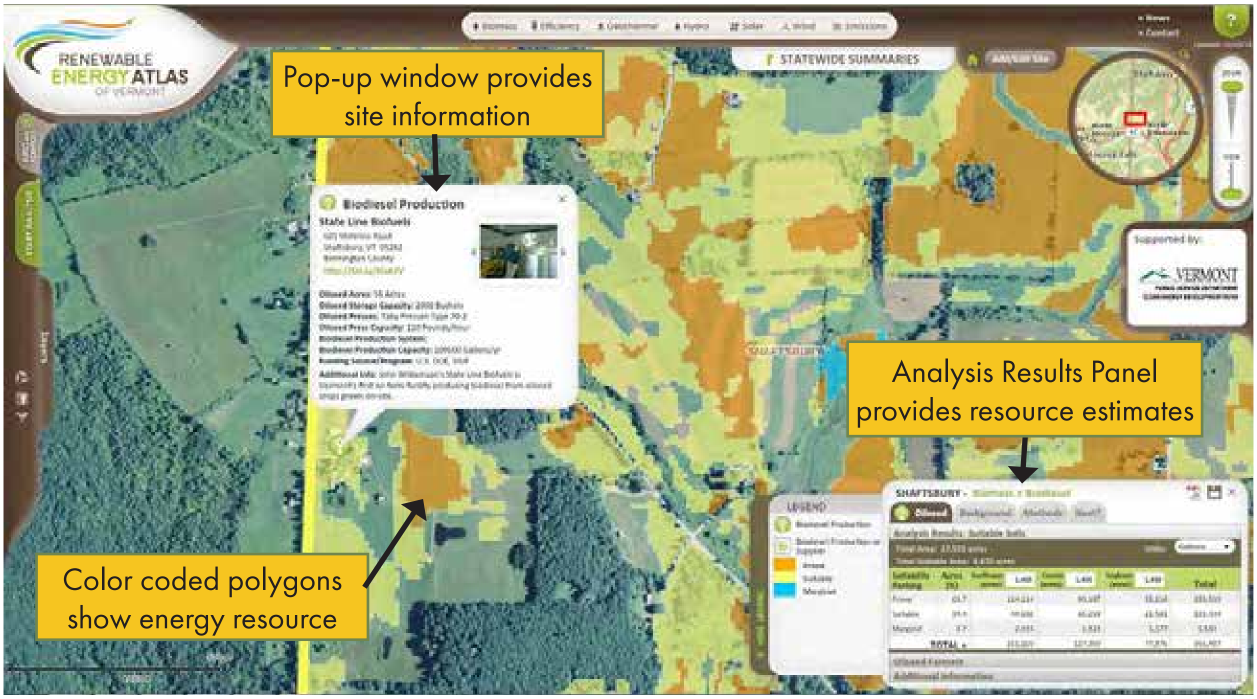
BIOMASS: The biomass layer refers to biologically-based feedstocks such as algae, food waste, grasses, methane, oilseed crops, and wood that can be converted into energy sources such as biodiesel, ethanol, and wood chips / pellets, which can run vehicles, heat buildings, or generate electricity. Atlas users had several options to choose from under the Biomass category: Oilseed Crop-based Biodiesel; Algae-based Biodiesel; Waste Vegetable Oil-based Biodiesel; Grass Energy; Anaerobic Digesters; "Waste"-to-Energy; and Woody Biomass.

- **Oilseed Crop-based Biodiesel:** Three crops that have been successfully grown in Vermont and converted into biodiesel were spatially depicted and analyzed: Canola, Sunflowers, and Soybeans.

At the time, no existing spatial data existed for the distribution of these biodiesel crops in Vermont. VCGI created the oilseed crop data layer using information from the USDA Natural Resources Conservation Service (NRCS) plants database growth requirements, input from Dr. Heather Darby (University of Vermont Extension), in-house data, and structured queries provided by the local USDA NRCS office while adhering to applicable Sustainable Biodiesel Alliance Baseline Practices within a number of their Sustainable Feedstock Categories. In cooperation with NRCS, VCGI queried the plant requirements for each crop from the Soil Survey Geographic Database (SSURGO) to produce a gross distribution extent of soil types. The SSURGO dataset exists for all counties in Vermont (except Essex County), but the data quality varies from county to county. To control and minimize soil erosion, those soils that are "highly erodible" were removed from consideration (i.e., not visible as a map polygon). Units for this data were provided in acres. Dr. Darby provided conversion values for those acres that appeared in the Analysis Results Panel (i.e., converting each crop type into bushels per acre for prime, suitable, and marginal soils; and then converting bushels in gallons; and acres into gallons of biodiesel).

When an Atlas user clicked on Biodiesel and selected "Oilseed Crop," they would see a map of agricultural soils (e.g., Prime, Suitable, Marginal) as color coded polygons that met oilseed crop growing conditions. Existing biodiesel production facilities were depicted as clickable map points. The Analysis Results Panel calculated conversion values on the fly (e.g., bushels per acre; oil (gallon) per bushel; and biodiesel (gallon) per acre).

RENEWABLE ENERGY ATLAS — OILSEED BIODIESEL LAYER SELECTED



In this example, the Town of Shaftsbury—home of State Line Biofuels—has been selected. Orange, yellow, and blue polygons indicate soil types. The pin for State Line Biofuels has been clicked on and a pop-up window describing the facility is visible. The Analysis Results Panel provides conversion values.

- **Algae-based Biodiesel:** Second generation biofuels such as algae are expected to produce substantially more fuel, using far less land, than first generation biofuels. National research and development was co-locating prototype algal photobioreactors with CO_2 and other greenhouse gas emitting facilities to aid in algal growth.

When an Atlas user clicked on Biodiesel and selected "Algae" the process was that they would see a map of existing methane digester locations (i.e., map pins) and wastewater treatment facility locations. This layer was speculative in the sense that it did not indicate how much algae could be produced, but rather where it might be produced.

- **Waste Vegetable Oil-based Biodiesel:** Waste vegetable oil produced at food establishments can be converted through the transesterification process into biodiesel.

When an Atlas user clicked on Biodiesel and selected "Waste Vegetable Oil" the map would populate with pins at the location of Food Establishments. This layer was speculative in the sense that we could identify the locations of most restaurants/food establishments but had no means of estimating the volume of waste vegetable oil being generated.

- **Grass Energy:** This layer considered two fast growing perennial grasses, switchgrass and big bluestem. National and international experts overwhelmingly emphasized switchgrass and big bluestem at the November 12, 2008 Vermont Grass Energy Symposium.

VCGI applied the same process used to develop the Oilseed Crop-Based Biodiesel layer, but, in this case, Dr. Sid Bosworth (University of Vermont) was consulted. When an Atlas user clicked on Grass Energy, they would see a map of agricultural soils (e.g., Prime, Suitable, Marginal) as color coded polygons that met perennial grass growing conditions. Existing pellet making facilities were depicted as clickable map points. The Analysis Results Panel calculated conversion values on the fly (e.g., tons per acre and million BTUs per acre).

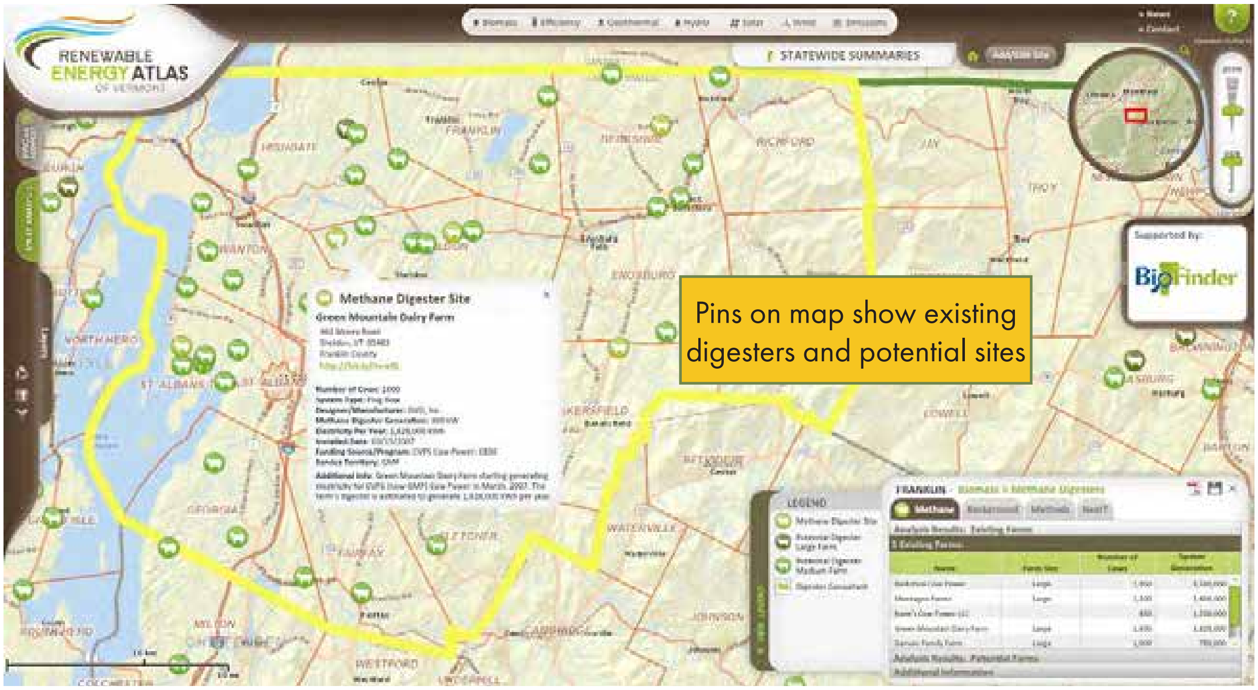
- **Manure / Methane:** Anaerobic digesters, or biodigesters, transform cow manure, corn silage, haylage, and other biological material into "biogas" or methane. Anaerobic digesters are basically covered tanks that heat up as the biological material decomposes in the absence of oxygen. Bacteria in the digester turn the biological material into biogas that can then be piped to a generator to create electricity and heat for the farm and/or be sold to the grid.

Methane digester sites were collected and verified from multiple sources, including "certificates of public good" issued by the Vermont Public Service Board, and AgSTAR, a program of the U.S. Environmental Protection Agency. When an Atlas user clicked on Manure/Methane, the process was that they would see a map of existing methane digester sites as well as large and medium dairy farms.

- **Waste to Energy:** Waste, in this case, referred animal waste, food waste, and electricity generation at landfills.

When an Atlas user clicked on "Waste" to Energy a map of dairy farms, restaurants, and landfill methane sites would appear. As with other layers, this layer was speculative in the sense that, except for landfill methane, it only indicated possible locations that waste was being generated.

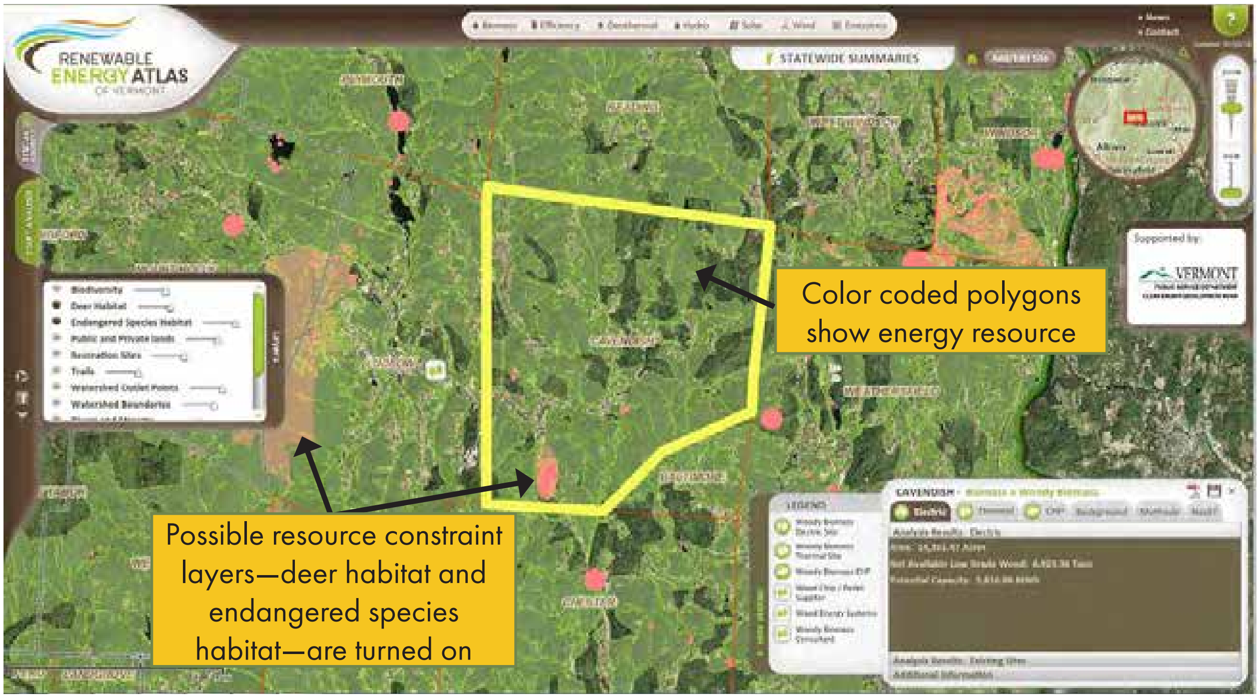
RENEWABLE ENERGY ATLAS — DIGESTER LAYER SELECTED



- **Wood (Chips / Pellets):** Wood chips / pellets can be burned in a boiler for heat, or to produce steam which then causes a turbine to rotate and generate electricity, or for combined heat and power possibilities.

VCGI worked with the Biomass Energy Resource Center (BERC) to develop this data layer. BERC has national and Vermont-specific expertise on a wide range of forest health and wood energy issues. BERC had developed a method of estimating the amount of Net Available Low-grade Growth (NALG) wood. This estimation is useful because it reports only the appropriate capacity of Vermont forests beyond existing demand for wood fiber (e.g., saw logs and firewood), however the estimations were limited to the county level. As part of a pilot project in Addison County, BERC developed an approach that allocated county level data to the town level. All forest land cover is extracted from the 2006 National Land Cover Dataset and further filtered using GIS to remove "mask" portions of the land base that should not be included for various reasons (e.g., ecological constraints). The product of available forest acreage data was input to a spreadsheet model using county specific USDA Forest Service data for forest ownership, inventory, composition, and growth on a per acre basis in order to calculate the estimated net annual growth of low-grade wood at the town level.

RENEWABLE ENERGY ATLAS — WOODY BIOMASS LAYER SELECTED



When an Atlas user clicked on Woody Biomass a map with color coded polygons indicating the forest resource as well as pins indicating woody biomass users appeared. The Analysis Results Panel calculated NALG wood in the selected boundaries on the fly and reported available tons. ►

- **Geothermal:** We focused on ground source heat pumps. There are four basic kinds of geothermal heat pump systems: Closed Loop Systems (vertical, horizontal, and pond) and Open Loop Systems (wells or water bodies).

No readily available data layer existed for the geothermal systems, but a composite layer for Closed and Open Loop Systems was constructed by VCGI. As with several other layers, the Geothermal layer was speculative in the sense that it does not indicate how much heat / energy can be produced, but rather where geothermal systems might be located.

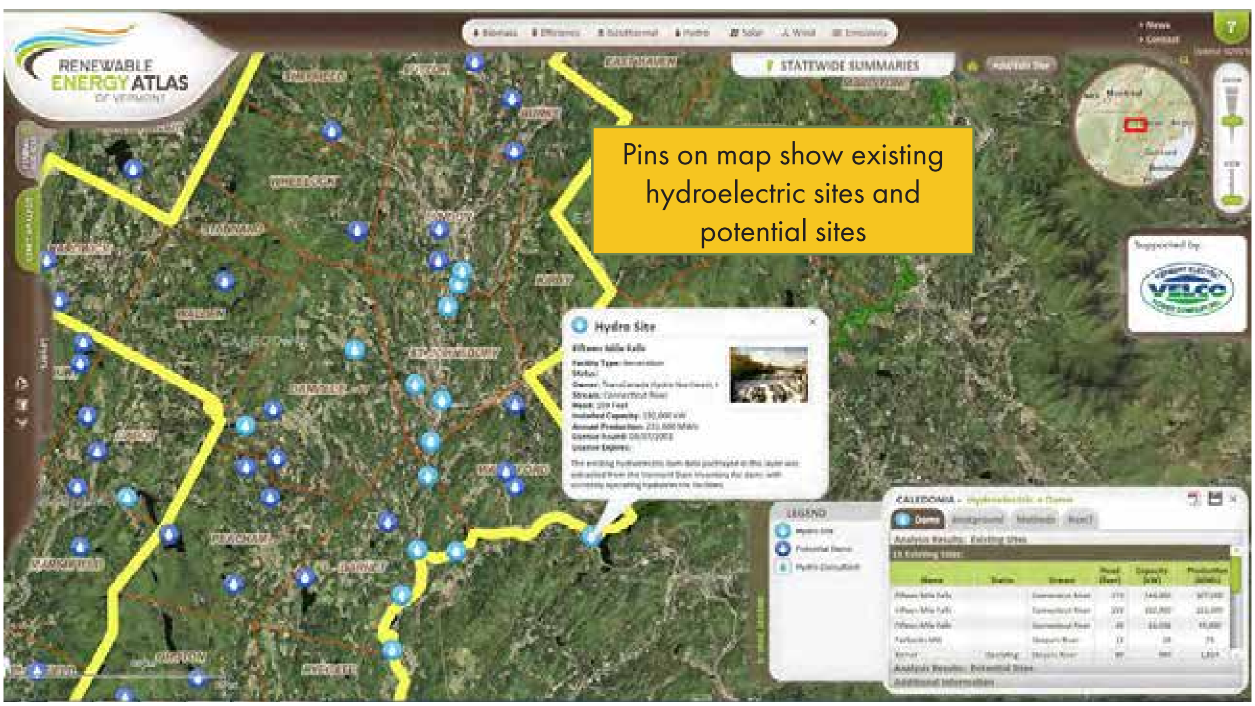
Closed Loop Horizontal Systems: According to the U.S. Department of Energy, Closed Loop Horizontal Systems are generally most cost-effective for residential installations, particularly for new construction where sufficient land is available. It requires trenches at least four feet deep. The most common layouts either use two pipes, one buried at six feet, and the other at four feet, or two pipes placed side-by-side at five feet in the ground in a two-foot wide trench. In this case, VCGI queried the SSURGO database for areas where the depth to bedrock was greater than 5 feet — under the presumption that it would be easier to dig these sites.

Closed Loop Pond System: According to the U.S. Department of Energy, a supply line pipe is run underground from the building to the water and coiled into circles at least eight feet under the surface to prevent freezing. The coils should only be placed in a water source that meets minimum volume, depth, and quality criteria. In this case, VCGI generated a data layer of all water bodies at least 1/2 acre in size, again, under the presumption that it would be easier to find possible locations for closed loop pond systems.

Open Loop Systems: this type of system uses well or surface body water as the heat exchange fluid that circulates directly through the GHP system. Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge. This option is obviously practical only where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met. In this case, VCGI generated a data layer of existing water wells.

- **Hydro:** Refers to all hydroelectric generating sites. We also included potential hydro sites based on an analysis conducted by [Community Hydro].

RENEWABLE ENERGY ATLAS — HYDRO LAYER SELECTED



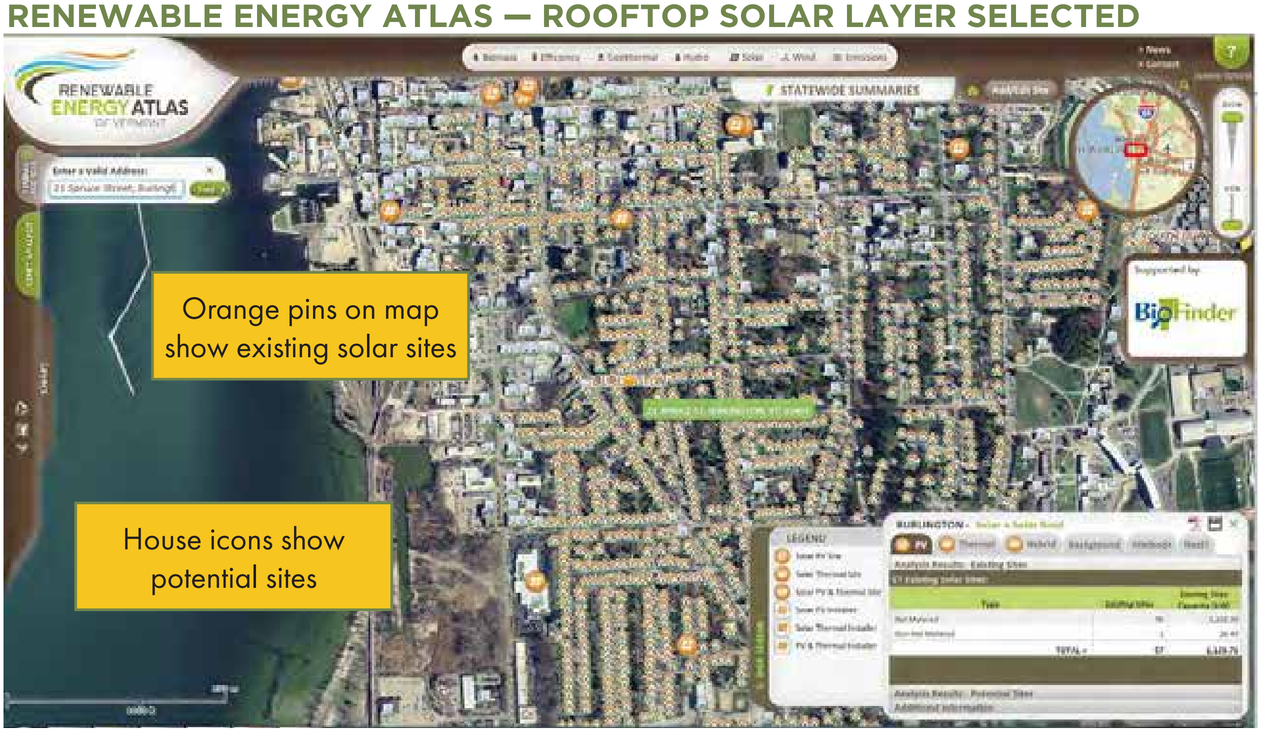
VCGI and the Vermont Agency of Natural Resources had previously developed the Vermont Dam Inventory that could be queried for electricity generating sites. In 2007, Community Hydro (Lori Barg) produced a report, *The Undeveloped Hydroelectric Potential of Vermont*, that provided energy estimates for small dams throughout Vermont.

When an Atlas user clicked on Hydro a map appeared that showed pins for existing and potential hydro sites.

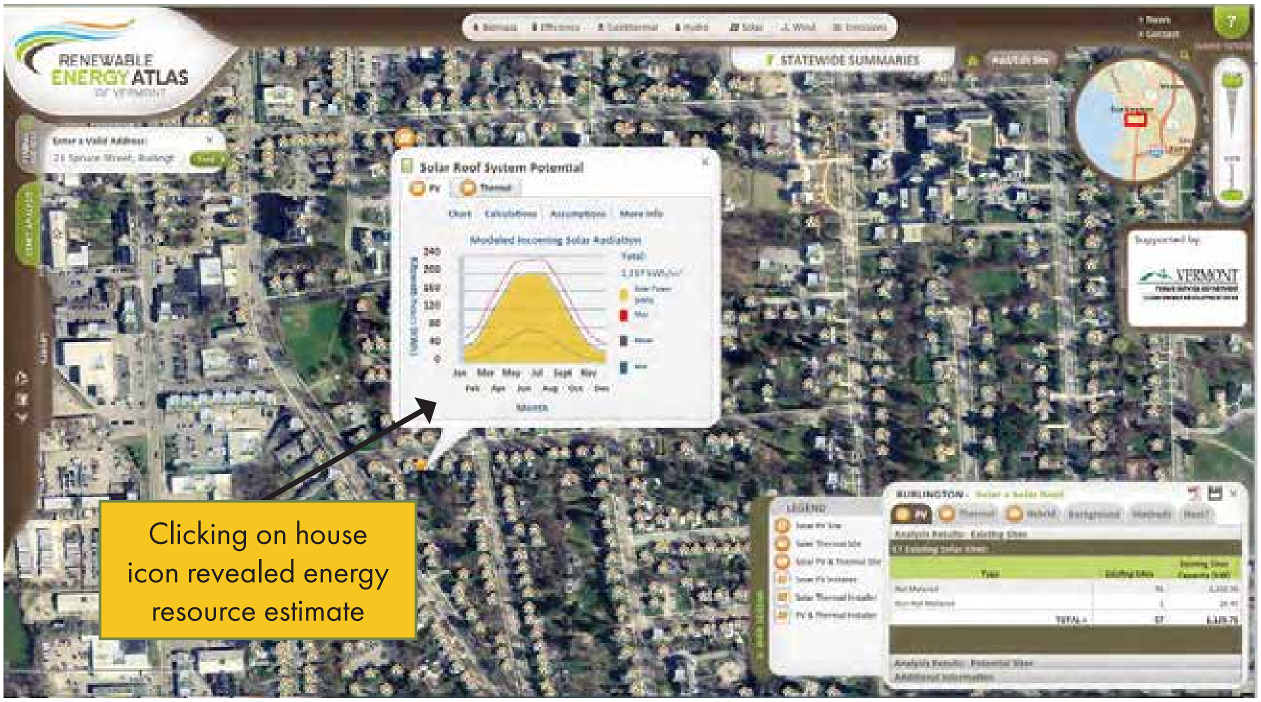
- **Solar:** Photovoltaic systems use the power of the sun to create electricity, while hot water systems convert sunshine into heat.

VCGI used the ESRI Solar Radiation tool for computing solar insolation for rooftops and on the ground. This tool accounted for topography and provided a large degree of control over the process. One critical control is a "height offset" that was used to model the solar insolation at an average height above ground (e.g., 20 feet) where solar panels are likely to be placed on a southerly facing roof at an optimal pitch. Known derate factors were applied to the optimal estimated solar values to account for site-specific variables deviating from the ideal, such as roof aspect and tilt. The ground analysis showed solar radiation organized by slope in color coded polygons.

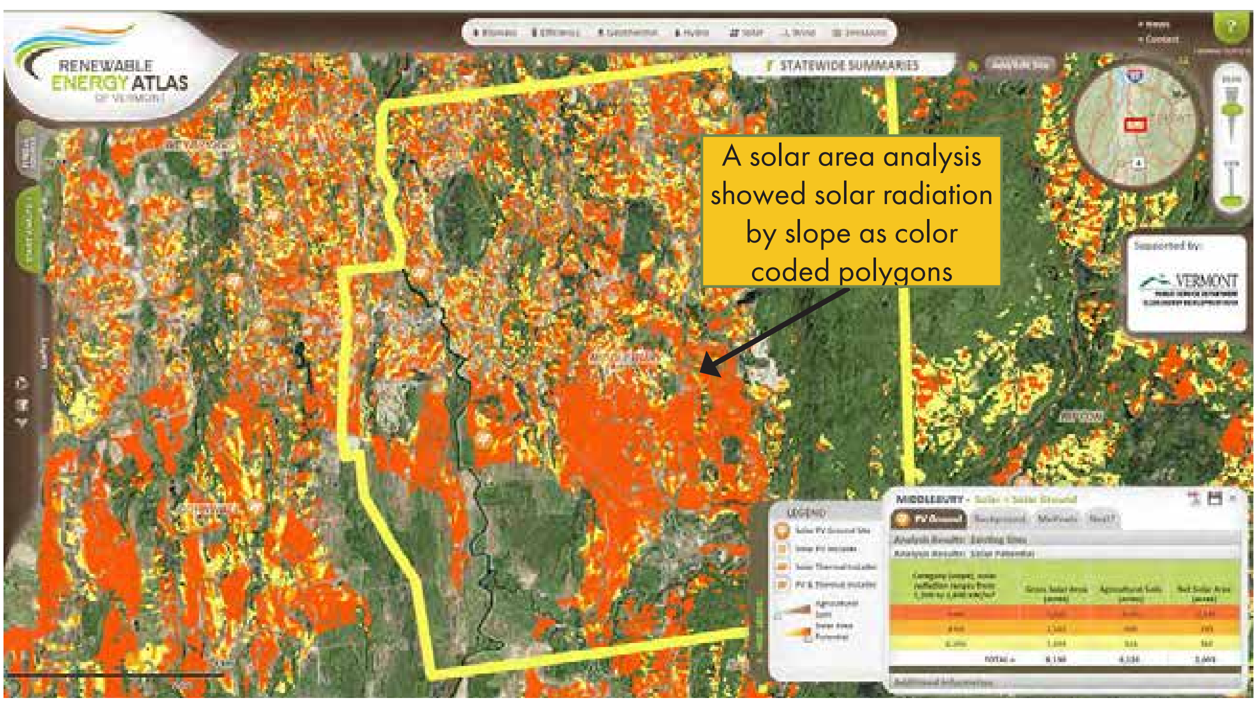
RENEWABLE ENERGY ATLAS — ROOFTOP SOLAR LAYER SELECTED



RENEWABLE ENERGY ATLAS — ROOFTOP SOLAR DETAIL



RENEWABLE ENERGY ATLAS — GROUND-MOUNTED SOLAR



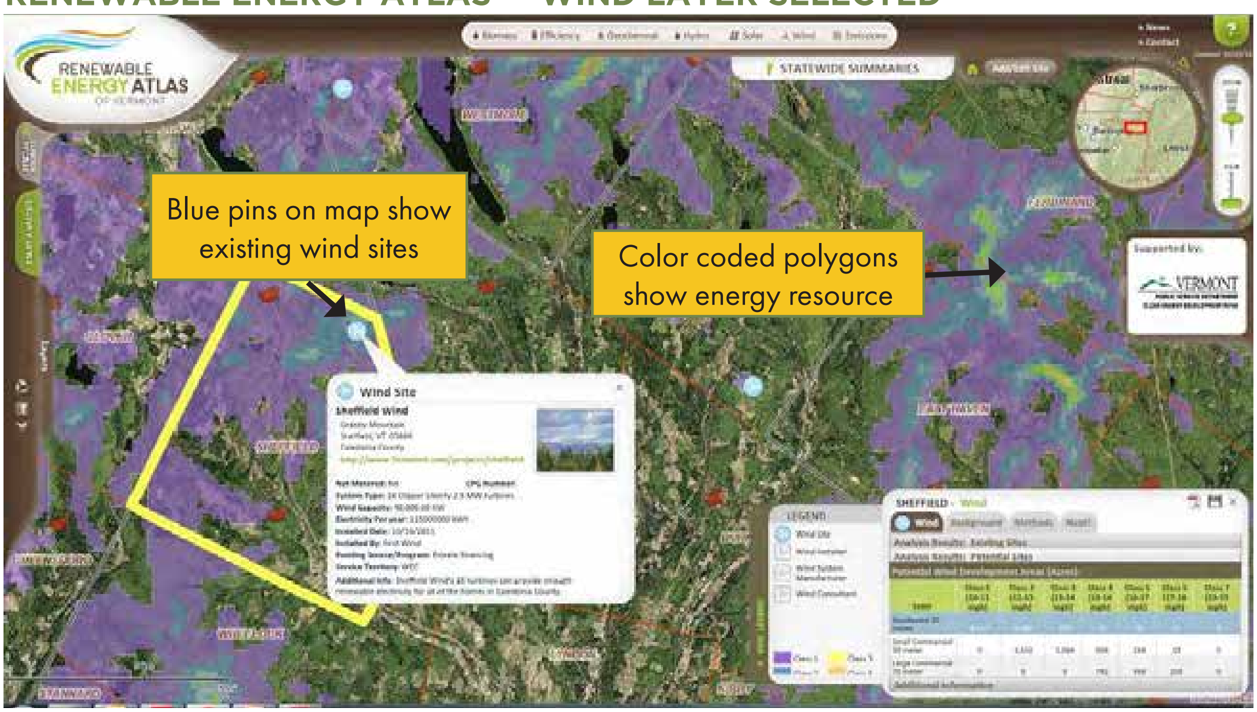
When an Atlas user clicked on Solar they had the option to choose Roof or Ground systems. For Roof Systems, a map appeared that showed orange pins for existing solar PV sites and house or building icons for potential sites. Clicking on potential sites generated a pop-up up window for solar radiation at that location, as well as derate tools for orientation, angle, and shading. For Ground Systems, orange pins appeared depicting existing ground mounted solar PV sites, while color coded polygons appeared for solar radiation.

- **Wind:** Wind power converts the kinetic energy of wind into electricity.

A collaborative effort between the Massachusetts Technology Collaborative, the Connecticut Clean Energy Fund, and the Renewable Energy Trust contracted AWS Truepower to produce the "Wind Resource Maps of Northern New England," a digital 200 meter (m) resolution dataset of predicted mean wind speed across northern New England at wind turbine hub heights of 30m, 50m, 70m, and 100m above effective ground level. This was the best "off the shelf," readily available data *and* it was publicly available.

When an Atlas user clicked on Wind they would be able to select 30m, 50m, or 70m hub heights which would appear as color coded polygons of mean wind speed. Points would appear for existing wind sites. The Analysis Results Panel would count the number of acres of land within the selected boundary by wind speed and hub height.

RENEWABLE ENERGY ATLAS — WIND LAYER SELECTED



Lessons Learned

- Use of proprietary programming software (i.e., ESRI's ArcGIS) increasingly constrained our ability to make updates to the Atlas (e.g., bulk upload of renewable energy sites was desired but not possible). Staff changes at Fountains Spatial also reduced our ability to make Atlas changes. Consequently, when we transitioned from the Renewable Energy Atlas to the Energy Action Network's **Community Energy Dashboard** we used open source software.
- The user interface of the Atlas proved to be overly complicated for some users. When we transitioned to the Dashboard we tested all features more extensively and made the user interface more intuitive.
- Bioenergy site development using the Atlas was of low interest to users compared to solar energy and wind siting and the overall statistical information that could be generated at town and county levels.
- VSJF did not have the staff capacity to provide deep technical assistance and education and outreach efforts to the many community energy groups in Vermont. This necessarily constrained the overall impact of the Atlas.

COMMUNITY ENERGY DASHBOARD

BrighterVermont
CommunityEnergyDashboard
BUILDING A BETTER ENERGY FUTURE. TODAY.

In 2014, an opportunity to work with the Energy Action Network (EAN)—a network of nonprofit, business, government, and community energy leaders—emerged that allowed VSJF to evolve the Energy Atlas into a more robust tool—the Community Energy Dashboard. VSJF led the conceptualization and development of the Dashboard, which was released in May 2016. The Dashboard has many more features than the Energy Atlas in order to serve public engagement and technology innovation leverage points, including:

- **Energy Atlas:** The Energy Atlas remains a tool for mapping town, county, and Regional Planning Commission boundaries for existing and potential renewable energy sites. With the tool, users can turn on additional "constraints" (e.g., endangered species habitat) in order to identify new potential sites that take environmental resources into account. Users can also crowdsource their own information.

- **Statistics:** Energy installations included in the Atlas database aggregate into real-time renewable energy installations, installed capacity, and electrical generation statistics for every town, county, and Regional Planning Commission in Vermont (e.g., Burlington, Franklin County, and Northeastern Vermont Development Association). Statistics allow users to see how their community ranks compared to other communities.

- **Analysis:** Statistics compiled by the Atlas and other official sources can then be turned into data visualizations (e.g., Renewable Electricity Sites) using software called Tableau that showcase long-term trends.

- **Stories:** The Dashboard is also a central repository for a growing list of Vermont energy stories, including Vermont Bioenergy Initiative created Bioenergy Now! videos and bioenergy stories.

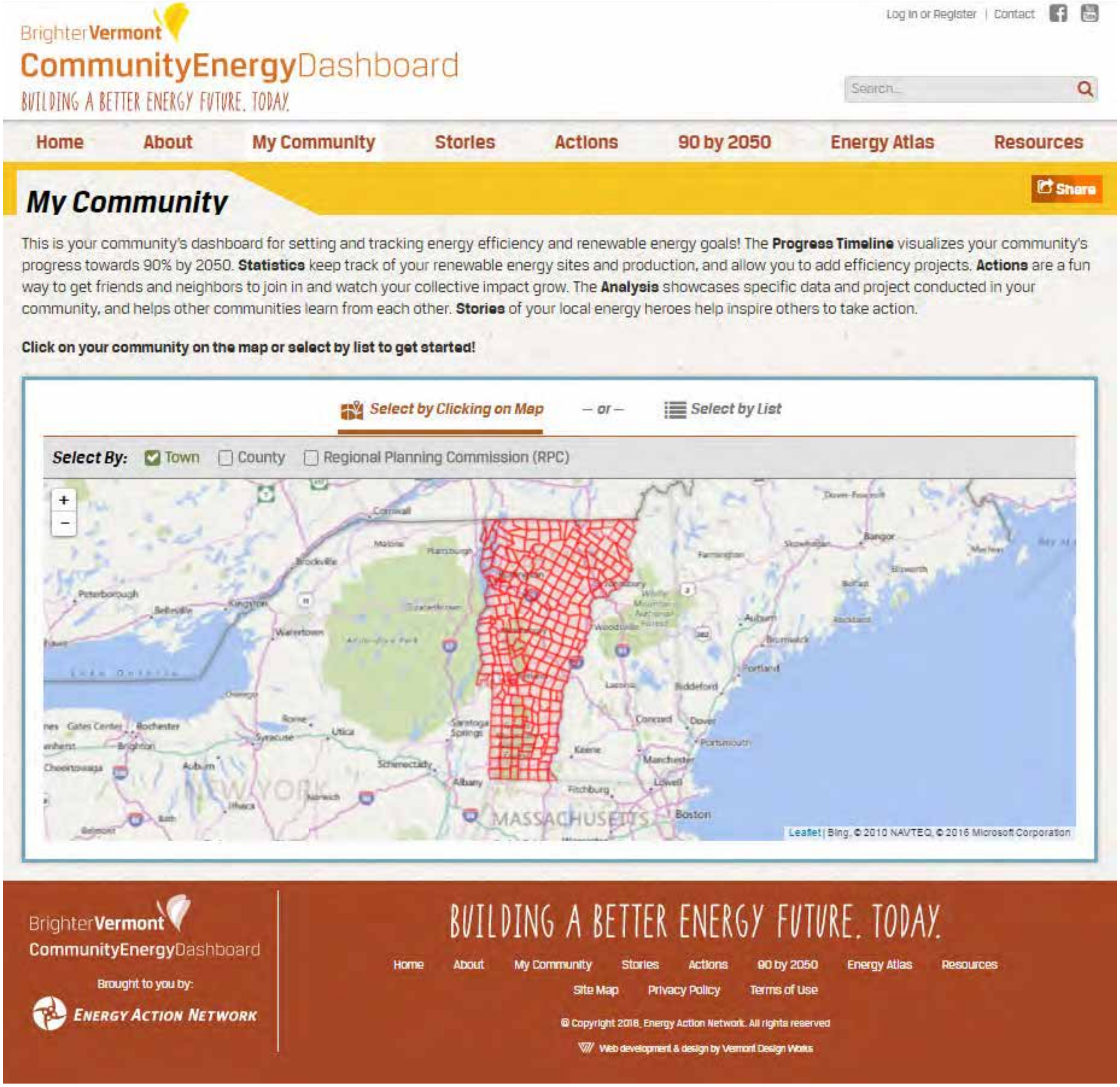
- **Progress Timeline:** A Progress Timeline for every community in Vermont allows Dashboard users to track community progress towards meeting 90% of local energy needs through efficiency and renewables by 2050. Each Progress Timeline includes heat and transportation calculations.

- **Actions:** Action "tiles" provide an interactive way for Dashboard users to add individual, business, municipal, school and farm actions in order to showcase the collective impact of their community.

COMMUNITY ENERGY DASHBOARD — HOMEPAGE

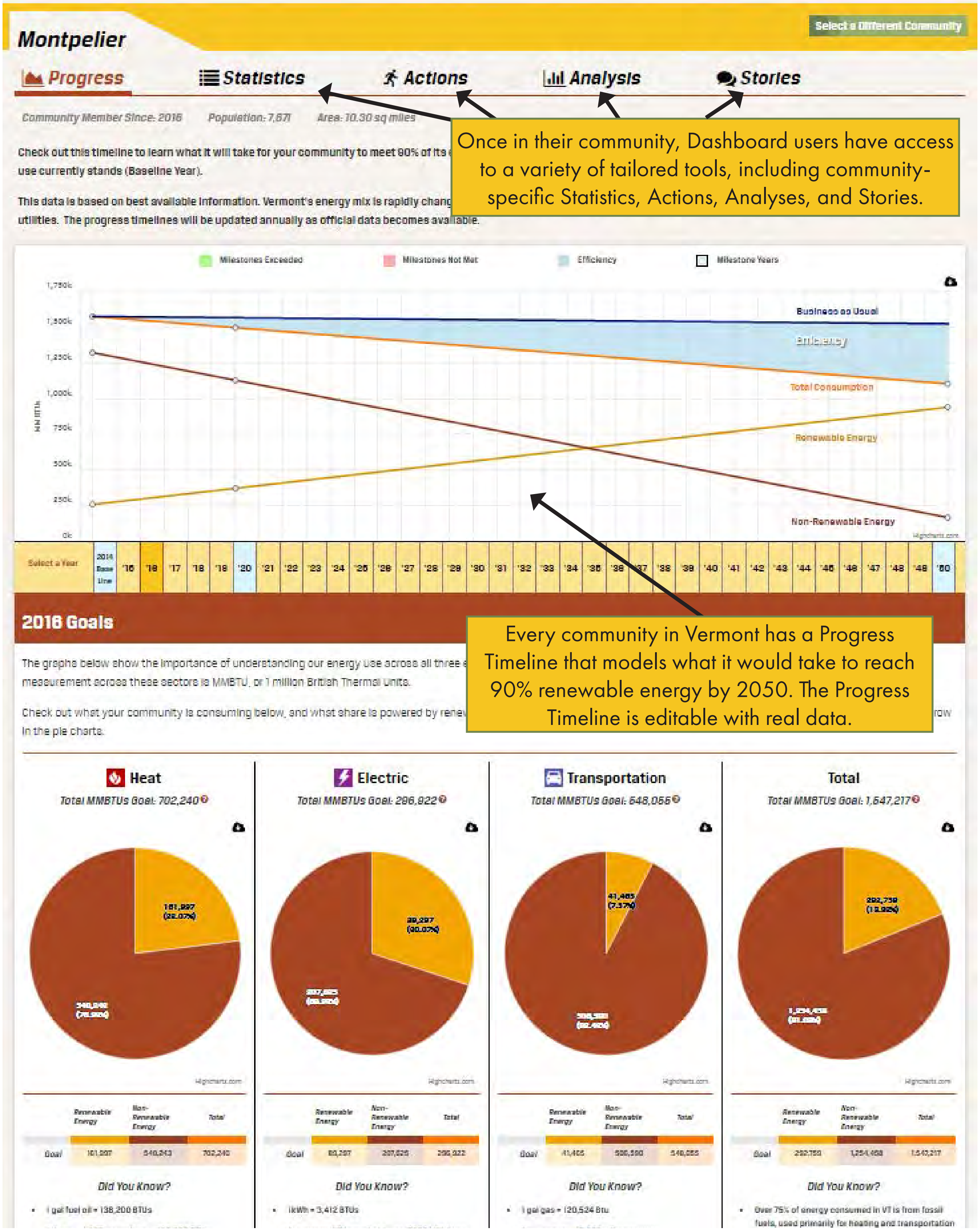
The Community Energy Dashboard homepage features a rotating Stories carousel; links to "Find Your Community!" and "Take Action!"; a rotating carousel of Actions taken by individuals, communities, and businesses; and navigation to all of the other pages on the website.

COMMUNITY ENERGY DASHBOARD — MY COMMUNITY SELECTION



The My Community page features selection options for every Town, County, and Regional Planning Commission in Vermont. Users can select their community by clicking directly on the map or by selecting from a list.

COMMUNITY ENERGY DASHBOARD — PROGRESS TIMELINE



COMMUNITY ENERGY DASHBOARD — COMMUNITY STATISTICS

Montpelier

Select a Different Community

Progress | Statistics | Actions | Analysis

Community Member Since: 2016 | Population: 7,671 | Area: 10.30 sq miles

These statistics allow your community to track local renewable energy sites and production data, and see how you rank against ... come from official "Certificates of Public Good" and are updated quarterly. In addition you can add information on efficiency proj... dd a Site".

Statistics are automatically generated for every Town, County, and Regional Planning Commission from installation and capacity data in the Energy Atlas

150 Renewable Energy & Efficiency Sites in Montpelier

143 Solar Sites

Hide Details | View on Atlas

Ground-mounted PV: Fixed Rack

Number of Sites	5	Total Electricity Capacity	533.30 kW	Annual Electricity Generation	840,024 kWh
Rank in VT	162	Rank in VT	69	Rank in VT	69

Ground-mounted PV: Pole

Number of Sites	0	Total Electricity Capacity	0 kW	Annual Electricity Generation	0 kWh
Rank in VT	n/a	Rank in VT	n/a	Rank in VT	n/a

Ground-mounted PV: Tracker

Number of Sites	3	Total Electricity Capacity	36 kW	Annual Electricity Generation	64,676 kWh
Rank in VT	107	Rank in VT	96	Rank in VT	96

Roof-Mounted PV

Number of Sites	84	Total Electricity Capacity	765.65 kW	Annual Electricity Generation	801,083 kWh
Rank in VT	86	Rank in VT	49	Rank in VT	61

Hot Water

Number of Sites	51	Total Heat Capacity	4.68 MMBTU	Annual Heat Generation	0 MMBTU
Rank in VT	26	Rank in VT	22	Rank in VT	n/a

0 Wind Sites

Show Details | View on Atlas

1 Hydro Sites

Show Details | View on Atlas

4 Biomass Sites

Show Details | View on Atlas

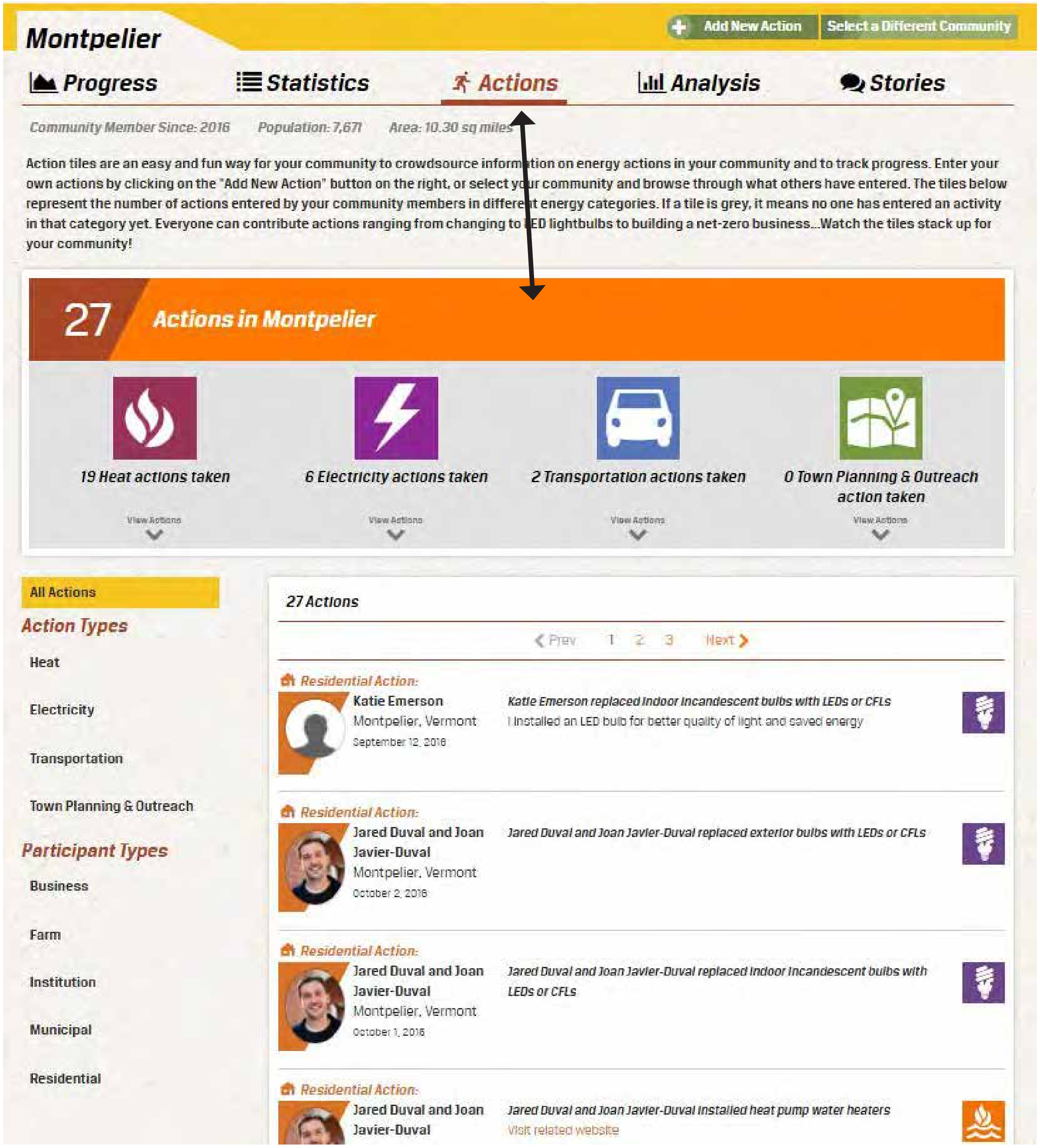
2 Efficiency (Crowdsourced) Sites

Show Details | View on Atlas

0 Heat Pump (Crowdsourced) Sites

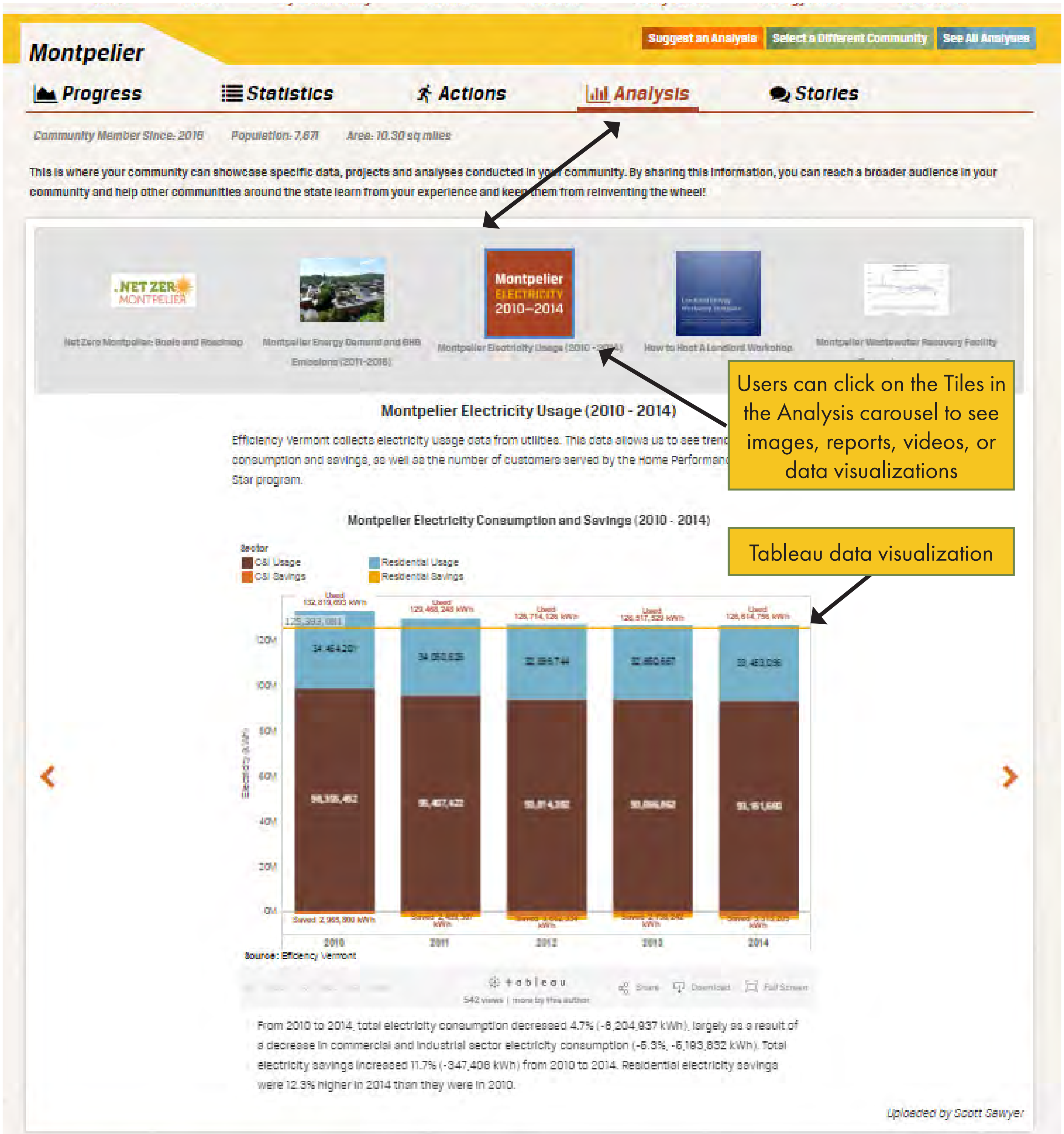
Show Details | View on Atlas

COMMUNITY ENERGY DASHBOARD — COMMUNITY ACTIONS



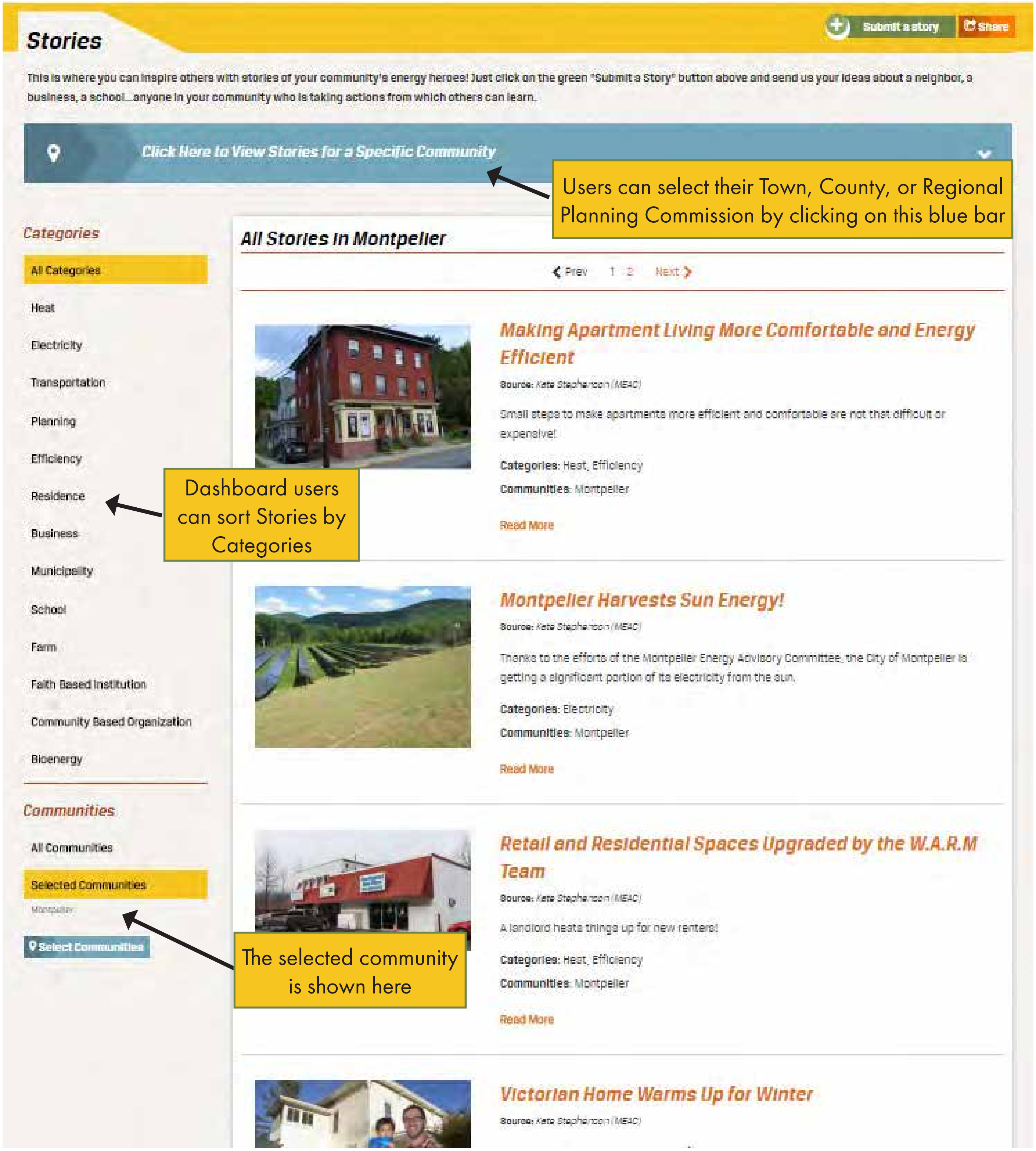
Dashboard users can click on a variety of Heat, Electricity, Transportation, and Town Planning & Outreach tiles to show that they have taken an Action. Actions can be sorted by Energy Type (i.e., Heat, Electricity) and by Participant Type (i.e., Business, Farm). The Actions are compiled for the community they live in, as well as the statewide total. Actions are also shown in a carousel on the homepage.

COMMUNITY ENERGY DASHBOARD — COMMUNITY ANALYSIS



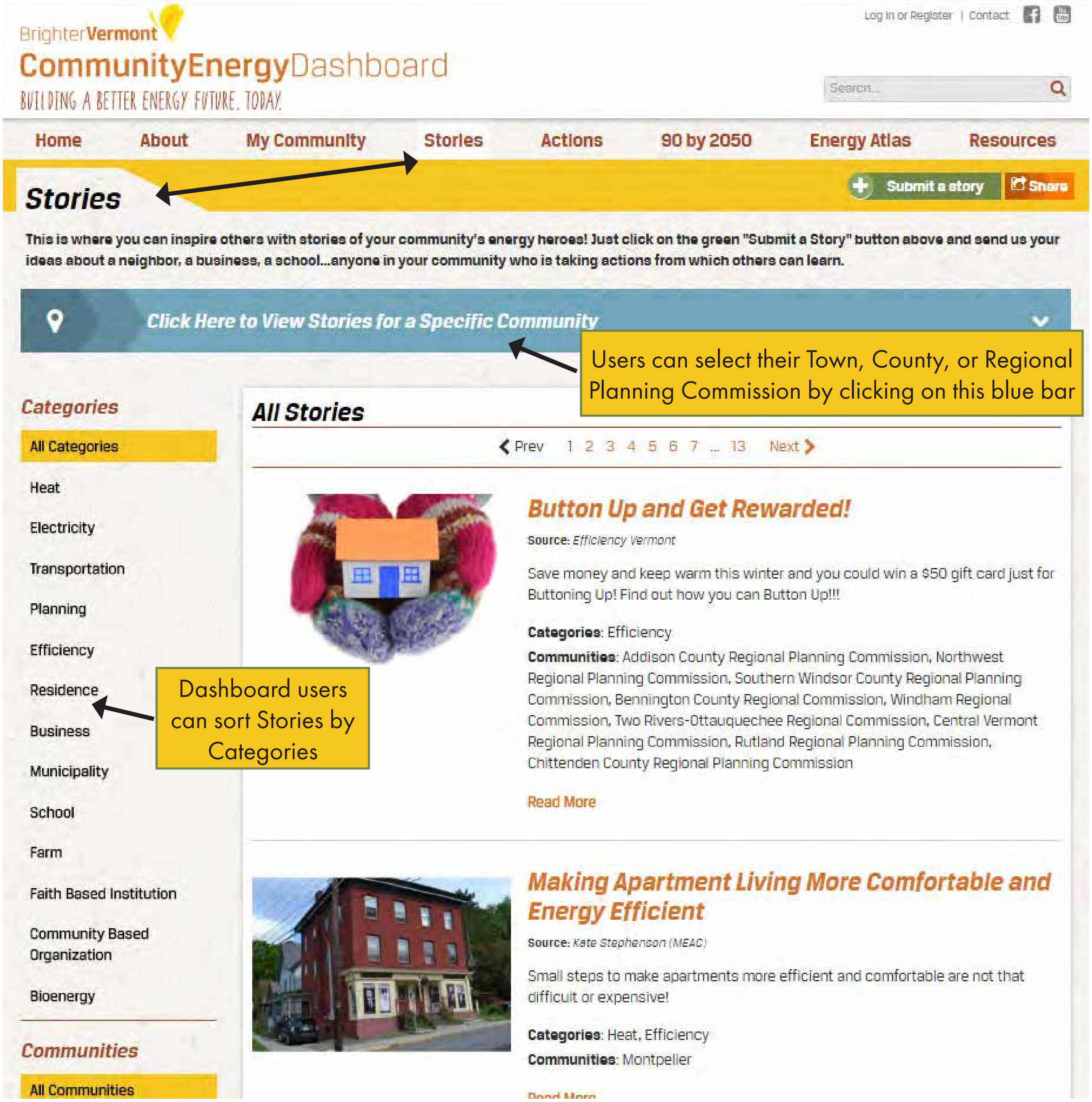
Every Town, County, and Regional Planning Commission has the ability to crowd source (i.e., upload) analyses that they have conducted for their community. Images, reports, videos, and Tableau data visualizations can all be uploaded.

COMMUNITY ENERGY DASHBOARD — COMMUNITY STORIES



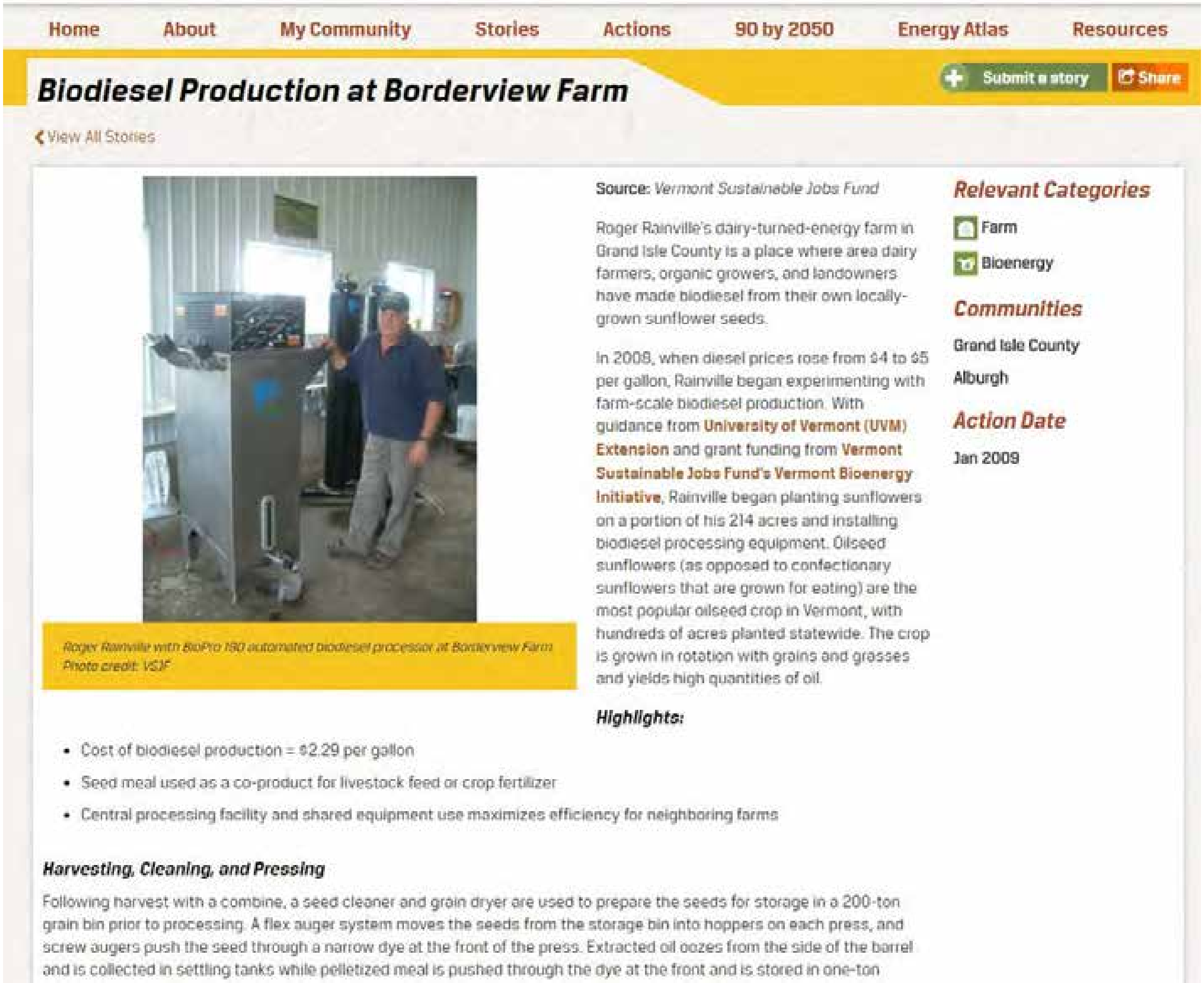
Clicking on Stories while on a "My Community" page shows Dashboard users only stories about their community. In this case, Stories about Montpelier are shown.

COMMUNITY ENERGY DASHBOARD — STORIES LANDING PAGE



By default, the Stories landing page shows all Stories in Vermont in chronological order. Dashboard users can sort Stories by selecting one or several Communities or by clicking on Categories. Dashboard users can submit their own stories by clicking on the green button at the top right of the screen.

COMMUNITY ENERGY DASHBOARD — STORY DETAIL PAGE



Home About My Community Stories Actions 90 by 2050 Energy Atlas Resources

Submit a story Share

Biodiesel Production at Borderview Farm

View All Stories

Roger Rainville with BioPro 190 automated biodiesel processor at Borderview Farm
Photo credit: VSJF

Source: *Vermont Sustainable Jobs Fund*

Roger Rainville's dairy-turned-energy farm in Grand Isle County is a place where area dairy farmers, organic growers, and landowners have made biodiesel from their own locally-grown sunflower seeds.

In 2008, when diesel prices rose from $4 to $5 per gallon, Rainville began experimenting with farm-scale biodiesel production. With guidance from **University of Vermont (UVM) Extension** and grant funding from **Vermont Sustainable Jobs Fund's Vermont Bioenergy Initiative**, Rainville began planting sunflowers on a portion of his 214 acres and installing biodiesel processing equipment. Oilseed sunflowers (as opposed to confectionary sunflowers that are grown for eating) are the most popular oilseed crop in Vermont, with hundreds of acres planted statewide. The crop is grown in rotation with grains and grasses and yields high quantities of oil.

Relevant Categories

Farm

Bioenergy

Communities

Grand Isle County

Alburgh

Action Date

Jan 2009

Highlights:

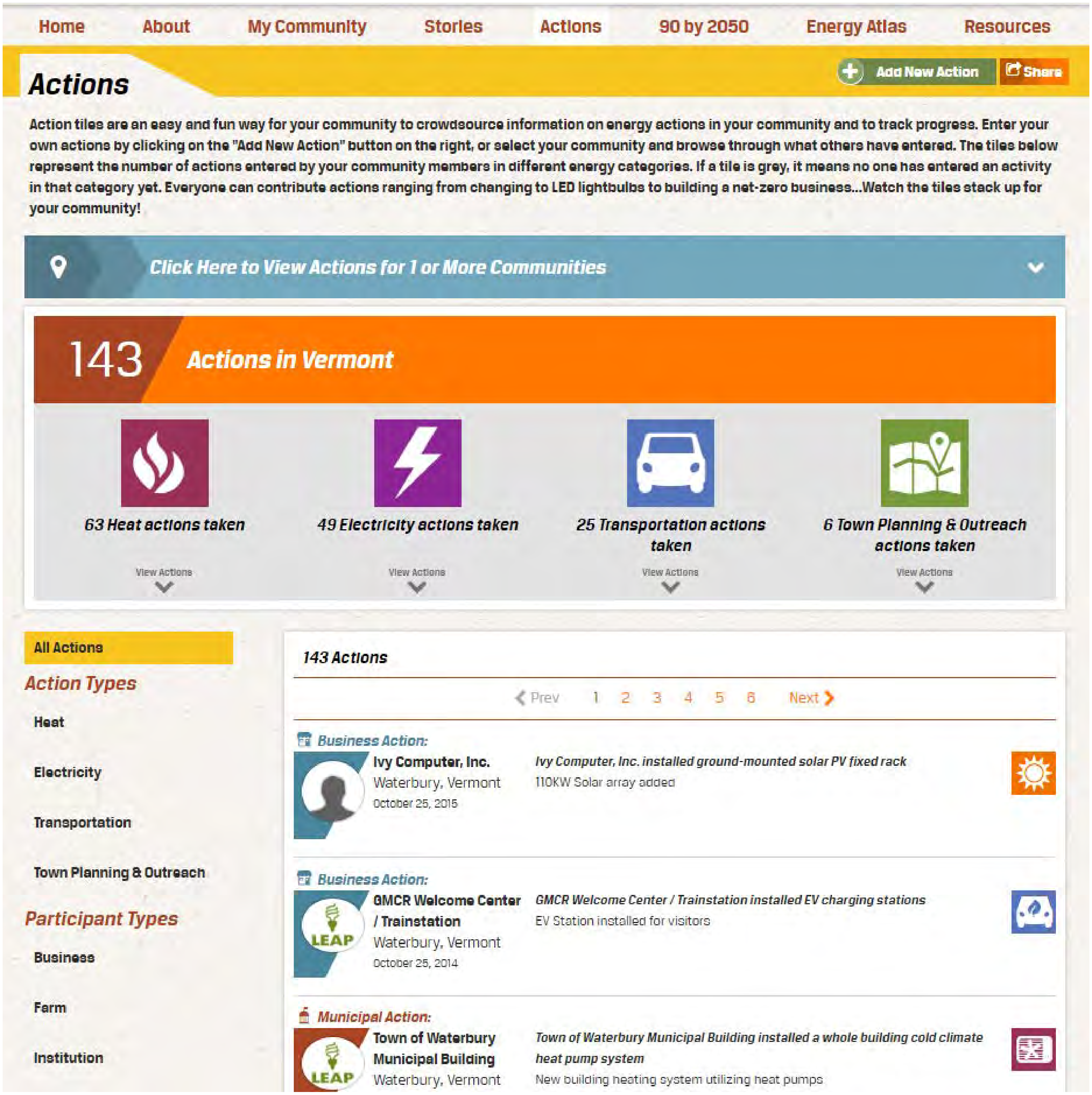
- Cost of biodiesel production = $2.29 per gallon
- Seed meal used as a co-product for livestock feed or crop fertilizer
- Central processing facility and shared equipment use maximizes efficiency for neighboring farms

Harvesting, Cleaning, and Pressing

Following harvest with a combine, a seed cleaner and grain dryer are used to prepare the seeds for storage in a 200-ton grain bin prior to processing. A flex auger system moves the seeds from the storage bin into hoppers on each press, and screw augers push the seed through a narrow dye at the front of the press. Extracted oil oozes from the side of the barrel and is collected in settling tanks while pelletized meal is pushed through the dye at the front and is stored in one-ton

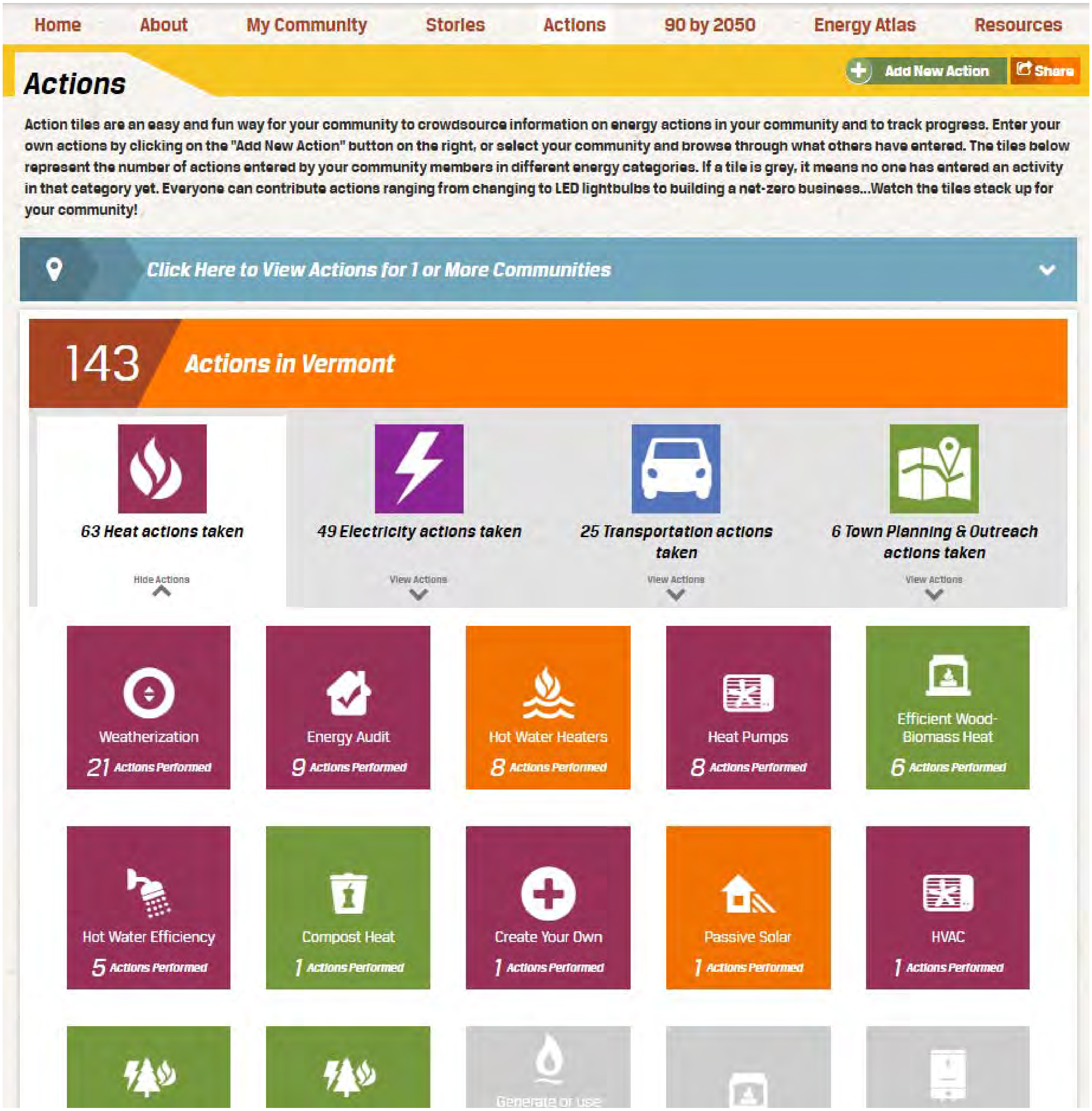
Clicking on a Story takes Dashboard users to a detail page that includes text and a photo or a video.

COMMUNITY ENERGY DASHBOARD — ACTIONS LANDING PAGE



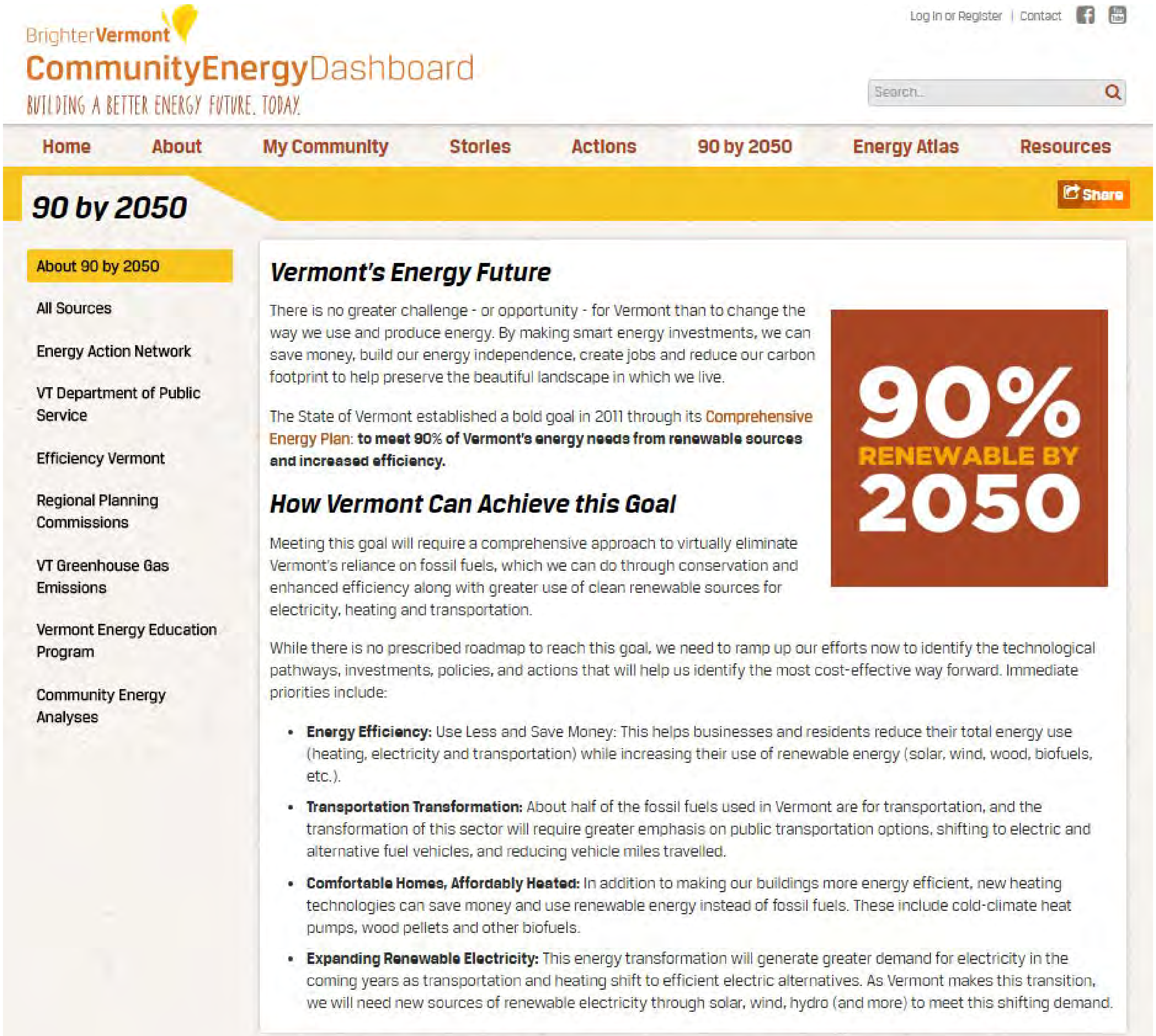
The Actions landing page shows all crowd sourced Actions entered by Dashboard users. Actions are categorized by Heat, Electricity, Transportation, and Town Planning & Outreach, as well as by Participant Type (i.e., Business, Farm).

COMMUNITY ENERGY DASHBOARD — ACTIONS DETAIL PAGE



Clicking on one of the major energy Action tiles reveals the subset of related Actions that Dashboard users have taken. Actions are shown from most to least, and greyed out tiles show Actions that have not been taken yet.

COMMUNITY ENERGY DASHBOARD — 90 BY 2050 LANDING PAGE



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CommunityEnergyDashboard

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Home | About | My Community | Stories | Actions | 90 by 2050 | Energy Atlas | Resources

Share

90 by 2050

- About 90 by 2050
- All Sources
- Energy Action Network
- VT Department of Public Service
- Efficiency Vermont
- Regional Planning Commissions
- VT Greenhouse Gas Emissions
- Vermont Energy Education Program
- Community Energy Analyses

Vermont's Energy Future

There is no greater challenge - or opportunity - for Vermont than to change the way we use and produce energy. By making smart energy investments, we can save money, build our energy independence, create jobs and reduce our carbon footprint to help preserve the beautiful landscape in which we live.

The State of Vermont established a bold goal in 2011 through its Comprehensive Energy Plan: **to meet 90% of Vermont's energy needs from renewable sources and increased efficiency.**

90% RENEWABLE BY 2050

How Vermont Can Achieve this Goal

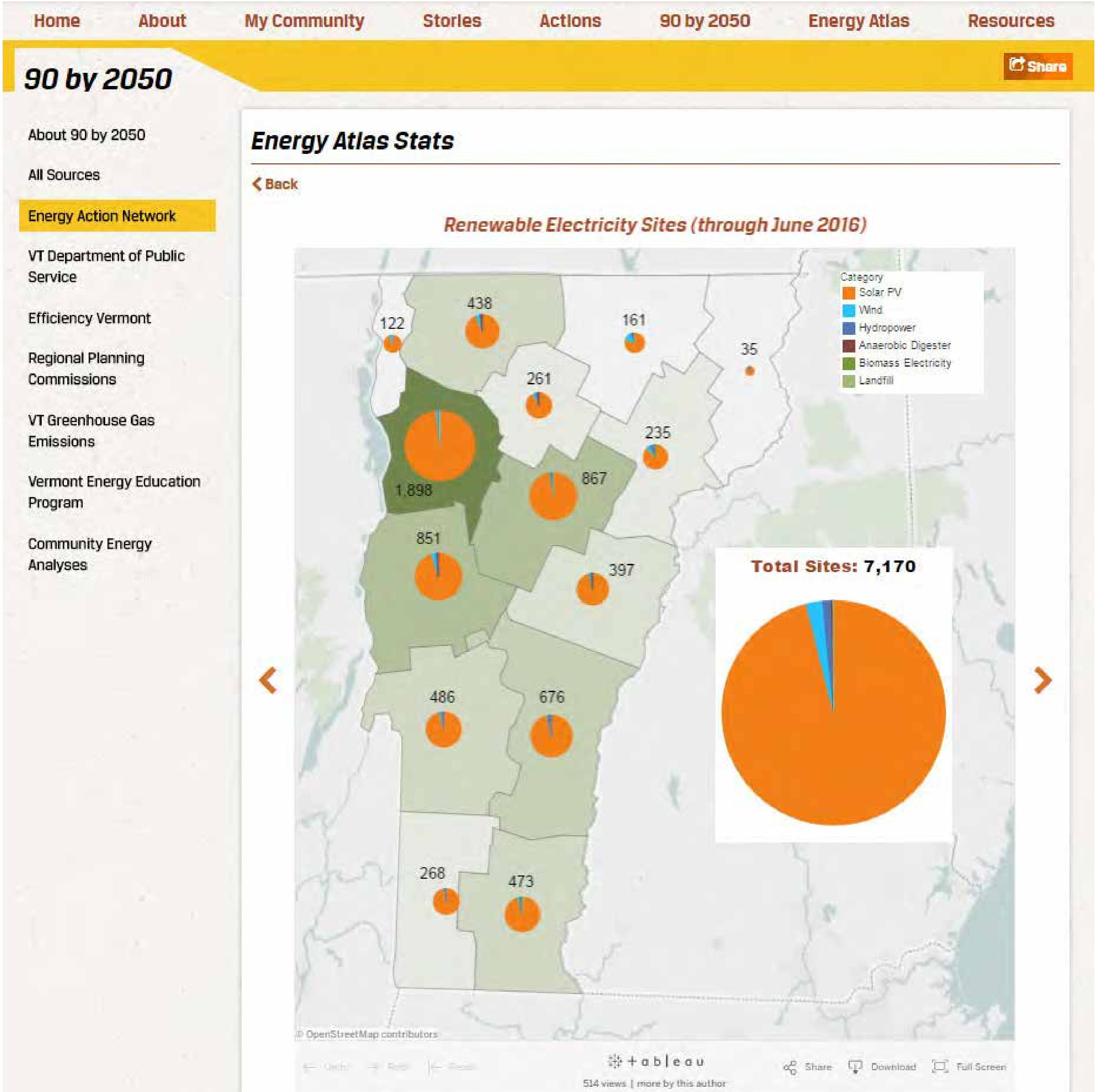
Meeting this goal will require a comprehensive approach to virtually eliminate Vermont's reliance on fossil fuels, which we can do through conservation and enhanced efficiency along with greater use of clean renewable sources for electricity, heating and transportation.

While there is no prescribed roadmap to reach this goal, we need to ramp up our efforts now to identify the technological pathways, investments, policies, and actions that will help us identify the most cost-effective way forward. Immediate priorities include:

- **Energy Efficiency:** Use Less and Save Money: This helps businesses and residents reduce their total energy use (heating, electricity and transportation) while increasing their use of renewable energy (solar, wind, wood, biofuels, etc.).
- **Transportation Transformation:** About half of the fossil fuels used in Vermont are for transportation, and the transformation of this sector will require greater emphasis on public transportation options, shifting to electric and alternative fuel vehicles, and reducing vehicle miles travelled.
- **Comfortable Homes, Affordably Heated:** In addition to making our buildings more energy efficient, new heating technologies can save money and use renewable energy instead of fossil fuels. These include cold-climate heat pumps, wood pellets and other biofuels.
- **Expanding Renewable Electricity:** This energy transformation will generate greater demand for electricity in the coming years as transportation and heating shift to efficient electric alternatives. As Vermont makes this transition, we will need new sources of renewable electricity through solar, wind, hydro (and more) to meet this shifting demand.

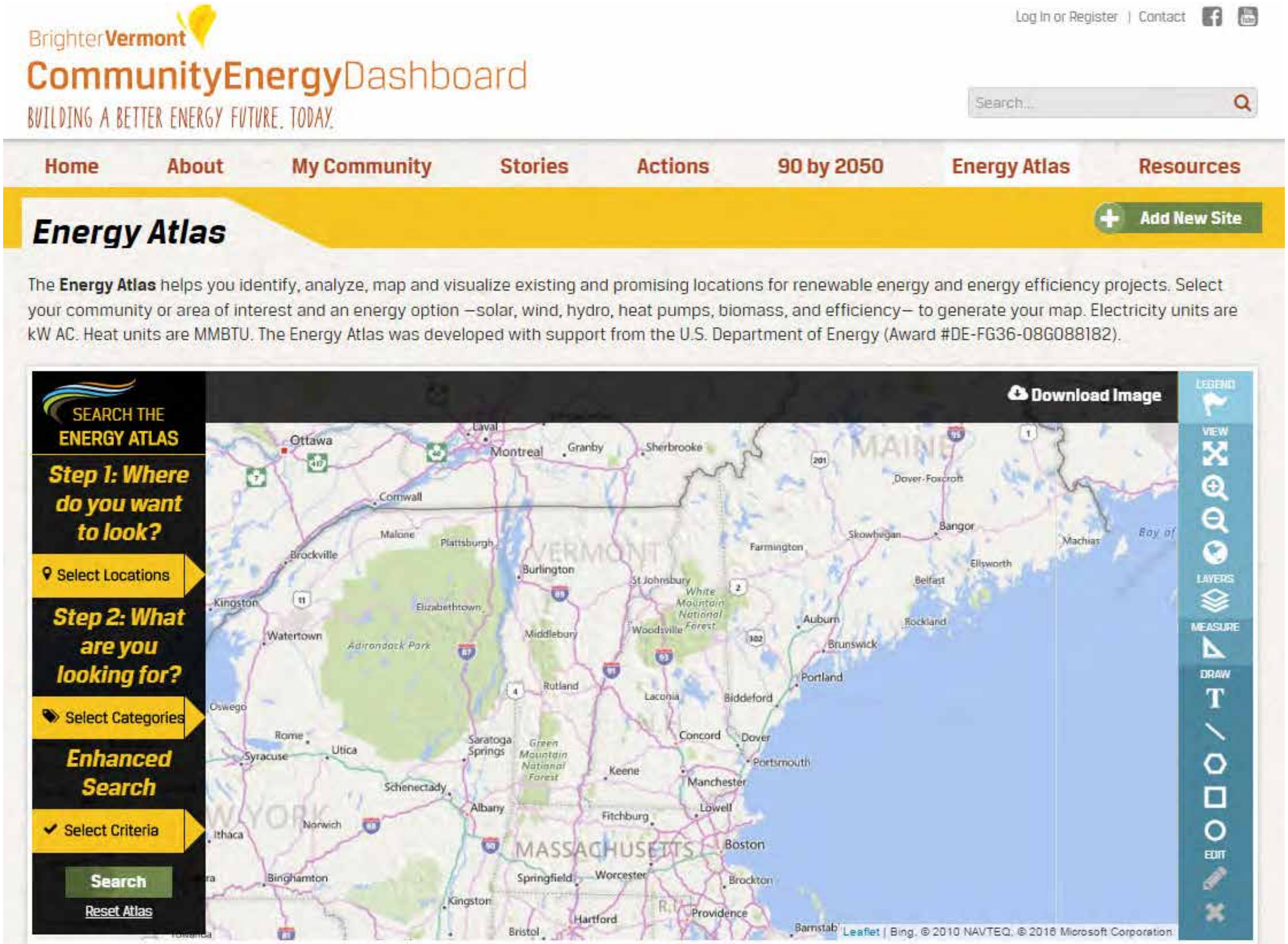
The State of Vermont has a bold goal: to meet 90% of its energy needs through increased efficiency and renewable sources by 2050. The 90 by 2050 landing page showcases big picture data analyses conducted by energy organizations in Vermont.

COMMUNITY ENERGY DASHBOARD — 90 BY 2050 DETAIL PAGE



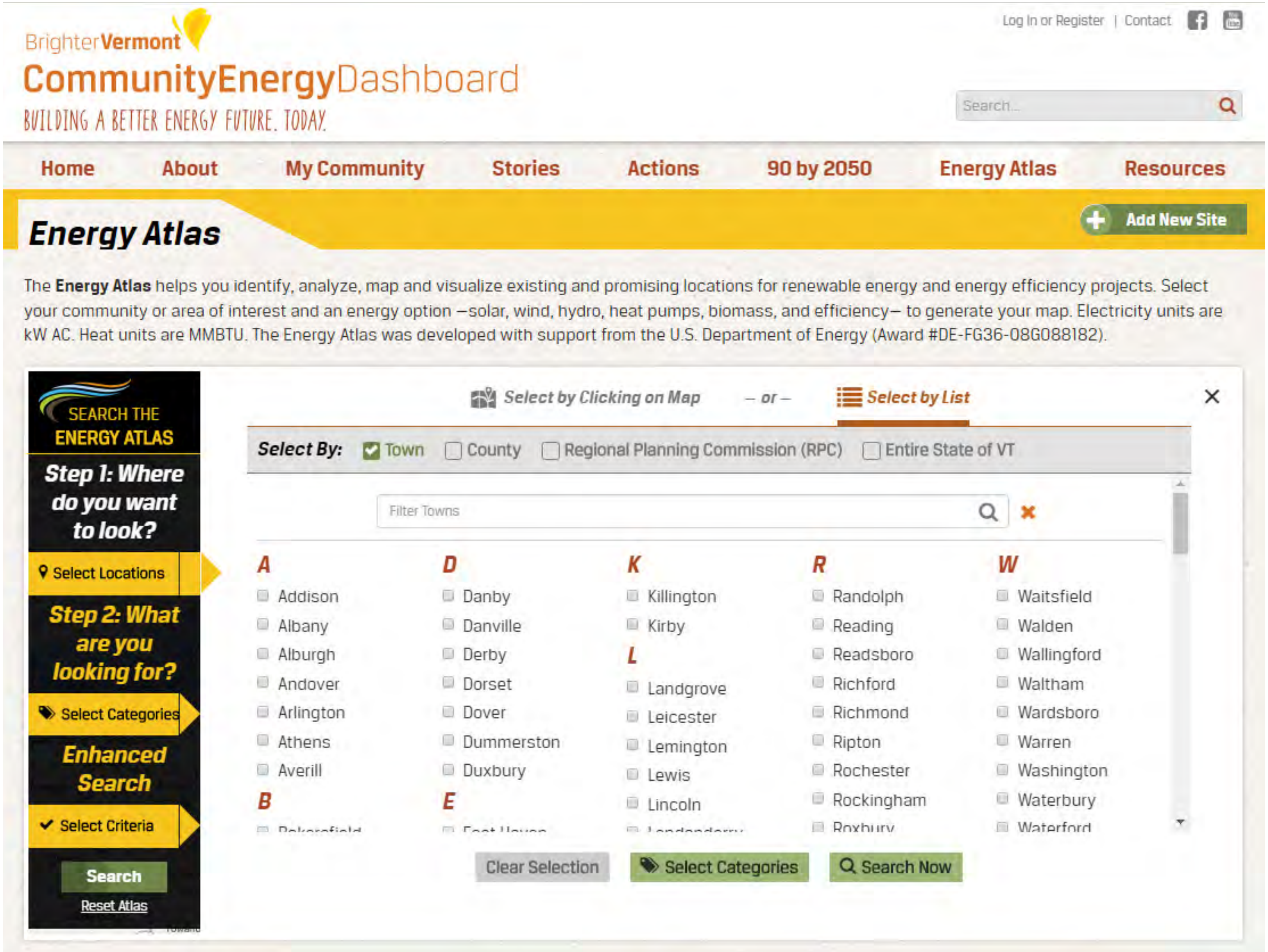
Graphics, including images, videos, and Tableau data visualizations can be uploaded to the 90 by 2050 pages. In this case, statistics from the Energy Atlas are used to provide a Statewide Summary of renewable electricity sites by county and energy category.

COMMUNITY ENERGY DASHBOARD — ENERGY ATLAS



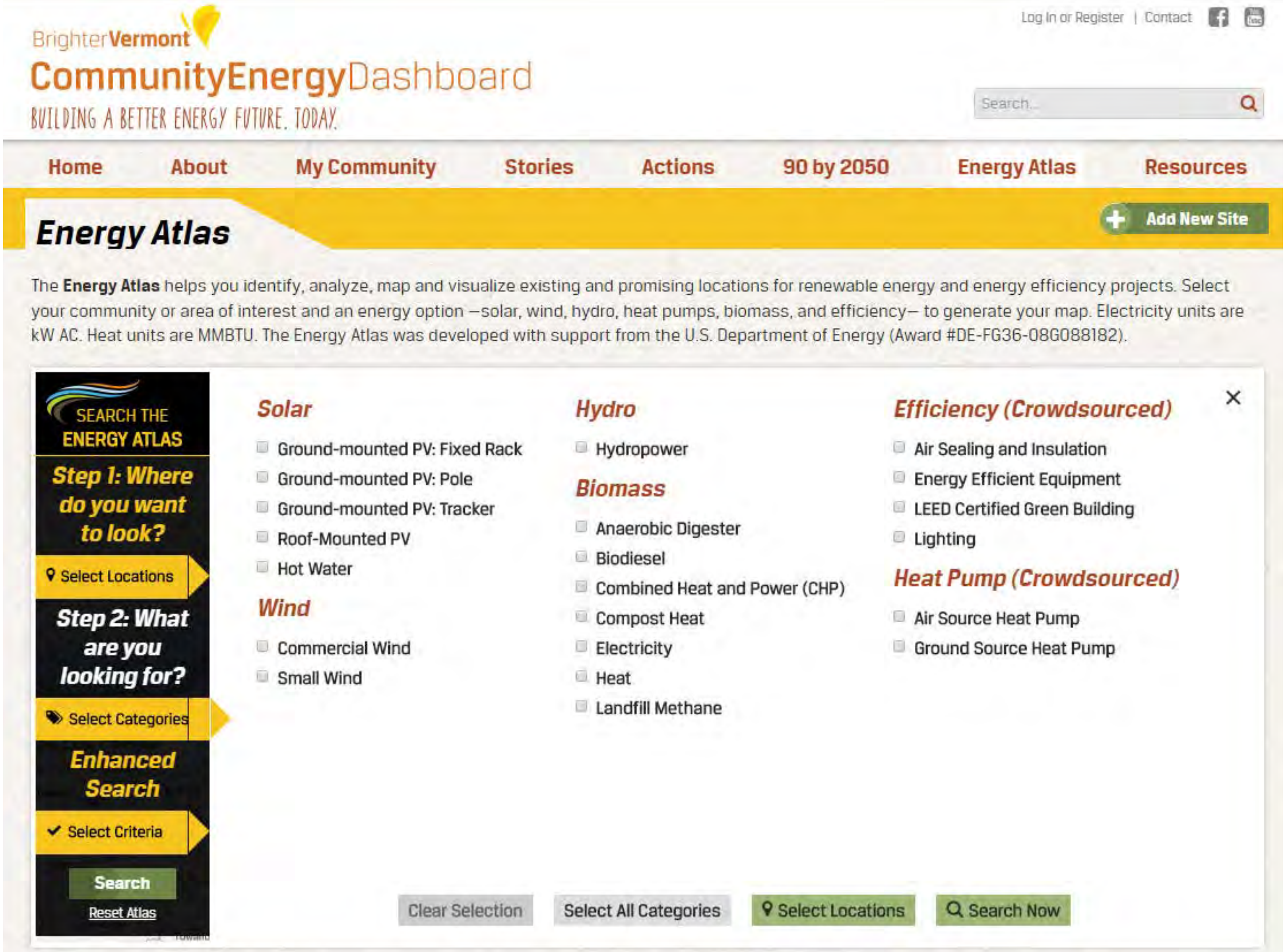
The Energy Atlas is now a major component of the Community Energy Dashboard. Data for all of the "sites" that appear on the map are collected from "certificates of public good" issued by the Vermont Public Service Board, the Vermont Dam Inventory, AgSTAR, and crowdsourcing. The sites database is a major content generator for the Dashboard. Beyond populating the Atlas, it provides Statistics for every community in Vermont, it helps to update the Progress Timeline, and data from the sites database is used to generate 90 by 2050 data visualizations.

COMMUNITY ENERGY DASHBOARD — ENERGY ATLAS SELECT LOCATIONS



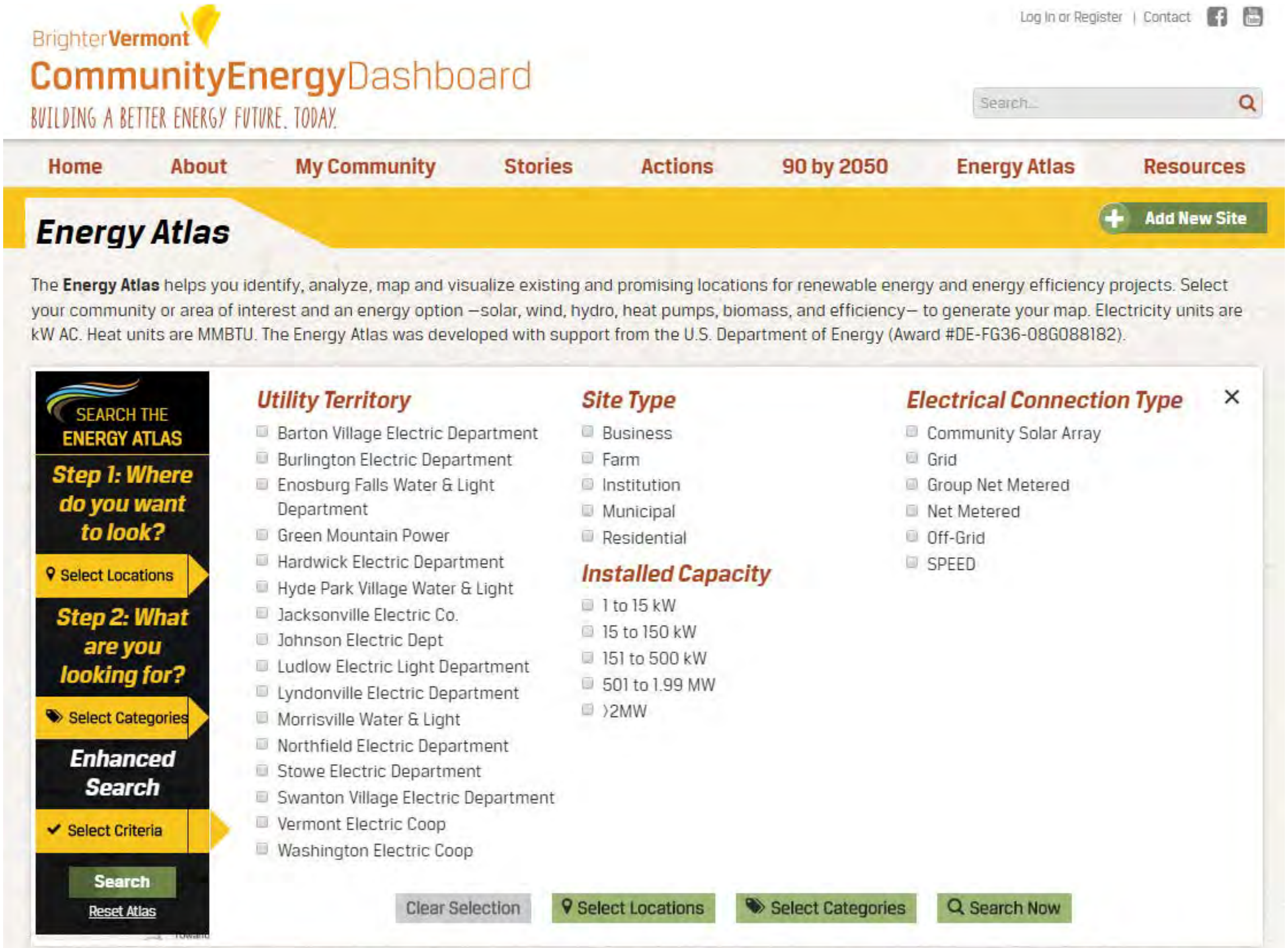
Dashboard users can select their community by clicking directly on the map or by selecting from a list. Dashboard users can start typing the name of their community using a filter tool to find their community more quickly. Users can click the green boxes in this window to select Energy Categories or generate a map immediately. They can also click on the yellow boxes to the left to select Energy Categories or Enhanced Search Criteria.

COMMUNITY ENERGY DASHBOARD — ENERGY ATLAS SELECT CATEGORIES



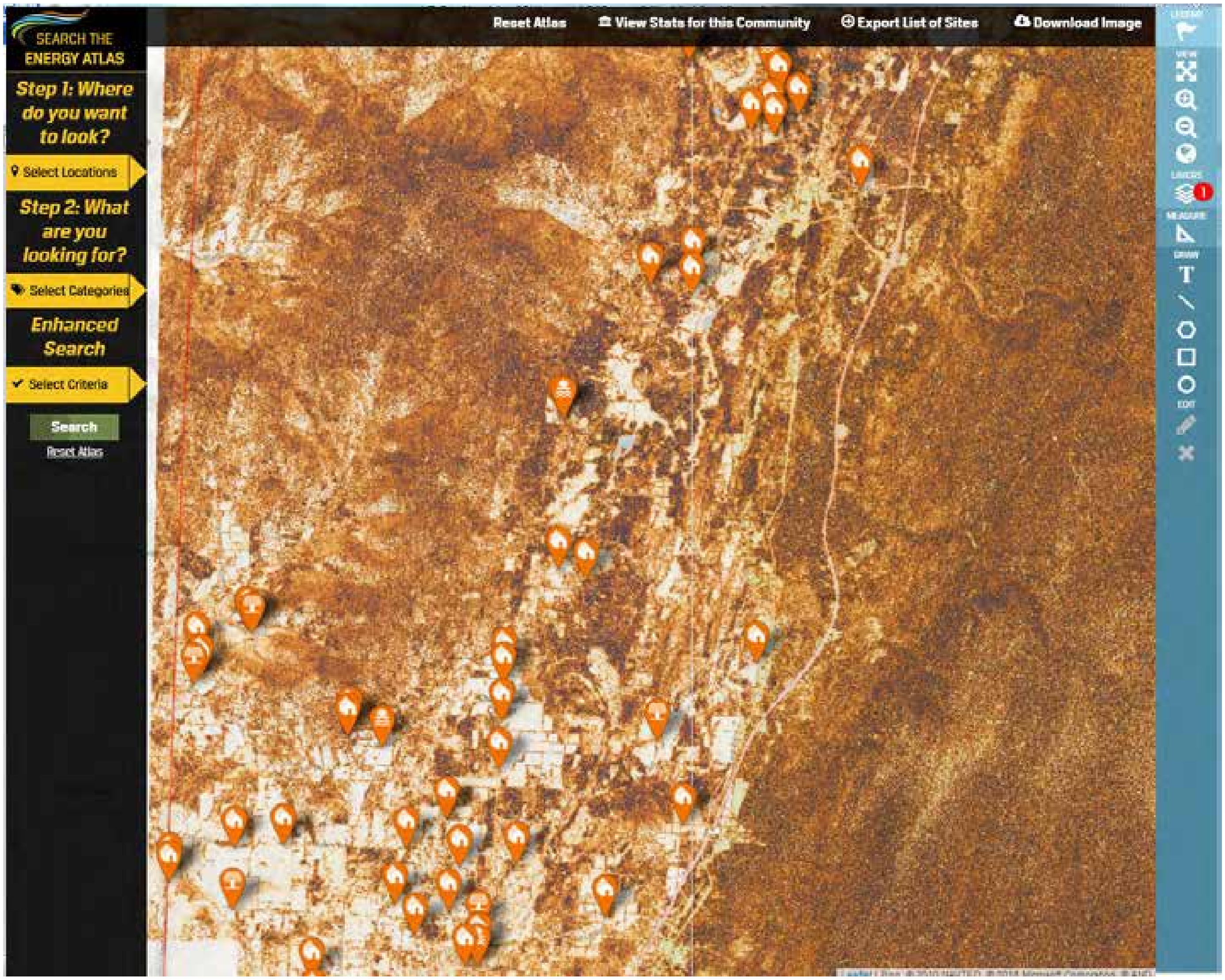
After selecting an area, Dashboard users can select one or many Energy Categories. This is an improvement over the original Energy Atlas, which allowed for selecting only one community at a time.

COMMUNITY ENERGY DASHBOARD — ENERGY ATLAS ENHANCED SEARCH



Dashboard users can select additional criteria to sort their results, including utility territory, site type (e.g., Farm, Residential), and system size.

COMMUNITY ENERGY DASHBOARD — SOLAR LIDAR SEARCH

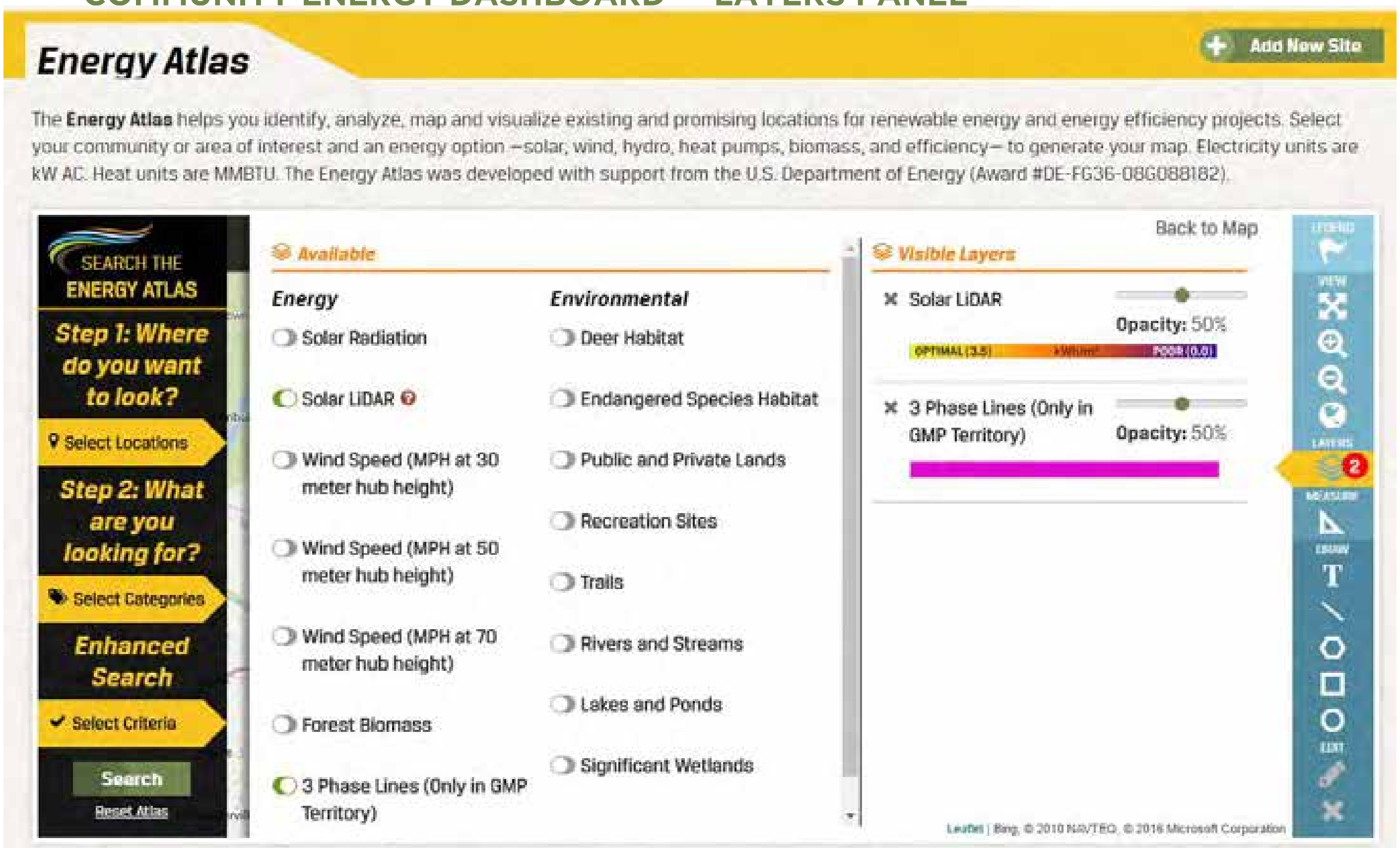


In this example, Bennington County has been selected as the area, and all solar types have been selected as the energy category. The fullscreen view switch has been toggled on.

Improved Solar Data

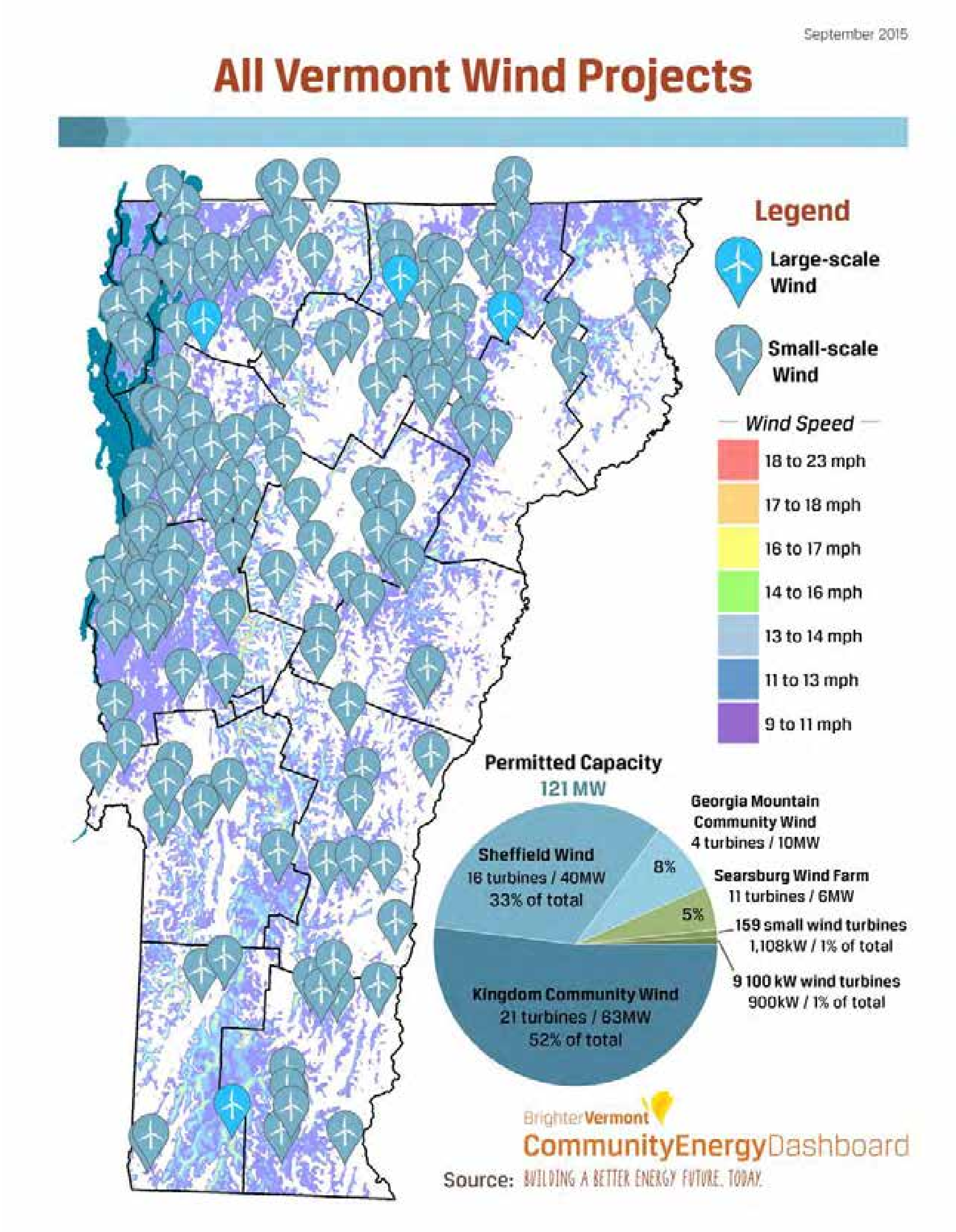
Highly accurate elevation data created using an airborne optical technique known as LIDAR (Light Detection and Ranging) is analyzed in concert with local shading, seasonal sun angles, day length and general climate and sun availability conditions relative to Vermont. The resulting data layer provides a level of accuracy that it is orders of magnitude greater than the ESRI Solar Radiation tool. The state currently has 45% coverage of this valuable resource with the Vermont LiDAR Initiative actively planning to acquire the remainder. The Dashboard will replace the solar data layers created with the ESRI Solar Radiation tool with the LIDAR data as it becomes increasingly available.

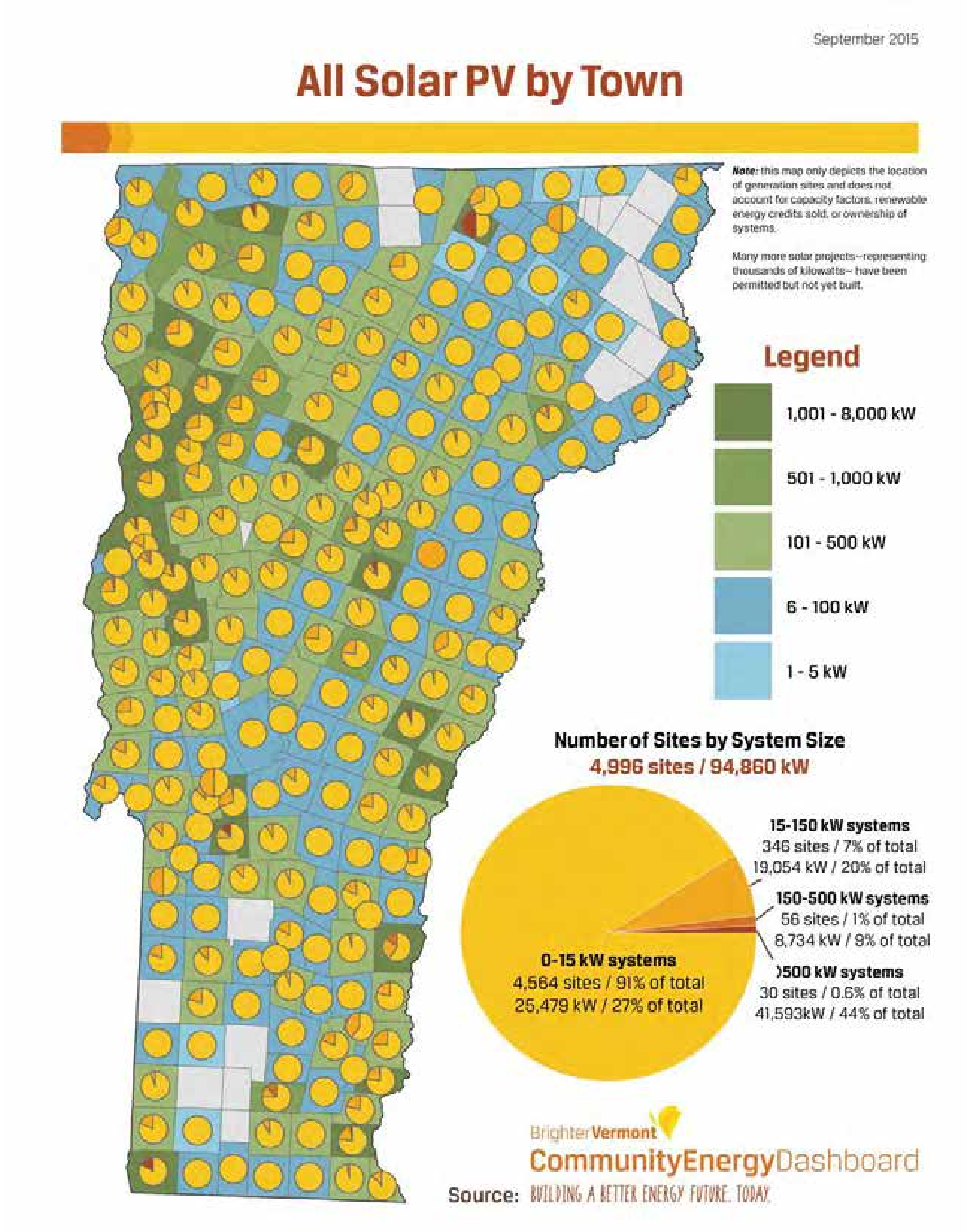
COMMUNITY ENERGY DASHBOARD — LAYERS PANEL



Dashboard users can view the Data Layers that are turned on and adjust their opacity. Drawing and labeling tools are also available in the blue toolbar on the right side of the screen.

The robust installed renewable energy sites database behind the scenes—created by VSJF for the Energy Atlas—also allows EAN and VSJF to create graphically interesting reports and infographics.




September 2015
All Solar PV by Town
Note: this map only depicts the location of generation sites and does not account for capacity factors, renewable energy credits sold, or ownership of systems.
Many more solar projects—representing thousands of kilowatts— have been permitted but not yet built.
Legend
1,001 - 8,000 kW
501 - 1,000 kW
101 - 500 kW
6 - 100 kW
1 - 5 kW
Number of Sites by System Size
4,996 sites / 94,860 kW
15-150 kW systems
346 sites / 7% of total
19,054 kW / 20% of total
150-500 kW systems
56 sites / 1% of total
8,734 kW / 9% of total
0-15 kW systems
4,564 sites / 91% of total
25,479 kW / 27% of total
>500 kW systems
30 sites / 0.6% of total
41,593kW / 44% of total
BrighterVermont
CommunityEnergyDashboard
Source: BUILDING A BETTER ENERGY FUTURE. TODAY.

NEXT STEPS

The Energy Action Network (EAN) is diligently working with the **Vermont Department of Public Service**, **Vermont Energy and Climate Action Network** (VECAN), town energy committees, **Vermont Energy Investment Corporation**, **Efficiency Vermont**, **Green Mountain Power**, municipal governments, and regional planning commissions to roll out the Dashboard. Many presentations, webinars, and hands-on tutorials have been provided since the launch of the website in May 2016.

Going forward, EAN will continue to build the capacity of these organizations to make full use of the Dashboard to document their progress toward meeting 90% of Vermont's energy needs through increased efficiency and renewable sources by 2050. In many respects, the mapping, data visualization, statistical analysis, and storytelling functions of the Dashboard make it the centerpiece of Vermont's 90 by 2050 agenda. It will increasingly help inform the siting guidelines recently passed as **Vermont Act 174**, which call for more community input.

Many enhancements are envisioned to continue to make the Dashboard user friendly and intuitive, including the ability to bulk upload Actions, the addition of other suitability layers (e.g., floodways), and the inclusion of data and analysis about climate change.

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