Putney Basketville Site Biomass CHP Analysis

Randolph Hunsberger and Gail Mosey

Produced under direction of the U.S. Environmental Protection Agency (EPA) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-08-0719 and Task No. WFD3.1001.

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Technical Report
NREL/TP-5D00-58803
October 2013

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The following people also provided material help in this analysis:

- Hervey Scudder of NECSIS provided several papers used for background data in this report.
- Dave Harris and Tom Moore, formerly of Putney Paper, provided thermal and electric use data for their facilities.
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- Jennifer Hushaw, Charles Levesque, and Eric Kingsley of Innovative Natural Resource Solutions provided help with the biomass resource analysis and in determining values for the BPE model inputs.

Executive Summary

The U.S. Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response Center for Program Analysis developed the RE-Powering America's Land initiative to reuse contaminated sites for renewable energy generation when aligned with the community's vision for the site.

The Putney, Vermont, Basketville site, formerly the location of a basket-making facility and a paper mill and woolen mill, was selected for a feasibility study under the program. Biomass was chosen as the renewable energy resource based on abundant woody-biomass resources available in the area. Biomass combined heat and power (CHP) was selected as the technology due to nearby loads, including Putney Paper and Landmark College.

Results

Estimates of available low-grade biomass, suitable for a biomass thermal, electric, or CHP facility, range from 78,000 to 380,000 green tons per year, depending on certain assumptions and on the collection region specified. Feedstock requirements for a biomass CHP facility serving Putney Paper's thermal load of 30,000 pounds per hour, and providing 600-kW electric gross, are expected to be between 36,000 and 44,000 green tons per year. Thus, it would appear that local biomass resources are adequate for the described facility—but these numbers should be confirmed, as described below.

Table ES-1 provides an estimate of the number of delivery trucks per day at Putney Paper for various fuels.

Table ES-1. Truck Deliveries for Putney Paper

Fuel Type	Capacity	Units	Trucks Per Day
Fuel oil No. 2	2,500	gallons	2–3
Fuel oil No. 2	4,000	gallons	1–2
Compressed natural gas (CNG)	350,000	scf[1]	2–3
Biomass	20	tons	5–6
Biomass	30	tons	4–5

Displacing compressed natural gas (CNG) or fuel oil with biomass would add between one and four trucks per day, on average, depending on the delivery capacity of the current fuel oil and future biomass trucks.

Utility bill savings are estimated at $6 million per year; biomass costs at $1.1 million to $2.2 million per year, and non-fuel operation and maintenance costs at $1.6 million to $1.7 million per year. Capital costs have been estimated to be $9 million to $11 million.

Solar on the Site

In May 2013 it was announced that Greg Wilson, the owner of the Basketville site, had contracted to install a 156-kW solar photovoltaic (PV) system on the site. This is located at the north end of the site and is currently operational.

[1] scf = standard cubic foot

Recommendations and Next Steps

Based on preliminary numbers, biomass-fired CHP is potentially a good option for the Basketville site. Further analysis should be undertaken to confirm assumptions used in this report, particularly biomass availability and cost, equipment sizing and cost, and operation and maintenance costs.

The impact of truck traffic should be evaluated for any biomass facility. As configured, this site should receive fewer than six trucks per day, seven days per week, although these would be offset by the elimination of propane and oil truck deliveries.

Local residents have concerns regarding air emissions from a biomass facility. The particulate emissions in particular should be quantified and weighed against emissions from the current burning of No. 6 oil.

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1 Background

The U.S. Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response Center for Program Analysis developed the RE-Powering America's Land initiative to reuse contaminated sites for renewable energy generation. EPA engaged the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) to conduct feasibility studies to assess the viability of developing renewable-energy-generating facilities on contaminated sites. The former Basketville manufacturing site in Putney, Vermont, was selected as one feasibility study under the program.

The area surrounding the site has ample woody biomass to support a bioenergy project (see Section 6). There is potential to sell electricity or steam to Putney Paper, which is located across the street from the site, and to Landmark College, which is within one-half mile of the site.

1.1 Scope of Work

This study evaluates the feasibility of installing either a heating plant or a combined heat and power (CHP) plant using woody biomass as feedstock and serving a nearby load.

The site and property are described in Section 3. Biomass properties, costs, and availability are covered in Section 4. State and regional energy use are described in Section 6, as are potential off-takers and associated loads. Codes and regulations are covered in Section 7.

1.2 Study Level and Uncertainty

This study is intended to be a high-level analysis, to serve as the first step toward deciding if conditions are favorable for a biomass project at the Putney Basketville site. As such, there is uncertainty in some key study components, including biomass availability and cost, equipment costs, operation and maintenance costs, and annual energy use.

Recommendations are provided in each section for next steps that will further reduce these uncertainties in the next level of analysis.

2 Development of Biomass Energy on Superfund Sites

One promising and innovative use of contaminated sites is to repurpose them for biomass heating and power systems. Biomass systems work well on Superfund sites where there is an adequate biomass fuel supply and favorable energy sales rates.

The cleanup and reuse of potentially contaminated properties provides many benefits, including:

- Preserving greenfields
- Reducing blight and improving the appearance of a community
- Raising property values
- Creating jobs
- Allowing for access to existing infrastructure, including electric transmission lines and roads
- Enabling a potentially contaminated property to return to a productive and sustainable use.

By taking advantage of these potential benefits, biopower can provide a viable, beneficial reuse—in many cases generating revenue on a site that would otherwise go unused.

The site in Putney, Vermont, is owned by Greg Wilson, who is also the owner of the Basketville basket company. The site under review is a former manufacturing site and is currently for sale. Wilson is interested in a potential renewable energy project on the site. As with many contaminated or formerly contaminated sites, the local community has significant interest in the redevelopment of the site, and community engagement is critical to match future reuse options to the community's vision for the site.

The subject site has potential to be used for other functions beyond the biopower project proposed in this report. Any potential use should align with the community vision for the site and work to enhance the overall utility of the property.

Most states rely heavily on fossil fuels to operate their power plants. There are many compelling reasons to consider moving toward renewable energy sources for power generation instead of fossil fuels, including:

- Using fossil fuels to produce power might not be sustainable
- Burning fossil fuels can have negative effects on human health and the environment
- Extracting and transporting fossil fuels can lead to accidental spills, which can be damaging to the environment and communities
- Fluctuating electric costs are associated with fossil-fuel-based power plants
- Burning fossil fuels emits greenhouse gases, possibly contributing to climate change.

3 Site Description

The property for this analysis is located at 7 Bellows Falls Road in Putney, Vermont. The property is approximately 6.1 acres; there are seven buildings on the site, some of which might be salvageable. Some of these buildings are currently used for storage and range in size from 192 ft^2 to 10,680 ft^2.

According to the application for the EPA RE-Powering study, a draft Corrective Action Plan (CAP) was developed in 2007 for the proposed reuse of the site as a 44-unit affordable housing development. Unfortunately, the redevelopment did not happen, so the CAP was not finalized. This CAP proposed to utilize clean fill to serve as a barrier to contaminated soils.

The RE-Powering application (p. 3) also states:

> Previous discussions about biomass in Putney have revealed community concern about the impacts of biomass combustion upon air quality and truck traffic. In addition, a possible limitation of the site, which needs further evaluation, is access/egress for delivery vehicles.

Figure 1 is a map of the northeastern United States from the RE-Powering application, showing the Windham region in southeastern Vermont. Putney is in the Windham region, very close to the border of New Hampshire.

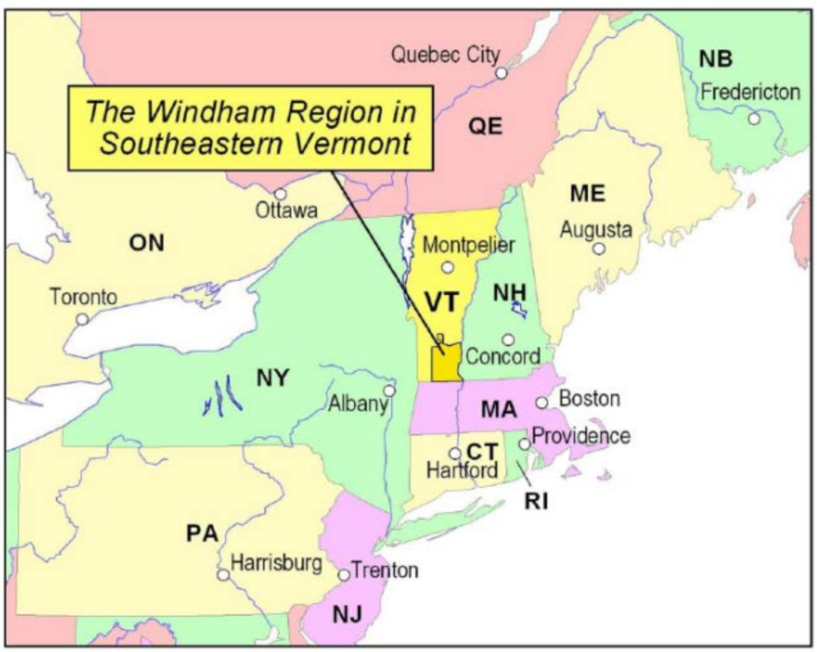

Figure 1. Map showing location of Windham region in southeastern Vermont

Source: WRC

Putney is in need of additional housing and jobs. This property has previously been considered as a location for apartments. As noted in the document *Sacketts Brook Sustainability Center*

Putney's Green Business Incubator,[2] "Putney needs more housing but Putney also needs more mid to high paying jobs. Simply creating housing will cause the lack of jobs to be a greater problem, and simply creating more jobs (or retail space) will exacerbate the existing housing problems." The current report considers bioenergy for this property, which will create additional jobs but will not address the housing issue.

3.1 Site Ownership and History

Records indicate that the property has been used for manufacturing various products since at least 1889, beginning with a wool mill factory, which was converted to a paper mill in about 1899. A basket production facility existed on the site from about 1969 to 2002.

Some environmental contamination occurred on the site during its time as a wool mill and as a paper mill. In addition, an underground storage tank, which was removed in 1998, seems to have leaked No. 2 fuel oil into the soil.

The site is adjacent to a general store, which sells gasoline. Indications are that the underground tanks at the general store might have leaked gasoline into the groundwater and soil.

Other possible contaminants on the site include volatile organic compounds (VOCs) from the staining of baskets and lead from paint used on the site's buildings.

3.2 Putney Village and Basketville Site Layout

Figure 2 is a map of the Putney Village Center. The Basketville site investigated in this analysis is depicted by the red dashed line at the top of the map.

[2] "Sacketts Brook Sustainability Center Redevelopment Proposal." Accessed June 19, 2013: http://energy.putney.net/files/docs/eco-park.pdf. http://projects.putney.net/basketville/slideshow/Basketville.html.

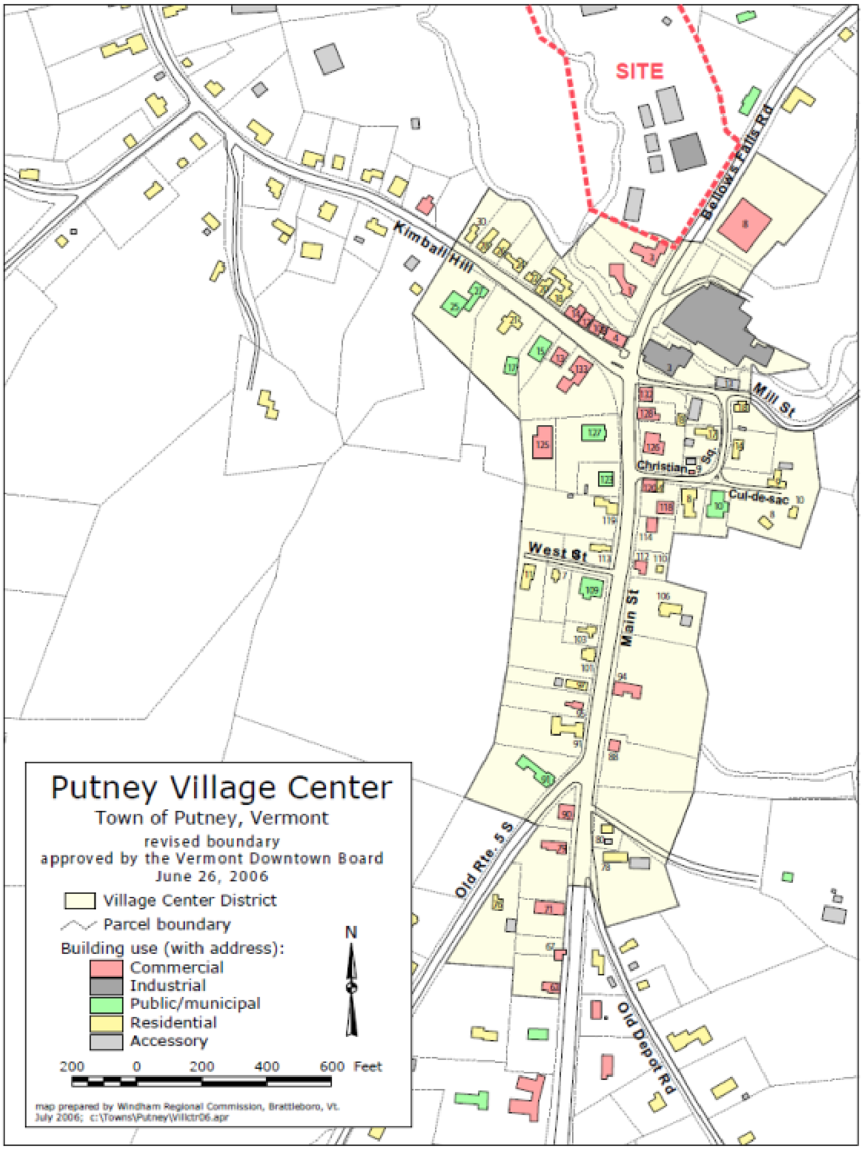

Figure 2. Putney Village Center map

Source: WRC

The site is in the shape of a large goldfish, as shown in Figure 3, which puts north at the left and east on top. The site has since been extended to include additional acres at the tail end of the property.

Figure 3. Putney Basketville site (outline) overlaid on an aerial photograph

Source: WRC

Figure 4 is a map of the site (with north at the top) showing the site in relation to some of the local buildings, including the Basketville store, the Putney Paper Company offices and mill, and other downtown buildings. The Putney Paper Mill is a potential purchaser of electric and thermal energy produced at the site. Arrows at the south end of the site indicate potential truck access routes—one to the south of Mountain Paul's General Store and one to the north.

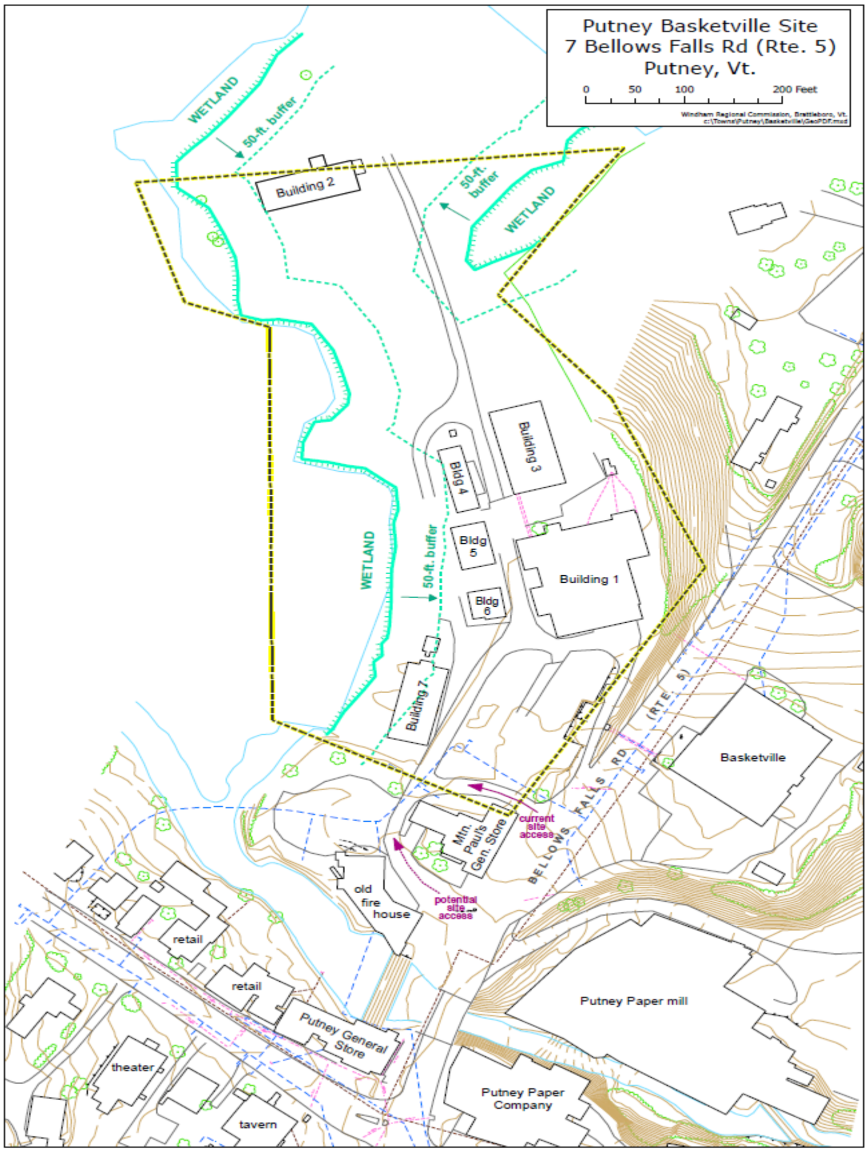

Figure 4. Putney site and surrounding local buildings

Source: WRC

3.3 Site and Town Photographs

The following photographs were taken by NREL during the site visit in September 2012.

Figure 5 is a view looking north along Route 5, with Mountain Paul's General Store in the left foreground. The site access is not visible but is just behind the black truck in the picture.

Figure 5. Mountain Paul's General Store with the Basketville site in the background. ***Photo by Randolph Hunsberger, NREL***

Figure 6 is a view of the site access, taken from the opposite side of Bellows Falls Road. This view is looking down the primary access route, to the left of the fence. The driveway drops sharply from the road, which can cause problems for long trucks. The site is on the right in this picture.

Figure 6. Photo of the site viewed across Bellows Falls Road. ***Photo by Randolph Hunsberger, NREL***

Figure 7 is a picture of the site from outside the boundary fence looking west.

Figure 7. View of the site over the fence. ***Photo by Randolph Hunsberger, NREL***

Figure 8 shows Buildings 5 and 4 (as designated in Figure 4). The windows of Building 5 are covered with plastic.

Figure 8. Two of the site buildings. ***Photo by Randolph Hunsberger, NREL***

Figure 9 was taken inside of one of the buildings that could potentially be used for storage of wood chips or for locating equipment.

Figure 9. Inside one of the site buildings. ***Photo by Randolph Hunsberger, NREL***

Another building that might be useful for storage or equipment placement is shown in Figure 10.

Figure 10. Inside a site building with large delivery doors. ***Photo by Randolph Hunsberger, NREL***

Figure 11 shows another view of buildings and interior roads on the site, looking north. Buildings labeled 4, 5, and 6 in Figure 4 are on the left; the corner of Building 1 is on the right of the photo.

Figure 11. More site buildings. ***Photo by Randolph Hunsberger, NREL***

Another possible storage building is shown in Figure 12.

Figure 12. Large roll-up door on a site building. ***Photo by Randolph Hunsberger, NREL***

3.4 Utility Provider

Green Mountain Power (GMP) is the utility serving the Town of Putney. GMP has a strong record of commitment to renewable energy projects in the region. GMP has expressed specific support for the “Baskets to Biomass” feasibility study and eventual deployment of the project. A letter of support from GMP is included in Appendix A.

3.5 Solar on the Site

In May 2013 it was announced that Greg Wilson, owner of the Basketville site, had contracted to install a 156-kW solar photovoltaic (PV) system on the site. This system is located at the north end of the site and is currently operational.

3.6 Recommended Activities for Next-Level Analysis

Existing bioenergy facilities range in size from a few acres up to hundreds of acres. Some of this space is required for equipment and some for feedstock storage. As part of a next-level analysis, it is important to determine the space required by an appropriate bioenergy facility, including fuel storage, and determine that it is compatible with other potential uses for the site.

Some of the buildings might be reused for a bioenergy facility, which would reduce capital costs. The buildings should be inspected by a structural engineer to confirm that they are safe for reuse.

4 Biomass Feedstock: Properties, Cost, and Availability

In this section, we look at woody feedstock properties and availability for a biomass facility in Putney.

4.1 Biomass Properties

Several important properties of biomass determine the operating success of a biomass heat or power facility, including energy content, moisture content (MC),[3] and ash content. Fuel handling and processing procedures determine wood cleanliness and chip size, which can significantly affect system reliability and maintenance.

In Vermont, wood MC typically ranges from 40% in summer and fall to 50% in winter. MC affects the efficiency of a biomass combustion process in a non-linear manner. For example, biomass might contain 4,000 Btu per pound of recoverable energy at 40% MC, and with 50% MC the recoverable energy may only be 3,133 Btu per pound. This represents a loss of more than 21% of the energy value. If prices are not adjusted based on feedstock moisture content, the cost per Btu greatly increases with increasing moisture content.

To explore the effect of moisture content on energy production, the Southeast Clean Energy Application Center's Wood Energy Calculator is useful.[4] See Figure 13 for an example of the program's inputs and outputs.

[3] In this report, moisture content is specified on a wet basis [i.e., MC, wb = weight of water ÷ (weight of water + weight of dry wood)]. In some industries, moisture content is reported on a dry basis (i.e., MC, db = weight of water ÷ weight of dry wood). Note that 50% MC, wb = 100% MC, db.

[4] Southeast Clean Energy Application Center. "Wood Energy Calculator." Accessed June 19, 2013: http://www.southeastcleanenergy.org/resources/calculators.aspx.

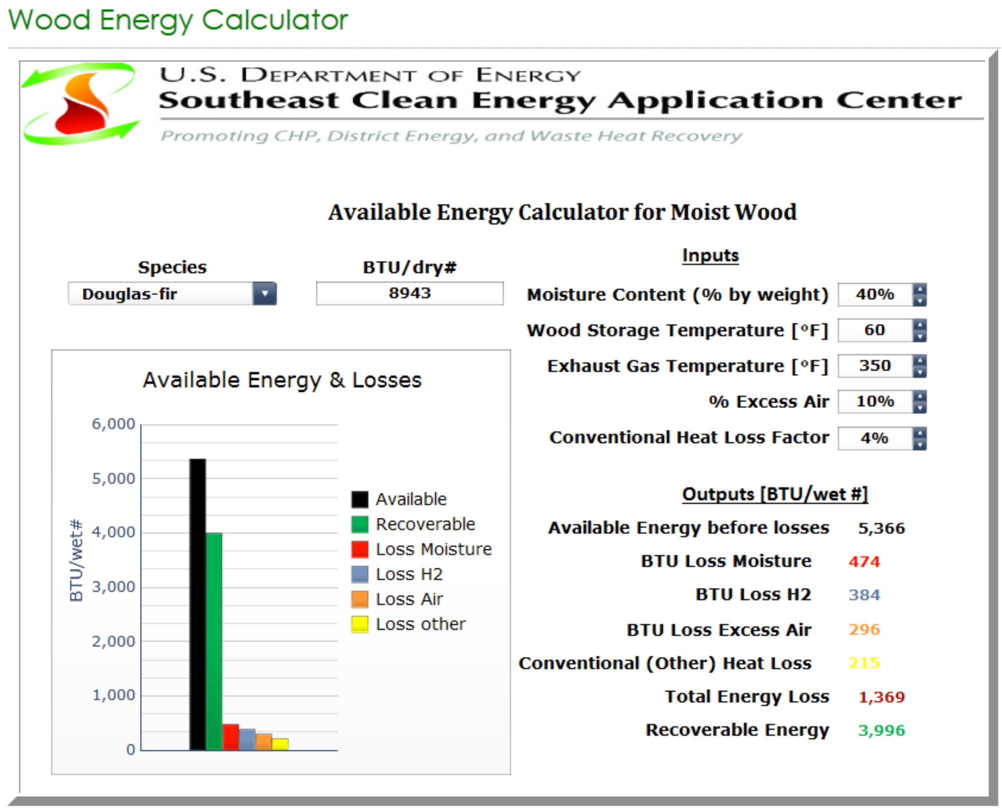

Figure 13. Southeast Clean Energy Application Center's Wood Energy Calculator

Source: DOE

4.2 Biomass Cost

An important factor in assessing the feasibility of a biomass project is the cost of the resource. We estimate that this material would have a delivered price of $30–$50 per green ton.[5] The North Springfield Biomass report[6] estimates a biomass delivered cost (for North Springfield) as follows:

> INRS projects that the 'wood component' of biomass fuel for this location will average $27.00 per green ton in 2011, and increase annually by 3%. In order to get a final delivered price, 2.1 times the price of gallon of diesel should be added; for example, if diesel averages $4.00 per gallon in 2011, the average delivered cost for biomass fuel is projected to be $34.40.

Diesel fuel is a significant component of the price, as it is used to fuel the delivery trucks, as well as the equipment used to harvest and process the biomass.

[5] In the Biomass Energy Development working group report, Thomas D. Emero, Managing Director - Development & Operations for Beaver Wood Energy, LLC, states, "Harvesters are desperately in need of a market such as the one the power plant will create where they can bring this material. The market price for forest residue **is currently and has been for many years around $30.00/ton**" (p. 194). We use this $30 per ton value as the floor price in our analysis.

[6] "Biomass Fuel Availability North Springfield, Vermont." Prepared for: North Springfield Sustainable Energy Project, A Project of Winstanley Enterprises, September 2011. Accessed September 11, 2013: http://swcrpc.org/wp/wp-content/uploads/2012/01/Exh.-Pet.-EWK-2.pdf.

4.3 Biomass Resource

Wood used for a biomass energy plant is generally the low-valued material, which is often the residue from harvest of more valuable material like saw logs for dimensional lumber. It can also result from land maintenance and clearing operations, thinning for fire mitigation, urban tree trimming, storm clean-up, power line right-of-way maintenance, and disposal of diseased trees (e.g., beetle kill). Note that this material is generally a waste product or a product of procedures that improve forest health or reduce risks to the forest or to people living near forests.

4.3.1 Renewable Energy Atlas of Vermont

The Renewable Energy Atlas of Vermont[7] (REA) is a website with GIS tools that allow the analysis of energy efficiency and renewable energy projects within the State of Vermont. These renewable energy projects include solar, wind, geothermal, hydro, and biomass. Biomass project types include biodiesel, perennial grasses, methane digesters, waste to energy, and woody biomass. Outputs of the woody-biomass analysis include potential for electric, thermal, and CHP production from the available resource, along with details about existing projects within a study area. Unfortunately, these data are constrained by the state border, so available resources and projects in neighboring states are not included in the analysis. NREL performed one analysis just for the town of Putney and a second analysis for the southern third of the state.

4.3.2 Putney Village Analysis

Figure 14 shows the region of the first biomass availability analysis, which only includes an area within Putney's town limits.

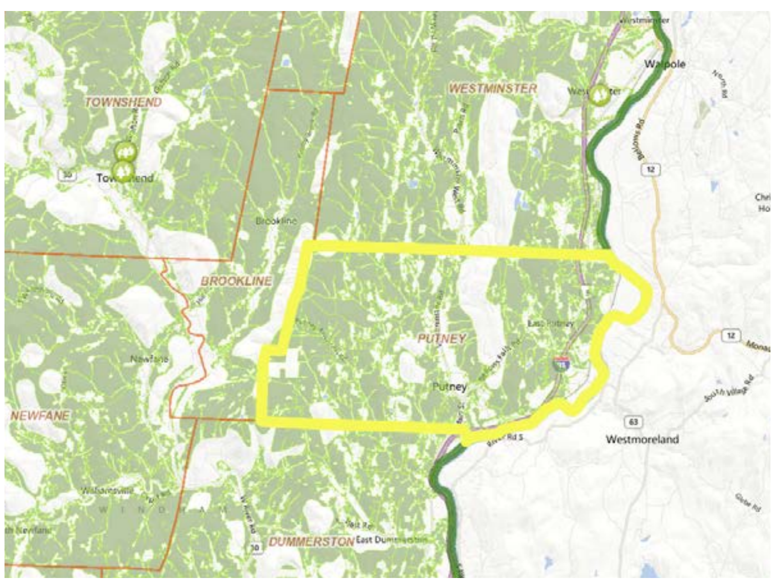

Figure 14. Region included in first analysis using the Renewable Energy Atlas of Vermont tool

Source: REA

According to the REA, the area of this analysis is 9,877 acres, with 6,146 green tons of wood available each year. This would be enough to produce about 4,400 MWh of electricity each year,

[7] Renewable Energy Atlas of Vermont. Accessed June 19, 2013: http://www.vtenergyatlas.com/.

which could be produced by a generator sized at about 600 kW and operating at an 85% capacity factor. There are no electric-generating facilities in this region fueled with biomass, according to the REA.

The REA indicates that the same amount of biomass could provide about 62,000 million Btu over the course of a year. If this were used to supply a constant load, such as an industrial steam process, it could supply about 8 million Btu per hour.

There are no existing large-scale woody-biomass thermal systems within this region.

4.3.3 Southern Vermont Analysis

A second analysis was performed using a larger area, as shown in Figure 15. Note that, though the boundaries of this region extend into neighboring states, the data in the analysis only includes resources and projects within the State of Vermont.

On this map, the round green icons indicate biomass thermal projects and the white rectangular icons represent suppliers of chips, pellets, or other forms of woody biomass. When viewing this map on the Vermont Energy Atlas website, clicking these icons will provide more information about each site.

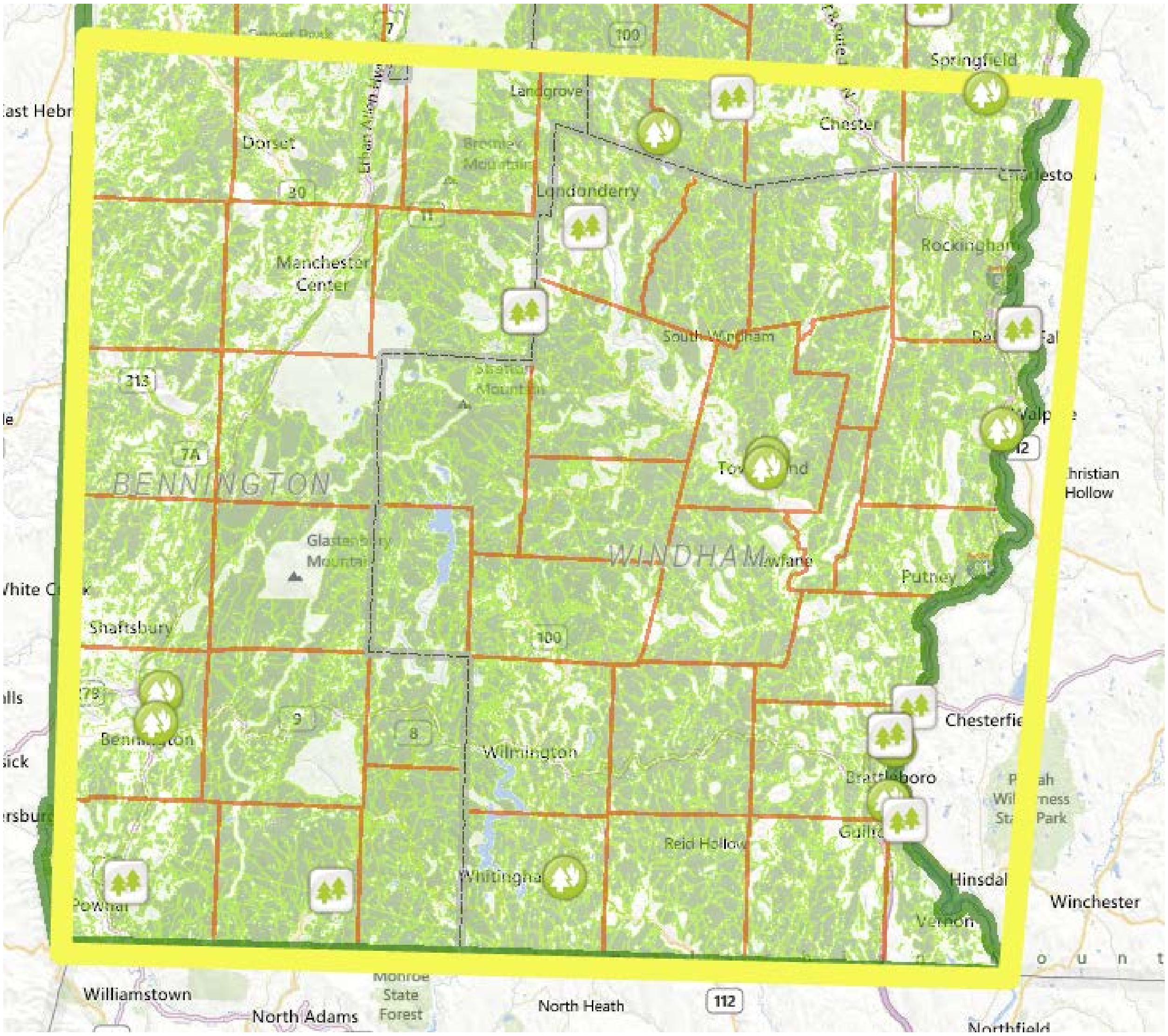

Figure 15. Southern Vermont region for REA analysis

Source: REA

The southern Vermont analysis, which includes an area of about 615,000 acres, estimated an annual availability of about 380,000 tons of low grade wood—enough to supply about 165,000 MWh per year of electric energy (22 MW at 85% capacity factor), or 2.3 trillion Btu of thermal energy (about 300 MMBtu/hr at constant load and an 85% capacity factor).

The program found no electric-generating or CHP facilities within the study area, but it did identify eight woody-biomass thermal sites, as shown in Table 1. Note that, with one exception, these projects are all school heating projects. *Keith Dewey* appears to be a commercial biomass boiler in Weston, Vermont, using wood or corn pellets to heat a greenhouse, apartment, office, garage, and house.

The total amount of wood used for these eight operations is small compared to the quantity of low-grade biomass within this region. Additional biomass would be available in neighboring states, particularly New Hampshire.

Table 1. Project Sites Using Woody Biomass to Produce Thermal Energy in Southern Vermont

8 Existing Woody Thermal Sites:

Name	Wood Energy System Manufacturer	Wood System Size - Thermal (MMBH)	Annual Wood Consumption (Tons)
Mt Anthony Middle School	Messersmith	4	610
Brattleboro Union High School	Messersmith	8	1,222
Whitingham Elementary School	Messersmith	3	125
Westminster Center School	Messersmith	1	260
Springfield High School	Messersmith	6	893
Keith Dewey	Maxim	0	0
Mt Anthony Union High School	Messersmith	6	810
Leland & Gray Union High School	Chiptec	1	308
	TOTAL »	0	4,228

Source: REA

4.3.4 Northern Forest Biomass Project Evaluator Model

To extend the analysis beyond the borders of Vermont, the Northern Forest Biomass Project Evaluator (BPE) model was used. This is a software model that runs under Microsoft Access and provides an assessment of biomass availability in the northeastern United States, including Maine, Massachusetts, New Hampshire, New York, Pennsylvania, and Vermont. It was created for the North East *State* Foresters Association by Innovative Natural Resource Solutions and can be found on their website.[8] The BPE identifies available biomass but does not identify existing projects.

The BPE model allows the user to determine a supply area by choosing specific counties or by evaluating a circular region centered on a user-defined latitude and longitude. The Basketville evaluation was centered on latitude of 42.97665 and longitude of -72.52153, with a radius of 30 miles from that center. This supply shed covers parts of 17 counties in three states: Massachusetts, New Hampshire, and Vermont.

NREL worked with Innovative Natural Resource Solutions, LLC, to develop appropriate assumptions for the BPE model. Details of the inputs, assumptions, and outputs are provided in Appendix B.

Figure 16 shows the BPE output from the model predicting accessible quantities of biomass in three categories for each year: high-value bolewood, low-grade bolewood, and tops and branches.

[8] North East *State* Foresters Association. Accessed June 19, 2013: http://www.nefainfo.org/.

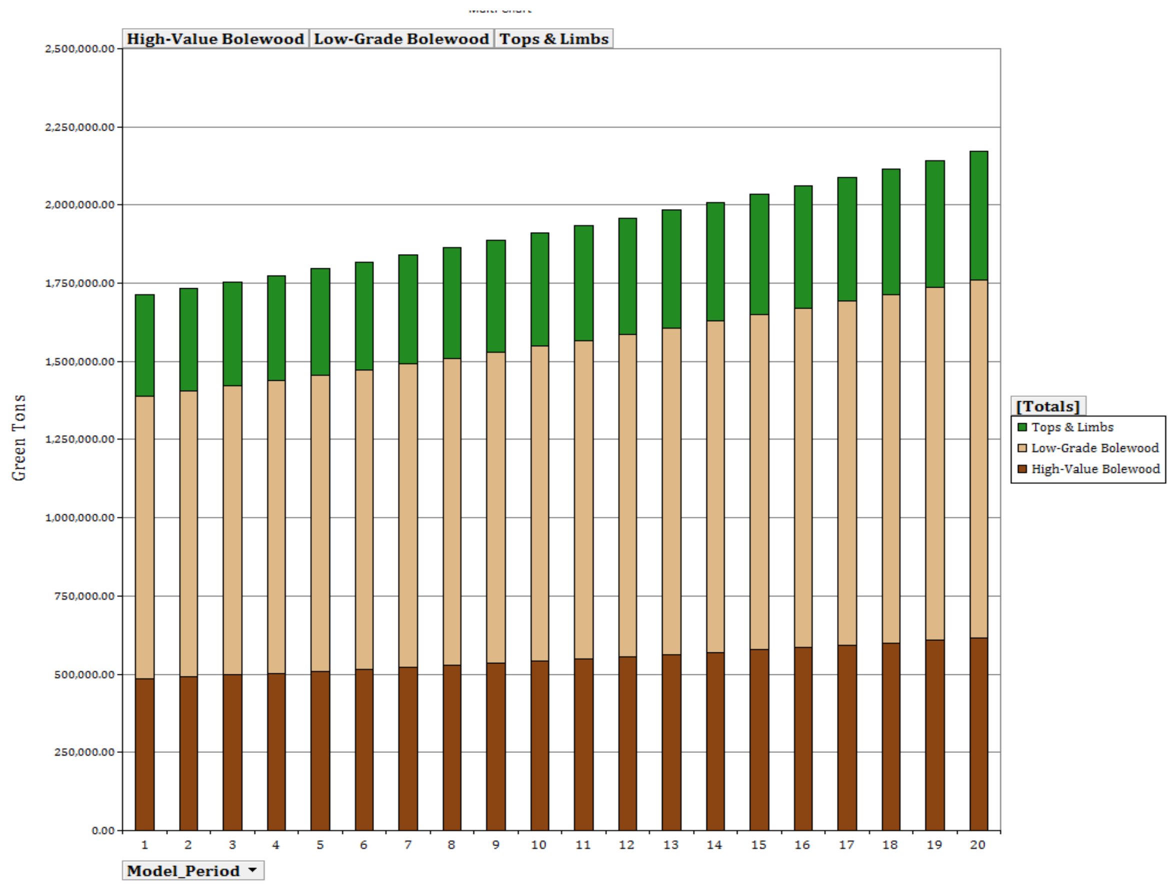

Figure 16. BPE model estimates of accessible quantities of biomass around Putney, Vermont

Source: INRS

The terms used in the BPE model are defined in Table 2.

Table 2. Terms Used in BPE Analysis

Variable Name	Definition
Net Annual Growth	The amount of net growth (accretion + ingrowth - mortality) occurring on timberland over a single model projection year, based on total aboveground biomass volume and the county-specific growth rate.
Low-Grade Growth	The portion of total net growth that is considered low-grade (suitable for harvest as pulpwood, firewood, or chips) rather than high-value sawlogs. This is based on the percent low-grade inventory key assumption. On some reports (where indicated), this value is a sum of low-grade bolewood AND the volume of tops and limbs, which are assumed to be completely low-grade material.
Accessible Growth	The amount of growth that is accessible for harvest—based on the likelihood that a given landowner will engage in timber management/harvesting operations and physical harvest limitations related to steep slopes, elevation, sensitive habitat, etc.
Accessible and Available Growth	The portion of growth on accessible timberland acres that is not already captured by existing timber harvest.
Tops and Limbs Extracted	This variable represents the amount of volume from the tops and limbs of harvested trees actually removed from the woods, based on the user-defined key assumption regarding the percentage of tops and limbs volume that is suitable/sustainable to extract.

Figure 17 shows accessible and available volume of three different woody-biomass material types over the course of a 20-year analysis, covering the region within 30 miles of the Basketville site. A biomass heat or power (or CHP) project would use mostly low-grade bolewood but could also use tops and limbs as a certain percentage (to be determined with the equipment manufacturer) of their feedstock.

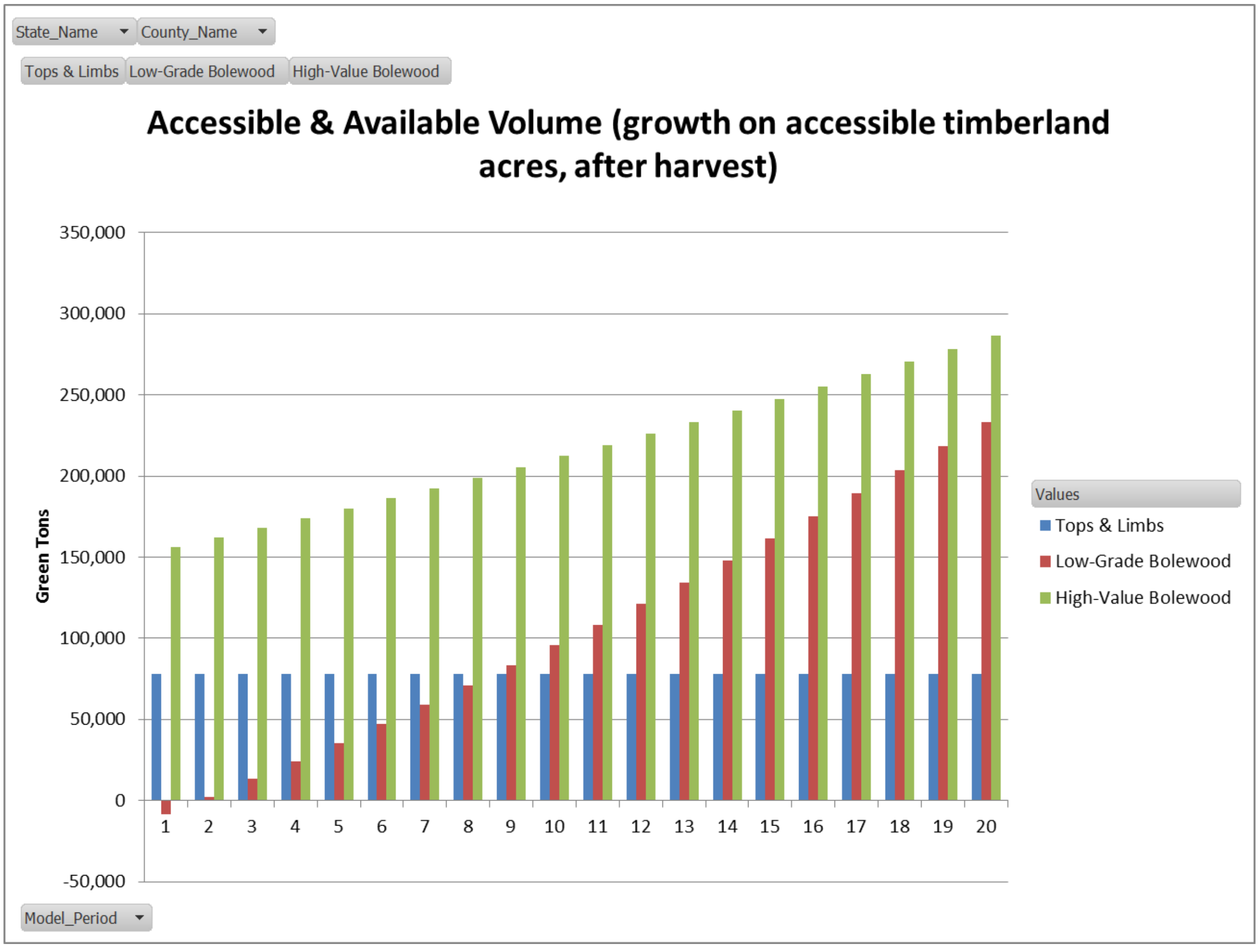

Figure 17. BPE results for Basketville

Source: INRS

4.3.5 Biomass Energy Resource Center Vermont Wood Fuel Supply Study 2010 Update

In 2010, the Biomass Energy Resource Center (BERC) produced an update to their 2007 Vermont Wood Fuel Supply Study. In this study, they estimated available wood resources based on three scenarios: the conservative scenario, the moderate scenario, and the intensive scenario. These scenarios were used to calculate the supply of net available low-grade growth (NALG) wood. They describe NALG as “wood that would be appropriate for use as biomass fuel above and beyond current levels of harvesting—available annually in the State of Vermont, including assessment of both Vermont’s counties alone and a larger study area comprising Vermont and the adjoining 10 counties of New Hampshire, Massachusetts, and New York.”[9]

The moderate scenario predicts about 900,000 green tons per year of NALG would be available in Vermont and over 3 million green tons per year when including the 10 surrounding counties.

[9] Biomass Energy Resource Center. “Vermont Wood Fuel Supply Study: 2010 Update.” p. 5. Accessed August 28, 2013: http://www.biomasscenter.org/images/stories/VTWFSSUpdate2010_.pdf.

It predicts about 166,000 green tons of NALG would be available each year in Windham County alone and about 880,000 GT/yr including the counties bordering Windham County.

4.3.6 Feedstock Summary

We have estimated biomass resource available around Putney using different tools, including the Renewable Energy Atlas of Vermont (REAVT), the Northern Forest Biomass Project Evaluator model (BPE), and the BERC 2007 Vermont Wood Fuel Supply Study (BERC Vermont Study).

The REAVT predicted an availability of 6,146 green tons per year within Putney and 380,000 GT/yr in the southern half of Vermont. The REAVT accounts for biomass and biomass projects within Vermont. Because Putney is very close to the New Hampshire and Massachusetts borders, it is important to evaluate biomass availability outside of Vermont.

The BPE predicted available values of tops and limbs, low-grade bolewood, and high-value bolewood for each year, within a 30-mile radius of the Basketville site. The BPE estimated accessible and available tops and limbs at a constant 78,000 green tons per year, low-grade bolewood starting near zero but increasing to about 200,000 GT/yr. These would be the primary feedstocks used for a biomass plant.

The BERC Vermont study predicted an availability of 166,000 GT/yr in Windham County and 880,000 GT/yr in Windham and surrounding counties.

4.4 Recommended Activities for Next-Level Analysis

The wide range of predicted available biomass for this region highlights the importance of performing a site-specific biomass resource assessment for a bioenergy facility.

As a next step, we recommend contacting foresters, wood utilization specialists, lumber mills, and others to get a firmer analysis of available biomass, biomass properties, and biomass cost. Some of these contacts are listed below in Table 3 and Table 4.

Table 3. Contacts for Assessing Biomass Resources and Cost

Name	Title	Organization	Phone	Email
Bob De Geus	Wood Utilization Specialist	Dept. of Forests, Parks & Rec.	802-241-3671	robert.degeus@state.vt.us
Dave Wilcox	State Lands Forester	Dept. of Forests, Parks & Rec.	802-476-0179	david.wilcox@state.vt.us
Jamie Fidel	VNRC		802-223-2328 ext. 117	jfidel@vnrc.org
Bill Guenther	Windham County Forester		802-257-7967	bill.guenther@state.vt.us
Kathleen Wanner	Executive Director		802-747-7900	kmwanner@comcast.net

Table 4. Mills

Mill Name	Road	City, State, ZIP	Phone
Allard Lumber	354 Old Ferry Road	Brattleboro, VT 05301	(802) 254-4939
Cersosimo Lumber Co.	1103 Vernon Street	Brattleboro, VT 05301	(802) 254-4508

5 Bioenergy Overview

Biopower, or biomass power, is the use of biomass to generate electricity. Biopower system technologies include direct-firing, co-firing, gasification, pyrolysis, and anaerobic digestion. Most biopower plants are direct-fired systems, which will be the focus of this section.

Co-firing refers to mixing biomass with fossil fuels in conventional power plants. Coal-fired power plants can use co-firing systems to significantly reduce emissions, especially sulfur dioxide. Typically, biomass is co-fired at a small percentage of the total heat input.

Pyrolysis is a thermal process that occurs without oxygen with outputs of syngas, liquids, and charcoal, which can be used to produce heat and power or reformed into liquid fuels and chemical products.

Anaerobic digestion is a biological degradation of organic matter without oxygen to produce biogas, which can be used in heat or electricity application.

Gasification systems heat biomass in a reduced oxygen environment to produce synthesis gas, a mixture of mostly hydrogen and carbon monoxide (CO). The synthesis gas, or syngas, can then be chemically converted into other fuels or products, burned in a conventional boiler, or used instead of natural gas in a gas turbine. Gas turbines are very much like jet engines, only they are used to turn electric generators instead of for jet propulsion. Gas turbines are very efficient, but the overall system efficiency can be further improved by operating them in a combined cycle arrangement. During combined cycle operation the exhaust gases are used to boil water for steam to provide additional power generation or heat.

The amount of energy produced by a biopower system depends on several factors, including the type of biomass, the technology employed, and numerous economic factors. Biopower systems can be sized to supply internal energy needs only or sized larger to feed energy to the grid for sale. Figure 18 shows a typical biopower direct-fired system.

Figure 18. Direct-fired biopower system. ***Photo from Wheelabrator Shasta Energy Co., NREL 07163***

These plants burn biomass feedstocks directly to produce steam. This steam drives a turbine, which turns a generator that converts the mechanical power into electricity. In some biomass plants, turbine extraction steam from the power plant is also used for manufacturing processes or to heat buildings. Such CHP systems increase overall energy efficiency. This makes sense when a large heat user is located nearby. These systems normally operate 24 hours per day and 7 days per week, with several weeks of down time per year for maintenance and repairs. Plants of this type are not normally cycled with many starts and stops. Frequent cooling and re-heating of equipment components leads to fatigue and failure, making it more cost-effective to operate around the clock, even though power rates are lower during off-peak hours. While direct-fired units are most common, the NREL biomass assessment team uses several tools to assess the optimal facility fuel, technology, plant size, and configuration for each particular location under consideration.

5.1 Bioenergy Equipment Determination

A biopower system type (and size) should be determined based on the energy requirements of the end-user, the cost of utility energy, and the availability of cost-effective biomass feedstock. The most common installation types are described below. In general, these systems can be divided into thermal energy only, power generation only, and combined heat and power (CHP) categories. The system choice is mostly dependent upon economics. The cost of fuel, the rate that power can be sold, and the rate available for the sale of thermal energy are a few of the key economic parameters.

5.2 Thermal Energy Only

Figure 19 illustrates a "thermal energy only" system in which biomass energy is converted to steam that is sent to a nearby business that utilizes the heat in the steam for heating, cooling, manufacturing, or any other number of industrial uses (boiler steam to load in Figure 19).

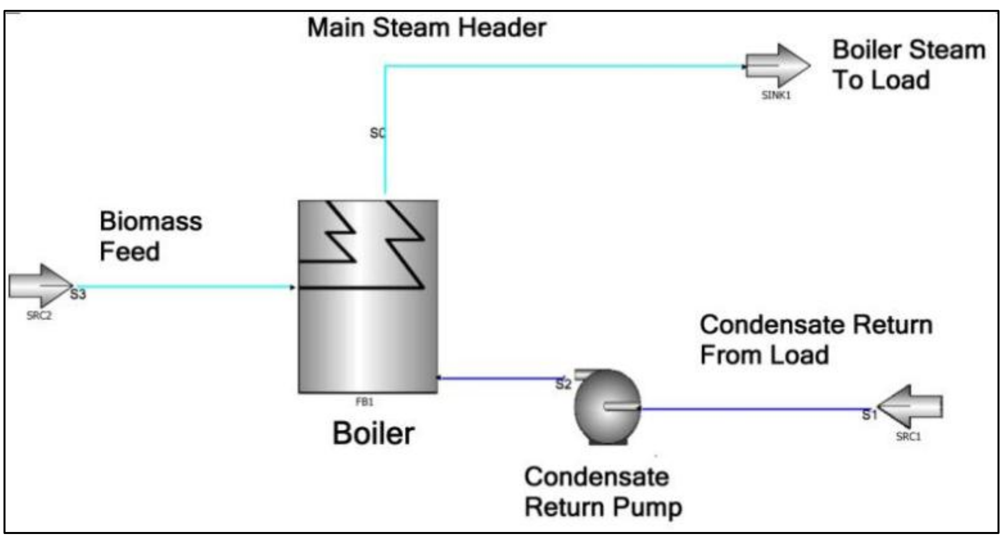

Figure 19. Thermal only biomass energy system

The steam is condensed as the energy is extracted and the warm condensate is pumped back to the biomass facility where it is reintroduced to the boiler and converted once again to steam. This type of system can be economical as the inefficiencies associated with generating electrical power on a small scale are avoided and the capital costs for a steam turbine, condenser, cooling tower, circulating water pumps, and other items are not incurred. High pressure, superheated steam is not required, making the boiler less expensive and easier to operate. This system is common and has been implemented for many decades in this country.

Finding a business that is close enough to accept steam without lengthy piping systems is often challenging. In many cases where a steam host is present, it makes sense to generate both steam and electricity.

5.3 Power Generation Only

Figure 20 illustrates a “power generation only” system in which biomass energy is converted into high pressure, superheated steam for introduction into a steam turbine. The turbine generates electricity at the most efficient rate practical depending on the size of the system. The steam is condensed at near vacuum to maximize efficiency. This is accomplished in a condenser, which uses cooling water that typically comes from an evaporative cooling tower. It is also possible to use a dry type of air-cooled condenser.

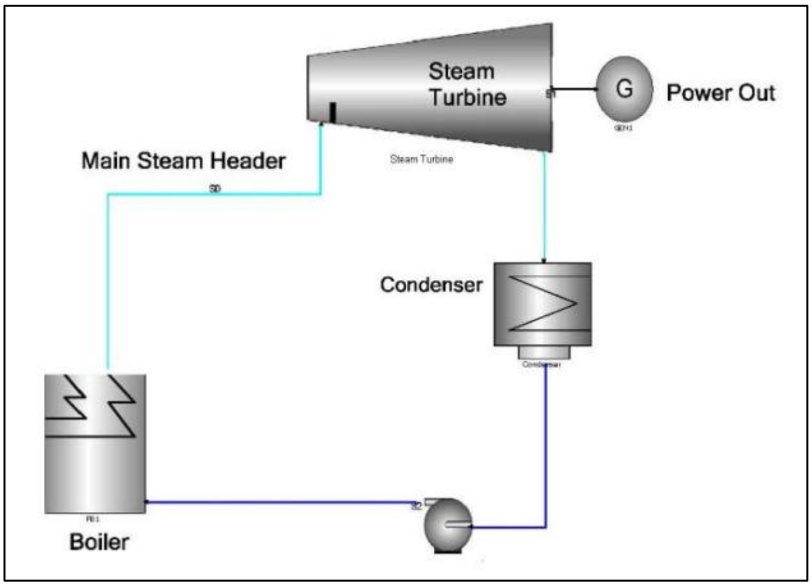

Figure 20. Power generation only biomass energy system (cooling tower not shown)

5.4 Combined Heat and Power

CHP is technically the concurrent generation of multiple forms of energy in a single system. CHP systems can include reciprocating engines, combustion or gas turbines, steam turbines, microturbines, and fuel cells. These systems are capable of utilizing a variety of fuels, including natural gas, coal, oil, and alternative fuels. While generating electric power, the thermal energy from the system can be used in direct applications or indirectly to produce steam, hot water, or chilled water for process cooling. Over 60% of biomass power systems use CHP.

For biomass direct-fired systems, the most common CHP configuration consists of steam from a biomass-fired boiler directed to a steam turbine. Steam is extracted at some point in this process to provide heat to meet internal requirements of the facility or steam for sale to a local steam host. The steam can be taken from the power process in three primary methods:

1. Main steam extraction
2. Extraction turbine
3. Back pressure turbine.

Main steam extraction extracts some of the boiler outlet steam prior to being introduced into the steam turbine. This high-pressure, high-temperature steam would typically have to be reduced in pressure and temperature prior to its final use. This is not the most efficient method for optimizing power output but avoids the cost of a more expensive extraction turbine (described below). The remaining steam runs through the entire length of the turbine and then discharges into a condenser at very low pressure (vacuum) to maximize the electric power generated. The condenser circulates large quantities of cooling water that is cooled by evaporation in a cooling tower or by an air-cooled condenser (Figure 21). By far the most common cooling method is a cooling tower, as it is less expensive and requires less power to operate, although a large quantity of water is evaporated. An air-cooled condenser is more expensive but is advantageous where large volumes of water are not available or water is expensive. Warm condensate is pumped back to the biomass facility where it is reintroduced to the boiler and converted once again to steam.

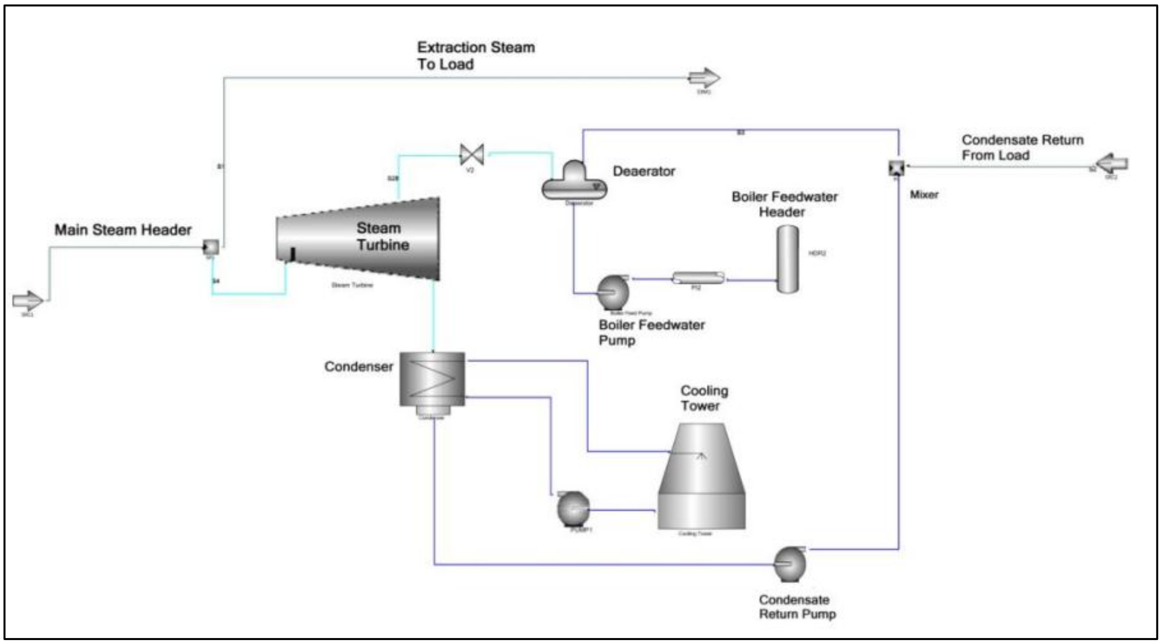

Figure 21. CHP main steam extraction

An **extraction turbine** accepts all boiler steam at its inlet and extracts the required process steam at some intermediate point along the turbine steam path. This allows the process steam to produce electric power prior to its extraction increasing the efficiency of the overall process. The cost for an extraction turbine is typically higher and is not normally utilized in smaller systems (less than 10 MW). The remaining steam continues through the lower-pressure stages of the turbine and then discharges into a condenser (Figure 22).

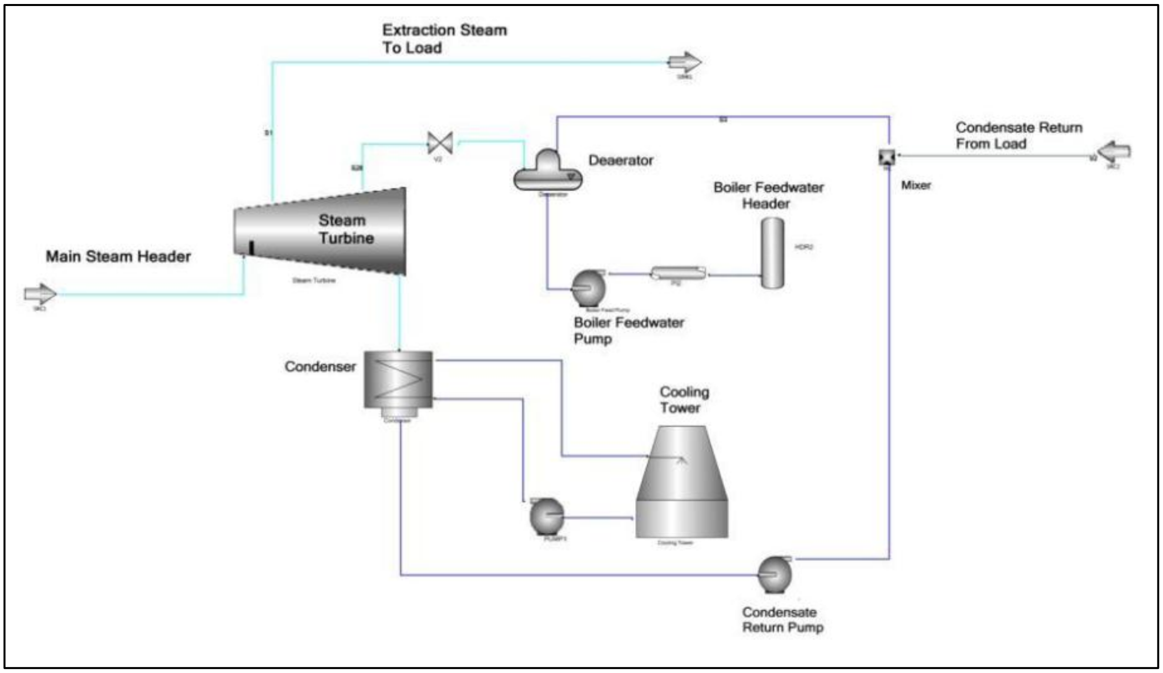

Figure 22. CHP extraction turbine

A **backpressure turbine** accepts all boiler steam at the steam turbine inlet but discharges all of the steam at the higher pressure required by the end steam user (Figure 23).

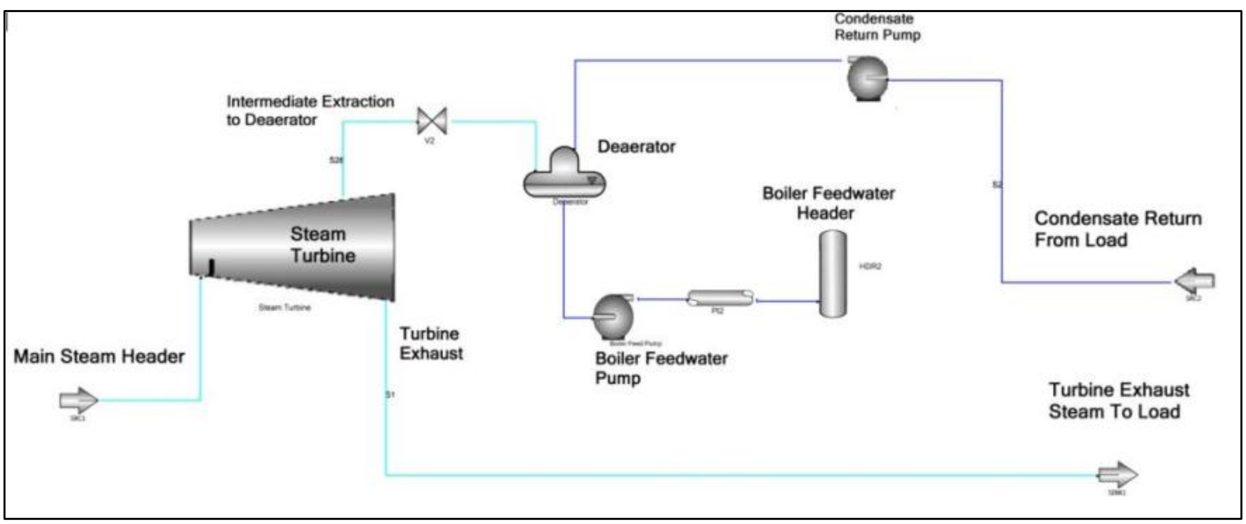

Figure 23. CHP backpressure turbine

There are considerable cost savings with this approach. The steam turbine is much less expensive because the lower-pressure sections of a turbine are the largest and costliest. There is no need for a condenser, a cooling tower, or large circulating water pumps to push the cooling water through the condenser. The steam is typically condensed by the load and then returns to the plant as warm condensate to be reheated and reintroduced to the system.

There are two disadvantages to this arrangement. First, the amount of electric power produced is greatly reduced due to the shortening of the turbine and the relatively high discharge pressure. Second, if the steam host reduces its steam requirements to a quantity less than the full steam turbine capacity, the steam turbine must be turned down, or the excess steam must be condensed by way of an external steam condenser, which would also require a cooling water source.

5.5 District Heating

District heating is defined as a central unit providing heat to nearby buildings and homes through a series of pipes carrying hot water or steam. The scheme generally includes a set of pipes—one pipe delivers hot water at a temperature between 180°F and 250°F. Heat enters a building's conventional heating system through a heat exchanger. After heat is extracted, another pipe returns water (104–160°F) to the central heating plant. Pipes are sometimes double walled and generally buried underground. District heating systems are most common in Scandinavia. In Denmark, district heating provides 60% of thermal energy with 17% derived from biomass.[10] Lower-temperature district heating systems are under development, using hot water as low as 122°F.[11]

Capital costs are high for district heating systems due to the network of piping and heat exchangers and other equipment that must be installed for each customer. Economics are usually best for district heating when waste heat can be obtained from a nearby power plant at minimal cost, when replacing electric heating systems, and in densely populated areas with high-rise apartments.

Several cities and universities have district heating systems powered by traditional energy sources. Most were built many decades ago. There are district heating systems in the United States but only two that use biomass as an energy source.

District Energy St. Paul operates a biomass district heating system in St. Paul, Minnesota.[12] It is also the largest hot water district heating system in the United States. The system operates from a CHP system using waste wood as a fuel source as well as a recently installed solar thermal system. The University of New Hampshire meets all heat and electricity requirements from a district system using methane from a nearby landfill.[13] Many other universities have district heating systems powered by traditional energy sources.

Montpelier, Vermont, is in the process of building a biomass-fired district heating system for the state government, city government, schools, and portions of the downtown area. This will be an upgrade to an existing wood-fired system.[14]

[10] "Renewable Heat Initial Business Case." DEFRA and BURR. United Kingdom. September 2007. Accessed January 8, 2013: http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file41432.pdf.

[11] Thorson, J.; Christiansen, C.; Marek, B. "Experience on Low-Temperature District Heating in Lystrup, Denmark." International Conference of District Energy. Portoroz, Slovenia, 2011.

[12] District Energy St. Paul. Accessed January 9, 2013: http://www.districtenergy.com/technologies/district-heating/.

[13] First University In Nation To Use Landfill Gas As Primary Energy Source." University of New Hampshire Media Relations. August 14, 2007. Accessed January 9, 2013: http://www.unh.edu/news/cj_nr/2007/aug/kb14landfill.cfm.

[14] Montpelier, Vermont. "District Heat Project." Accessed June 19, 2013: http://www.montpelier-vt.org/group/99.html.

5.6 Biopower System Components

A typical direct-fired biopower system has the following components:

- Major components
  - Fuel receiving, storage, and handling
  - Combustion system and steam generator
  - Steam turbine and electrical generator
  - Air pollution control
  - Condenser and cooling tower
- Other equipment and auxiliaries
  - Stack and monitoring equipment
  - Instrumentation and controls
  - Ash handling
  - Fans and blowers
  - Water treatment
  - Electrical equipment
  - Pumps and piping
  - Buildings.

5.6.1 Fuel Receiving, Storage, and Handling

Biomass can be received at the site by truck, rail, or barge. It can be delivered as chips, pellets, or logs, and brush can be processed on-site into chips. Wood chips are typically stored in a fuel yard (exposed or covered) or in storage silos (Figure 24).

Figure 24. Biomass storage options: (left) a fuel yard and (right) a fuel silo. ***Photos by (left) Warren Gretz, NREL 04736 and (right) Gerry Harrow, NREL 15041***

Wood pellets are stored in silos and are easily handled and fed with standard equipment. Fuel handling could be fully automated or semi-automated requiring some labor. A fully automated system will typically be installed below grade. Wood chips would be delivered by truck to the storage bin, and conveyor belts automatically feed the boiler. Automated systems are generally used to serve large facilities such as those evaluated in this study. Semi-automated systems are less expensive but require more labor. They typically include above-ground chip storage and a hopper with capacity to supply the boiler for a few days. An operator moves woody biomass from the storage area to the hopper as needed. Operator workload is estimated at 60–90 minutes per day.[15]

5.6.2 Combustion System and Steam Generator

The most common system for converting solid biomass fuel into energy is a direct-fired combustion system. The fuel is burned typically on a grate or in a fluidized bed to create hot combustion gases that pass over a series of boiler tubes transferring heat into water inside the tubes creating steam. The combination of the burning apparatus and the heat transfer surface areas are typically referred to as the boiler.

Boilers are differentiated by their configuration, size, and the quality of the steam or hot water produced. Boiler size is most often measured by the fuel input in millions of Btu per hour (MMBtu/hr), but it may also be measured by output in pounds per hour of steam produced. The two most commonly used types of boilers for biomass firing are stoker boilers and fluidized bed boilers. Either of these combustion systems can be fueled entirely by biomass fuel or co-fired with a combination of biomass and coal or other solid fuel.[16]

The traveling grate stoker boiler introduces fuel at one end of the furnace. The grate slowly moves the fuel through the hot zone until combustion is complete and the ash falls off at the opposite end.[17] The fuel is either dropped onto the grate and travels away from the feeder or it is thrown to the opposite end and comes back towards the feeder. The latter is called a spreader stoker. A fluidized bed boiler introduces feedstock into the bed with a heat transfer medium (typically sand).[18] The bed material is fluidized using high pressure air from underneath the grate creating a good mixing zone.

5.6.3 Steam Turbine

The steam turbine is a key component and major cost element for the facility. In many cases, additional cost can result in increased turbine efficiency, which must be assessed with regards to overall plant economics. The higher the steam inlet pressure and the lower the steam exhaust pressure, the more energy can be extracted from the steam. These both come at a cost and have to be balanced with the system economics. Typically, smaller systems use lower-pressure steam

[15] "Woodchip Fuel Specifications in the Northeastern United States." Biomass Energy Resource Center. Accessed January 8, 2013: http://www.biomasscenter.org/resources/publications.html.
[16] "Biomass Combined Heat and Power Catalog of Technologies." EPA. September 2007. Accessed January 8, 2013: http://www.epa.gov/chp/documents/biomass_chp_catalog.pdf.
[17] Johnson, N. "Fundamentals of Stoker Fired Boiler Design and Operation." CIBO Emission Controls Technology Conference. July 2012. Accessed January 10, 2013: http://www.cibo.org/emissions/2002/a1.pdf.
[18] Crawford, M. "Fluidized Bed Combustors for Biomass Boilers." ASME. September 2012. Accessed January 10, 2013: https://www.asme.org/kb/news---articles/articles/boilers/fluidized-bed-combustors-for-biomass-boilers.

and larger systems can afford to operate at higher pressures yielding more power production to compensate for the increased capital costs.

5.6.4 Air Pollution Control

Biomass is a relatively clean fuel and contains lower quantities of the pollutants commonly found in coal and other solid fuels. The primary pollutants of concern in biomass combustion are CO, NOx, and particulate matter (PM).

CO emissions are largely a function of good combustion. Good air mixing will oxidize most CO molecules into carbon dioxide (CO_2), which is not a regulated pollutant. The control of NOx is not always required, but NOx can be controlled by either selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR). SNCR is accomplished by the introduction of nitrogenous reagents (urea or ammonia) at specific temperatures, creating a reducing reaction. SCR is a similar process but also uses a catalyst to achieve higher removal efficiencies.

For PM, the small ash particles are captured in the fabric of large bags, and the bags are pulsed occasionally to dislodge the dust into an ash hopper for removal. These systems are known as fabric filters or baghouses. Electrostatic precipitators (ESP) are also commonly used for particulate removal.

EPA's "Final Air Toxics Standards for Industrial, Commercial, and Institutional Boilers at Area Source Facilities" was released on February 1, 2013, and applies to biomass boilers. The following provisions apply to new biomass boilers[19]:

- New boilers with heat input capacity greater than 10 MMBtu/hr that are biomass-fired or oil-fired must meet GACT-based numerical emission limits for PM
- New biomass-fired boilers with heat input capacity of 30 MMBtu/hr or greater must have filterable PM of less than 3.0E–02 lb per MMBtu of heat input
- New biomass fired boilers with heat input capacity of between 10 and 30 MMBtu/hr must have filterable PM of less than 7.0E–02 lb per MMBtu of heat input
- New biomass fired boilers with heat input capacity less than 10 MMBtu/hr must:
    - Minimize the boiler's startup and shutdown periods and conduct startups and shutdowns according to the manufacturer's recommended procedures. If manufacturer's recommended procedures are not available, you must follow recommended procedures for a unit of similar design for which manufacturer's recommended procedures are available. [20]

5.6.5 Condenser, Cooling Tower

As the steam exits the turbine, it is condensed for reuse in the cycle. The most common method is to use a steam surface condenser and a cooling tower. The surface condenser is a large vessel filled with tubes that circulate cool water from the cooling tower. The steam flows over the tubes condensing into a hot well at the bottom of the condenser. The cooling water that leaves the

[19] "National Emission Standards for Hazardous Air Pollutants for Area Sources: Industrial, Commercial, and Institutional Boilers." EPA. 2013. http://www.epa.gov/airtoxics/boiler/boilerpg.html
[20] Federal Register. Vol. 78, No. 22. Friday, February 1, 2013. Rules and Regulations. p. 7518

condenser is pumped back to the cooling tower, which uses evaporative cooling to cool the water for reintroduction into the condenser.

A large amount of water is lost due to evaporation from the cooling tower and that water needs to be replaced on a continuous basis. In areas where water is scarce and expensive, this introduces a large operating cost. In these cases, the water is commonly cooled by an air-cooled system. The capital costs for this equipment is higher and the electric power to operate the fans is higher, but no water is consumed with this method.

6 State and Local Energy and Utility Details

Vermont energy costs are higher than the New England average, and energy costs in New England are higher than in most of the continental United States. According to the U.S. Energy Information Agency (EIA), Vermont pays the third-highest amount of all states for natural gas, at an average of $16.62 per thousand cubic feet[21] (surpassed only by Florida at $18.18 and Hawaii at $49.59), and the second-highest average electricity cost, at $0.1997/kWh (residential sector).

Quick Facts from the EIA

- Vermont had the second-lowest per capita natural gas consumption of all states in 2010.
- Nuclear power accounted for about three-fourths of the electricity generated within Vermont in 2011, a higher share than any other state. (None of the power generated by Vermont Yankee is purchased within the state. See footnote 29 for more detail.)
- Twenty-one percent of Vermont's net electricity generation in 2011 was from conventional hydroelectric power.
- Vermont has a voluntary goal of generating 25% of electricity consumed in the state from renewable energy resources by 2025.
- In 2010, Vermont had the Nation's lowest CO_2 emissions from electricity generation.

6.1 U.S. Energy Information Administration

The EIA provides utility data by state and sector.[22] Tables of data for Vermont, by sector, are included below.

[21] 1,000 cubic feet of natural gas is approximately equal to 1 million Btu (MMBtu).
[22] U.S. Energy Information Administration. "Electricity." Accessed June 19, 2013: http://www.eia.gov/electricity/sales_revenue_price/index.cfm.

Table 5. EIA Residential Data, 2011

Entity	Class of Ownership	Number of Consumers	Sales (MWh)	Revenue (thousand dollars)	Average Retail Price (cents/kWh)
Barton Village, Inc.	Public	1,677	10,616	1,831	17.25
Central Vermont Pub Serv Corp	Investor Owned	137,137	978,975	155,784	15.91
City of Burlington Electric	Public	16,350	85,179	13,365	15.69
Green Mountain Power Corp	Investor Owned	80,888	574,877	91,839	15.98
Omya Inc.	Investor Owned	801	4,342	449	10.35
Town of Hardwick	Public	3,913	23,393	4,136	17.68
Town of Readsboro	Public	256	735	122	16.64
Town of Stowe	Public	3,227	22,281	4,075	18.29
Vermont Electric Cooperative	Cooperative	33,960	220,919	41,604	18.83
Village of Enosburg Falls	Public	1,467	13,110	2,104	16.05
Village of Hyde Park	Public	1,166	8,161	1,455	17.83
Village of Jacksonville	Public	646	3,572	602	16.85
Village of Johnson	Public	759	4,960	866	17.46
Village of Ludlow	Public	3,002	15,878	2,197	13.84
Village of Lyndonville	Public	4,780	32,903	4,859	14.77
Village of Morrisville	Public	3,336	20,983	3,256	15.52
Village of Northfield	Public	1,653	10,668	1,481	13.89
Village of Orleans	Public	582	4,106	531	12.92
Village of Swanton	Public	3,202	26,705	3,061	11.46
Washington Electric Coop	Cooperative	10,190	62,170	11,908	19.15

Table 6. EIA Commercial Data, 2011 (EIA Table 6)

Entity	Ownership	Number of Consumers	Sales (MWh)	Revenue (thousand dollars)	Average Retail Price (cents/kWh)
Barton Village, Inc.	Public	224	3,803	685	18.02
Central Vermont Public Service Corp	Investor Owned	23,137	840,624	118,854	14.14
City of Burlington Electric	Public	3,725	189,464	26,978	14.24
Green Mountain Power Corp	Investor Owned	14,674	699,198	91,957	13.15
Omya Inc.	Investor Owned	76	3,471	402	11.58
Town of Hardwick	Public	407	4,398	813	18.49
Town of Readsboro	Public	55	323	58	17.89
Town of Stowe	Public	753	40,804	6,010	14.73
Vermont Electric Cooperative	Cooperative	3,593	131,085	20,402	15.56
Village of Enosburg Falls	Public	174	2,875	466	16.20
Village of Hyde Park	Public	200	2,946	574	19.48
Village of Jacksonville	Public	50	649	112	17.32
Village of Johnson	Public	156	4,356	838	19.24
Village of Ludlow	Public	696	18,646	3,157	16.93
Village of Lyndonville	Public	778	11,631	1,950	16.77
Village of Morrisville	Public	576	16,743	2,730	16.31
Village of Northfield	Public	590	4,822	713	14.78
Village of Orleans	Public	84	2,282	323	14.16
Village of Swanton	Public	436	26,420	3,360	12.72
Washington Electric Coop	Cooperative	412	4,007	719	17.94

Table 7. EIA Industrial Data, 2011 (EIA Table 6)

Entity	Class of Ownership	Number of Consumers	Sales (MWh)	Revenue (thousand dollars)	Average Retail Price (cents/kWh)
Central Vermont Public Service Corp	Investor Owned	38	431,990	41,375	9.58
City of Burlington Electric	Public	13	70,291	8,132	11.57
Green Mountain Power Corp	Investor Owned	28	617,424	57,620	9.33
Omya Inc.	Investor Owned	2	124,183	10,545	8.49
Town of Hardwick	Public	24	3,979	692	17.39
Town of Stowe	Public	1	10,511	1,144	10.88
Vermont Electric Cooperative	Cooperative	8	77,909	7,752	9.95
Village of Enosburg Falls	Public	24	10,122	1,496	14.78
Village of Jacksonville	Public	5	862	145	16.83
Village of Johnson	Public	1	4,150	671	16.17
Village of Ludlow	Public	4	10,924	1,925	17.62
Village of Lyndonville	Public	42	23,407	3,461	14.79
Village of Morrisville	Public	3	7,290	1,013	13.90
Village of Northfield	Public	16	13,998	1,816	12.97
Village of Orleans	Public	1	6,912	1,039	15.04
Washington Electric Coop	Cooperative	11	3,152	413	13.10

6.2 Historical Fuel Costs

Figure 25 was created with data provided by the EIA.[23] It shows the residential price of heating oil[24] and of propane from 1990 to February 2013 and the wholesale price of propane from the end of 2004 to February 2013. All of these products have high price volatility, but the general trend, at least since about 2000, is upward. A trend line of residential heating oil price is included.

[23] U.S. Energy Information Administration. "Petroleum & Other Liquids." Accessed June 19, 2013: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=W_EPLLPA_PRS_SVT_DPG&f=W.

[24] Terminology used to identify oil varies; heating oil is also called #2 oil, number 2 oil, No.2 heating oil, home heating oil (HHO), fuel oil, etc.

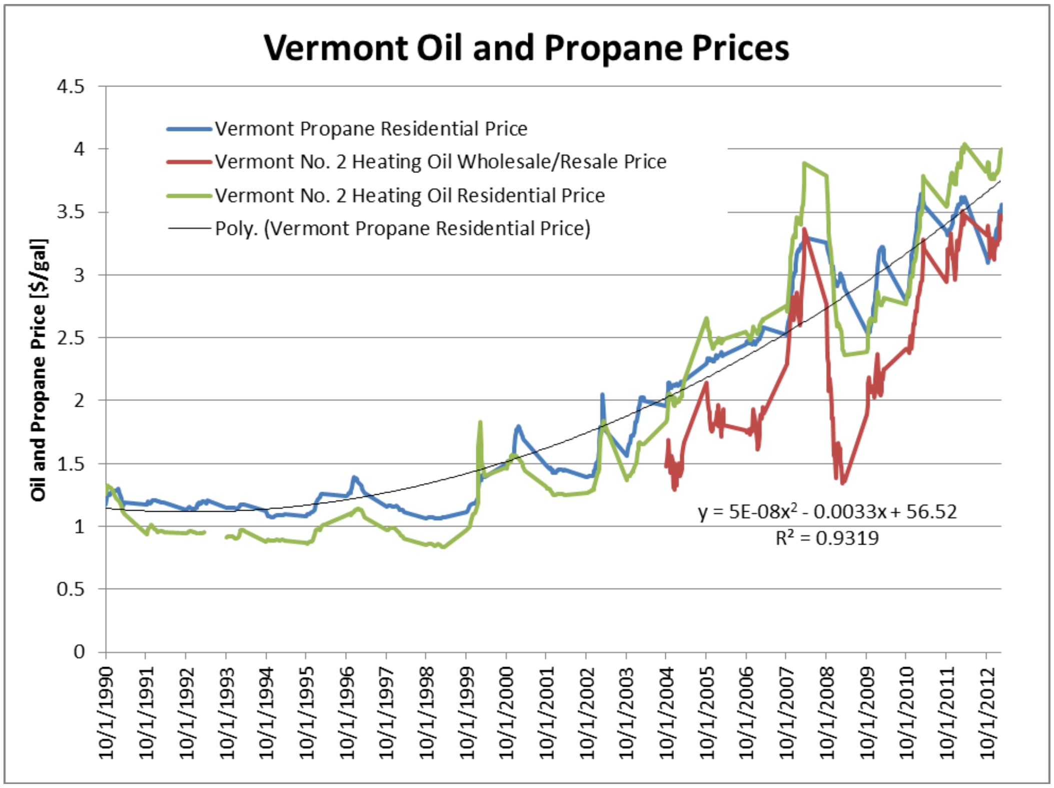

Figure 25. Historic thermal energy prices in Vermont

Table 8 shows prices for propane and No. 2 fuel oil for the beginning of 2013. The prices of both oil and propane have been above $3/gallon since about 2010.

Table 8. Vermont Heating Fuel Prices for 2013

Week of	Vermont Propane Residential Price ($/gallon)	Vermont No. 2 Heating Oil Wholesale/Resale Price ($/gallon)	Vermont No. 2 Heating Oil Residential Price ($/gallon)
1/07/2013	3.372	3.242	3.817
1/14/2013	3.370	3.270	3.826
1/21/2013	3.379	3.275	3.828
1/28/2013	3.506	3.294	3.894
2/04/2013	3.464	3.396	3.913
2/11/2013	3.48	3.477	3.981
2/18/2013	3.559	3.444	4.002

Propane has a higher heating value (HHV) of about 92,000 Btu/gal, and No. 2 oil has an HHV of between 137,000 and 141,800 Btu/gal for an average of 139,400 Btu/gal.[25] Heating oil at

[25] The Engineering Toolbox. "Fuel Oil and Combustion Values." Accessed June 19, 2013: http://www.engineeringtoolbox.com/fuel-oil-combustion-values-d_509.html.

$3.50/gal is equivalent to $25.11/million Btu, and propane at $3.50/gal is equal to $38.04/million Btu.

6.3 Renewable Energy in Vermont

As mentioned previously, about 50% of the electric energy consumed in Vermont is already being produced from renewable energy sources, including electricity from biomass. The *Vermont Comprehensive Energy Plan 2011* [26](CEP), citing EIA 2009 data, states that "biomass meets about 6% of the electric load in Vermont, including biomass electric facilities, farm methane, and landfill methane. About 14% of the state heating needs are met with biomass fuels, including cordwood."

According to the CEP, "The state has two biomass district energy systems already in place, in the Capitol complex in Montpelier and the state office complex in Waterbury. Several colleges in the state use wood in a district system, connecting several buildings to one boiler" (CEP p. 199). Montpelier is developing a biomass-fired district heating system, which is expected to reduce oil consumption by 100,000 to 500,000 gallons per year, depending on final system size and connections.

A detailed breakdown of energy production by source can be found in the CEP.

6.4 Vermont Town Energy Data

From the Vermont Town Energy Data Website[27]:

> Efficiency Vermont collected electricity usage and savings data for Vermont's towns in the development of the Renewable Energy Atlas of Vermont, a project undertaken by the Vermont Sustainable Jobs Fund.
>
> This annual snapshot provides municipalities, energy committees, and individuals with information about a town's historical energy usage, and can help to increase awareness about energy consumption. As part of its effort to help Vermonter's reduce their electricity use, Efficiency Vermont receives customer electric usage results from the state's utilities. The Burlington Electric Department collects this data for Burlington customers.

When this data is sorted largest to smallest by commercial kilowatt-hour usage it indicates that, out of the 248 towns, Putney has the 26th-largest consumption. Putney has the 76th-largest usage in the 2010 residential kilowatt-hours category.

6.5 Vermont's Electricity Portfolio

Currently, Vermont produces approximately half of the electricity it uses in-state and imports the other half from Canada and other New England states.[28] According to the EIA, Vermont

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[26] Volume 2 – Facts, Analysis, and Recommendations, Section 5.8.1.1, p. 83

[27] Efficiency Vermont. "Vermont Town Energy Data." Accessed June 19, 2013: http://www.efficiencyvermont.com/about_us/energy_initiatives/vt_town_energy.aspx.

[28] Page, G. "Renewable Energy Sources in Vermont: A Status Report." Vermont Energy Partnership, May 2010. Accessed June 19, 2013: http://www.vtep.org/documents/VTEP%20ISSUE%20BRIEF%20-%20Renewable%20Energy%20Sources%20in%20Vt%20-%20A%20Status%20Report%20May%202010.pdf .

Yankee's nuclear power[29] accounts for about three-fourths of the electricity generated within Vermont.[30] Non-hydroelectric renewable energy sources, including wood, wood waste, and wind, account for between 5% and 10% of state electricity production.

In total, Vermont needs an estimated 700 MW of electricity to meet current demand. Peak demand is about 1,000 MW.[31]

6.6 Site Electric Utility Information

The local utility is GMP. They have provided a letter of support for this project, and it is included in Appendix A.

GMP provides an incentive of $0.06/kWh for PV systems, but the rate is calculated differently for biomass due to different generation profiles of the two technologies. For a biomass plant, the Vermont Public Service Board (PSB) net-metering rules only allow projects up to 500 kW. For biomass systems up to this size, power is currently worth almost $0.14/kWh generated. There is no adder for biomass like there is for solar. For systems larger than 500 kW, a power purchase agreement (PPA) with GMP would be required. Selling price under a PPA is currently about $0.08/kWh.[32]

6.6.1 Feed-In Tariff Program

In 2009, the Vermont Legislature created the feed-in tariff (FIT) program, which guarantees a subsidized price for solar, wind, and methane projects of 2.2 MW or less. The total capacity is capped at 50 MW. Assuming a full build-out of the 50 MW and optimum efficiency of a mix of wind, solar, and methane projects, it is reasonable to project 25 MW of output from FIT-supported projects in the near future.[33]

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[29] None of this power is purchased with the State of Vermont (http://www.vpr.net/news_detail/93840/vy-still-online-without-vermont-utility-contracts/). The Vermont Yankee Station is still in operation, though the long-term outlook is unclear. Last year the plant was granted authorization from the NRC to operate for another 20 years. However, the plant owner Entergy is currently before the Vermont Public Service Board seeking state authority to operate for the same additional 20 years, and that is being opposed by the Vermont Public Service Department and a number of intervening parties. The board will likely make its decision in the late fall of this year (2013). No Vermont utilities currently have a power purchase agreement (PPA) for electricity from the station with Entergy. No major generation facilities have been constructed in the state with the aim of replacing VY power. A number of utilities are now taking power from the Seabrook nuclear plant in New Hampshire (personal email from Aaron Kisicki, Special Counsel, Vermont Public Service Department).

[30] U.S. Energy Information Administration, State Energy Profiles, "Vermont." Accessed June 19, 2013: http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=VT.

[31] ISO-New England: Vermont 2010 State Profile. http://isonewengland.org/nwsiss/grid_mkts/key_facts/vt_01-010_profile.pdf. [Note: 2010 profile no longer available; updated to 2012-13: www.iso-ne.com/nwsiss/grid_mkts/key_facts/final_vt_profile_2012-13.pdf.]

[32] Lorraine, D. Personal communication. National Account Manager, Green Mountain Power, Colchester, VT, 27 February 2013.

[33] Page, G. "Renewable Energy Sources in Vermont: A Status Report." Vermont Energy Partnership, May 2010. Accessed June 19, 2013: http://www.vtep.org/documents/VTEP%20ISSUE%20BRIEF%20-%20Renewable%20Energy%20Sources%20in%20Vt%20-%20A%20Status%20Report%20May%202010.pdf .

6.6.2 Heating Fuel in Putney

There is currently no natural gas sold in Putney. Fuel for thermal applications is typically provided by heating oil (No. 2 or No. 6) or by propane. Both of these fuels are delivered by truck.

Figure 26 shows an oil truck on Putney's main street, and Figure 27 shows propane tanks outside of the Putney General Store.

Figure 26. Fuel oil delivery truck passing through Putney. ***Photo by Randolph Hunsberger, NREL***

Figure 27. Propane tanks outside the Putney General Store. ***Photo by Randolph Hunsberger, NREL***

There has recently been some interest in shipping compressed natural gas (CNG) to some areas of Vermont not currently served by pipeline. One possible customer of this natural gas is Putney Paper, discussed in 6.7.1.

6.7 Recommended Activities for Next-Level Analysis

The next step in this analysis should be to enter into discussions with GMP regarding interconnection requirements, size limitations, electricity purchase rates, and any charges that might be incurred by the site or any potential off-takers.

Trucked CNG is currently being marketed to large users in this region of Vermont. The price of this gas should be accounted for in an updated analysis.

6.7.1 Potential Off-Takers and Loads

A biomass heating, power, or combined heat and power (CHP) plant can either be built to provide heat or electricity to an on-site load or to have for sale. Electricity can be sold to a local or distant load, but this will almost always involve one or more electric utility companies.

Thermal energy generated for sale can usually only serve a load that is located fairly close to the point of production. If the load is too distant, the cost for distributing the heat becomes excessive.

For the Basketville site we consider two potential users ("off-takers") of both the electricity and thermal energy that could be generated: Landmark College and Putney Paper.

6.8 Landmark College

Landmark College has a campus located about one-half mile from the site by road. In a direct line, the distance is about 2,000 feet. The college has 24 buildings and over 340,000 square feet of heated space.

Figure 28 shows the relative locations of the Basketville site on the left and Landmark College on the right; road directions are marked in purple and a red line shows the direct path between them.

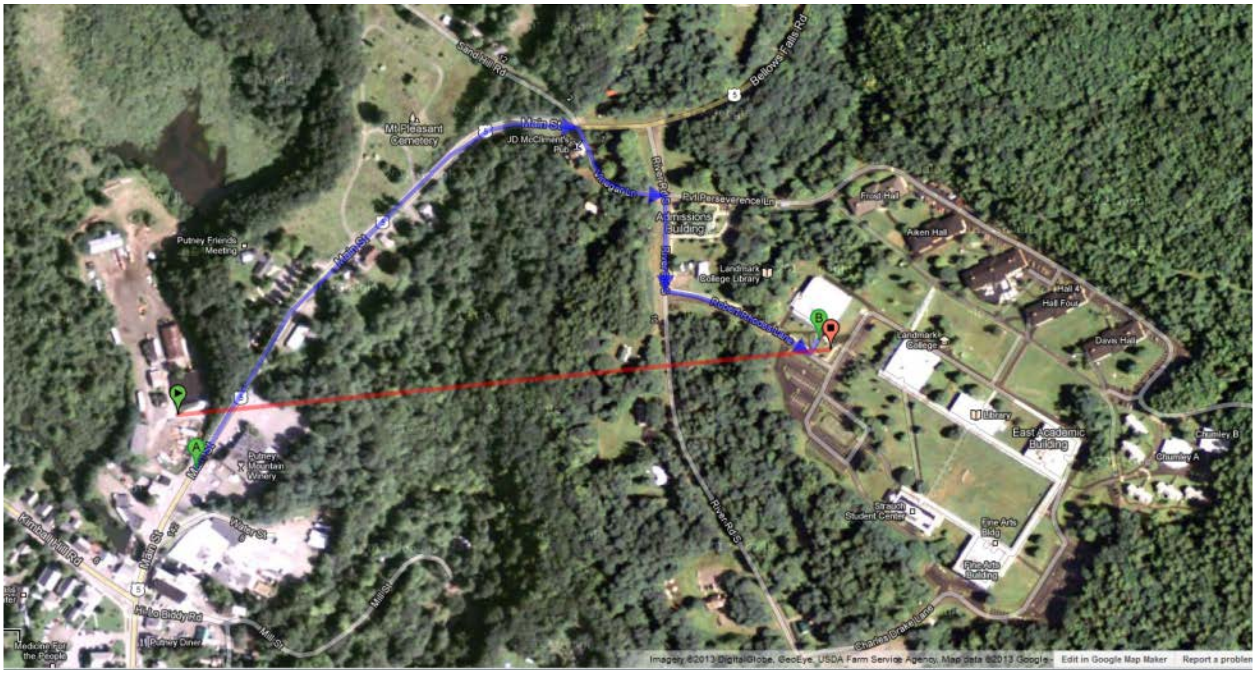

Figure 28. Aerial view showing the Basketville site and Landmark College

Image generated in Google Maps

Landmark College supplied utility data for a 3-year period. This data includes consumption of gas, propane, and electricity. The data is summarized in the next two sections.

A previous proposal has been produced evaluating the feasibility of a biomass heating system for the campus. That report, developed by M. Pierce of NECSIS in March 2012,[34] indicates that five of the campus buildings have boilers that are in need of replacement.

The NECSIS proposal estimates costs to develop a biomass-fired district heating for the campus at around $4 million, including insulated underground piping and a building for housing the biomass equipment and fuel storage. The proposal was for two biomass boilers—12.2 and 4.3 MMBtu/hr—and one or two oil boilers for serving peak load and for backup systems. The NECSIS biomass proposal also predicts a peak heating load of 8.6 MMBtu/hr.

A biomass fuel cost of $50/ton is provided, with the biomass to be provided by Cersosimo Lumber in Brattleboro, which is about 11 miles south of the site.

6.8.1 Thermal Details

The data that Landmark provided included propane data representing 16 tanks (labeled in the provided file as: Plb shop, Lib Gen, Maint, FAB, Stu Ctr, Dryers, BBQ tanks, Aiken, Chumley, Kitchen, Daycare, Rvr Rd II, Middle Gen, EAB, Br1 & 2, and Br 3,4,5). This data covers 3 years—2010, 2011, and 2012. Data for each year runs from mid-July of the previous year through mid-year of the indicated year. For example, the 2012 data runs from July 12, 2011, through June 11, 2012. The total propane use over this period went from 70,505 gal in 2010, to

[34] A Proposal for a New Biomass Heating System for Landmark College. M. Pierce. Brattleboro, VT. 28 Mar 2012.

73,784 gal in 2011, to 63,951 gal in 2012, for an average of about 69,400 gallons per year. At 92,000 Btu/gal of propane, that is an average of about 6,400 MMBtu/yr. Figure 29 shows the annualized average propane use, where each data point represents one year of data.

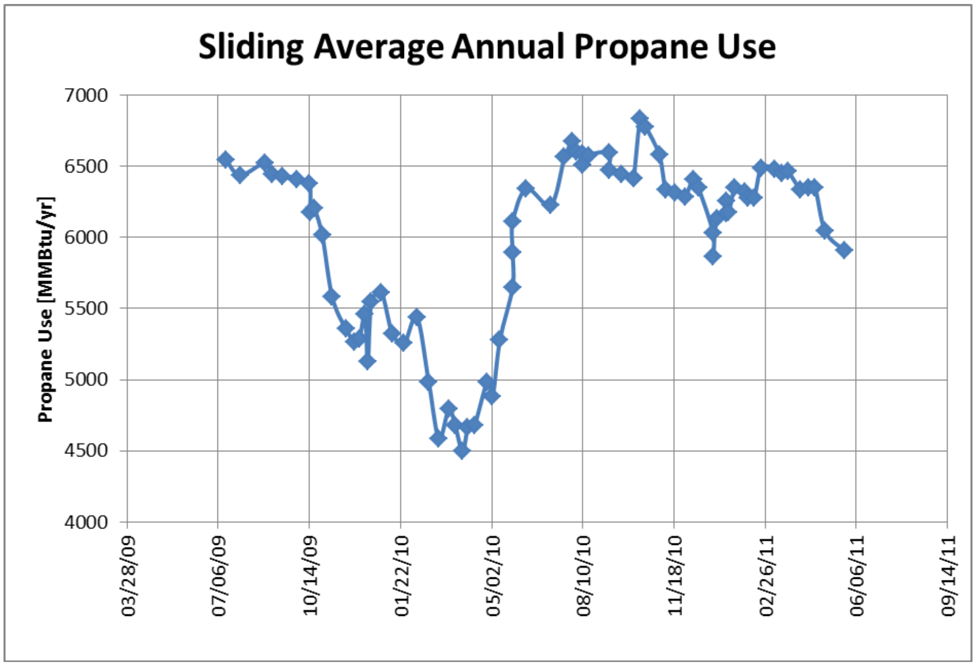

Figure 29. Annualized propane use at Landmark College

Landmark also provided No. 2 oil consumption data for Aiken/Frost, Middle, Hall 4, Davis, Library, Stu Center, and Sport Cent. This data covered the period from January 9, 2009, to December 25, 2011. Over that time, oil use averaged 115,000 gal/yr.

Table 9. Oil Deliveries at Landmark College

	Gallons Delivered								gal/yr	MMBtu/yr
Date	Aiken	Middle	Hall 4	Davis	Library	Stu Center	Sports Center	**Total**	**Total annualized oil use**	**Total annualized oil use**
01/06/09	4500	4534	3000	3600	5087		3006	23,727	119,376	16,641
02/17/09	3025	4555			5090	6043	2500	21,213	127,149	17,725
04/01/09	5000	2500	5000	5000	2500			20,000	112,995	15,752
07/16/09		6119	4921	3843	2548		6059	23,490	100,483	14,007
07/19/09						5116		5,116	107,594	14,999
11/06/09	8830							8,830	110,000	15,334
12/16/09		6000	2500	2500	6000			17,000	128,541	17,919
02/03/10	5000	2000	3500	2000	6500	6500	6000	31,500	124,210	17,315
03/25/10		7059						7,059	100,773	14,048
05/17/10			3711	3777				7,488	105,803	14,749
08/18/10	6500	4200	4200	2000	5101	5100	3500	30,601	128,751	17,948
12/23/10		5072			2450			7,522		
01/09/11	6090		5068	6080	2530	3789	3814	27,371		
02/13/11		5066	2533		5070			12,669		
04/03/11	5043	3020						8,063		
04/05/11			2013	2517	2013	3029	2517	12,089		
08/15/11	4001	5010	5160	5085	4080	3570	3530	30,436		
	47,989	55,135	41,606	36,402	48,969	33,147	30,926	294,174		
	16%	19%	14%	12%	17%	11%	11%			

Figure 30 shows the sliding annualized average oil consumption data. Note that the rise and fall in oil consumption starting at the end of 2009 corresponds with a similar opposite trend in propane consumption.

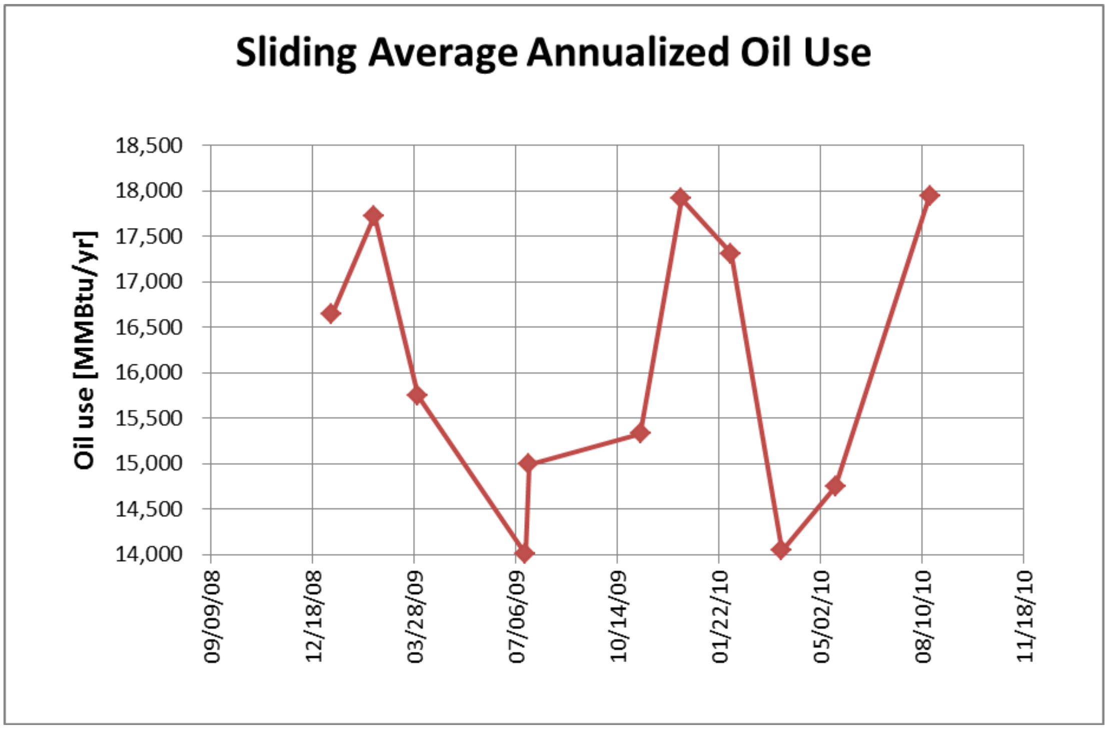

Figure 30. Oil use at Landmark College

Based on the provided data, the average total thermal energy use at Landmark College is 20,000 MMBtu/yr, with a standard deviation of about 1,322 MMBtu/yr.

Figure 31 shows the monthly propane and oil use at Landmark, along with the total use. This chart covers the period for which we had data for both fuels. It appears that the majority of the thermal load is being served by oil—though the deliveries are less frequent so that could be misleading.

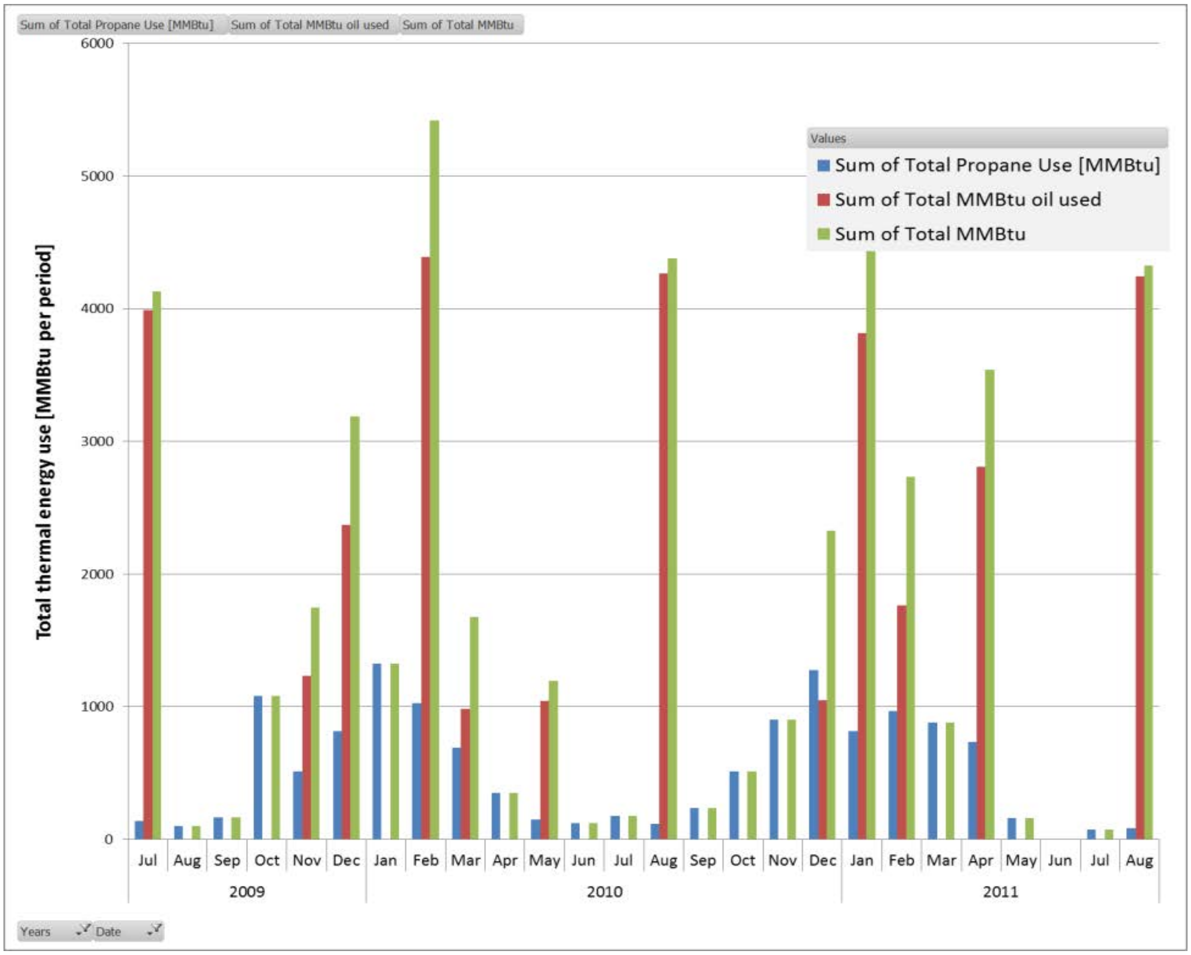

Figure 31. Total thermal energy use at Landmark College

The college spent $133,000 on propane for 2012. Oil expenses were not provided, but based on an average price of $3.05/gal and 13,420 gallons, the expected cost would be about $41,000. If the same amount of oil is used in 2013, with the price now at $3.34/gal, the cost would be about $45,000.

6.8.2 Electrical Details

In 2012, Landmark College used just over 3.1 million kWh of electricity, at a total cost of about $370,000. This works out to a rolled-up cost[35] of $0.118/kWh. Actual costs are divided into several component categories, including energy use charges that averaged $0.091/kWh during on-peak hours and $0.067/kWh during off-peak hours; peak power demand charges averaged $12.65/kW peak during on-peak hours and $3.28/kW peak during off-peak hours. These charges made up 96% of the entire Landmark electric bill in fiscal year 2012. Other charges include a power factor charge, an energy efficient charge, and a customer charge.

[35] This is also called the levelized cost of electricity (LCOE) and is calculated by dividing the total electric bill by the total electric energy (kWh) consumed.

6.8.3 Electricity Use and Cost

Table 10 provides a summary of electric energy and peak power demand for the college for fiscal year (FY) 2012 (July 2011–June 2012), divided into on-peak and off-peak use.

Table 11 provides the cost for each component of energy and power use, along with total costs for these components. Note that power demand charges account for about 29% of these portions of the total bill. There are some other small cost components that are not shown in this analysis, bringing the total cost for FY 2012 to $369,882.

Table 10. Landmark College FY 2012 Electric Energy Consumption and Power Demand[36]

Energy and Power Demand			
	kWh	**kWp**	
	Energy use	**Power demand**	
On-peak	1,736,317	6,638	
Off-peak	1,408,354	5,765	
Total	3,144,671		

Table 11. Landmark College FY 2012 Electric Energy Consumption and Power Demand Cost

Energy and Power Cost			
	$	**$**	
	Energy use	**Power demand**	**Total**
On-peak	157,147	83,990	241,137
Off-peak	94,759	18,886	113,645
Total	251,906	102,876	354,782

The power demand charges shown above typically represent the peak consumption for a defined period, usually based on a 15-minute sliding window. The load factor is the ratio of the average demand for a period divided by the peak demand for that same period. For FY 2012, the load factor at Landmark College ranged from a low of 57% to a high of 76%, with an average of 63%, based on the total kilowatt-hours consumed and the on-peak peak demand for each month.

A load factor of 70% or higher is considered a good load factor, and typical load factors for educational facilities range from 75% to 80%. In general, a higher load factor indicates lower load profile variability. For the same energy usage, reducing the peak demand will increase load factor and reduce the levelized cost of electricity (LCOE) purchased from the utility. This becomes important when trying to estimate total savings due to electricity produced by a renewable energy facility.

6.9 Putney Paper

Putney Paper has two facilities in Putney, located near the Basketville site. One of these facilities is on the Connecticut River, about 1 mile from the site, and the other is almost directly across the street from the site. The distance between the Basketville site and the nearby Putney Paper

[36] In this table, energy use is designed at **kWh**; peak power is designed as **kWp**.

facility is about 400 feet, as shown in Figure 32. It might be possible to position the biomass facility to decrease that distance, which could reduce capital costs and thermal losses.

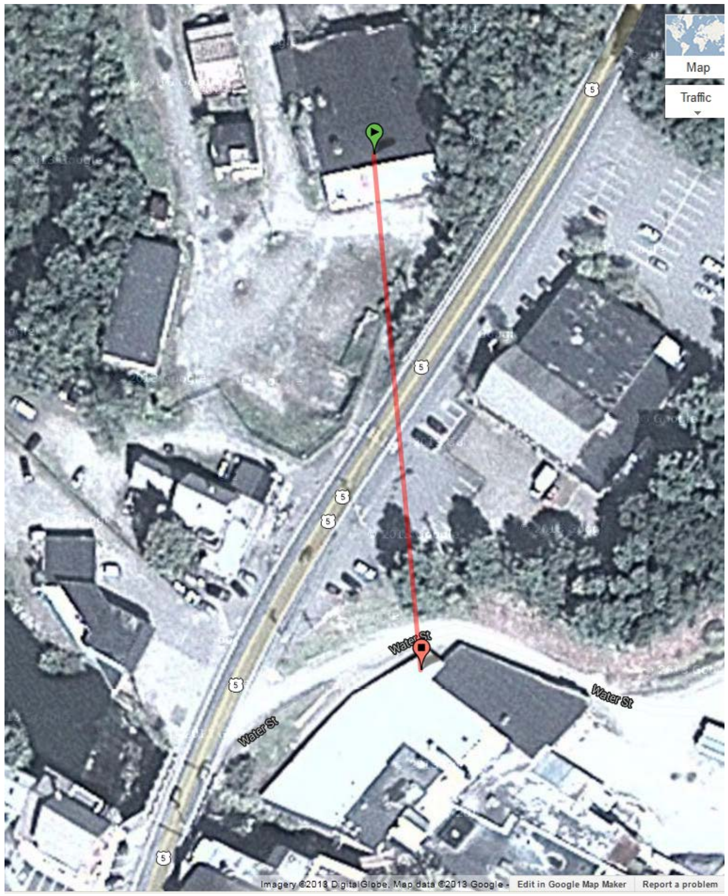

Figure 32. Relationship between the site and Putney Paper

Image generated in Google Maps

Putney Paper has indicated that they would *not* be interested in owning a biomass plant but would be interested in purchasing heat or electricity produced—if the economics were favorable.

During the NREL site visit, a meeting was held at the Putney Paper offices. Notes from that meeting are included in Appendix E.

Putney Paper has provided a letter of support for a biomass project at the Basketville site; this letter is included in Appendix F.

6.9.1 Putney Paper Operations and Utility Details

The paper mill downtown makes big roles from recycled material and the converting plant converts big roles (jumbos) into finished paper towels and napkins, for example, and employs 115–130 people. Putney Paper does not use pulp chips in their operation; they recycle paper into new products. Materials are delivered and shipped out by truck, with a total of 9–11 trucks per day coming to the site, mostly during regular business hours.

Putney Paper has signed an agreement for delivery of CNG by truck (there is no natural gas pipeline to the area) to replace approximately 100% of their oil (though they will keep No. 2 oil for backup). It is not a take-or-pay agreement, nor an exclusive arrangement, meaning that they are still interested in receiving thermal energy from a biomass facility. They expect the cost of natural gas to be less than $15/MMBtu delivered but did not have a firm number at the time of NREL's site visit in September 2012.

In January 2013 it was announced that Putney Paper Company was sold to Soundview Paper Company of Elmwood Park, New Jersey. It is unknown how that acquisition will affect the potential of selling steam or electricity to Putney Paper.

6.9.2 Electrical Details

The paper plant operates 24 hours per day in the winter and slightly less in the summer. Putney Paper did not supply energy use and billing data but said that their LCOE is $0.11/kWh (all in—see the discussion in Section 6.8 regarding electricity cost components at Landmark College).

Putney Paper said that their average electricity consumption is 2.6 MW at the mill near the Basketville site, and that they use about 50,000 kWh per day.

The power at the plant is currently somewhat unreliable, with short-term outages about five or six times per year. The restart process after an outage costs the plant about $2,500/hr, and, according to Putney Paper, "it might take 2 hours to restart after an outage."

6.9.3 Thermal Details

The plant uses saturated steam at 145 PSI, produced by two 20,000 pound per hour (PPH) boilers. Putney Paper has a steam load 24 hours per day—about 25,000 PPH in the summer and 30,000 PPH in the winter. Their average oil consumption is on the order of 750 MMBtu/day.

They estimate the efficiency of their existing boiler at about 80%, and indicated that, if a biomass system is put in at the Basketville site, it would tie-in to the header just after the boilers.

6.9.4 Analysis

Due to a high steam and electric use, nearly constant demand, and high energy prices, Putney Paper has nearly an ideal scenario for a biomass heating or CHP plant. Landmark College has a significant load, but high load variability and long distance from the site means that it would be considerably more expensive to provide thermal energy compared to supplying Putney Paper.

For economic reasons, we evaluated small single-stage backpressure turbines sized to provide up to 30,000 PPH of steam to Putney Paper. We estimated the distance from the site to the Putney Paper facility at 400 ft. A 6-inch line would have a pressure drop of about 13 psi, and an 8-inch line would have a drop of about 3 psi. Any bends, elbows, or other restrictions in the line would increase the pressure drop, as would increasing the pipe run, so we assumed a pressure drop of 5 psi. As we wanted the steam to arrive at the plant at 145-psi gage [160 psi absolute (psia)], we configured the turbine with an exhaust pressure of 165 psia. The saturation temperature at that pressure is 366°F, and the system was designed with 10 degrees of superheat to avoid condensing the steam in the line. This resulted in the configuration shown in Table 12.

Table 12. Back-Pressure Steam Turbine Design Parameters

Parameter	Value	Unit
Desired Turbine Speed	6,000	rpm
Inlet Flow	30,000	lb/hr
Inlet Pressure	700	psia
Inlet Temperature	705	°F
Inlet Flange Diameter	4	inches
Exhaust Pressure	165	psia
Exhaust Temperature	377	°F
Outlet Flange Diameter	8	inches
Estimated Output	600	kW

Note that this system could theoretically provide all of Putney Paper's steam requirements and offset 600 kW of their typical 2.6-MW load.

6.9.5 Utility Cost Reduction

At a capacity factor of 90%, this system would displace about 13 MWh per day of electricity and about 675 MMBtu/day of oil—which is about 4,800 gallons per day at 139,400 Btu per gallon. With fuel oil at $3.30/gal and electricity at $0.11/kWh ($110/MWh), this would reduce the utility bills by about $17,000 per day and $6 million per year. (Actual reduction would probably be less than this, as the reduction in energy use and peak demand would alter the LCOE from the utility, but we did not have sufficient data to evaluate this.)

Other costs incurred are discussed below.

6.9.6 Biomass Consumption and Cost

The Steam System Assessment Tool was designed for DOE's Southeast Clean Energy Application Center. It can model various heat and CHP system configurations. We first modeled the existing plant, which does not have a steam turbine. This model is shown in Figure 33. Note that the model shows a condensing steam turbine, but it is producing 0 kW. A turbine is shown in the model whether one is included in the system or not.

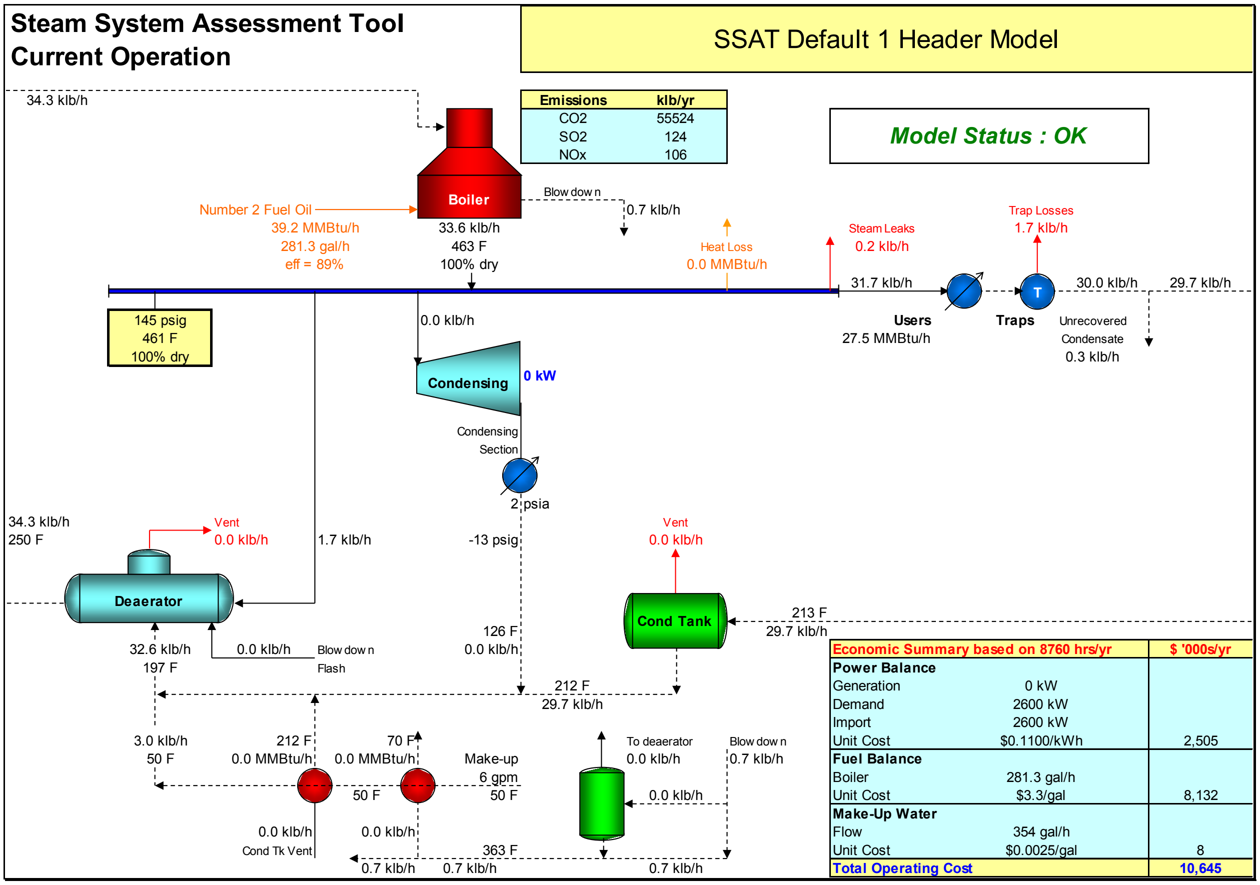

Figure 33. SSAT model of the current Putney Paper steam system with no steam turbine

The "Current Operation" model predicted a total operating cost of $10.6 million for fuel, electricity, and water.

The model was then modified[37] to include a back-pressure turbine, operating as described in Table 12. To account for pressure drop between the facilities, the turbine exhausts at 150-psig. Figure 34 shows this configuration. Again, ignore the condensing turbine, as there is not one included in the analysis. The thermal load is being used to condense the steam.

[37] In actuality, a one-header was first modeled, as shown in Figure 33, and then a two-header model was created to include the use of a back-pressure turbine. We have shown the one-header model for simplicity.

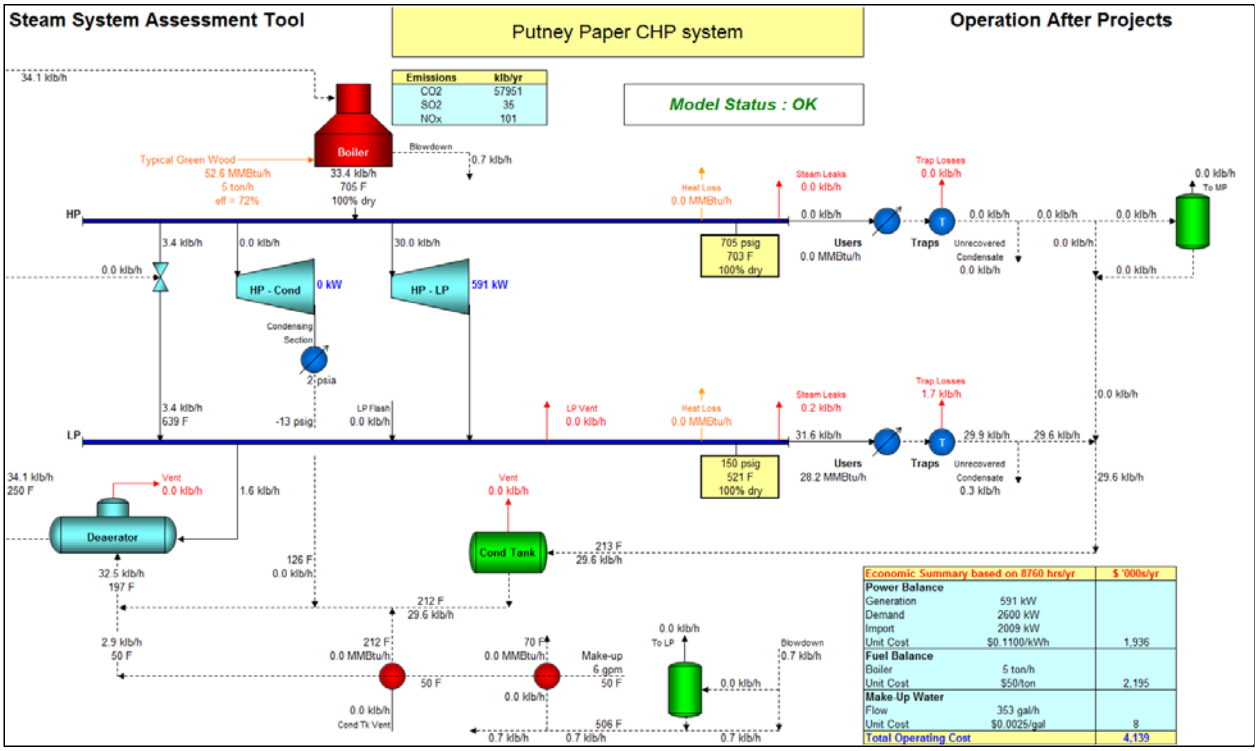

Figure 34. SSAT model for Putney Paper, with CHP system installed, at Basketville site

Table 13 provides a comparison of the current operation at Putney Paper to producing CHP from biomass at the Basketville site. The CHP system reduces power cost by 22% and thermal fuel cost by 73%. In addition, net emissions of CO_2, sulfur oxides (SOx), and NOx are also reduced. Note that all values given are approximate. Power station emissions are based on U.S. averages and not on Vermont-specific data, so reductions listed are probably overstated.

Table 13. SSA Model Results Comparing Current Operations to CHP Option

Putney Paper CHP system

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	2,505	1,936	569	22.7%
Fuel Cost	8,375	2,195	6,180	73.8%
Make-Up Water Cost	8	8	0	0.4%
Total Cost (in $ '000s/yr)	**10,888**	**4,139**	**6,749**	**62.0%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO2 Emissions	57184 klb/yr	57951 klb/yr	-767 klb/yr	-1.3%
SOx Emissions	127 klb/yr	35 klb/yr	92 klb/yr	72.5%
NOx Emissions	110 klb/yr	101 klb/yr	8 klb/yr	7.4%

Power Station Emissions	Reduction After Projects	Total Reduction	
CO2 Emissions	8123 klb/yr	7356 klb/yr	-
SOx Emissions	25 klb/yr	117 klb/yr	-
NOx Emissions	18 klb/yr	26 klb/yr	-

Note - Calculates the impact of the change in site pow er import on emissions from an external pow er station. Total reduction values are for site + pow er station

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	0 kW	591 kW	-	-
Power Import	2600 kW	2009 kW	591 kW	22.7%
Total Site Electrical Demand	2600 kW	2600 kW	-	-
Boiler Duty	40.3 MMBtu/h	52.6 MMBtu/h	-12.3 MMBtu/h	-30.5%
Fuel Type	Number 2 Fuel Oil	Typical Green Wood	-	-
Fuel Consumption	289.7 gal/h	5 ton/h	N/A	-
Boiler Steam Flow	33.6 klb/h	33.4 klb/h	0.1 klb/h	0.4%
Fuel Cost (in $/MMBtu)	23.70	4.76	-	-
Power Cost (as $/MMBtu)	32.24	32.24	-	-
Make-Up Water Flow	354 gal/h	353 gal/h	1 gal/h	0.4%

Turbine Performance	Current Operation	After Projects
HP to LP steam rate	Not in use	20 kWh/klb
HP to Condensing steam rate	Not in use	Not in use

Marginal Steam Costs	
(based on current operation)	
HP ($/klb)	56.92
LP ($/klb)	29.72

Cost savings provided above do not include capital cost debt service or non-fuel operations and maintenance costs. Those costs are described below.

6.9.7 Biomass System Capital Costs

Because of the many different possible equipment types, different combinations of heat and electricity production, and different fuels, it is very difficult to estimate capital costs for biomass CHP installations. We have relied on limited published data to estimate costs for a system that would serve the needs of Putney Paper.

Figure 35 shows capital costs for fuel handling equipment as a function of throughput capacity. Estimates for a system to serve Putney Paper are for a system that would consume 100–120 tons (90–110 metric tons, or tonnes) per day. This is at the low end of the chart, indicating that the capital costs for this equipment would be in the range of $26,000/tonne/day, for a total cost of $2.3 million to $2.8 million. Adjusting for inflation, this would come to $2.6 million to $3.2 million in 2014.

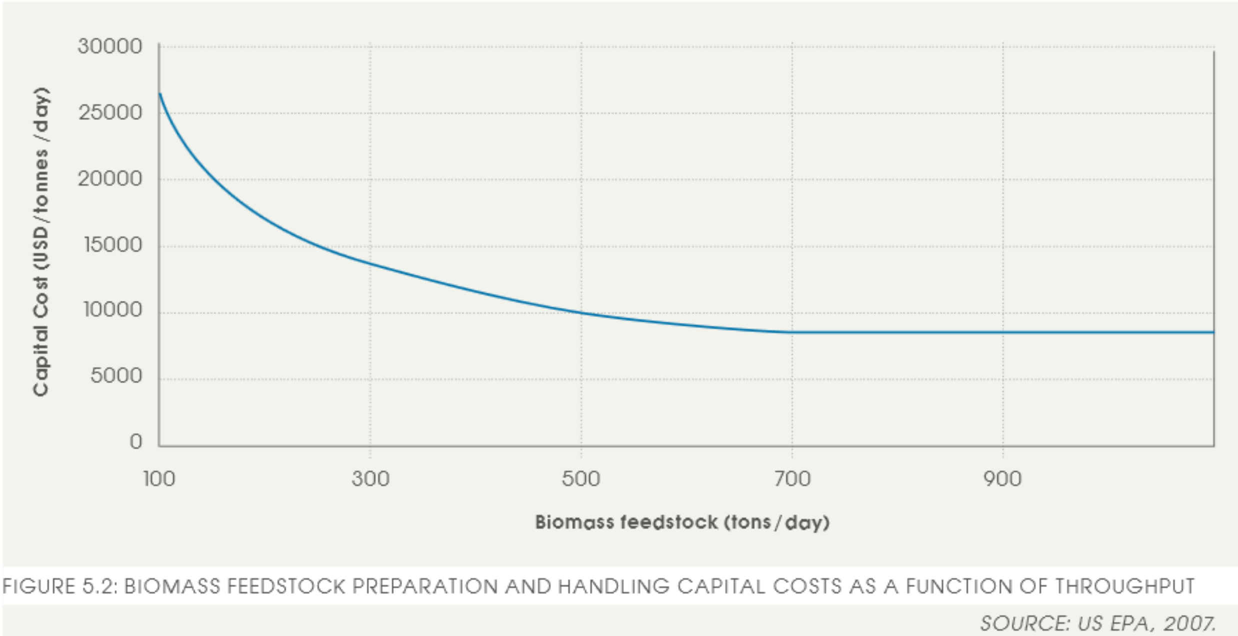

Figure 35. Biomass feedstock preparation and handling capital costs as a function of throughput
Data source: US EPA[38]

Total remaining equipment capital costs are very roughly estimated at $7 million–$8 million, for a total price of $10 million–$11 million, with the prime mover only contributing about 10% of that total.

6.9.8 Biomass System Operation and Maintenance Costs

Non-fuel O&M costs can be divided into fixed and variable costs. For a rough order of magnitude estimate, fixed costs (e.g., labor, replacement parts, and insurance) are often given as a fraction of capital costs. Variable costs are a function of wear-and-tear and include maintenance, ash disposal, and consumables. Table 14 shows ranges of fixed and variable O&M for various types of systems.

Table 14. Biomass System O&M Costs

Technology	Fixed O&M (% of installed cost)	Variable O&M (USD/MWh)
Stokers / BFB / CFC boilers	3.2 - 4.2 3 - 6	3.8 - 4.7
Gasifier	3 6	3.7
AD systems	2.1 - 3.2 2.3 - 7	4.2
LFG	11 - 20	n.a.

SOURCES: US DOA, 2007; US EPA, 2009; AND MOTT MACDONALD, 2011.

Source: IRENA Renewable Energy Technologies: Cost Analysis Series. Biomass for Power Generation[39]

[38] IRENA. "Biomass for Power Generation." June 2012. Accessed June 19, 2013: http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-BIOMASS.pdf. Costs include equipment for receiving, processing, storage and fuel metering conveyors, meters, and pneumatic transport.

Fixed O&M costs for a small system tend to be at the high end of the scale, as items like labor become less per unit of energy as systems get larger.

Variable O&M costs provided are for electric power systems. For a CHP system with a small electric component relative to the thermal component, Table 14 probably underestimates the variable O&M cost component.

Based on capital costs of $9 million–$11 million and a fixed O&M rate of 5% of capital costs, we estimated fixed O&M at about $500,000/yr. We estimate variable O&M costs at $5/1,000 pounds of steam produced, based on methods discussed in EPA's Biomass Combined Heat and Power Catalog of Technologies.[40] At 30,000 PPH and 85% capacity factor, this component of O&M is estimated at $1.1 million–$1.2 million per year, for total O&M costs of $1.6 million–$1.7 million per year.

6.10 Truck Traffic Impact of Various Fuels

Here we briefly review the truck traffic due to fuel oil, CNG, and biomass to Putney Paper.

6.10.1 Fuel Oil

The traditional fuel used at both Putney Paper and at Landmark College has been fuel oil No. 2 and fuel oil No. 6 (also called bunker C oil or bunker oil). No. 2 fuel oil is lighter than No. 6 but has a lower energy density or heating value. The heating value of No. 2 fuel oil varies, but for the purposes of this analysis is estimated to be about 140,000 Btu/gal; No. 6 fuel oil has a heating value around 154,000 Btu/gal. This analysis assumes that any imported CNG or biomass would displace No. 2 fuel oil.

Fuel oil delivery trucks, like the one shown in Figure 26, range from about 2,500–4,000 gallon capacity. At 140,000 Btu/gal, 2,500 gal is equal to 350 MMBtu and 4,000 gal is equal to 560 MMBtu.

6.10.2 Compressed Natural Gas

NREL spoke with NG Advantage. [41] They informed us that the CNG used at Putney Paper will be delivered by trailer. Each trailer holds the equivalent of 350,000 standard cubic feet (scf) of usable natural gas[42] but compressed to 3,600 psi. At 1,000 Btu/scf, a trailer provides about 350 MMBtu to the plant.

6.10.3 Biomass

Biomass delivery trucks can typically hold approximately 20 green tons of biomass per truck. At an energy content of 5,500 Btu per green pound, 20 tons of wood chips have an energy content of about 220 MMBtu.

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[39] IRENA. "Biomass for Power Generation." June 2012. Accessed June 19, 2013: http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-BIOMASS.pdf.

[40] U.S. Environmental Protection Agency. "Biomass Combined Heat and Power Catalog of Technologies." September 2007. Accessed June 19, 2013: http://www.epa.gov/chp/documents/biomass_chp_catalog.pdf.

[41] Lavoie, D. Director of Business Development NG Advantage, Milton, VT. Phone call. 5/17/2013 8:05 a.m.

[42] Trailer gas pressure is remotely monitored by NG Advantage, and trailers are typically swapped out when gas pressure drops to about 300 psi.

6.10.4 Trucks Summary for Putney Paper

Table 15 summarizes the carrying capacity for trucks delivering various fuels. A truck carrying 30 tons of biomass has slightly less capacity than a 2,500-gal fuel oil delivery truck or a CNG trailer.

Table 15. Truck Capacities for Various Fuels

Fuel Type	Capacity	Units	Capacity [MMBtu]
Fuel oil No. 2	2,500	gallons	350
Fuel oil No. 2	4,000	gallons	560
CNG	350,000	scf	350
Biomass	20	tons	220
Biomass	30	tons	330

Feedstock requirements for a biomass CHP facility serving Putney Paper's thermal load of 30,000 PPH and providing 600-kW electric gross are expected to be between 36,000 and 44,000 green tons per year. Table 16 provides an estimate of the number of deliver trucks per day at Putney Paper for various fuels.

Table 16. Truck Deliveries for Putney Paper

Fuel Type	Capacity	Units	Trucks per day
Fuel oil No. 2	2,500	gallons	2-3
Fuel oil No. 2	4,000	gallons	1-2
CNG	350,000	scf	2-3
Biomass	20	tons	5-6
Biomass	30	tons	4-5

Displacing CNG or fuel oil with biomass would add between one and four trucks per day, on average, depending on the delivery capacity of the current fuel oil and future biomass trucks.

6.11 Recommended Activities for Next-Level Analysis

There are several details to discuss regarding potential energy off-takers in a follow-on analysis:

- Determine if Putney Paper is still interested in purchasing thermal or electric energy (or both) from a Basketville biomass facility
- Include the new truck delivery of CNG in an economic analysis of any biomass project
- Complete an analysis on providing heat or power to the Landmark College campus
- Evaluate the economics of a thermal-only facility to supply Putney Paper
- Evaluate other configurations for CHP that might give more flexibility, such as use of a condensing turbine or an extraction turbine
- Refine rough order of magnitude capital costs and O&M costs for an economic analysis.

7 Codes and Regulations

This section discusses regulations and codes that could impact a biomass energy project on the site.

7.1 State and Local Codes and Regulations

The following are taken directly from the Biomass Energy Development Working Group Final Report, January 17, 2012.[43] A letter from Aaron Adler, Legislative Counsel, states that the following is a "summary of current state laws under which the impacts of woody-biomass development projects would be reviewed, including electric generation stations, district heating, and non-generation stations such as wood pellet manufacturing plants. District heating may or may not include cogeneration. Below we list and summarize permits and approvals that appear likely to apply to such projects. This list is limited to permits and approvals related to environment and land use and may not be exhaustive. The permits or approvals potentially apply to all the types of projects under discussion except where noted below in italics" (p. 54).

- **"Land use permit under Act 250** *(manufacturing facility, district heating)*. See 10 V.S.A. § 6001(3). An Act 250 permit would be required for a manufacturing facility such as a wood pellet plant, or a district heating project, if one of the jurisdictional thresholds is met. Relevant jurisdictional thresholds include:
    - For a commercial project, construction on a tract exceeding 10 acres in a town with zoning and subdivision bylaws or exceeding one acre in a town that does not have both such bylaws. 10 V.S.A. § 6001(3)(A)(i), (ii); Act 250 Rule 2(C)(5)(a). These thresholds would be relevant to a wood pellet plant.
    - For a municipal project, construction involving the physical alteration of more than 10 acres of disturbed land. 10 V.S.A. § 6001(3)(A)(v); Act 250 Rule 2(C)(5)(b). This threshold would be relevant to a municipal heating district.

  Under the Act 250 process, a district environmental commission would measure the project against a list of environmental, land use, and economic criteria, including criteria related to air and water pollution, soil erosion, tariff, impact on governmental services, aesthetics, historic sites, wildlife habitat, growth in the town and region, agricultural and forest soils, energy conservation, and conformance with local and regional plans. 10 V.S.A. § 6086(a) (p. 54).

- **Certificate of public good under 30 V.S.A. § 248** *(woody biomass electric generation facility)* issued by the Public Service Board (PSB). A woody biomass electric generation facility requires a certificate of public good (CPG) from the PSB unless it is operated solely for on-site electricity consumption by the owners. 30 V.S.A. § 248(a)(2).

  Review under 30 V.S.A. § 248 measures a project against economic, energy planning, land use, and environmental criteria. The PSB is required to give "due consideration" to most of the Act 250 criteria and to the plans and recommendations of the local governmental bodies and the recommendations of the regional planning commission. 30 V.S.A. § 248(b).

[43] Legislative Council. "Biomass Energy Development Working Group Final Report." 17 January 2012. Accessed August 28, 2013: www.leg.state.vt.us/REPORTS/2012LegislativeReports/272678.pdf.

Electric generation facilities subject to PSB approval under 30 V.S.A. § 248 are exempt from Act 250. 10 V.S.A. § 6001(3)(D)(ii). In the case of woody biomass electric generation that is part of a district heating or manufacturing project, exemption of the generation from Act 250 may require clear demarcation and coordination of jurisdiction between the PSB and the district commission, assuming Act 250 applies to the heating or manufacturing project. (p. 55)

- **Municipal land use permit** *(manufacturing facility, district heating)*. Depending on whether a municipality has adopted land use bylaws and what land uses it has chosen to regulate, a municipal land use permit may be required for a woody biomass manufacturing plant or a district heating project. Municipalities often require conditional use approval for commercial projects, which at a minimum must include review of the impact of the project on community facilities, the character of the area affected, traffic, bylaws and ordinances in effect, and utilization of renewable energy resources. A municipality may include other standards in conditional use review, including one or more of the Act 250 criteria. 24 V.S.A. § 4414(3). State law exempts from local land use review electric generation that is subject to PSB approval. 24 V.S.A. § 4413(b); 30 V.S.A.§ 248. This may raise issues for demarcating and coordinating jurisdiction between a town and the PSB. (p. 55)
- **Air pollution control permits** for construction or operation or both. 10 V.S.A. §§ 556, 556a; Vt. Air Pollution Control Regulations §§ 5-401, 5-501, 5-5003. The Agency of Natural Resources (ANR) administers the air pollution control program through the Air Pollution Control Division (APCD) of the Department of Environmental Conservation (DEC). Broadly speaking, these permits are required for sources of air contaminants and establish limits or controls on emissions of the contaminants to protect air quality. Id.; see also 10 V.S.A. § 558. (p. 55)
- **Permits for discharges to water.** As a delegated state under the Clean Water Act and under authority of the state's own water pollution control act, ANR administers a variety of discharge permits through DEC. These permits protect water quality. 33 U.S.C. § 1251 et seq., 10 V.S.A. chapter 47. Different permits apply to different types of discharges.
    - Stormwater discharge permits apply to stormwater discharges from construction or operation or both. Each of these types of facilities will require authorization under the Construction General Permit for stormwater discharges into state waters or conveyances leading to state waters during construction if the total land disturbance will be one acre or more. ANR, General Permit 3-9020 for Stormwater Runoff from Construction Sites § 1.1 (2008).
    - Each facility also may require a permit for stormwater discharges from the operation of the facility. These requirements may arise under federal or state law or both. The jurisdictional "triggers" for federal and state stormwater permits differ. For example, federal law applies to stormwater discharges from conveyances into U.S. waters (broadly defined). 33 U.S.C. § 1311(a), 1342(a), 1362(6), (7), (12), (14). State law requires a stormwater operating permit if the total impervious surface will be one acre or more and provides that ANR may require such a permit regardless of acreage if the discharge is into stormwater impaired waters. See, e.g., 10 V.S.A. § 1264(d)(1)(D) and (E).

- The review of a stormwater discharge may occur under a general or individual permit, depending on the facility and the discharge and whether the receiving water is not stormwater-impaired. See ANR, Vermont Multi-Sector General Permit 3-9003 for Stormwater Discharges Associated with Industrial Activity § 1.3 and Appendix D (2006); General Permit 3-9015 for New Stormwater Discharges to Waters That Are Not Principally Impaired by Collected Stormwater Runoff § B (2003).
- Other discharge permits may be required if the facility has a water discharge that is not stormwater. 10 V.S.A. §§ 1259, 1263. The term "discharge" means placing, depositing, or emitting wastes, directly or indirectly, into an injection well or state waters; the term "wastes" is broadly defined. 10 V.S.A. § 1251(3), (12). There are direct discharge, indirect discharge, and underground injection control (UIC) permits. A direct discharge permit will apply to a discharge that is delivered by a conveyance (including over land) right to a surface water. An indirect discharge means any discharge to groundwater, whether subsurface, landbased, or otherwise. 10 V.S.A. § 1251(15). UIC permits apply to injection wells used as a means of discharging waste into the ground. 10 V.S.A. § 1251(14). (p. 55-56)

- **Potable water supply and wastewater permit.** A potable water supply and wastewater permit is required from ANR before, among other things, the construction of a new building or structure unless an exemption applies. 10 V.S.A. §§ 1973, 1974. These permits are required in order to protect human health and the environment by ensuring that water supplies are potable and that on-site waste disposal systems are properly constructed and operated. 10 V.S.A. § 1971(1). One or more of the facility types under discussion may be served by its own on-site water supply or wastewater system. However, if a site is served by municipal water or wastewater systems, it is possible that a permit may be granted based on proof that the facility has obtained an allocation from the municipality for water supply or wastewater disposal or both based on the facility's estimated use (p. 56).
- **Other potential permits**. Other permits or approvals could apply depending on the facts and circumstances of a proposed project and the relevant site. For example, a permit or conditional use determination from ANR would be required if one of the facilities is proposed to be constructed within a significant wetland or the required buffer zone of such a wetland. 10 V.S.A. § 913(a). The review process for such a proposal evaluates its impacts on the functions and values of the wetland. 10 V.S.A. §§ 914(a), 6025(d)(5)(A)-(K); Vt. Wetland Rules § 9 (2010)" (p. 57).

7.2 Federal Codes and Regulations

The size and design of the plant, the method of steam and power generation, and local permitting requirements ultimately affect the actual permits required for a biopower plant. State agencies generally handle permitting.

The federal regulations and permits potentially required for a biopower project include:

- National Emission Standards for Hazardous Air Pollutants covers boilers[44]
- EPA's National Ambient Air Quality Standards says combustion devices must emit below stated levels[45]
- 2011 EPA Clean Air Act pollution standards requires biomass boilers over 10 million Btu/hr for 876 or more hours per year to meet numeric emission standards[46]
- 40 CFR Part 89 limits emissions on non-road internal combustion engines[47]
- 40 CFR Part 60 limits emissions on steam generating units over 10 million Btu/hour
- 40 CFR Part 63 requires reciprocating internal combustion engines or generators over 300 hp to meet specific CO standards
- Resource Conservation and Recovery Act Subtitle D covers solid wastes and says the facility might be considered a waste processing facility[48]
- 40 CFR Part 257 sets disposal standards for owners of non-municipal non-hazardous wastes, which would include a facility accepting food wastes
- National Pollutant Discharge Elimination System covers what happens to wastewater from the facility[49]
- Prevention of Significant Deterioration and construction permits requires any new major source of pollutants to conduct analysis and use best control technologies[50]
- Risk management plan requires new facilities to development a plan if certain chemicals are stored.[51]

[44] EPA. "Rules and Implementation." Accessed June 19, 2013: http://www.epa.gov/ttn/atw/eparules.html.
[45] EPA. "National Ambient Air Quality Standards." Accessed June 19, 2013: http://www.epa.gov/air/criteria.html.
[46] "Final Air Toxics Standards For Industrial, Commercial, and Institutional Boilers at Area Source Facilities." EPA. 2011. Accessed January 8, 2013: http://www.epa.gov/airtoxics/boiler/area_final_fs.pdf.
[47] "Code of Federal Regulations. Title 40. Chapter 1 – Environmental Protection Agency. Subchapter C – Air Programs. Parts 50-99."U.S. Government Printing Office. Accessed January 8, 2013: http://www.gpo.gov/fdsys/browse/collectionCfr.action?collectionCode=CFR.
[48] "Code of Federal Regulations. Title 40. Chapter 1 – Environmental Protection Agency. Subchapter I – Solid Wastes. Parts 239-282."U.S. Government Printing Office. Accessed January 8, 2013: http://www.gpo.gov/fdsys/browse/collectionCfr.action?collectionCode=CFR.
[49] EPA. "National Pollutant Discharge Elimination System Compliance Monitoring." Accessed June 19, 2013: http://www.epa.gov/compliance/monitoring/programs/cwa/npdes.html.
[50] EPA. "Prevention of Significant Deterioration (PSD) Basic Information." Accessed June 19, 2013: http://www.epa.gov/NSR/psd.html.
[51] EPA. "Risk Management Plan (RMP) Rule." Accessed June 19, 2013: http://www.epa.gov/oem/content/rmp/.

8 Conclusions and Recommendations

Estimates of available low-grade biomass range from 78,000–380,000 green tons per year, depending on the tool used and the collection region specified. Feedstock requirements for a biomass CHP facility serving Putney Paper's thermal load of 30,000 PPH and providing 600-kW electric gross are expected to be between 36,000 and 44,000 green tons per year. Thus, it would appear that local biomass resources are adequate for the described facility—but these numbers should be confirmed, as described below.

Utility bill savings are estimated at $6 million per year, biomass costs at $1.1 million–$2.2 million per year, and non-fuel operation and maintenance costs at $1.6 million–$1.7 million per year. Capital costs have been estimated to be $9 million–$11 million.

Key recommendations include:

- Determine the space required for an appropriate bioenergy facility, including fuel storage
- Inspect the existing buildings to confirm that they are safe for reuse
- Perform a site-specific and project-specific biomass resource assessment
- Contact foresters, wood utilization specialists, lumber mills, and others to get a firmer analysis of available biomass, biomass properties, and biomass cost
- Hold discussions with GMP regarding interconnection requirements, size limitations, electricity purchase rates, and any charges that might be incurred by the site or any potential off-takers of electricity from a biomass power or CHP plant
- Account for the price of this gas in an updated analysis
- Determine if Putney Paper is still interested in purchasing thermal or electric energy (or both) from a Basketville biomass facility
- Perform an economic analysis of providing heat or power to the Landmark College campus
- Evaluate the use of a thermal-only facility
- Study the rough order of magnitude capital costs and O&M to refine them
- Perform an economic analysis on each biomass heat and power option presented when better numbers for costs and energy savings are acquired.

Appendix A. Green Mountain Power

Notes From Meeting With Green Mountain Power

Notes from a meeting with Don Lorraine of GMP in September, 2012, are summarized here:

- GMP is interested in a PPA for any renewable power
- Interconnection size restriction is limited due to distribution equipment
- He can get Putney Paper load data (15 min.)
- Net-metering laws in Vermont for systems up to 500 kW, interconnected to GMP
- Cannot just be a generator under net metering
- The system could be grouped with Putney Paper and credited to Putney Paper bill.

Green Mountain Power—Letter of Support

GMP provided the following letter of support for this project.

GREEN MOUNTAIN POWER

Chris Campany, AICP ASLA
Executive Director
Windham Regional Commission
139 Main Street, Suite 505
Brattleboro, VT 05301

May 16, 2011

RE: Green Mountain Power's Renewable Generation Support

Dear Chris:

Green Mountain Power is committed to support Renewable Generation Projects throughout our service territory. We currently are the only utility in Vermont that provides an additional $.06 incentive for every kilowatt-hour generated by a net metered solar PV installation.

There are two ways Green Mountain Power supports renewable generation projects: 1) through a state mandated net metering option where the project needs to be grouped with an existing account consuming approximately the same amount of energy or 2) we will enter into negotiations for a Purchase Power Agreement (PPA) with customers that intend to site generation and not choose the net metering path.

We are committed as a company to encourage the deployment of various renewable generation technologies and look forward to working with your team to assist you with your project as you explore the suitability of the Basketville Warehouse site in Putney for the generation of renewable energy.

Best regards,

Don Lorraine

Don Lorraine
Green Mountain Power
Commercial Account Manager

Green Mountain Power Corporation 163 Acorn Lane Colchester Vermont 05446-6611 P(802)864-5731 F(802)655-8419 www.gmpvt.com

Figure A-1. Green Mountain Power letter of support

Appendix B. NEFA BPE Model Details

This section provides some of the inputs and outputs used in the Biomass Project Evaluator (BPE) model for estimating biomass availability over a 20-year period.

The following tables provide county-level forestry data by state within a 30-mile radius of the Basketville site.

Table B-1. NEFA BPE Biomass Data—Massachusetts

Growth, Volume, and Species Type Composition for Selected FIA Data

State: Massachusetts	Average Per Acre Volume of All Live Biomass (green tons)				Total Per Acre Volume of All Live Biomass	Net Growth of All Live Trees (thous GT/year)	Total Timberland (acres)	Timber Quality % of Forest Volume in Low vs. Higher Grade Material*		
County	Softwoods	% SW	Hardwoods	% HW				Grade 1 or 2	Grade 3	Grade 4+ or Ungraded
Franklin	24.4	36.3%	42.8	63.7%	67.2	360.1	236,342	29%	20%	51%
Worcester	49.3	58.8%	34.5	41.2%	83.9	-45.8	26,979	31%	25%	44%
						314.3	263,322			

State Timberland Acreage Totals, by Ownership Group

State Name	Owner Group	Timberland Acres	
Massachusetts			
	Federal	56,743	1.9%
	Municipal	353,687	12.0%
	Private	1,965,413	66.9%
	State	559,910	19.1%
Total:		2,935,752	100.0%

Average annual growth for selected counties:	1.19	green tons/ac/year
Average growth rate	1.6%	

Table B-2. NEFA BPE Biomass Data—New Hampshire

New Hampshire County	Average Per Acre Volume of All Live Biomass (green tons) Softwoods	% SW	Hardwoods	% HW	Total Per Acre Volume of All Live Biomass	Net Growth of All Live Trees (thous GT/year)	Total Timberland (acres)	Timber Quality % of Forest Volume in Low vs. Higher Grade Material* Grade 1 or 2	Grade 3	Grade 4+ or Ungraded
Hillsborough	10.7	17.7%	49.9	82.3%	60.6	57.8	67,848	34%	27%	39%
Sullivan	25.4	41.3%	36.0	58.6%	61.4	221.5	136,165	21%	25%	55%
Cheshire	27.0	38.4%	43.3	61.6%	70.3	551.9	447,319	35%	21%	44%
						831.2	651,332			

State Timberland Acreage Totals, by Ownership Group

State Name	Owner Group	Timberland Acres	
New Hampshire			
	Federal	677,360	14.6%
	Municipal	226,215	4.9%
	Private	3,527,296	76.0%
	State	209,792	4.5%
Total:		4,640,662	100.0%

Average annual growth for selected counties:	1.28	green tons/ac/year
Average growth rate	1.8%	

Table B-3. NEFA BPE Biomass Data—Vermont

State

Vermont County	Average Per Acre Volume of All Live Biomass (green tons) Softwoods	% SW	Hardwoods	% HW	Total Per Acre Volume of All Live Biomass	Net Growth of All Live Trees (thous GT/year)	Total Timberland (acres)	Timber Quality % of Forest Volume in Low vs. Higher Grade Material* Grade 1 or 2	Grade 3	Grade 4+ or Ungraded
Windham	27.2	36.5%	47.4	63.5%	74.6	716.2	514,668	35%	21%	44%
Windsor	8.0	13.3%	52.2	86.7%	60.2	94.8	97,554	33%	22%	44%
Bennington	12.2	18.8%	52.5	81.2%	64.6	61.6	159,573	31%	25%	44%
						872.6	771,794			

State Timberland Acreage Totals, by Ownership Group

State Name	Owner Group	Timberland Acres	
Vermont			
	Federal	398,137	8.9%
	Municipal	48,775	1.1%
	Private	3,644,349	81.4%
	State	385,458	8.6%
Total:		4,476,719	100.0%

Average annual growth for selected counties:	1.13	green tons/ac/year
Average growth rate	1.5%	

As discussed in Section 4, we worked with Jennifer Hushaw of INRS, LLC, to develop key assumptions for this model; these values are shown in Table B-4.

Note that only a few of the counties included in the analysis are visible within the lower table.

Table B-4. NEFA BPE Assumptions

A. General

Inventory:
% of total standing bolewood volume that is low grade: 65%

Harvest of Sawtimber:
% of total sawtimber harvest that is high-value (sawlog quality): 50%

Removal of Residuals:
% of tops and limbs inventory that is suitable/sustainable to extract : 75%

B. Private Timberland Ownership

% Corporate	5.0%
% Farm	2.0%
% Other Private	93.0%

% Other Private: 1-50acre parcels	30.0%
% Other Private: 50+acre parcels	70.0%
Total:	100.0%

This value must equal 100%.

View Timberland Acres with Current Proportions
(click to open/close table)

		Acres derived from FIA database				Acres based on private ownership proportions assumptions (above)			
State	County	Federal	State	Municipal	Private Land (Total)	Corporate	Farmer	Other Private 1-50 ac	Other Private 50 ac+
Massachusetts	Franklin	7,019	31,225	7,870	159,647	7,982	3,193	44,542	103,930
Massachusetts	Worcester	3,941	4,500	0	7,019	351	140	1,958	4,570
New Hampshire	Hillsborough	1,306	0	6,109	46,845	2,342	937	13,070	30,496
New Hampshire	Sullivan	0	3,917	6,794	111,867	5,593	2,237	31,211	72,825
New Hampshire	Cheshire	5,223	31,606	25,399	311,092	15,555	6,222	86,795	202,521
Total	1,448,405	149,524	73,353	62,818	1,162,710	58,136	23,254	324,396	756,924

C. Percentage of Acres in Different Ownership Categories that are Accessible for Harvesting

Federal	15.0%	Corporate	90.0%
State	30.0%	Private Parcels 1-50 acres	50.0%
Municipal	10.0%	Private Parcels 50+ acres	70.0%
Farmer	50.0%		

D. Percentage of Accessible Acres that are Removed from Harvesting due to Physical Factors

Slope	1.0%	Deer Yards	0.0%
Elevation	1.0%	Stream Buffers	1.0%
Wetlands	0.5%	Easements	0.5%
Distance to Roads	1.0%	Other	0.0%

Total % Physically Inaccessible Acres: 5.0%

Ownership Category	Total Acres of Timberland	Accessible Acres
Federal	149,524.41	22,428.66
State	73,353.00	22,005.90
Municipal	62,817.67	6,281.77
Corporate	58,135.50	52,321.95
Farm	23,254.20	11,627.10
Other Private:		
Parcels 1-50acres	324,396.09	162,198.05
Parcels 50+acres	756,924.22	529,846.95
Total:	**1,448,405.09**	**806,710.38**

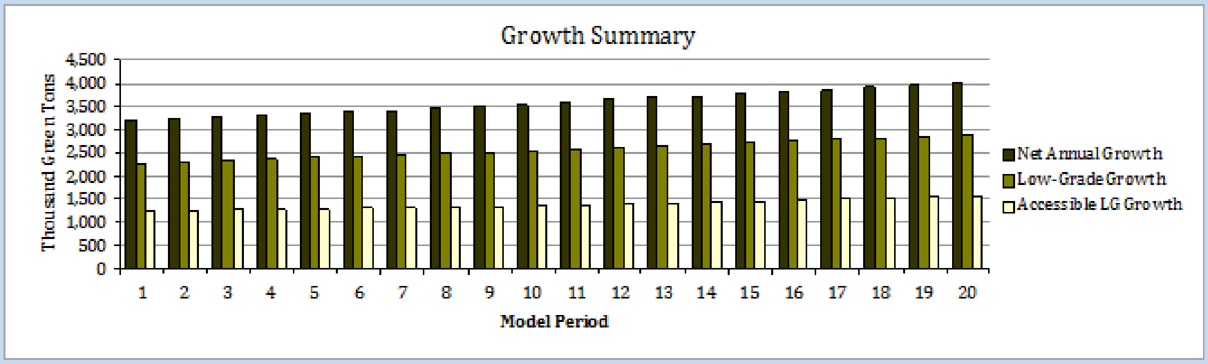
Net Accessible Timberland: **766,374.86**

Percentage of Timberland Acres Discounted for Accessibility: 52.9%

The BPE model allows the user to project changing or constant rates of usage of high-value and low-value timber and changes in growth rate and land use over the project evaluation period (in this case 20 years). We set all values to constant with the following results.

Table B-5. BPE Growth Summary Report

Growth Summary Report



* Low-grade includes all growth in tops and limbs, as well as low-grade growth in bolewood.

** Accessible is the portion of total growth that occurred on timberland acres that are accessible to harvest, based on the user defined key assumptions regarding ownership and physical accessibility

			Total Growth			Accessible** Growth		
	Total Biomass per acre (Green Tons)	Net Accessible Timberland (000 Acres)	Low-Grade* (000 GT) +	High-Value (sawtimber) (000 GT) =	Total Net Annual Growth (000 GT)	Low-Grade* (000 GT) +	High-Value (sawtimber) (000 GT) =	Total (000GT
Period: 1	134.67	755	2,278.41	902.08	3,180.48	1,227.10	485.89	1,712.99
Period: 2	135.77	755	2,304.96	912.65	3,217.61	1,241.65	491.67	1,733.32
Period: 3	136.89	755	2,332.01	923.41	3,255.42	1,256.46	497.56	1,754.02
Period: 4	138.04	755	2,359.54	934.37	3,293.91	1,271.54	503.56	1,775.10
Period: 5	139.21	755	2,387.58	945.53	3,333.11	1,286.90	509.67	1,796.57
Period: 6	140.41	755	2,416.14	956.89	3,373.03	1,302.55	515.89	1,818.44
Period: 7	141.64	755	2,445.22	968.47	3,413.69	1,318.48	522.23	1,840.71
Period: 8	142.90	755	2,474.84	980.25	3,455.09	1,334.71	528.68	1,863.39
Period: 9	144.19	755	2,505.01	992.26	3,497.27	1,351.24	535.25	1,886.49
Period: 10	145.51	755	2,535.74	1,004.48	3,540.22	1,368.08	541.95	1,910.03
Period: 11	146.86	755	2,567.04	1,016.93	3,583.97	1,385.23	548.77	1,934.00
Period: 12	148.23	755	2,598.93	1,029.62	3,628.54	1,402.71	555.71	1,958.42
Period: 13	149.64	755	2,631.41	1,042.54	3,673.95	1,420.51	562.79	1,983.30
Period: 14	151.09	755	2,664.50	1,055.70	3,720.20	1,438.64	570.00	2,008.64
Period: 15	152.56	755	2,698.21	1,069.11	3,767.32	1,457.12	577.34	2,034.46
Period: 16	154.07	755	2,732.55	1,082.77	3,815.32	1,475.94	584.82	2,060.76
Period: 17	155.61	755	2,767.55	1,096.69	3,864.23	1,495.12	592.44	2,087.56
Period: 18	157.19	755	2,803.20	1,110.87	3,914.07	1,514.65	600.21	2,114.86
Period: 19	158.80	755	2,839.53	1,125.31	3,964.84	1,534.56	608.12	2,142.68
Period: 20	160.44	755	2,876.54	1,140.03	4,016.57	1,554.84	616.18	2,171.03

Table B-6. BPE Growth and Available Volume, 20-Year Projections

All States and Counties

Model Projection Year	***** All units 000 gt **** Inventory Period Start	+ Periodic Growth	- (Sawlog Harvest	+ Low-Grade*)	= Inventory Period End	Available Volume** Low-Grade Bolewood	+ Tops and	+ High-Value	= Total
1	193,512	3,180	330	1,302	195,061	-87	78	156	148
2	195,061	3,218	330	1,302	196,647	-76	78	162	164
3	196,647	3,255	330	1,302	198,270	-65	78	168	181
4	198,270	3,294	330	1,302	199,932	-54	78	174	198
5	199,932	3,333	330	1,302	201,634	-43	78	180	216
6	201,634	3,373	330	1,302	203,375	-31	78	186	234
7	203,375	3,414	330	1,302	205,157	-19	78	193	252
8	205,157	3,455	330	1,302	206,980	-7	78	199	270
9	206,980	3,497	330	1,302	208,846	5	78	206	289
10	208,846	3,540	330	1,302	210,754	17	78	212	308
11	210,754	3,584	330	1,302	212,707	30	78	219	327
12	212,707	3,629	330	1,302	214,703	43	78	226	347
13	214,703	3,674	330	1,302	216,746	56	78	233	368
14	216,746	3,720	330	1,302	218,834	69	78	240	388
15	218,834	3,767	330	1,302	220,970	83	78	248	409
16	220,970	3,815	330	1,302	223,153	97	78	255	430
17	223,153	3,864	330	1,302	225,386	111	78	263	452
18	225,386	3,914	330	1,302	227,668	126	78	271	474
19	227,668	3,965	330	1,302	230,001	140	78	278	497
20	230,001	4,017	330	1,302	232,386	155	78	287	520

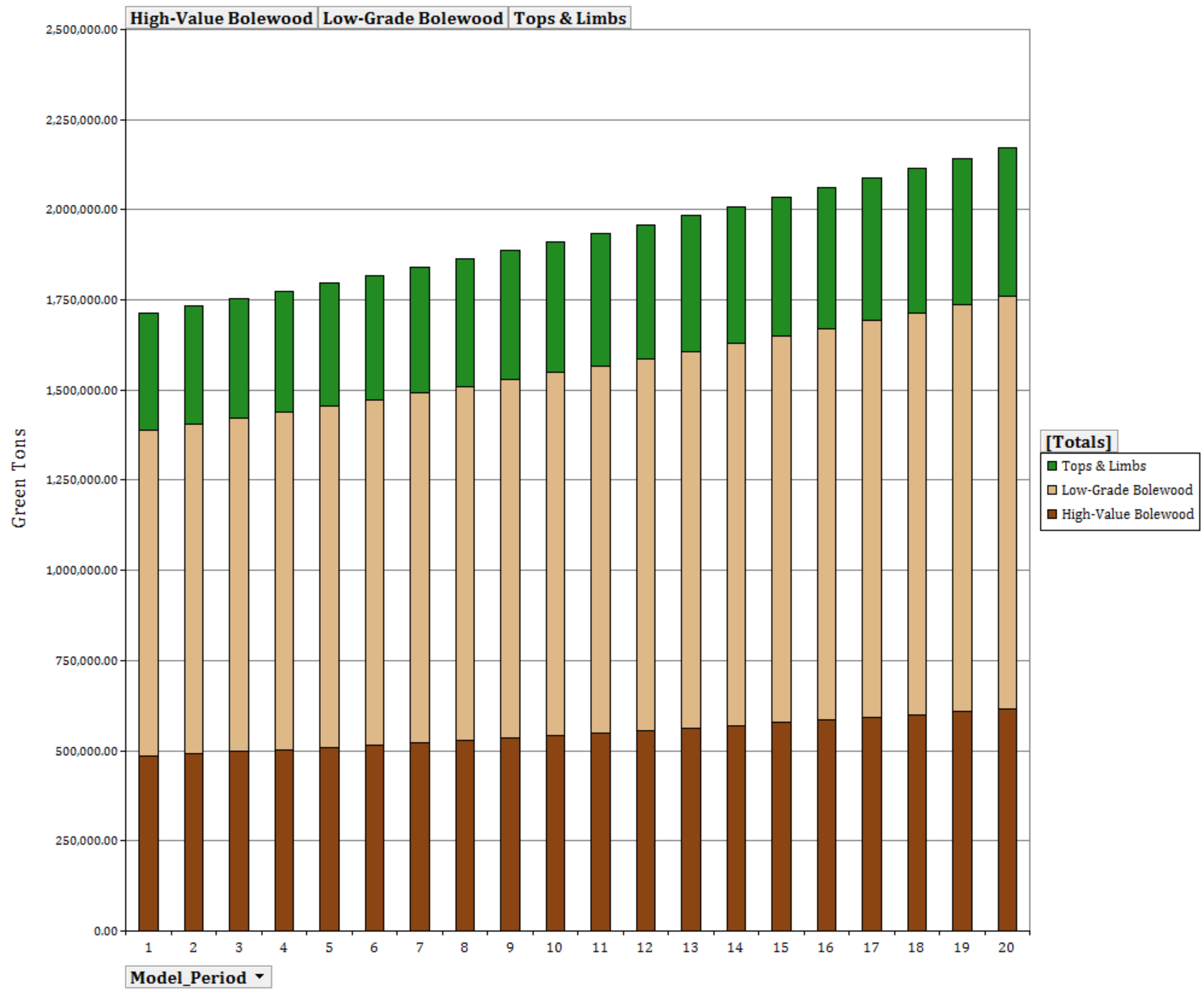


Figure B-1. BPE model—projected biomass availability

Appendix C. Nearby Biomass Projects

Pellets

According to the Vermont Biomass Energy Development Working Group, the only pellet mill in Vermont[52] is the Vermont Wood Pellet Company in Clarendon—about 60 miles from Putney. According to their website,[53] this facility produces about 10,000 tons of pellets per year.

The Biomass Magazine Pellets Map[54] lists a second facility in Vermont—Beaver Wood Energy in Fair Haven. This plant is about 80 miles from Putney and has a capacity, according to Biomass Magazine, of 110,000 tons per year. This facility seems to be associated with the proposed Fair Haven Energy Center, described below.

Biomass[55]

Currently, two power plants burn wood and wood waste to generate electricity. The East Ryegate power station in Caledonia County generates 20 MW. However, state energy officials say the Ryegate contract might not be renewed after it expires in 2012. In Burlington, Burlington Electric Department's McNeil Generating Station burns wood chips at 50 MW.

Three other biomass electrical generating plants have been proposed: New England Alternative Energy in Fair Haven, 30 MW; Winstanley Energy in Springfield, 25 MW; and a plant of similar output on the site of the former Pownal dog racing track. All three projects are in the exploratory, pre-permit stages. Due to reported financing issues, the Winstanley plant project has stalled since November 2008.

In Vermont, biomass efforts tend to focus on direct thermal generation for schools and building complexes and several smaller-scale biomass power generators, including Brattleboro Kiln Dry (0.38 MW), Pampanoosuc Mills (0.05 MW), Bell Gates Lumber (0.075 MW), and the North Country Hospital (0.265 MW). Green Mountain College is installing a biomass boiler that will produce net-metered electricity. Middlebury College has installed a biomass boiler that is combined with its steam turbine electrical generators and provides net-metered power.

In total, operational biomass capacity is approximately 70 MW (assuming Ryegate contract is renewed after 2012); estimated additional capacity in the near-future: 0.

VTEP strongly supports the aggressive development of in-state renewable power to help meet the state's energy demand with new sources of clean, safe, affordable, and dependable electricity. To address the energy deficit described above, VTEP supports a foundation of clean, dependable, and competitively priced electricity from a renewed contract with Hydro-Québec and the relicensing of the Vermont Yankee nuclear power plant.

[52] "Biomass Energy Development Working Group Final Report." January 17, 2012. State House. Accessed June 19, 2013: www.leg.state.vt.us.
[53] Vermont Wood Pellets. Accessed June 19, 2013: www.vermontwoodpellet.com.
[54] Biomass Magazine. Accessed June 19, 2013: http://biomassmagazine.com/plants/map/pellet.
[55] Page, G. "Renewable Energy Sources in Vermont: A Status Report." Vermont Energy Partnership, May 2010. Accessed June 19, 2013: http://www.vtep.org/documents/VTEP%20ISSUE%20BRIEF%20-%20Renewable%20Energy%20Sources%20in%20Vt%20-%20A%20Status%20Report%20May%202010.pdf .

North Springfield Sustainable Energy Project

A biomass CHP facility has been proposed for Springfield, Vermont, by Adam Winstanley and Weston Solutions. This project is being called the North Springfield Sustainable Energy Project (NSSEP). It is expected to be sized at about 25-MW electric and would include a thermal loop to provide heat to industrial customers at an industrial park.

North Springfield is about 32 miles north of Putney, so any project at that location would use resources from a supply shed significantly overlapping one for a Putney biomass project.

According to Innovative Natural Resource Solutions LLC's report *Biomass Fuel Availability North Springfield, Vermont:*[56]

> The North Springfield Sustainable Energy Project is developing a wood-fired biomass electricity facility for North Springfield, VT. When running as a baseload plant, the facility would expect to consume between 400,000 and 440,000 green tons of wood per year. This assumes an average moisture content of 45% (varies by season and species) and an average BTU value of 4,625 per pound (9.25 MM per ton); these are typical for biomass in this region.

More information about the North Springfield project is available at their website: http://www.northspringfieldbiomass.com/.

[56] Innovative Natural Resource Solutions. "Biomass Fuel Availability North Springfield, Vermont" (p. 4), September 2011. Accessed August 28, 2013: http://swcrpc.org/wp/wp-content/uploads/2012/01/Exh.-Pet.-EWK-2.pdf.

Appendix D. Site Visit

A site visit was held in Putney on September 5–6, 2012. The meeting agenda is provided.

Table E-1. Putney Meeting Agenda

Wednesday, September 5th		
Time	**Group/Type**	**Participants**
9:00am-10:00am	Site Visit – Town of Putney officials, town of Putney energy coordinator, owner or owner rep., WRC staff, BDCC staff	Greg Wilson, Cynthia StoddarD, Daniel Hoviss, Bob Stevens, Susan McMahon, Cullen Meves, Josh Laughlin
10:00am-11:00am	Small meeting at town offices with group above to discuss reuse strategies	Greg Wilson, Cynthia StoddarD, Daniel Hoviss, Bob Stevens, Susan McMahon, Cullen Meves, Josh Laughlin
11:00am-5:00 pm	Potential Users of power and economic development interests	
11:00am-12:00pm	• Putney Paper Mill	Tom Moore (unconfirmed)
12:00pm-1:00pm	Lunch	
1:00pm-4:00pm	• Village merchants, Village tour	
4:00pm-5:00pm	• Transition Putney	Daniel Hoviss and others
5:00pm-7:00pm	Dinner	
7:00pm-8:30pm	Community meeting to gather input for site evaluation	

Thursday, September 6th		
Time	**Group/Type**	**Participants**
12:00pm-1:00pm	Lunch	
1:30pm-2:30pm	County Forrester	Bill Guenther
?	UVM Ag Specialist	Vern Grubinger
5:00pm-7:00pm	Dinner	
7:00 p.m.	WRC Energy Committee and Brownfields Committee co-sponsor meeting to discuss NREL and initial findings. This would be held in Putney, but open to the region.	

Public Meeting

The following concerns were brought up at the public meeting, held in Putney on September 5, 2012:

- Truck traffic
- Emissions/air inversions
- Proximity to town well and wetlands
- What will be the water source and the total water resource needs?
- What is the scale of the generation project?
- Who will own the plant?
- Cumulative impacts of pellet burners at Putney Central School, Grammar School, and new project
- What are specific southern Vermont feedstocks?
- Can we look into energy storage ability?

- What is the cost of a solar study for this site?
- Will local sawmills be used as feedstock sources?
- Will the tax credits be sold?
- What is the total available source of feedstock in the Region?
- What will be the percentage of additional air pollutants added to the air space of the village?
- Are there other EPA grants for this work?

Meeting with Putney Paper

A meeting was held with Putney Paper (PP) on September 4, 2012. Summary notes from that meeting are below.

Attendees: CFO, Tom Moore, Manager of Production Dave Harris, Susan McMahon, Randy Hunsberger

PP's operation is 100% recycle, they do not use chips.

Materials come in by truck:

- Three trucks per day finished product (from mill to conversion)
- Four to five trucks per day fiber
- One truck per day fuel
- One to two trucks per day fiber clay
- 9-11 trucks per day total
- Trucking is mostly during regular business hours
- They have signed an agreement for CNG, delivered by truck, to replace approximately 100% of their oil
- They will probably replace number six oil with number two oil for backup
- They do not have a take or pay agreement
- It is not an exclusive arrangement
- They will spend $300,000–$500,000 to upgrade their boilers to dual fuel
- They expect the cost of natural gas to be less than $15/MMBtu delivered
- They expect to spend about 45% less than they did with number six oil
- The plant operates 24 hours per day, slightly less in summer
- Their LCOE is $0.11/kWh (all in)
- They would be interested in electricity as well as steam
- The plant uses saturated steam at 145 psi

- They have two 20,000-PPH boilers
- They have a steam load 24 hours per day—about 25,000 PPH in summer and 30,000 PPH in winter
- They use 750,000,000 Btu per day of oil
- They estimate the efficiency of their existing boiler at about 80%
- If a biomass system is put in at the Basketville site it would tie into the header just after the boilers
- Average electricity consumption is 2.6 MW at the mill near site; they use about 50,000 kWh per day
- Power is currently somewhat unreliable; outages are short-term
- The restart process costs about $2,500/hr, and it might take 2 hours to restart after outage
- This happens about five or six times per year
- The paper mill downtown makes big roles from recycled material
- The plant near Putney converts big roles (jumbos) into finish paper towels, napkins, etc. (converting plant)
- Putney Paper employs 115 to 130 people.

Appendix E. Putney Paper Letter of Support

As part of the RE-Powering application, Putney Paper provided the following letter of support for a biomass project at the Basketville site.

May 18, 2011

Susan McMahon
Associate Director
Windham Regional Commission
139 Main Street, Suite 505
Brattleboro, Vermont 05301

Dear Ms. McMahon:

As the manager of Putney Paper Mill, I support the Windham Regional Commission's application for a U.S. EPA RE-Powering Feasibility Study for this site Basketville Warehouse site. Putney Paper Mill, an operating paper mill that employs 117, is a neighbor to the property.

Putney Paper Company is located next to the Connecticut River in Putney Vermont – on the same site where paper making has been a continuous process since 1818. The manufacture of tissue paper began in 1869 when the Eagle Paper Mill was established. Early twentieth-century documents refer to it as the oldest manufacturer in the United States of high grade toilet tissue. There was great pride in New England craftsmanship then, and that same pride continues today as Putney Paper supplies recycled paper products to an environmentally responsible market.

Putney Paper has been manufacturing napkins, towels, and wrapping tissue entirely from 100% recycled paper for over 50 years. We use a blend of recovered waste paper and post-consumer waste paper. To provide a quality product we utilize state of the art cleaning and deinking equipment. Putney's complete product line meets the recycled content guidelines required by local, state and federal governments. Putney Paper is committed to keeping waste paper out of landfills and providing our customers with a sensible, environmentally conscious alternative line of paper products. We proudly display our usage of recycled paper on all of our packaging.

The cost of energy, particularly oil used to produce steam, has increased the cost to run the mill dramatically and we are having a tough time being able to afford to bring our product to market. Our business is facing some tough decisions on our ability to run this plant. Due to this we are very intrigued about the possibility of developing renewable affordable energy across from our business. We feel that this project, if feasible, could make a major difference in our ability to continue to produce paper at this site.

We look forward to partnering with you and the other partners on the feasibility study and are committed to a successful implementation of the project.

Sincerely,

Dave Harris
Manager

Figure E-1. Letter of support from Putney Paper

Appendix F. Solar Option

Although it is not an official part of this analysis, another technology of interest at the Basketville site is solar power. This site has good solar exposure, has three-phase electric on-site and could be a great example location for different types of solar installations, providing local renewable energy and the possibility of off-grid power during emergencies and for the town's public drinking water system located nearby. NREL did not spend any time reviewing this option, but Daniel Hoviss[57] with E-Solutions provided solar and shading data, with permission to include it in this report.

According to the Vermont Energy Partnership report,[58] *Renewable Energy Sources in Vermont*, as of May 2010 there were …

> …no large, commercial solar generators providing power directly into Vermont's electric grid. Central Vermont Public Service's 50 KW Solar Array contributes power directly into the grid. Green Mountain Power hopes to have completed a 200 KW array in Berlin by the end of the summer. At least two businesses (Green Mountain Coffee and National Life) have installed solar arrays of more than 100 KW that are "net metered," with the power they produce being sold into the system and its value deducted from the company's power bill. "Net metering" is the preferred system for most residential solar systems, as well. There are also several applications, but nothing in construction yet, for projects through the Feed-In Tariff of 2.2 MW or less…

According to SEIA, falling costs make solar more affordable than ever.

- The average cost of a completed PV system dropped by 33% in the third quarter of 2012 compared to the third quarter of 2011.
- The average price of a solar panel has declined by 58% since the first quarter of 2011.
- While these price drops are beneficial for the end user, the sharp fall in prices, driven in part by a global oversupply, has put a serious strain on solar manufacturers worldwide.

Solar Energy is an Economic Engine

As the solar industry grows, so does its impact on the economy. According to The Solar Foundations *Solar Job Census 2012*, there were over 119,000 solar workers in the United States, a 13.2% increase over employment totals in 2011.[59] These workers were employed at 5,600 businesses, operating at over 6,500 locations in every state. The increasing value of solar installations has injected life into the U.S. economy as well. In 2011, solar installations were valued at $8.4 billion, compared to $6 billion in 2010. Vermont ranks 24th in installed PV capacity as of the third quarter of 2012.

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[57] Hoviss, D. Email. E-Solutions. Chairperson at Putney Energy Committee and Town Energy Coordinator of Putney, VT.

[58] Page, G. "Renewable Energy Sources in Vermont: A Status Report." (p. 4) Vermont Energy Partnership, May 2010. Accessed August 28, 2013: http://www.vtep.org/documents/VTEP%20ISSUE%20BRIEF%20-%20Renewable%20Energy%20Sources%20in%20Vt%20-%20A%20Status%20Report%20May%202010.pdf .

[59] The Solar Foundation. "National Solar Jobs Census 2012." Accessed June 19, 2013: http://thesolarfoundation.org/research/national-solar-jobs-census-2012.

As of March 2013, the Town of Putney is actively seeking proposals for a solar electric system to offset a portion of its electric usage. Solar is the cleanest way to produce power and fits perfectly with the reuse plan for brownfields.[60]

PV System Mockup

Daniel Hoviss provided an illustration of potential PV arrangements located on the Putney Basketville site. Figure F-1 shows six potential PV layouts, ranging in size from 15 kW to 85 kW. Two systems in this design would be ground-mounted, three would be roof-mounted, and one would be designed as a covered parking area (southern unit). As indicated in the legend, total size of all systems would be about 240 kW.

Figure F-1. Potential PV system layouts

Courtesy of Daniel Hoviss, E-Solutions

Solar Shading Analysis

Hoviss provided shading analyses for three different options: the north section with trees removed, the north section without removing trees, and the south section of the property. These analyses are presented below, without comment. Please note that Hoviss did not include specific estimated output for the systems in the mockup, only general shading analysis for a 50-kW system.

[60] SEIA. "Solar Industry Data." Accessed June 19, 2013: http://www.seia.org/research-resources/solar-industry-data.

Analysis of North Section, With Trees Removed

Location Description

GPS coordinates: 42.97868 latitude, -72.521706 longitude, 49.4 altitude

System parameters: Fixed-axis, 55.0 kW at 30.0-degree tilt and 180.0-degree azimuth

Time zone: Eastern Standard Time

Winter Solstice day length: 8.9 hrs

Summer Solstice day length: 15.3 hrs.

Solar Path

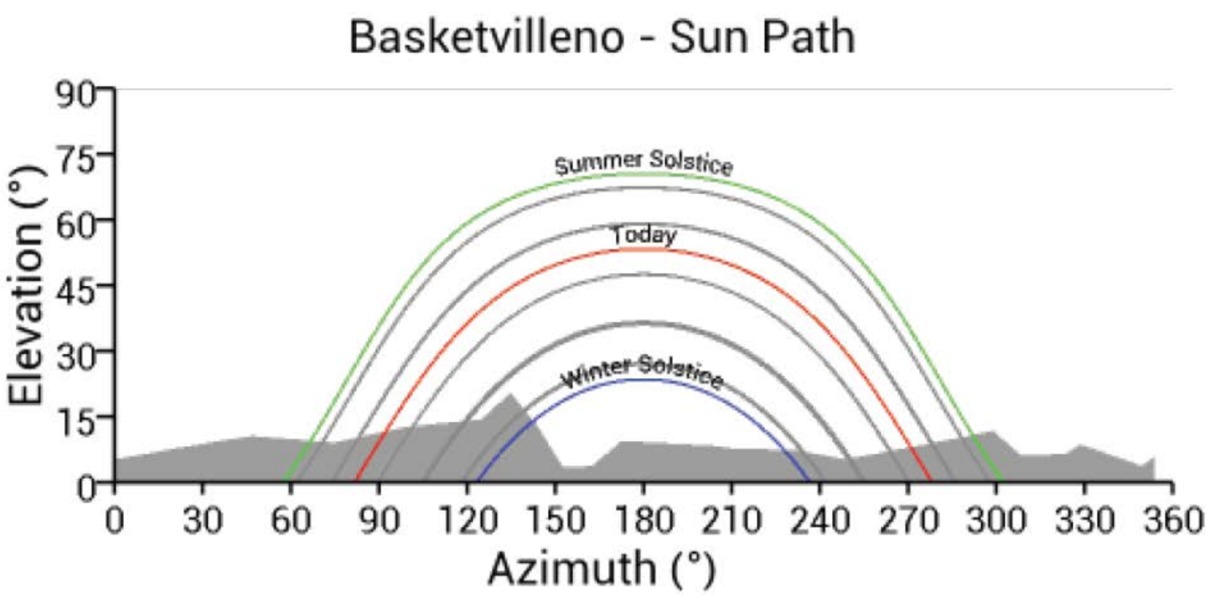

Figure F-2. Basketvilleno—Sun path

Shading Losses

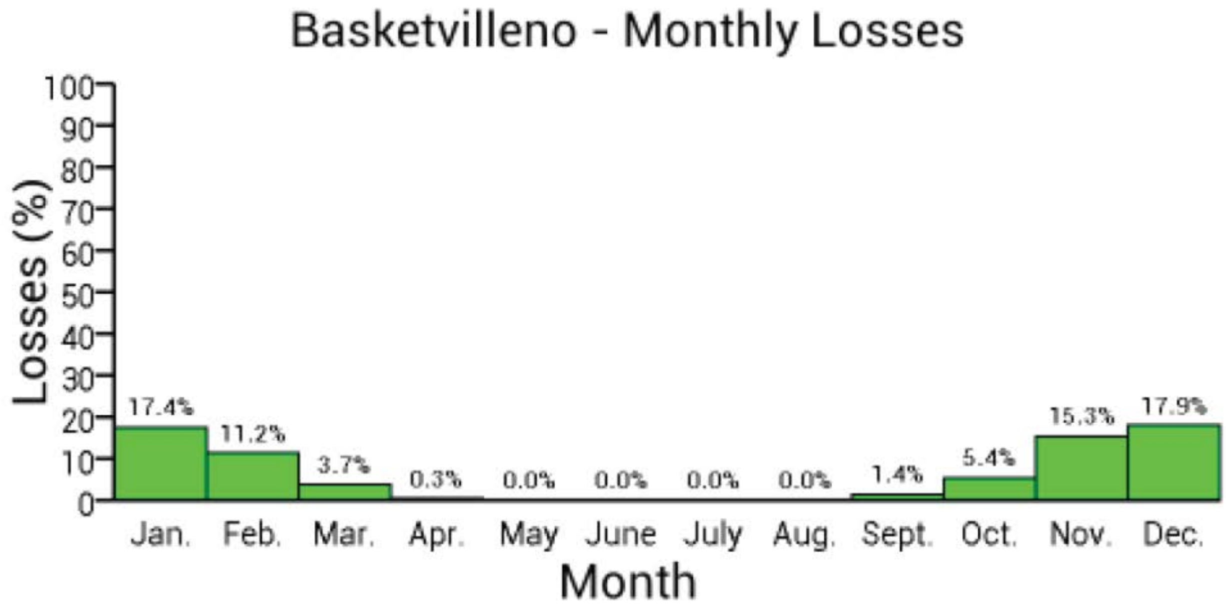

Figure F-3. Basketvilleno—Monthly losses

The total yearly sun hour losses are 5.3% due to shading.

System Output Results

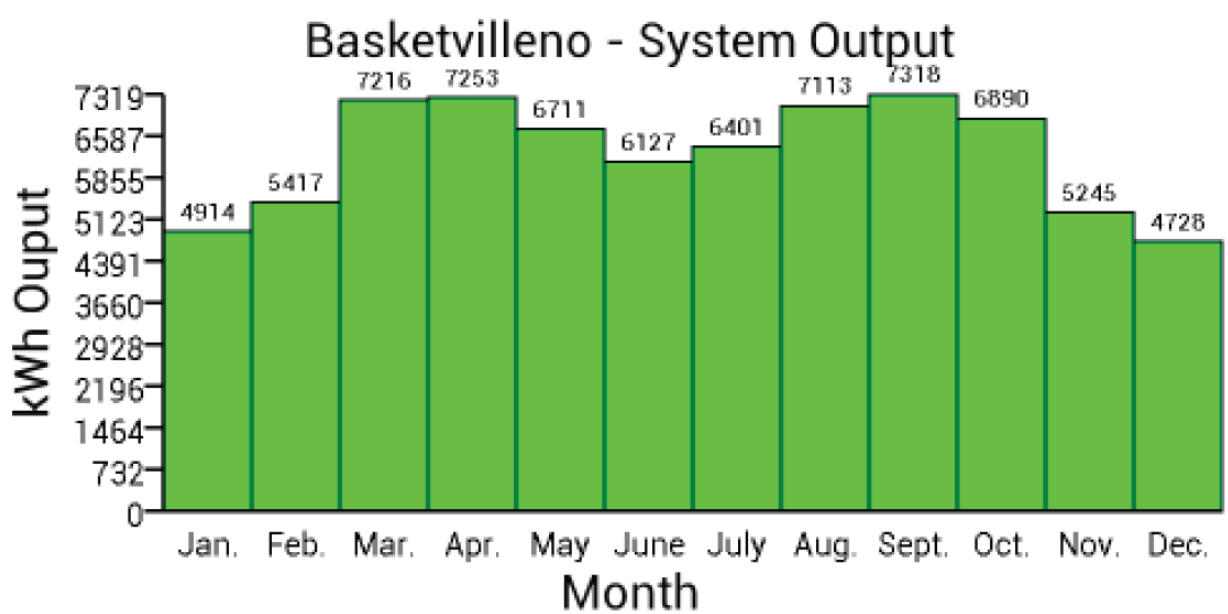

Figure F-4. Basketvilleno—System output

Total System Output

The total estimated system output of this location is 75,332.8 kWh/yr. Without shading there is a total possible output of 79,968 kWh/yr. This location will lose 4,635 kWh/yr or 5.7% due to shading.

Analyzing the Results

The solar path graph illustrates the path of the sun; 180 degrees is due south and 0, 360 degrees is due north. The shading losses chart illustrates the percentage of monthly hours lost due to shading in respect to the total possible hours over the horizon. These two graphics should be used in conjunction with each other. There may be significant hours lost in the morning or late afternoon; however, this does not necessarily mean the location is not conducive to solar power.

Analysis of North Section, With Trees in Place

Location Description

GPS coordinates: 45.0 latitude, -72.0 longitude, 0.0 altitude

System parameters: Fixed-axis, 55.0 kW at 30.0-degree tilt and 180.0-degree azimuth

Time zone: Eastern Standard Time

Winter Solstice day length: 8.7 hrs

Summer Solstice day length: 15.5 hrs.

Solar Path

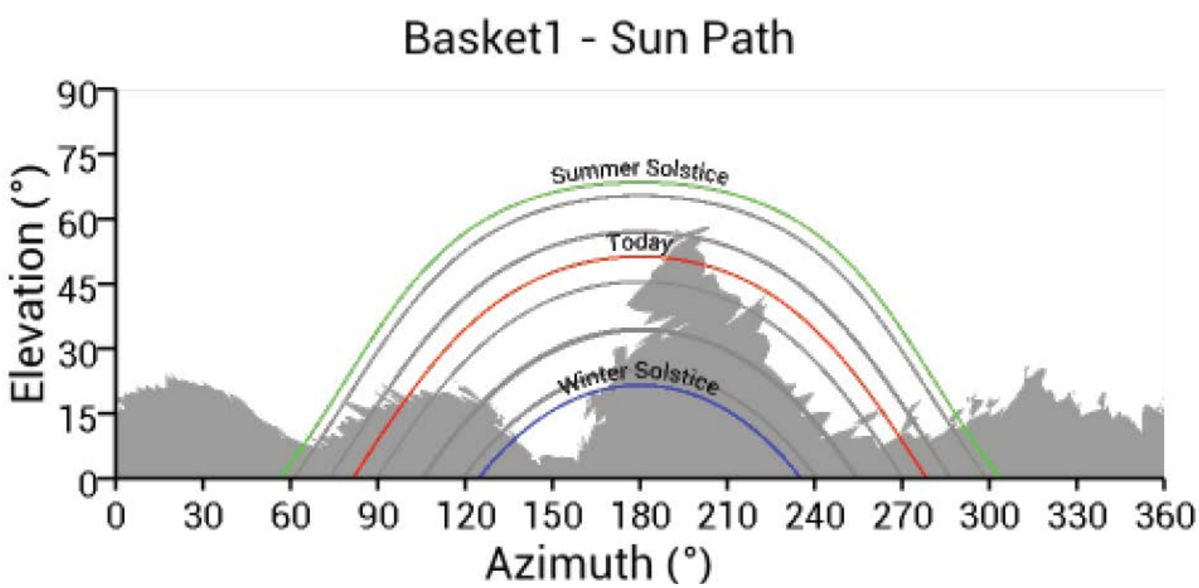

Figure F-5. Basketville 1—Sun path

Shading Losses

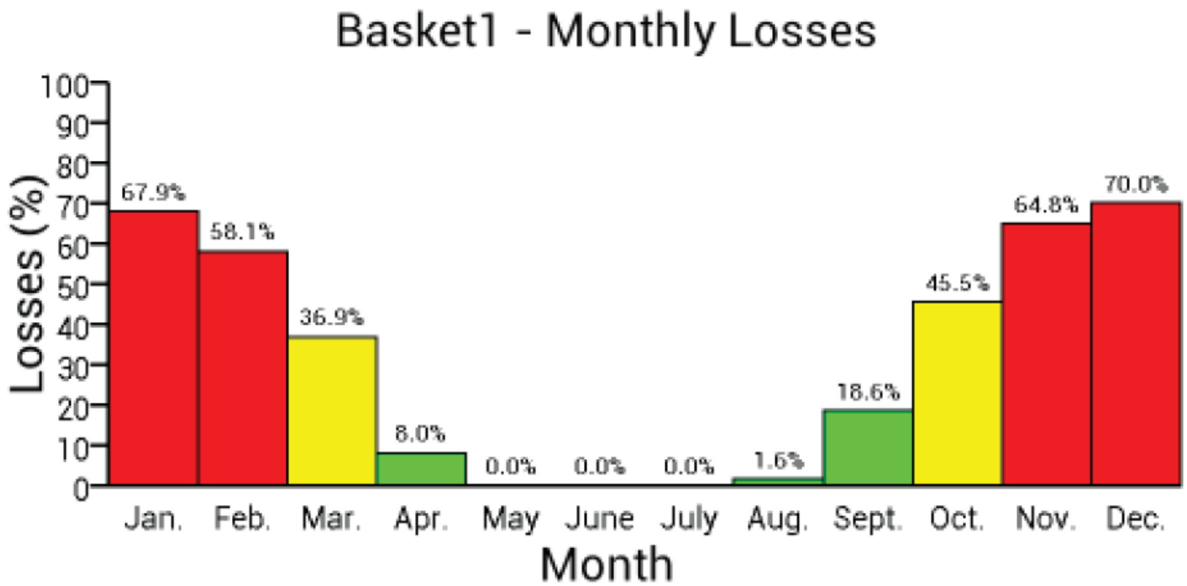

Figure F-6. Basketville 1—Monthly losses

The total yearly sun hour losses are 27.56% due to shading.

System Output Results

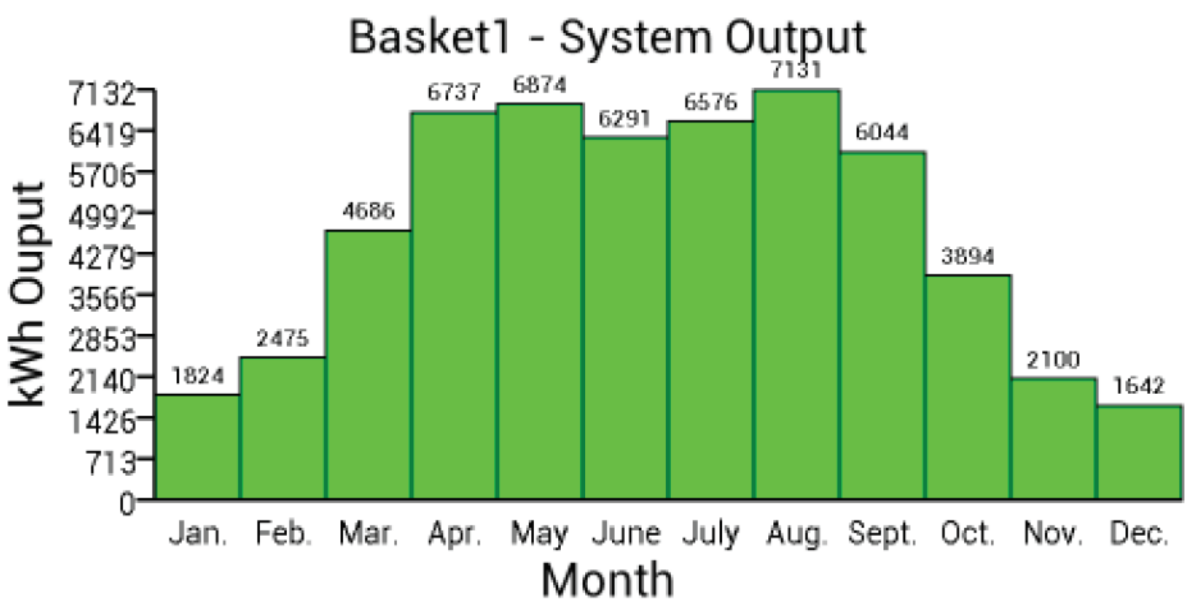

Figure F-7. Basketville 1—System output

Total System Output

The total estimated system output of this location is 56,273 kWh/yr. Without shading there is a total possible output of 79,466 kWh/yr. This location will lose 23,193 kWh/yr or 29.1% due to shading.

Analyzing the Results

The solar path graph illustrates the path of the sun; 180 degrees is due south and 0, 360 degrees is due north. The shading losses chart illustrates the percentage of monthly hours lost due to shading in respect to the total possible hours over the horizon. These two graphics should be used in conjunction with each other. There might be significant hours lost in the morning or late afternoon; however, this does not necessarily mean the location is not conducive to solar power.

Analysis of South Section

Location Description

GPS coordinates: 42.97868 latitude, -72.521706 longitude, 49.4 altitude

System parameters: Fixed-axis, 55.0 kW at 30.0-degree tilt and 180.0-degree azimuth

Time zone: Eastern Standard Time

Winter Solstice day length: 8.9 hrs

Summer Solstice day length: 15.3 hrs.

Solar Path

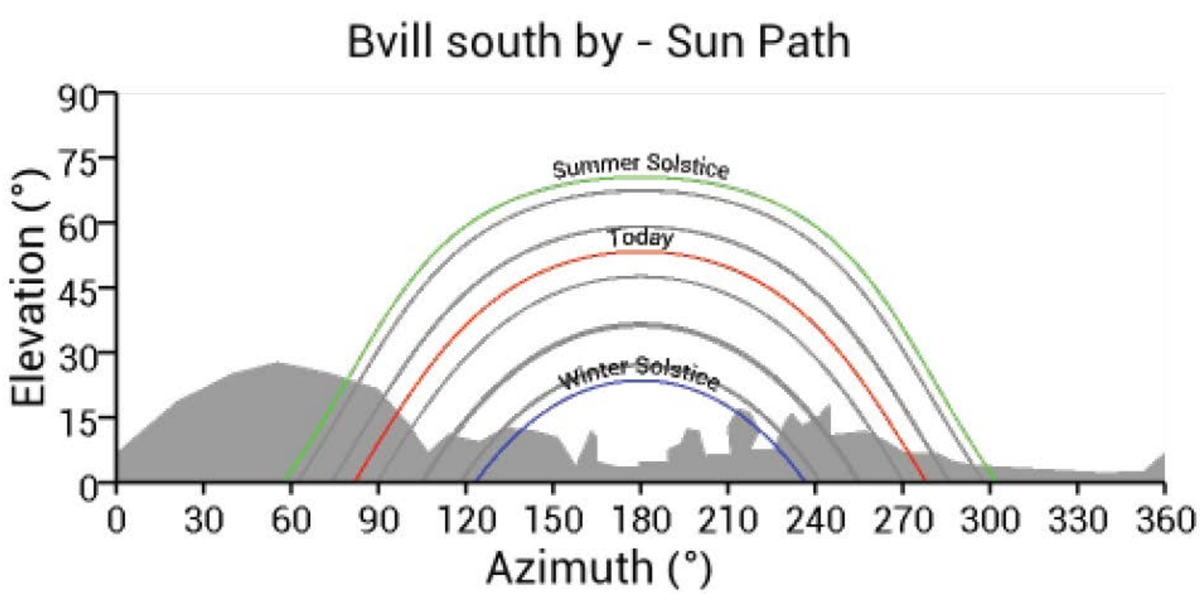

Figure F-8. Basketville South—Sun path

Shading Losses

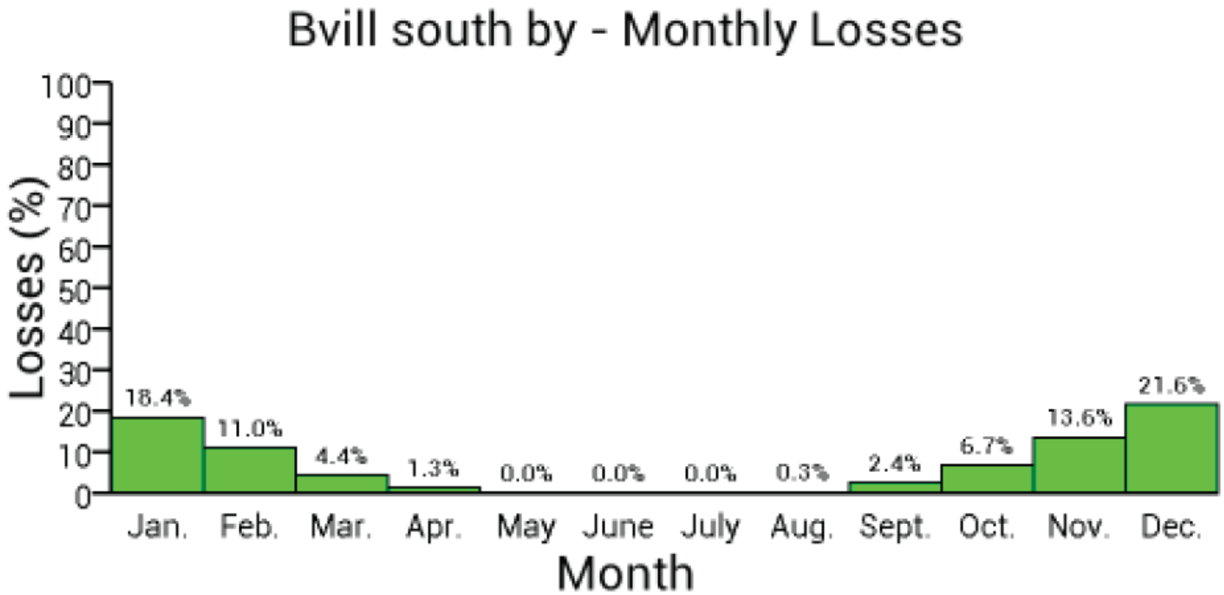

Figure F-9. Basketville South—Monthly shading losses

The total yearly sun hour losses are 5.86% due to shading.

System Output Results

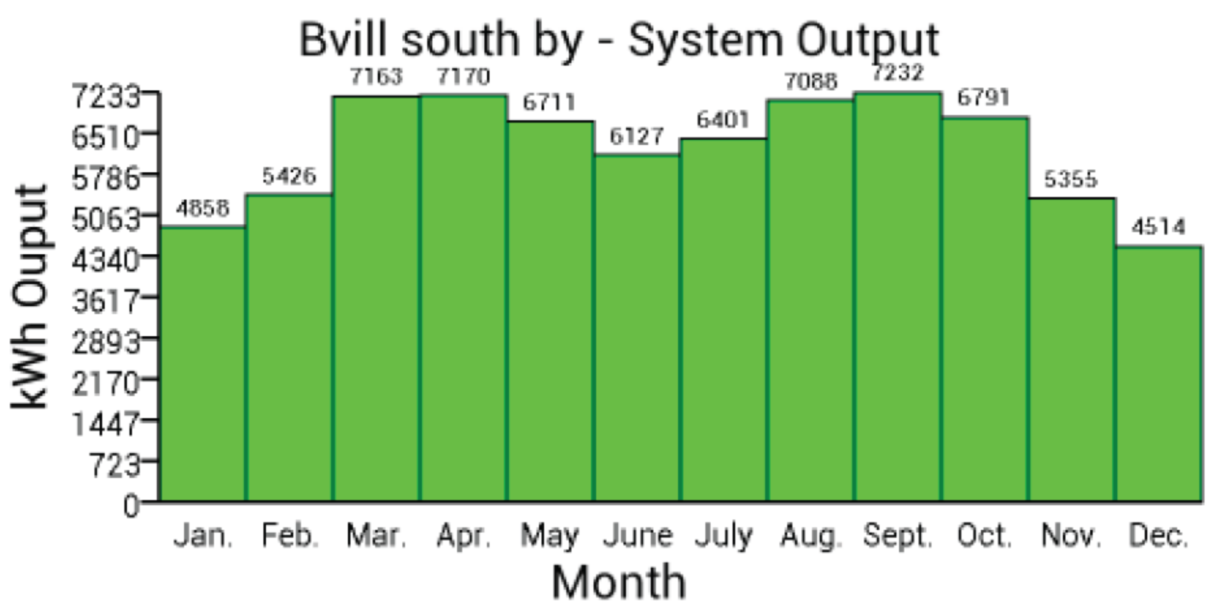

Figure F-10. Basketville South—System output

Total System Output

The total estimated system output of this location is 74,836 kWh/yr. Without shading there is a total possible output of 79,968.2 kWh/yr. This location will lose 5,132 kWh/yr or 6.4% due to shading.

Analyzing the Results

These graphs were created with a smartphone device, using one fixed angle, not multiple angles, so real-world results might vary depending on the type of mounting system used and if the array is adjustable.

The solar path graph illustrates the path of the sun; 180 degrees is due south and 0, 360 degrees is due north. The shading losses chart illustrates the percentage of monthly hours lost due to shading in respect to the total possible hours over the horizon. These two graphics should be used in conjunction with each other. There may be significant hours lost in the morning or late afternoon; however, this does not necessarily mean the location is not conducive to solar power.