Grass Energy in Vermont and the Northeast

Prepared by:

Wilson Engineering
902 Market Street
Meadville, PA 16335
Office: (814) 337-8223

For:

Vermont Sustainable Jobs Fund

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Executive Summary **3**

Background **8**

Vermont Grass Energy Partnership 8

Purpose and Objectives 9

Benefits of Grass Energy **11**

Lower Fuel Costs 11

Improved Economic and Energy Security 12

Reduced Carbon Emissions 12

Increased Productivity on Marginal Lands 13

Riparian Buffer Strips and Highly Erodible Lands 13

Models for A Thermal Grass Energy Economy **15**

Closed Loop No Processing Model 16

Regional Processing Model 17

The Consumer Pellet Market Model 18

Small-Scale On-Farm Processing 19

In Summary 20

Grass Energy Crop Production **21**

Giant Miscanthus General Profile 22

Switchgrass General Profile 24

In Summary 26

Processing/Densification **27**

Bales, Pellets, Briquettes, and Cubes 27

Pellets 28

Cubes 31

Thermal Combustion Equipment **32**

Pellet Appliances for the Consumer Market 32

Institutional/Commercial Scale Boilers 33

Emissions from Combustion 34

Mineral Content 36
Alternative Markets for Grass Energy Crop 37
Fiber Source 37
Animal Bedding 37
Compost 38
Resin 38
Soil Filter 38
Noise and Odor Filter 39
Absorbent Markets 39
Dairy Rations 39
Conservation Plants 40
Wildlife Habitat 40
Recommendations for Designing a Robust Grass Energy Program in Vermont 41
Pilot Demonstration Projects 42
Conclusions 48
References 51
Appendix A 54
Correspondence from Paul Patterson 54
Appendix B 56
Switchgrass Budget for Biomass Production 56

EXECUTIVE SUMMARY

The Vermont Grass Energy Partnership has been exploring the potential of harvesting grass crops grown on marginal farmland to offset fossil fuels used in thermal applications. The purpose of this report is to explore whether grass thermal energy can be a viable industry in Vermont. The task included reviewing publications, interviewing people involved in developing aspects of the industry, summarizing the current state of the industry, identifying models for successful projects, and recommending the next steps for moving the industry forward.

The benefits of developing grass energy include: supporting local economic development by providing a profitable market for crops grown on marginal land, reduced energy cost compared to oil and propane, increased energy independence and security by replacing imported oil with locally grown renewable energy, and environmental benefits, like reduced net carbon dioxide (CO_2) emissions (versus oil and propane) and reduction in erosion and nutrient runoff from a permanent crop on marginal acres and in riparian buffer zones.

Virtually all grass or agricultural residues have significant energy content and have been investigated for thermal energy use. In the Scandinavian countries there are district energy systems that use wheat straw as the main fuel. Agricultural residues such as corn stubble generally have higher ash content than grasses due to large amounts of soil being harvested with the residue and therefore are not as desirable for thermal applications as dedicated grass energy crops. At today's market values however, grass crops have uses in addition to thermal energy such as mulch, bedding, or other fiber sources that can be considerably higher in value than thermal energy value. As fossil fuel price continues to escalate, markets for grasses will shift to favor thermal energy.

1. Switchgrass pellets. Shelburne, Vermont, 2011.

Dedicated grass energy crops such as giant miscanthus, switchgrass, and reed canarygrass have higher yields and minimal inputs compared to other species of grasses. Of these crops, switchgrass and giant miscanthus are considered to be the better choices due to higher energy value and lower ash content. There has been a lot of research and much is known about switchgrass and to a lesser extent giant miscanthus. These perennial crops, once established, can be productive for 10 to 20 years or longer, and will grow on marginal soils and require minimal inputs to be productive. Work throughout the Northeast and in Vermont suggests that, for grass energy to be a profitable crop for the farmer, yields need to approach 4.5 tons per acre with farm gate prices at $80 per ton.

There are four models for grass energy projects in the Northeast:

- **Closed Loop No Processing :** The crop is grown on local acres, baled and stored at the site, and burned with minimal processing in combustion equipment that can handle large round or square bales. Potential sites with adequate thermal loads for a practical project could include college campuses with district heating systems, hospitals, office complexes, prisons, or large commercial facilities.
- **Small Scale On-Farm Processing:** As is the case with Closed Loop No Processing, the crop is grown on local acres and baled and stored on-site. A small stationary or mobile pelletizer is used to process grass bales into pellets, cubes or briquettes. The grower can use the fuel on-site or sell it to local markets. The difference between this model and Closed Loop No Processing is the further step of processing bales into densified fuel. Versions of this model that have been investigated include: a small-scale on-site pelleting operation, two mobile pelleting operations that travel to farms to process grass feedstock, small-scale on-farm briquetting and a moderately sized mobile briquetter.
- **Regional Processing:** A central processing plant would purchase baled hay from local farmers, and then grind, dry and densify the grass into cubes, briquettes, or pellets and deliver fuel to multiple commercial or institutional thermal installations. In this model, cubes or briquettes may have an advantage over pellets due to lower processing costs including energy input. Processing and furnace installations would have to be developed concurrently with equipment designed to match the form of the fuel.
- **Consumer Pellet Market:** A central processing plant would produce a standardized pellet for use in installed pellet stoves, furnaces and boilers. While there are currently pellet stoves available and in development that can handle the higher ash volume from grass fuels, installation of these stoves has been limited thus far, and generally there is increased labor and maintenance compared to wood pellets.

Of the models above, Small Scale On-Farm Processing has the greatest challenges due to the complexity of the process and the overall inefficiencies of densifying grass energy on a small scale. While briquetting and cubing require less processing than pellets, it still will be hard to justify the investments in drying, processing and densifying without economies of scale.

There are several barriers that make it unlikely that grass pellets will gain widespread acceptance in the consumer pellet fuel market without a significant price advantage over wood, which does not currently exist. These barriers are: significantly higher ash content compared to wood, clinkering (the fusion of ash into hard chunks) caused by lower ash fusion temperatures, lower heat energy content of grass compared to wood, and increased processing costs in producing a grass pellet compared to wood pellets due to increased wear on processing equipment. There has been some investigation and interest in marketing a grass/wood pellet blend to gain wider consumer acceptance; however this would have to have a clear price advantage to the pellet fuel manufacturer, which may not be attainable, to gain consumer acceptance.

The model that would be the easiest to implement with minimal incentives is the Closed Loop No Processing model, where minimal investment is required in harvesting and processing. Standard haymaking equipment can be employed to harvest the same or similar grass for fuel. Systems are commercially available that can accept large round or square bales and automatically deliver them to the furnace. In this scenario, grass energy can compete favorably with wood on an energy content basis (cost per Btu), due to reduced hauling, processing and storage costs.

The Regional Processing model, which matches specific thermal installations to processing capacity, would also make sense for Vermont. However, important considerations are the significant investment in both processing equipment and end use installations, and a high level of coordination to accomplish this. It would also require a public commitment to monetizing all of the environmental benefits of grass energy, including renewable energy and watershed improvement, to be sustainable.

Equipment has been developed or adapted and tested for all scales of grass thermal combustion. Pellet stoves, furnaces and boilers from multiple manufacturers have been tested by Cornell University (forages.org/index.php/grass-biofuels/research/demonstrations) and rated for emissions and ash handling characteristics. In general, the stoves that performed best are capable of multiple combustion settings and have aggressive ash handling characteristics. The Scandinavian countries have led the way in development of mid-sized boilers capable of direct delivery of whole bales and automated ash handling. Both domestic and international commercial and industrial boilers are available for installation. These boilers have moving grates to deal with the ash and automated system controls, with flue gas sensors for fine tuning the combustion process.

Boiler emissions from combustion of grass energy crops when compared to wood are generally higher in particulate matter (PM), oxides of sulfur (SO_x,) and oxides of nitrogen (NO_x) due to the mineral composition of the fuel. Additional concerns in grass combustion are the alkali metals, chlorine, and potassium that, when combined with silica, can form corrosive deposits and gases on boilers and furnaces. By managing soil conditions and harvesting methods, the quantity and composition of the ash content of grasses can be somewhat controlled during growth to minimize impacts. In larger boilers where emissions controls are required (> 3.0 million Btu per hour input), PM emissions can be mitigated; however when compared to wood, added costs are associated with burning grasses.

For grass thermal energy to be viable as an industry in Vermont, additional value or incentives need to be established to overcome inherent barriers for use. These incentives could be in the form of portfolio standards for utilities to carve out a portion of the Renewable Energy Credits for renewable thermal projects, and incentives for planting and establishing grass energy crops. Vermont has a significant environmental problem that may provide the ideal vehicle to establish grass energy crops and incentivize the planting and use for thermal energy: managing nutrient runoff from agricultural activities into Lake Champlain. Switchgrass and other perennial grasses are recommended crops on highly erodible soils and for riparian buffer zones around waterways. In addition to reducing runoff, these crops act as bio-filters that trap sediment and take up significant quantities of phosphorus and nitrogen. If these acres are harvested and used for thermal applications, significant quantities of nutrients will be removed and concentrated in the ash and diverted from the watershed.

To move grass energy forward, support of two avenues seem the most promising. The first would be a project to demonstrate the **Closed Loop No Processing** model. The thermal energy load should be substantial enough to justify the investment in combustion equipment, establish the grass energy crop, and provide operating savings that will ensure funds for maintaining the system over time.

The second and more promising approach for a larger-scale sustainable impact would be to pursue a **Regional Processing** model demonstration based around Lake Champlain nutrient reduction. Incentives would need to be offered to induce farmers to make changes in agricultural practices. This model requires establishing a regional processing plant that would receive and process grass harvested from buffer zone plantings and deliver this fuel to a large- to mid-sized biomass energy system, thereby supplying institutional or industrial thermal loads in the lake region. While this approach would require considerable work to develop, it is likely to have a much greater opportunity for moving grass thermal energy forward in Vermont as well as having a positive economic and environmental impact.

There are a core group of stakeholders committed to implementing grass thermal energy in Vermont and the Northeast. These include public and private economic and environmental agencies, farmers, equipment providers, and end users. To be sustainable, overcome market barriers and provide a significant economic and environmental contribution to Vermont, grass energy must provide enough benefits to create multiple profitable enterprises. This will require a focused public and private commitment to demonstrate successful models and carve out incentives to achieve public goals.

BACKGROUND

Vermont Grass Energy Partnership

Since 2008, Vermont Sustainable Jobs Fund (VSJF) has been exploring the potential for perennial grasses grown in Vermont to meet a portion of the state's heating demand and reduce the consumption of non-renewable fossil fuels. The Vermont Sustainable Jobs Fund teamed up with the University of Vermont (UVM) Plant & Soil Science Department and the Biomass Energy Resource Center (BERC) to form the Vermont Grass Energy Partnership in an effort to explore the potential for grass energy in Vermont. Early stage agronomic research from Cornell University, REAP Canada, and businesses like Ernst Biomass, Show-Me-Energy Co-op, and others encouraged the formation of the Vermont Grass Energy Partnership. This partnership, along with other public and private sector collaborators, is working to identify challenges in the bioenergy supply chain (from field to end energy use), and develop possible solutions to those challenges.

The Partnership has been investigating agricultural best practices for high-biomass producing perennial grasses, densification of grass and grass/wood blends, and testing the performance and emissions of grass pellet fuels in high-efficiency biomass heating systems. The results of this multiphase analysis led to recommendations on how best to cultivate and utilize grass energy in Vermont and the Northeast region. The partnership has helped fund pilot and demonstration projects for fuel densification and combustion equipment, by collaborating on a technical assessment of grass pellets for boiler fuel (www.biomasscenter.org/images/stories/grasspelletrpt_0111.pdf) and funding a private enterprise, Renewable Energy Resources, to develop a mobile on-farm briquetter.

The Grass Energy Partnership considers its effort essential to developing markets in order to provide an opportunity for agriculture to contribute to the overall energy demand in the state and the region. The State of Vermont has a goal of 90% reduction in greenhouse gas emissions by 2050, and bioenergy is part of the renewable energy and efficiency mix needed to meet that target. The goal of the Grass Energy Partnership is to establish a market value for energy crops that will allow marginally productive or abandoned farm land to become more productive, and will help to meet the state's renewable energy goals. There is already a sizeable area of pre-existing reed canarygrass, and some growers and processors are establishing high-yielding warm season biomass crops like switchgrass and big bluestem in Vermont. To-date, however, there are few acres under cultivation to support the commercialization of grass energy.

2. Switchgrass field at Meach Cove Farm, Shelburne, Vermont, 2012.

Grass grows well in Vermont and the region. The equipment for growing, harvesting and storing grasses already exists in abundance in the state. Perennial grasses can be grown on marginal lands not well suited for continuous row crop production and/or in open rural land currently not in agricultural production. Because these perennial crops are harvested annually they can help level demand for forest biomass, which is increasing, while adding important water quality and wildlife benefits by controlling erosion, reducing fertilizer use and providing cover and food for migrating and nesting birds. In addition, more marginal land in perennial grasses means greater amounts of sequestered carbon in the root systems and soil.

Grass biomass could make a sizeable contribution to the state's heating needs over time. In addition to new commercial entrepreneurial activity, grass energy production and processing has the potential to create opportunities for farmers and other landowners to produce fuel for their own heating or small scale processing, or marketing the fuel as a value added crop.

Purpose and Objectives

As a result of the Vermont Grass Energy Partnership and a number of other projects in the region, there is an existing body of knowledge on growing, processing, and using grass for energy. However, this opportunity has not fully developed into a marketable option for growers, landowners, fuel processors and dealers, equipment manufacturers and vendors, nor homeowners or communities. There are still some uncertainties around the viability of using grass for energy, and as a result some are hesitant to move forward with grass energy plantations or system installations that will support grass combustion.

This state-of-the-science review was undertaken to assess the current state of knowledge and identify the remaining critical questions that need to be answered in order to commercialize this opportunity. Through literature reviews and interviews, information was collected to answer three key classes of questions:

1. What is the current state of the science and technology regarding grass fuel processing logistics, combustion and use in the Northeast? What do we know? What can we apply from neighboring states and eastern Canada?
2. What can we learn from businesses and other early adopters that are currently producing and/or using grass fuels for space heating in the Northeast region? How are these systems being financed? If they're producers, what are the barriers to market entry? How are these barriers being overcome? If they're heating with grass fuels, what costs did they incur and is the system meeting expectations?
3. What remaining work needs to be done to move grass energy to commercialization in the Northeast, generally, and specifically in Vermont? What are the critical next steps, gaps in knowledge or technology, and/or missing links in the supply chain (from field to flue)?

The results of this work will contribute to the Grass Energy Partnership's strategic planning of next steps for the grass energy program.

BENEFITS OF GRASS ENERGY

Locally produced biofuels can provide benefits to the local economy and environment. The key to establishing a grass energy economy is to identify and capitalize on all of these benefits. The economic and environmental benefits that can be achieved by using grasses to offset fossil fuels for thermal applications include:

- Lower fuel costs
- Improved economic and energy security
- Reduced carbon emissions by offsetting fossil fuels and soil sequestration
- Grass energy crops acting as riparian buffers to reduce and remove nutrients from watersheds
- Grass energy crops acting to reduce erosion and nutrient runoff on highly erodible soils
- Allowing land marginally suited for traditional crops to be more productive

Lower Fuel Costs

Grass fuel has significantly lower energy costs compared to oil or propane, and is competitive with wood fuel in energy costs. Grass and wood energy content on a dry basis can vary by species and portion of the plant harvested by as much 15%, and generally grass energy content is slightly lower than wood energy. The exception is switchgrass, which is competitive with wood in energy content.[26,33] Table 1 used standard values for high heat value for fuels published by the Greenhouse Gases Regulated Emissions, and Energy Use in Transportation Model (GREET), adjusted for moisture content.

Table 1: Net Fuel Costs Comparison

	Price per Unit	Units	Energy Content (1) HHV mmBtu per unit	Moisture Content (wet basis)	(3) Net Conversion Efficiency	Net Cost Per mmBtu
(4)Grass Bales	$110	ton	12.778	18%	77%	$11.18
(2) Wood Chips	$65	ton	10.622	40%	69%	$8.81
Natural Gas	$7	Mcf	1.089	-	77%	$8.38
Grass Pellets	$200	ton	14.336	8%	78%	$17.79
Wood Pellets	$230	ton	16.287	8%	79%	$17.83
Propane	$2.10	gallon	0.091	-	78%	$29.32
#2 Fuel Oil	$3.50	gallon	0.138	-	79%	$31.80

(1) HHV source of values GREET (The Greenhouse Gases Regulated Emissions, and Energy Use in Transportation Model) adjusted for moisture content
(2) Assumes Wood Chips and Wood Pellets derived from Bole Wood
(3) Combustion efficiency based HHV of fuel & combined combustion & heat transfer efficiency of 0.85 for all fuels except wet wood chips which uses combined combustion & heat transfer efficiency of 0.80
(4) Assumes grass bales are $80 per ton at farm gate & $30 per ton transportation costs

Improved Economic and Energy Security

Because Vermont imports all petroleum and natural gas derived products consumed in the state,[31] using locally-produced fuel like grass energy to replace fossil fuels in thermal applications keeps dollars spent on energy in the state. Local investment and labor are employed in the growing, harvesting, processing and delivery, stimulating economic activity. Added price stability can be achieved, as supply chains for locally produced energy are less likely to be affected by international events.

Reduced Carbon Emissions

In a peer reviewed report, researchers found that replacing fossil fuel with grass thermal energy significantly reduces CO_2 emissions.[32] Reduction of greenhouse gas emissions by substituting switchgrass pellets for fuel oil and natural gas would result in 66.2 kg CO_2 equivalent per GJ (or 153.9 pounds per million Btu) and 71.5 kg CO_2e (or 166.2 pounds per million Btu), respectively.[32] Additional CO_2 offset is achieved over time by the buildup of carbon in the soil from switchgrass. In a study conducted by the USDA Agricultural Research Service (USDA-ARS), the buildup of soil organic carbon (SOC) had an annual average increase that exceeded 2 Mg per year over a 9 year period, equating to 7.3 Mg per hectare (or 2.95 Mg per acre) per year of CO_2e being sequestered.[16]

Increased Productivity on Marginal Lands

Switchgrass or giant miscanthus can be productive on land that is marginal for traditional row crop production. This can include land that was formally in pasture when there was more livestock farming and use of pasture in Vermont. These are acres that are not suited to row crop production due to drainage, rocks or shallow soils, and have been taken over by weeds such as goldenrod and thistle. While they may be harvested occasionally for hay crop or annually brush-hogged to remove woody plants, yields are marginal with little nutritional value as hay. Once established, switchgrass and giant miscanthus take minimal inputs to remain productive and their deep root structure and aggressive spreading from rhizomes tend to crowd out weeds and build soil organic matter.

Riparian Buffer Strips and Highly Erodible Lands

Incorporating grass energy into riparian buffers can provide multiple benefits in the Lake Champlain watershed, where agricultural activities contribute significantly to nonpoint source nutrient loading. Nutrient loading of Phosphorus (P) and Nitrogen (N) from dairy manure and chemical fertilizers applied to agricultural fields contribute to high nutrient loads in Lake Champlain watershed. Riparian buffer strips have a proven track record of intercepting nutrient flows from agricultural non-point source pollution of waterways.

Benefits that that can be achieved with grass energy include: providing permanent cover on highly erodible lands and removal of nutrients to reduce and clean up run-off from farms and developed landscapes. Switchgrass is highly effective in removing phosphorus, a very damaging nonpoint source pollutant in agricultural areas. This crop has been show to remove as much as 95 percent of the sediment, 80 percent of the total nitrogen, and 78 percent of the total phosphorus from the soil.[20] This uptake of nutrients by the plant provides a method of removing excess minerals from a watershed when the crop is harvested and the ash concentrated by combustion. The harvested biomass could be used for energy or an array of alternative uses.

Research in Vermont reported that warm season grasses remove on average 44 pounds of nitrogen and 6 to 36 pounds of P_2O_5 per acre per year. Removal rates varied by yield, variety, time of harvest and location. Work done by USDA-ARS in Lincoln, Nebraska compared nutrient removal rates for switchgrass at 5 locations with 6 varieties at each location.[13] Removal rates for phosphorous varied from 1,297 to 6,445 mg per kg (or 588 to 2,923 mg per pound) of crop harvested with total phosphorous content typically 0.004 percent of total dry matter of harvested switchgrass.

Current Vermont agricultural rules for medium and large farms (greater than 200 animals) require a 25' permanent cover buffer strip along waterways. In a study by Lee et al., buffer strips expanded from 23' to 53.5' can reduce total maximum daily load, (TMDL) of phosphorous and nitrogen an additional 20 percent.[20] The wider strips also performed significantly better (>100%) in higher rainfall events.[20] The nutrient flows are removed both from overland flows of nutrients and ground water flows of nutrients.

To prevent nutrient loading of the tributaries that lead to Lake Champlain, Vermont has developed an incentive program called VABP (Vermont Agriculture Buffer Program). The program offers a 5 year rental contract for the installation of conservation grassed buffers on crop land. Unlike CREP, VABP consists of planting harvestable grassed buffers. Payments of $123 per acre to cover the establishment cost of new buffers, plus an additional annual incentive payment of $90 - $150 per acre/per year are made to the farmers. The grasses are allowed to be harvested between June 1 and September 1.

3. Baling switchgrass at Meach Cove Farm, Shelburne, Vermont, 2012.

MODELS FOR A THERMAL GRASS ENERGY ECONOMY

Models for implementing grass energy projects include: Closed Loop No Processing, Regional Processing, Consumer Pellet Market and Small-Scale On-Farm Processing. **Closed Loop No Processing** is implemented at a specific site with fuel being handled in bales and without any additional processing, such as chopping or pelletizing. **Regional Processing** requires multiple installations or a large single user, and would be designed to match the fuel handling of the combustion appliances with either briquettes or cubes, with grass energy acquired from multiple growers in the region. **Consumer Pellet Market** produces a standard pellet that would be used in pellet combustion systems installed in residential, institutional, and small commercial settings. **Small-Scale On-Farm Processing** combines growing and processing to produce pellets, briquettes or cubes on the farm in either a stationary mill or a mobile mill that travels to individual farms; the fuel can be used on-site or sold to a limited local market**.** Table 2 summarizes characteristics of each model.

Table 2. Grass Energy Models

Model / Characteristic	Closed-Loop no Processing	Regional Processing	Consumer Pellet Market	Small Scale on Farm Processing
Grass Location	On-site or nearby farms	< 50 mile radius of processing	< 50 mile Radius of processing	On-site or nearby farms
Finished Fuel Form	Bales	Cubes or Briquettes	Standard Pellets	Pellets, Cubes or Briquettes
Typical Furnace Technology and Scale	Whole bale feeder & (automatic and manual are available) size >150 kW	Automatic fuel and ash handling, furnaces match type of fuel processing Size >500 kW	Pellet furnaces and Boilers with positive ash handling. size <100 kW	Appliances match the fuel type with automatic fuel feed and ash handling
Facility Type	Institutions, Small Commercial, District Heat	Institutions, medium to large scale installations	Homes, businesses and small commercial	Scale matches fuel type and furnace technology

Closed Loop No Processing Model

For the Closed Loop No Processing model, the crop is grown on or near the use site, is harvested and stored as large square or round bales, and burned in appliances that can accept whole bales without additional processing. The advantages of this model are minimal processing, fewer equipment needs and costs, lowest cost fuel, and maximum CO_2 offset of any of the grass energy models due to reduced processing of the fuel.[32] There is minimal investment required on the fuel production and handling side as traditional agriculture equipment can be used to establish energy crops on marginal acres on-site or on nearby farms under contract. Standard agricultural equipment can be used to harvest and handle the crop, providing the farmer or landowner additional income, or energy savings without requiring a large capital investment. Once projects are identified and funding is in place, establishment of grass energy crops and installation of the biomass combustion systems can be implemented on a parallel track. The disadvantage of using whole bales is that they are bulky and have low energy density compared to pellets, briquettes, or cubes. This requires additional room for storage of material, more labor for fuel handling, and provides habitat for attracting rodents in an institutional setting.

Combustion appliances that can handle whole bales, with either automatic or manual feeding, are commercially available. A partial list of manufacturers that have advertised the ability to utilize baled feedstock includes Axe Biotech (www.axebiotech.ie/), DP Cleantech (www.dpcleantech.com/), Innovaat (www.innovaat.com/), Limes Innovation, LIN-KA (www.linka.dk/), Skanden (www.skanden.com/), and Skelhoje Maskinfabrik. Efficiencies, levels of automation, capital costs, and operating costs vary depending on the manufacturer, equipment, and project application.

Combustion appliances generally range in size from 150 to 1,000 kW (or 0.5 to 3.5 MMBtu per hour, heat input). These system sizes are suited for small institutional to industrial scale installations. Potential sites with adequate thermal loads for a practical project could include college campuses with district heating systems, hospitals, office complexes, prisons, chicken houses or process loads such as grain drying. District heating installations using agricultural residues have operated for over 20 years in Scandinavian countries. In general, automated appliances have a conveyor system onto which multiple bales are placed. Bales then travel to a pre-processing chamber before being fed into the combustion chamber. Grass-burning combustion systems generally have a moving grate for handling ash. Another style of whole bale-appliance relies on manually placing individual bales in the combustion chamber. As the fuel feed rate cannot be varied with this type of system, it is usually accompanied by large thermal storage that will allow the appliance to burn at a constant rate and store any energy that exceeds demand. This thermal storage enables the combustion appliance to burn more efficiently and reduces carbon monoxide (CO) and particulate matter (PM) emissions that are the result of starving the combustion process of oxygen to control heat output.

Regional Processing Model

The regional processing model requires multiple commercial or institutional thermal installations and a fuel processing site for grass drying and densification. Using traditional equipment for establishment and harvest, farmers would be contracted to grow grass and deliver bales to the regional processer. The bales can be stored by the farmers and delivered as needed to the processor or stored at the processing site. In this model, as demand and processing are developed simultaneously, the plant can produce cubes or briquettes to match the fuel handling capabilities of the combustion unit installations. The advantage of producing cubes or briquettes compared to pellets is that less energy is required in size reduction and extrusion of the fuel, thereby lowering overall production costs. Densification costs for briquettes compared to pellets and cubes compared pellets are reduced by $47 and $50 per metric ton (or $43 and $45 per US ton), respectively, over the pelleting cost of $107 per metric ton (or $97 per US ton).[32]

Challenges for the Regional Processing model are the large investment required for installation of biomass combustion units and the processing plant, and to establish grass energy crop acres. All of these projects would have to occur simultaneously. While there are some institutional sized biomass boilers installed in Vermont, most of these systems, from fuel and ash handling to emissions equipment, are designed for wood chips and wood pellets. These installations are generally stoker type systems with manual ash handling where buildup of ash and clinkers on the grate would cause additional labor and maintenance.

One way to implement the Regional Processing model in Vermont would be to develop regional processing and commercial installations in conjunction with a program to incentivize establishment of grass energy crops as riparian buffer zones to reduce watershed nutrient loading. The Regional Processing model could provide enough demand to allow establishment of significant areas of riparian buffer zones. This would allow grass energy to monetize the additional benefits to the environment in addition to fuel cost savings. Another scenario to implement this model could be the development of alternative markets for densified grass products and allow thermal grass energy projects to develop over time. These alternative markets would allow the processing plant to achieve economies of scale to spread capital and labor costs over higher volumes of sales.

The Consumer Pellet Market Model

The Consumer Pellet Market model would build a processing plant to produce a standardized pellet. This regional processing plant would contract with farmers within a radius of less than 50 miles, who would grow and harvest the crop for delivery to the plant. This model would rely on substituting grass pellets for wood pellets in installed pellet appliances competing directly with wood pellets for consumer sales. Grass pellets would not meet the ash content to qualify as premium grade pellets (i.e., less than 1% ash). Blends of wood and grass pellets could qualify as standard grade pellets (less than 2% ash) while straight grass pellets would be classified as utility grade pellets (less than 6% ash). In the home heating market in the Northeast nearly all pellets being marketed are sold as premium pellets.

Published data for discounts of lower grade pellets does not seem to be available. Bob Miller of Enviro Energy, LLC (www.enviroenergyny.com/), in Unadilla, New York, is marketing a limited quantity of grass pellets for heating, and estimates the discount of these sales over premium wood pellets is $25 to $35 per ton. Chris Haley of Squier Lumber and Hardware Inc. (www.squierlumber.com/), in Munson, Massachusetts, who markets significant quantities and multiple brands of bagged pellets, said, based on past experience in marketing off brand pellets to the consumer market, that to sell significant quantities of grass pellets would require a discount of $70 to $85 per ton, compared to wood pellets. Haley believes that there would be a smaller market at a somewhat lower discount based on perceived value, and stated that there is some brand loyalty and consumers who are using 2 tons per year are not likely to purchase a lower quality to save $60 per year. While there are pellet stoves currently available and in development that can handle the clinkers and ash resulting from burning grass pellets, installations are limited. Additional barriers for grass pellets to compete with wood pellets in the consumer market include increased quantity of ash for removal and disposal, more frequent cleaning of the flue and heat exchanger surfaces due to alkali mineral deposits, and increased PM emissions, each a result of the increased quantity and composition of ash from grass pellets compared to wood.

One intermediary product that has been investigated by the Vermont Grass Energy Partnership is grass-wood pellet blends. A 2009 study included blending up to 25% grass with wood to produce a mixed pellet with lower ash and less clinker formation than a straight grass pellet that would be more suitable for the consumer market and technology current commercially available.[33] There are significant challenges at the processing plant to processing and mixing grasses and wood into pellets in a plant designed to produce wood pellets.[33] A more practical method of producing a grass/wood pellet fuel mix may be to blend grass pellets with wood pellets in the ratio desired, though this has not been tested at this time.

The challenges of inferior fuel quality and limited installations of appliances that can effectively handle the increased ash, make the Consumer Market Pellet model unlikely to be successful in the current market scenario. If wood pellet supplies were to tighten significantly and petro-fuel prices were to escalate significantly, the consumer market may be an option in the future. At that time, appropriate technology would need to become established in the market-place and the barriers to utilization of grass fuel would need to be overcome.

Small-Scale On-Farm Processing

In the Small-Scale On-Farm Processing model, farmers use conventional equipment to establish and harvest the crop, storing it in baled form. Four approaches have been pursued for small-scale on-farm densification in the Northeast.

Vermont Technical College has acquired a small mobile pellet mill through grant funding. This unit has been used as part of an educational research program and successfully produced pellets at the rate of 300 to 500 pounds per hour. The pellets are being test-burned in an on-campus wood pellet boiler, where students will measure combustion efficiency and emissions. [27]

Two versions of the portable pellet mill have been funded by grant dollars and technical assistance from USDA-NRCS in New York and Pennsylvania. In New York, the Hudson Valley Grass Energy Partnership has developed a mobile pellet mill that is being used for demonstrations and to produce pellets on area farms on a limited scale. Capacities up to 1.5 tons per hour have been achieved. The Pennsylvania portable pellet mill is smaller in scale than the New York model and both are still in the stage of testing and development.[28]

Meach Cove Farms is working with Renewable Energy Resources, LLC to install an on-farm briquetting machine at their facility in Shelburne, Vermont to process switchgrass and giant miscanthus grown on the farm for thermal energy use.[12] The facility is installing a multi-fuel boiler that is capable of burning grass or wood pellets or briquettes. RER is also developing a mobile briquetter for use on farms with support from Vermont Sustainable Jobs Fund.

While this model is in practice in Vermont, there are significant challenges to on-farm processing, like steep overhead and labor costs because it is hard to achieve any economy of scale. There is also a significant learning curve to achieve efficient rates of production.

In Summary

The models presented here that appear to be the most promising to pursue for Vermont are the Closed Loop No Processing model and the Regional Processing model. The Closed Loop No Processing model can be instituted on a single site with combustion equipment selected specifically for the application; fuel savings are maximized by eliminating processing and transportation costs; and total investment is minimized over other models. The Regional Processing model can achieve and capitalize on both renewable energy and sustainability goals and additional environmental goals critical to Vermont (e.g., cleaning up Lake Champlain).

While individual companies may pursue the Small-Scale On-Farm Processing model and the Consumer Pellet Market model, the inefficiencies and barriers to market entry are unlikely to cause these models to have a significant role in Vermont's renewable energy economy in the near future.

GRASS ENERGY CROP PRODUCTION

This review focuses on two primary perennial crops for biomass feedstock: switchgrass and giant miscanthus. They both share the following traits in common:

- Provide feedstock for heat, electricity, or liquid fuels
- Are fast growing and high yielding in short periods of time
- Help reduce carbon emissions compared to other crops
- Grow well on marginal land, such as wet soils, so they do not compete with other food crops
- Tolerate cold and drought conditions
- Provide numerous environmental and wildlife benefits
- Have attractive rates of return compared to other uses of marginal land

Also, both biomass crops can be grown on marginal unproductive and fallow soils, including:

- Land that is not currently in agricultural production because of soil types and accessibility
- Land with nutrient management and runoff concerns
- Land owned and underutilized by absentee landlords
- Areas not in competition with profitable commercial agricultural practices, except in highly sensitive areas with nutrient management concerns
- Land with low productivity status, (i.e., hay land that is not managed for high production). Often this land produces very marginal returns with as little as 1-2 tons of hay per year.

Millions of acres of idle and marginal lands in the Northeast are conducive for growing these energy crops. As the market for bioenergy products develops, these energy crops can provide an important source of material for heat, fiber, or liquid fuels like cellulosic ethanol. Although these crops have different cash flow profiles and management considerations, switchgrass and giant miscanthus both can provide viable economic returns.

There is significant land area in Vermont that is marginal for agricultural food crops that can support grass energy crops and provide a revenue stream for farmers and landowners. See the most recent USDA, NASS (www.nass.usda.gov/) crop share acreage data for Vermont in the following table:

Table 3. Vermont Acres Available for Biomass Production (acres)

Total Vermont Acres Available for Biomass Production	***600,704**
Acres Available in Area of Interest (Franklin, Chittenden, and Addison Counties)	
Franklin County	71,753
Chittenden County	47,383
Addison County	34,150
Total Acres in Area of Interest	153,286

* Based on idle/fallow lands & other hay/non-alfalfa[29]

Current work conducted by Dr. Sid Bosworth at the University of Vermont points to switchgrass and giant miscanthus as the two warm season grasses that hold the most potential for biomass in Vermont and the Northeast.[3,6,30] USDA has worked with switchgrass continually since 1936, initially for livestock feed, but for over 20 years as a bioenergy crop. Giant miscanthus has also been studied more recently by USDA, and is taking the spotlight because of its high productivity and carbon sequestration abilities.[18] Experts interviewed at the University of Vermont and Pennsylvania State University agree that switchgrass and giant miscanthus are the two best warm season grasses at this time, based on multi-year field trials.

While both grasses have their distinct role in energy production, they also have distinct differences from an establishment, production, and yield perspective. This section will discuss the similarities, the differences and the justification for choosing the correct species of grass for establishing a grass energy program in Vermont.

Giant Miscanthus General Profile

Giant miscanthus is a sterile hybrid used for bioenergy that is established with rhizomes. Giant miscanthus is established by transplanting rhizomes or giant miscanthus tissue cultures in 1 inch blocks. It grows up to 12 feet high and has produced yields of 7 to 10 tons per acre after year 1 and 2 of establishment at sites in the Northeast. While stands have only recently been established in Vermont, stands at other locations have been productive for 15 – 20 years after establishment. It requires significant volumes of water to achieve the higher yields and performs best in wetter soils which makes it ideal for marginal lands. It is known for its soil improvement capacity and sequestration.[18] This crop does require specialized equipment for establishment and harvest, the latter because high yield and thick stem structure requires higher capacity mowers and balers in order to successfully harvest the crop. More research is required in Vermont on giant miscanthus yields and stand longevity, but the superior yields and suitability for thermal energy make it a promising alternative to other perennial grasses.

Giant miscanthus costs more to establish in the first year due to preparation of the field and planting, at about $1,018 per acre; the costs are lower in the second year, at about $175 per acre. For yield comparison, liquid fuel production equivalent is used to compare among species. Giant miscanthus produced 1,000 to 1,300 gallons of ethanol equivalent per acre.

4. Researcher Sid Bosworth with giant miscanthus at Meach Cove Farm, Shelburne, Vermont, 2011.

Giant miscanthus should be well adapted to the climate in Vermont, and has an excellent performance record on marginal lands. The distinct advantage of giant miscanthus is high yields that are double the yield of switchgrass. Dr. Sid Bosworth from the University of Vermont documents yields of over 7 tons of giant miscanthus per acre in Shelburne, Vermont in 2012 on a somewhat poorly-drained soil; however, he concluded that giant miscanthus needs more evaluation before being considered a viable option for Vermont.[4]

Three possible suppliers of giant miscanthus are:

1. New Energy Farms, Canada

   New Energy Farms (www.newenergyfarms.com/) supplies tissue cultures in a 1 inch block for planting. Their technology, CEEDS™, does have some advantages in its ease of establishment. Their charge for the rhizomes and planting would range from $600-$1,000 per acre, though a larger establishment of 2,000 acres or more would qualify for bulk pricing. The landowner would be responsible for preparing their land as if they were planting soybeans; this is typically around $200 per acre depending on the state of tillage of the land to be planted. The company does require a 6 to 12 month notice.

2. REPREVE, Georgia

   REPREVE (www.repreve.com/) handles a variety of giant miscanthus called Freedom. This variety needs more research for northern climates, and supplies could be an issue for a larger scale project.

3. Aloterra

Aloterra (aloterraenergy.com/) has the largest supply of rhizomes in the USA, and have the most planters,[21] which makes this option the most viable for establishing giant miscanthus acreage in Vermont. If Aloterra was selected, they offer two options for farmers. With the first option, farmers would need to prepare the fields through tilling, in the same manner as soybean planting. After tilling and prepping, an investment of $500-$700 per acre would cover establishment including planting equipment, staff time and rhizomes. This option, owning the crop and paying the establishment cost, requires producers to establish their own contracts on the commercial side. If a commercial consumer agrees to buy the product, then the growers and end users can work back and forth to establish a sound marketing plan. The second option is for farmers to simply lease a substantial block of land to Aloterra. Aloterra then does the planting and the marketing of giant miscanthus. This option could help an area get acreage established with little to no investment cost on the producer's part.

Aloterra recommends the establishment of about 2,000 acres of Vermont marginal lands with giant miscanthus, in order to produce an eventual yield potential of plus or minus 20,000 tons per year. They reason that an area needs a critical mass of acreage to develop the infrastructure for planting, harvesting, and processing and plant material utilization. According to Aloterra, 2,000 acres would make for a viable economic unit. Thermal energy projects of a corresponding scale could then be conceptualized and implemented in close proximity to the acreage, or the acreage can be planted in close proximity to the project.

Switchgrass General Profile

Switchgrass is a warm-season bunch grass native to the northeast. Switchgrass grows well on marginal soils that perform poorly for traditional agricultural production. It tolerates wet soils, and drought conditions. There are several varieties which research in Vermont points to as being the most productive, such as "Cove-in-Rock" and "Shawnee." Switchgrass is planted from seed, and takes 2 to 3 years to develop into a harvestable crop. Establishment and harvesting is accomplished with conventional equipment widely available in Vermont.

Establishment costs for year 1 and 2 were recently documented by NEWBio (www.newbio.psu.edu/) in concert with Ernst Conservation Seeds (www.ernstseed.com/).[36] First year establishment costs were $363 per acre, and second year costs were $180 per acre. For comparison to giant miscanthus, yields are equivalent to 500 to 700 gallons of ethanol per acre.

Switchgrass has its own unique advantages as a grass energy crop, even though its yields are lower than giant miscanthus. These include low establishment cost and a huge array of alternative uses that improve environmental water and soil pollution issues. Additional benefits are:

5. Researcher Sid Bosworth with switchgrass, UVM Extension Horticultural Farm, Burlington, Vermont, 2011.

- Switchgrass is a well-known crop. There is science to back up its culture, production, varieties and harvest techniques.[23,17,3,5]
- There is solid science to demonstrate its capacity to sequester carbon, filter soil and water pollutants, contain and protect soils, plus a unique capacity to protect waterways from nitrogen and phosphorus.[23]
- More alternative uses have been developed from switchgrass than from giant miscanthus, including: forage extender for dairy cattle feeding, bedding, mushroom compost, particle board component and stream buffers. (see Alternative Use section, page 33)

The sole supplier of switchgrass seed is Ernst Conservation Seeds in Meadville Pennsylvania. Calvin Ernst, President of Ernst Conservations Seeds, also recommends about 2,000 acres of switchgrass as a good starting point for Vermont. Ernst states that this amount of acreage would provide for the development of the infrastructure for growing and processing switchgrass. A pellet plant, and/or other processing and utilization of the biomass, would be viable with this amount of acreage.[17] Dr. Sid Bosworth demonstrated that the switchgrass varieties of "Cove-n-Rock" and "Shawnee" have the most production potential for Vermont.[4]

A closer analysis of switchgrass reveals distinct advantages in protecting the environment in sensitive areas such as Lake Champlain. Numerous studies, including one conducted by the USDA , Environmental and Economic Analysis of Switchgrass: Production for Water Quality Improvement in Kansas, published in *The Journal of Environmental Management*, (www.ncaur.usda.gov/research/publications/publications.htm?seq_no_115=159948) reports on the positive environmental advantages of switchgrass. This analysis indicates that switchgrass plantings and production in areas of intense commercial and agricultural farming can reduce NO_3 – N (nitrate as nitrogen) surface runoff and sediment by a range of 34 to 99 percent. Other studies confirm these findings.[20]

In Summary

The following table compares giant miscanthus and switchgrass across a number of characteristics.

Table 4. Comparison between Switchgrass and Giant Miscanthus

Characteristic	Switchgrass	Giant Miscanthus
Growing Cycle	Harvested annually for 20 years	Harvested annually for 20 years
Planting Stock	Seed	Rhizomes
Plants per Acre	About 8 pounds of seed	About 6,000 rhizomes
Establishment Cost	$500/acre	$1,500/acre
Yields per Acre	4-6 dry tons/year	8-12 dry tons/year
Fertilizer	Needed for maintenance applications	Not needed
Herbicide Use	At establishment phase	At establishment phase
Pests/Diseases	Few known	Unknown
Harvest Method	Conventional hay equipment	Conventional hay equipment
Harvest Timing	Generally in late winter/early spring	Generally in late winter/early spring
Invasiveness	Some cultivars are not invasive	Noninvasive
Feedstock Properties	High BTUs, low water content, low ash content	High BTUs, low water content, low ash content
Liquid Fuel Yield Equivalent	300 – 400 gal	1000 - 1,300 gal
Establishment Period	2 years	2 years
Second Year Yield	Approx. 2 tons	Approx. 6 tons
Alternative Uses	Numerous - see alternative use section	Numerous - see alternative use section
Carbon Sequestering Ability	Excellent	Excellent
Soil Nutrient Filtering Capacity	Excellent	Excellent
Soil Building Capacity	Excellent	Excellent

(See references 1, 15, 17, 23, and 24)

PROCESSING/DENSIFICATION

Bales, Pellets, Briquettes, and Cubes

Grass can be combusted as bales or can be further processed and densified to produce pellets, briquettes, and cubes. The advantages of using bales for energy are minimal processing and input costs. This form of grass energy is the least expensive to produce and delivers the greatest cost savings compared to densified forms of grass fuel. The advantages of densifying the grass are higher energy density for improved storage and transport economics, easier handling for combustion equipment, and reduced dust for the end user.

Processing cost estimates were developed in the peer reviewed manuscript.[32] Given an assumed cost of $83.48 per dry metric ton (or $75.73 per dry US ton) of baled switchgrass at the farm gate, the estimates for all costs including capital costs to produce pellets is $190.65 per megagram (Mg, equivalent to metric ton, or $172.95 per US ton); $143.18/Mg (or $129.89 per US ton) for briquettes; and $140.71/Mg (or $127.65 per US ton) for cubes.[32]

Regardless of the type of processing, the same steps are followed to harvest, store, and deliver the crop:

- The grass is harvested by traditional methods used to produce dry hay: mowing, raking, and in-field baling.
- The crop is dried in the field to below 20 percent moisture content (wet basis) to prevent molding or spontaneous combustion in storage.
- Grass is baled in large square or round bales with bulk densities of 6 to 8 pounds per cubic foot (dry basis) for storage.
- The bales are delivered for direct use or for further processing. All three densification methods use extrusion to create pressure and heat to compress and bind the grass, resulting in bulk densities up to 35 pounds per cubic foot.

Following is a more detailed description of the three types of densified grass fuels, pellets, briquettes, and cubes.

Pellets

Fuel Standards

The Pellet Fuel Institute (pelletheat.org/) has developed standards for residential and commercial densified fuel. The standards include 3 grades, Premium, Standard and Utility. The voluntary standards program provides ranges for: bulk density, size, durability, fines, ash, moisture and chloride content. The major differences between grades are the ash content with less than 1 percent required to be classified as Premium, less than 2 percent required for Standard and less than 6 percent for Utility. The following table compares the three standards of pellet fuel across a number of characteristics.

Table 5. PFI Pellet Fuel Quality Parameters

	Size, Diameter (mm)	Moisture Content (%)	Ash Content (%)	Bulk Density (lb. per cubic foot)	Fines Content (%)	Chloride (ppm)
Premium	5.84 - 7.25	≤ 8.0	≤ 1.0	40.0 - 46.0	≤ 0.50	≤ 300
Standard	5.84 - 7.25	≤ 10.0	≤ 2.0	38.0 - 46.0	≤ 1.0	≤ 300
Utility	5.84 - 7.25	≤ 10.0	≤ 6.0	38.0 - 46.0	≤ 1.0	≤ 300

* Adapted from http://pelletheat.org/pfi-standards/

6. Switchgrass pellets, Brandon, Vermont, 2011.

The areas where grass pellets would likely have trouble meeting these standards are bulk density, chloride content, and ash content. Bulk densities of grass pellets typically are about 75 to 85 percent of the density of wood pellets;[34] however, this is unlikely to be a major barrier to market acceptance. Chloride in grasses can be managed somewhat by controlling fertilization and harvest timing in the field. Typical chloride content of grass is 0.01 to 1.0 percent.[9] Ash content can be reduced in the field for switchgrass by managing fertilizer, soil type where grown, and harvest timing. Allowing the crop to overwinter in the field can significantly reduce ash content, though it still typically remains above the level to qualify for either Premium or Standard grades with typical ash content from 2.5 to 4.7 percent.[26]

Pellet Production in the Northeast

In the Northeast, Enviro Energy LLC (www.enviroenergyny.com/) in Unadilla, New York is producing grass pellets on-farm with a part-time production schedule. Products include pellets for fuel, pellets for mulch and soil enhancement, and pellets of barley straw for treating ponds.[22] Ernst Biomass, LLC (www.ernstbiomass.com/) in Meadville, Pennsylvania is producing pellets in a commercial facility that has a rated capacity of 5 tons per hour. Their pellets are marketed as an absorbent for use around gas well drilling sites, for animal bedding and as a forage extender for feeding cattle.[14] Vermont Technical College (VTC) in Randolph acquired a small pellet machine mounted on a trailer through a grant from Vermont Sustainable Jobs Fund. It is used as an education and research tool and produces pellets from grass energy crops grown by researchers at the University of Vermont in Burlington. A Froeling (www.froeling.com/us/) pellet boiler on the VT Technical College campus is set up to test burn grass pellets. In New York, the Hudson Valley Grass Energy Partnership has developed a mobile pellet mill that is being used for demonstrations and has been used to produce pellets on area farms on a limited scale. Capacities up to 1.5 tons per hour have been achieved.[28]

Making Grass Pellets

The wood pelleting process starts by conveying sawdust or wood chips into a hammer mill where particle size is reduced for pneumatic conveyance to a dryer. The material is dried to approximately 8 percent moisture then collected in a cyclone and conveyed to a second hammer mill where the size is further reduced. The material is then run through a conditioner where moisture can be adjusted or a binding agent is added prior to entering the pelleting machines. The pellets are then cooled after exiting the pellet machines before entering bulk storage.

7. Buskirk Grass Pellets, Vermont Technical College, 2012.

Making grass pellets follows the same basic steps as wood pelleting with the exception that some preprocessing of the bales is required to feed into the first hammer mill; typically this is done in a tub grinder. The other major difference in processing grass into pellets is that the ground grass is less dense than wood and requires different conveyors and metering screws to get material into the first hammer mill. This lower density also results in lower throughput through the pelleting machines and reduces their rated capacities by approximately 25% compared to pelleting wood.[14] A typical pelletizing machine, rated at 5 tons per hour for wood, will have a maximum throughput with grass of 3.5 to 4 tons per hour.

While switchgrass performs well versus other grasses for yield, energy content and total ash content, it is the most difficult grass to get to form into a durable pellet.[14,22,26] This problem can be reduced by blending switchgrass with other grass crops or binding agents.

Another challenge for making grass pellets compared to wood pellets is the volume and composition of the ash in grasses. This results in increased wear of dies and metal surfaces over which the material flows, thereby increasing operating and maintenance costs for the processor.[14] Substantial investment and modifications to existing wood pelleting process lines would be required to produce either a blended wood and grass pellet or a whole grass pellet. It is likely that it would be more practical to design a new plant or processing line with grass pellets as the primary feedstock. If a blended pellet is desired for consumer acceptance, whole grass and whole wood pellets could be mixed to achieve the desired blend.

Briquettes

Briquettes are densified like pellets, but are extruded through larger dies forming a larger fuel. Briquetting machines can form logs or pucks that are typically 1.5 to 3 inches in diameter. They are a lower density fuel than pellets, but have the advantage of requiring less processing and energy input than pellets. Bulk densities are typically 20 to 25 pounds per cubic foot.

Briquetters can tolerate larger particle sizes in the initial feedstock, which reduces both the amount of equipment and energy needed in the process. The typical process delivers bales into a tub grinder that can grind grass into particles small enough, ½ inch or less, so that additional size reduction is not required. Some method for drying may be needed as material has to be less than 12 percent moisture in order for the briquettes to maintain their shape. From the tub grinder, grass is conveyed to a mixing/metering bin for delivery into the briquetter. The total energy input required to produce a briquette is approximately 33 percent of the energy required to make a pellet and wear on equipment is less than when making pellets.[32]

Typical throughput of a briquetter is approximately 1 to 2 tons per hour and the process of forming briquettes is more forgiving and less precise than forming pellets. In the Northeast, Ernst Biomass, LLC experimented with a CF Nielsen (www.cfnielsen.com) riquetting machine (model 5500 with a 55kW motor and 75 mm die). Production capacity up to 1.5 tons per hour was achieved throughput processing switchgrass into briquettes.

Ernst supplied briquettes to Benton School District who installed a biomass boiler manufactured by Advanced Recycling Equipment (www.advancedrecyclingequip.com) for one heating season. Issues arose with clinkering and operation of the boiler, and resulted in the school district converting to wood chip fuel after the initial season. The briquetter is now being leased to someone using it to make wood briquettes.

Renewable Energy Resources, LLC is installing a small capacity briquetter at their testing facility located at Meach Cove Farm in Shelburne, Vermont. A mobile briquetting machine is also in the final stages of completion and testing that is being developed by RER with funding assistance from Vermont Sustainable Jobs Fund.

Cubes

Cubes are made with equipment that is adapted from the original John Deere mobile alfalfa hay cubers.[21] The stationary equipment consists of a conditioning/mixing bin, a large diameter wheel with 1 to 1.5 inch square dies and an internal press wheel that forces material out thru the dies. Minimal size reduction of the grass material, similar to what is required for briquettes, can be achieved in a tub grinder. Grass moisture content should be less than 12 percent and bulk densities of cubed material are similar to briquettes, at 20 to 25 pounds per cubic foot. One cubing machine can produce 6 to 10 tons of pellets per hour, achieving significantly higher throughputs per unit than either pellet or briquetting machines.[32]

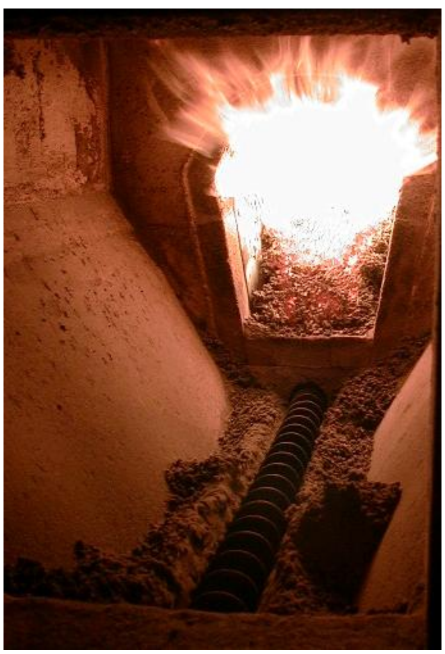
Cubes may be more practical than briquettes in the Regional Processing Model as one machine can produce 3 to 4 times the throughput of one briquetting machine with 11 percent less energy input per ton produced.[32] Mesa Reduction and Engineering, LLC (www.mesareduction.com/) in Auburn, New York has produced cubes from grass and agricultural residues for test firing in larger boilers. Warren & Baerg Manufacturing Inc. (www.warrenbaerg.com) in Dinuba, CA manufactures cubers and has successfully produced cubes in test runs with multiple biomass fuels including giant miscanthus and switchgrass.

THERMAL COMBUSTION EQUIPMENT

Pellet Appliances for the Consumer Market

There are pellet stoves, furnaces and boilers currently available, labeled as multi-fuel and sized for the consumer (residential-scale) market, that have successfully burned grass pellets. Typically, adjustments to the stove must be made to burn grass fuel and there are some limitations. For instance, appliances that are able to adjust the fuel feed rate and air-to-fuel ratios over a broad range, have an automatic and/or mechanical method of removing ash from the fire pot or grate, and have ample ash storage bins that can easily be dumped, have proven to be best adapted to burn grass pellets. The variability in percent of ash content and the mineral composition of the ash requires additional effort from the user to tune these appliances to effectively burn grass pellets.

Cornell University tested the burning of grass pellets in multiple pellet appliances (forages.org/index.php/research-gb). The best performing stoves for efficiency and handling of the ash were the Quadrafire S, Europa 75, Harman P43 S, Skanden (Reka), B and LEI BB100, B.[9] In addition, an ongoing research and demonstration project being conducted by Cornell Cooperative Extension, Delaware County, and the Catskill Watershed Corporation with funding by the NYC Watershed Agricultural Council, has installed several pellet stoves in residences. This work is being done as part of an effort to facilitate the development of a local grass energy economy. The report on the performance of the stoves tested is currently being developed and will be available in 2014.



8. Grass pellet combustion, Meach Cove Farm, Shelburne, Vermont, 2010.

As for boilers, LEI (www.leiprod.com/leiproducts) manufactures flexible fuel boilers capable of multiple fuel feed and air adjustments with aggressive ash handling in the 100,000 to 500,000 Btu per hour range that can burn grass pellets. New Horizon Corporation (www.newhorizoncorp.com) has modified a Furtura MultiBio Boiler with a moving grate for burning grass pellets. Biomass Energy Works is developing a multi-fuel boiler specifically for multiple fuels including grass pellets.[7]

There are several barriers to grass pellets making in-roads into the consumer wood pellet market. These include the relatively small number of installed appliances that can effectively burn grass, and reality of increased ash handling, which is up to 10 times the ash of premium wood pellets. The mineral composition of the ash in grass is generally higher in elements that cause the formation of clinkers at lower temperatures than occurs in wood ash. These minerals (potassium, sodium, chlorine, sulfur, and silica) in the ash form compounds that tend to be more corrosive than wood ash and form caked deposits on heat exchangers. In tests conducted by Cornell comparing PM emissions from these appliances, the increased ash content of the grass fuel related directly to increased PM emissions from these appliances.[9] Typically, grass pellets are 4 to 7 percent lower in energy value than standard or premium grade wood pellets.

In 2009, the Vermont Grass Energy Partnership experimented with blending various grass species and concentrations of mixed grass and wood pellets and then conducted combustion and emissions tests. As expected, these experiments yield results such that the higher the percentage of wood in the pellets the lower the ash content, and the higher the ash fusion temperature for all grass species.[33] Blending grass with wood could be an effective strategy for introducing grass energy into the consumer market. However, there are several barriers on the pellet production side that make this an unlikely model for widespread market penetration.

Handling and processing grasses for pellet production would require a significant investment in specialized equipment, essentially creating a second line at the wood pellet plant. Including grass as a percentage of the pellet would tend to lower the value of the pellet as ash content would increase and heating value would decrease. To get pellet manufactures to make the investment required to include grass in wood pellet blends, there would need to be a significant price advantage for grass raw material cost, which currently does not exist.

Institutional/Commercial Scale Boilers

Biomass boilers in this range generally exceed 500,000 Btu per hour of output and can go up to 20 million Btu per hour or larger. Systems are available to utilize baled feedstock for fuel. Fuel feeding ranges from loading a full bale directly into the combustion unit (burning one at a time), or loading multiple bales on a conveyor system to be shredded and metered into the combustion unit. These systems can be cost effective since they can utilize baled grasses which typically have a lower energy cost than feedstock requiring additional processing such as pucks, briquettes, cubes, and pellets. A partial list of manufacturers, listed alphabetically, that have advertised the ability to utilize baled feedstock are Axe Biotech (www.axebiotech.ie), DP Cleantech (www.dpcleantech.com), Innovaat (www.innovaat.com), Limes Innovation, LIN-KA (www.linka.dk), Skanden (www.skanden.com), and Skelhoje Maskinfabrik. Efficiencies, levels of automation, capital costs, and operating costs can vary depending on the manufacturer, equipment, and application.

In larger scale boilers up to 27 million Btu/hr output, Wellons (www.wellons.com), Hurst (www.hurstboiler.com), Ebner Vyncke (www.vyncke.com), and AFS (www.afsenergy.com) all manufacture moving step grate units with automated ash handling that should effectively remove clinkers and deal with higher ash volumes. These boilers are designed to burn wood chips but could effectively burn a briquette, cube or pellets. Some pre-processing or grinding of bales would be required to adapt the fuel feeding systems of these units in order to accept grass energy without densification. While the equipment in this size range is commercially available there are very few, if, any installations of this equipment in Vermont. The majority of the existing installations at institutions in Vermont are smaller systems (0.5 to 20 MMBtu per hour) that burn wood chips, with fixed grates where ash is raked out of the boiler. If grass was used in these units, the ash would clinker and harden onto the grates, sealing off the under fire air flow and are thus not suitable for type of fuel source.

There are fewer equipment barriers for new installations in this market size, compared to the consumer, or residential, market. This is because the combustion equipment is larger and is available with moving grates and has a more robust ash handling system with multiple fuel and combustion air settings. Boilers with moving grates and more robust ash handling are more expensive than fixed grate boilers. The higher volumes of ash and lower fusion temperatures can cause increased fowling of boiler tubes that require additional maintenance.

Tests conducted in Vermont (mentioned earlier) show a direct correlation between PM emissions and the higher ash volumes of grass fuels.[33] For boilers that require emissions permitting (typically above 3.0 million Btu/hr, heat input) additional costs for PM controls may be required to meet permitted levels. For larger boiler installations, some form of densification or preprocessing of the fuel would be important to minimize fuel storage and handling requirements. This would require the simultaneous development of a boiler installation and a processing facility.

Emissions from Combustion

As mentioned earlier, emissions testing was conducted burning grass, grass and wood pellet blends and straight wood pellets, as part of earlier research by the Vermont Grass Energy Partnership. The tests compared pellet and pellet blends from 3 different grass sources, switchgrass, reed canarygrass, and mulch hay and were performed on a 500,000 Btu/hr Solagen boiler with no emission controls. It should be noted that CO, NO_x, and PM emissions are unique to each furnace being tested and are greatly affected by the boiler tuning. Generally speaking, compared to wood pellets, it should be expected that unfiltered PM emissions will be directly related to the percentage of ash by weight produced by the fuel. The testing confirmed that the greater the percent of grass in the fuel, the higher the level of PM emissions. It is also expected that the NO_x and SO_x emissions will be directly related to the level of sulfur and nitrogen present in the fuel. [33] The following table compares particulate emissions and ash content across wood pellets and several blends of grass-wood pellets.

Table 6. Particulate Emissions and Ash Content

Sample	Total Particulate Emissions (lbs./MMBtu)	Ash Content (%)
Control (100% wood)	0.052	0.35
S1 (100% Switchgrass)	0.066	4.32
R1 (100% Reed canarygrass)	0.18	6.67
M1 (100% Mulch hay)	0.25	5.12

For appliances smaller than 3.0 million Btu per hour (heat input), generally no permitting or emissions controls are required; however there is a trend toward greater restrictions and scrutiny of PM emissions from smaller solid fuel appliances on both the federal and state regulatory levels.

For commercial scale biomass furnaces, cyclones and steel mesh or fabric filters are sometimes employed, but are not required for systems below 3.0 million Btu input. For systems above 3.0 million Btu per hour, fuel input PM controls are generally installed to meet emissions limits. While SO_x, NO_x, and PM emissions would generally be higher for grasses than wood, the emission levels can meet permitting limits with proper tuning and PM controls. Ash volume and composition of the fuel can be managed by grass species, the soil the crop is grown on, the amount and source of fertilization of the crop, and how the crop is harvested.[26]

Mineral Content

Alkali metals, including chlorine and potassium, combine with silica in grass energy to form silicates the have lower fusion temperatures which cause clinkering and fowling of heat exchanger tubes. Potassium is the most prevalent of the alkali metals found in grass energy crops and is directly related to application of potassium chloride fertilizers, which can be controlled. The alkali metals in the ash, especially chlorine, can cause excessive corrosion in combustion appliances.[8]

ALTERNATIVE MARKETS FOR GRASS ENERGY CROP

Building a commercial scale pellet plant or regional processing facility for grass requires a substantial investment. An owner will need to be able to have a market for the plant's production soon after coming online or success is unlikely. In addition, if farmers are to invest in growing grass energy crops they need some assurance that a market exists. Alternative markets for grass pellets or grass energy crops can be a solution to allow early year financial success while grass thermal energy markets are being developed. The following alternative markets have been identified and successfully developed by switchgrass growers and processors interviewed for this project:

- Fiber source for plates, cups, packing materials, etc. (compostable)
- Animal bedding
- Compost for mushroom growers
- Resin in particle board
- Soil nutrient filter (nitrogen & phosphorus)
- Noise & odor filter for concentrated livestock facilities
- Absorbent markets
- Dairy ration inclusion
- Stream buffers and conservation plants
- Wildlife habitat

Fiber Source

Fiber markets for giant miscanthus are currently being developed. As a fiber source, this species is being considered for inclusion in paper cups and plates, fiberboard, and cardboard/paper. Giant miscanthus is also being considered for carbon fiber composites for automobile components. Global carbon fiber use is poised to grow by about 30 percent within the next 5 years. With only 10 carbon producers producing 95 percent of the world's fiber, the supplier/processor relationships should be strengthened. This opens up a solid market for fiber from giant miscanthus and switchgrass.

Animal Bedding

Switchgrass and giant miscanthus can be used as premium bedding in a variety of agricultural livestock production sectors. Both grasses have a very high absorption rate and are in many ways superior to wood shavings and small grain straw. Switchgrass and giant miscanthus are currently being used in chicken and turkey facilities, dairy facilities, and equine facilities. Shortages of straw, wood shavings and sawdust are driving this market in areas of the country with high livestock concentrations. Current research trials are being conducted in the Northeast to evaluate giant miscanthus as a poultry bedding source. This is removed between flocks and burnt through biomass conversion as a heating source.

Compost

Switchgrass and giant miscanthus are currently being used as a substrate for the commercial mushroom business in Ontario. Wheat straw, the substrate of preference in the past, is in low supply with a high price tag. Compounding the supply and price problem is the fact that modern hay baling and processing of straw is reducing fiber size and rendering straw as a less desirable substrate for mushrooms. Last year, Ontario growers sold switchgrass to mushroom producers for 5 percent inclusion in their growing substrate. Trials in 2013 were being conducted at a 50 percent inclusion rate. With land rent rates as high as $350 per acre in Ontario, producers are seeing good profits when growing switchgrass for the mushroom industry. During the establishment year of switchgrass, producers are using spring wheat as a mass crop for switchgrass, which has dramatically helped with establishment cost.

Resin

Currently, the particle board industry uses primarily formaldehyde-based resins. These resins are sourced from petrochemicals, and are deemed harmful to human health. Switchgrass and giant miscanthus both can be processed to produce phenolic type resins from lignin and wood-like lignin composites. Don Nott, a switchgrass producer in Ontario, is working with a private fiber board company in Ontario to develop markets for resins from switchgrass fiber, and fiber board from switchgrass or giant miscanthus.

Soil Filter

Switchgrass and giant miscanthus are very effective in the capturing and holding of soil nutrients. The nutrients, nitrogen and phosphorus, that are used to produce stems and leaves can be harvested and removed from the soil, or turning in the harvest can allow nutrients to recycle to plants' roots and rhizome system. At the same time, significant amounts of carbon sequesters to the root and rhizome system and soil organic matter is improved. In areas where nutrient runoff is wreaking havoc with water quality (e.g., Lake Champlain and the Chesapeake Bay), both switchgrass and giant miscanthus can be used as a conservation planting to hold soil and soil nutrients in place. Giant miscanthus requires soil tillage only once during its establishment, with stands producing at prolific levels for 20 plus years. Switchgrass has been shown to be established by using no-till systems with cover crops, such as spring wheat. These stands also have a lifespan of twenty years. Therefore, both crops are highly effective at holding soil and soil nutrients in place. Harvesting these crops allows pollutants (N and P) to be removed on a yearly basis. Growing these crops in areas of concentrated livestock and poultry production could have a very beneficial impact on environmental water quality issues. Using these crops on marginal lands that serve as edge of field buffers to streams, waterways and bodies of water, can reduce the propensity for runoff erosion and N and P loss and pollution.

Noise and Odor Filter

Poultry houses and hog houses emit significant amounts of ammonia (NH_3), dust particles and noise from tunnel fan emissions. In a study conducted by USDA and NRCS, switchgrass and giant miscanthus wind breaks were capable of reducing dust up to 67 percent, odors up to 67 percent, and ammonia, which varied with plant species.[25]

Absorbent Markets

Currently switchgrass pellets are being marketed as a bio-absorbent for the oil and gas industry. During the process of drilling and fracking oil and gas wells, oil and other environmental pollutants can be spilled. The energy companies that perform the drilling have very stringent environmental regulations, and must be prepared to remove any potentially harmful products. Absorbents are used to capture these spills, so the pollutants can be disposed of in an environmentally sound procedure. Ernst Conservation Seeds is currently pelletizing their acreage (about 4,000 acres) of switchgrass and marketing to the oil and gas industry. Aloterra is also actively looking to develop this market.

Dairy Rations

Dairy herd nutrition has advanced to a level where fiber now has a value as a ration component. Historically, dairy rations had an abundance of fiber, however, technological advances in ration formulations, forage harvesting, and ration delivery systems have led to a fiber shortage on many dairy farms. Switchgrass has been successfully fed on dairy farms and fills an important void in ration fiber content. In addition, the low potassium level of switchgrass makes it an ideal inclusion in dairy cow rations, where excessive K can cause an array of metabolic problems. Large herds with multiple groups of animals use an enormous amount of forage, and switchgrass can play an important role in dairy cattle production, growth, and health, in addition to economic benefits.

Conservation Plants

Switchgrass and giant miscanthus performs well as a conservation planting through erosion control, restoration, and development of wildlife habitat. These grasses are adapted to a wide range of sites, and perform with excellent results on marginal grounds. Both grasses stabilize soils and nutrients in environmentally sensitive areas, including stream banks, waterways, dikes and gullies, and other highly erodible lands. At the same time they also capture and hold soil and water pollutants such as excess nitrogen and phosphorus.

Wildlife Habitat

Switchgrass and giant miscanthus provide excellent habitat for wildlife when used exclusively or in combination with other plant species. The vertical growth pattern provides cover for many bird species such as pheasants, and allows for quality nesting sites. Both grasses also provide excellent cover for deer.

RECOMMENDATIONS FOR DESIGNING A ROBUST GRASS ENERGY PROGRAM IN VERMONT

This “current state” investigation of grass energy for Vermont brings to light significant issues which must be addressed in order to chart a path forward. Both literature review and interviews with experts in this field identified a range of barriers to wider adoption of grass thermal energy including: consumer acceptance due to highly variable ash and mineral content of grasses compared to wood; limited installations of appliances capable of burning grass due to clinkering; higher value markets for grass hay crops compared to their value for energy use; and lack of established markets for grass energy crops.

This investigation of grass energy also offered strong support for the benefits and positive potential for grass thermal energy in Vermont. These included energy independence, energy cost savings, local economic development by keeping energy dollars spent in the local economy, CO_2 reduction, grass energy crops assisting in cleaning up waterways and productive uses of marginal land.

Interviewees were nearly unanimous in stressing the need for successful demonstration projects to provide exposure and education on the potential for grass energy. However, a demonstration alone without monetizing incentives to capitalize on all benefits derived from grass energy is unlikely to make a significant contribution to the renewable energy profile of Vermont.

Based on review of the current research and interviews we make the following recommendations to develop a grass energy industry in Vermont.

1. Focus on switchgrass and giant miscanthus for grass energy due to the following attributes: superior yields on marginal soils; higher energy than other grasses; and root structure for superior performance as a riparian buffer.

2. Provide incentives for both the thermal benefits and watershed improvement benefits of grass energy crops in order to encourage both the establishment of grass energy crops in riparian buffers and the installation of grass thermal energy combustion and processing equipment.

3. Establish a sustainable demonstration project using the Closed Loop No Processing model.

4. Establish a sustainable demonstration of the Regional Processing model that is of a scale to make a significant impact on the Lake Champlain watershed.
    a. Include incentives for planting energy crops in riparian buffer zones.
    b. Include incentives for establishing a regional processing facility.

c. Include incentives for installing and using grass energy from the buffer zones for thermal loads.

While there are many grasses that have been suggested for use as grass energy crops, switchgrass and giant miscanthus come to the forefront based on potential yields on marginal land and energy and ash content compared to mulch hay and reed canarygrass. Switchgrass and giant miscanthus both have documented nutrient removal rates for phosphorus and nitrogen, the major water pollutants in Lake Champlain.

Pilot Demonstration Projects

There are two important components to implementing any project: establishing the grass energy crop and developing a market for the product by installing grass-burning combustion systems. Further, since building a market for heating fuel will take some time and grass takes three years to become fully established, Vermont should devise incentives that can begin expanding acreages in grass for energy as a first step. A grass heating fuel market can be built simultaneously, and growers can take advantage of alternative fiber markets until the heating fuel market is well established. There are two grass energy models that we believe have potential to be sustainable in Vermont, Closed Loop and Regional Processing, that could be tied to environmental incentives to clean up Lake Champlain.

A **Closed Loop model** demonstration, to be sustainable, requires choosing the correct site. The correct site should have acres available for establishing the grass energy crop and conventional haying equipment readily available to harvest the crop (either owned or custom harvesters). While every site will be unique and require detailed analysis, a good starting point for a general facility profile is:

- Current fuel is oil or propane
- Annual heating costs are greater than $100,000
- Central heating distribution is possible
- 65 acres or more exists for growing an energy crop (assuming grass fuel is replacing 30,000 gallons of fuel oil and grass yields are 4.5 tons per acre)
- There is owner commitment to the project
- There is sufficient space for storage

While grant funding for the demonstration will be an important component, the project needs to be able to be sustained on its own merits. The thermal load and the fuel savings need to be great enough to justify the return on investment in both equipment and added labor over the current heating equipment and fossil fuel used.

A **Regional Processing** model demonstration, while more complicated to implement than the Closed Loop model, can provide significantly greater economic and environmental benefits. For this model to be sustainable, the demonstration project will need to capitalize on all environmental and economic incentives and be at a scale to support development of a regional infrastructure. It must also demonstrate a significant impact on Lake Champlain water quality and offset the use of fossil fuel. Every project is unique and requires detailed analysis but generally the minimal requirements of a Regional Processing model demonstration would be:

- Establishing five hundred acres of switchgrass in new or expanded buffers along waterways feeding into Lake Champlain. At 4.5 tons per acre this would supply 2,250 tons (dry) grass fuel per year.
- Incentives for growers that provide profit equal to what the same acreage would yield if planted to corn.
- Installation of grass heating system at a facility (or multiple facilities in close proximity) using more than 230,000 gallons of oil per year, with a demand of 2,250 dry tons of grass energy per year. Establishing a processing facility or large bale supply entity to provide long term contracts with the biomass combustion plant and growers.
- Commitment from the owner of the combustion facility.
- Commitment from farmers to grow the crop.
- Public commitment to provide incentives for both the grower and the end user for some period of time.

The grass fuel use could be at one site or a combination of sites in close proximity to significant agricultural acres in the Lake Champlain watershed. Dairy processing plants, hospitals, public or private campuses with a district heating system would be potential sites.

For incentives to capitalize on all of the environmental benefits, the Vermont Agricultural Buffer Program and the electric utility portfolio standards could be used as templates. The goal is to provide equal profit to the producer that the same acreage would yield if planted with corn, volumes of demand to a processor or broker to justify establishment of the supply chain, and savings to the owner of the combustion facility to justify the investment and labor required over the present system. Public and private long term commitments are required to provide the farmer with assurances of a market and the owner of the biomass system with a long term fuel source.

A variation of a regional processing plant would be to secure a third party owner or broker who would purchase and store bales of grass for the project and manage supply and delivery to the plant. This would reduce fuel processing costs and investment in a regional processing plant while increasing material handling costs for the owner of the combustion facility.

The impacts of this scale of demonstration project would be:

- 55 miles of 75' wide riparian buffer zone established
- 16,000 pounds of phosphorus removed from the Lake Champlain Watershed
- 20,000 pounds of nitrogen removed
- 230,000 gallons of #2 fuel oil offset
- 2,250 metric tons of CO_2e offset
- $429,000 savings per year in fuel purchase costs
- $731,000 total cost over 12 years of subsidy to match net corn profit, or a public mandate to require 75' buffers without financial incentive

While some of the nutrients removed by the grass energy crop will be offset by nutrients that would have been removed from established 25-foot buffer zones, it is clear from the research that expanding the zones from 25 to 75 feet will make a substantial contribution to the total maximum daily load (TMDL) reductions. It is also true that wider zones with root structures like switchgrass will be much more effective in trapping sediment during major rainfall events.[20]

Providing returns to farmers equal to growing corn would require a $576 per acre subsidy in year 1 and $426 per acre subsidy in the first two years of establishment and $46 per acre in each successive year to provide equal profit to growing corn for grain (assuming that the grass energy crop has a value of $80 at the farm gate). The 500 acres in 75' wide riparian buffers that are outlined above would cost a total of $731,000 in subsidies over 12 years while having a major impact on water quality in the watershed where implemented. The alternative is requiring 75-foot buffers without any financial inventive.

A project such as this would also provide a very visible demonstration model for grass thermal energy. The energy cost savings to a dairy processing plant or institution for offsetting fuel oil would be substantial; however, a significant capital investment in equipment and infrastructure would be required upfront. There are several options to incentivize the installation of biomass combustion equipment including grants, subsidized financing, and thermal renewable energy credits. For the right project, it is certainly possible that energy savings could provide enough incentive to implement a project with minimal additional subsidies. At a minimum, some technical assistance to provide a detailed feasibility assessment is recommended to help move a project forward.

Table 7 below provides assumptions used to develop the summary of key impacts. Tables 8 and 9 on the following pages are twenty year cash flow budgets for switchgrass and giant miscanthus crops respectively; they are not adjusted for inflation. These budgets are developed using the VABP funding already in place to demonstrate additional subsidy required to provide equal profit to growing corn grain on the same acres. It should be noted in years 3, 4 and 5 the net income to the farmer is $100 per acre greater than the estimated net profit from corn.

Table 7. Assumptions for Regional Processing Demonstration Project

Briquette Contract Price (delivered)*	$164 per ton
Grass Energy Yield	4.5 tons per acre
Energy content of Briquettes	14.34 mmBtu per ton
Net thermal conversion efficiency (grass)	77%
Fuel oil price	$3.50 per gallon
Fuel oil energy yield	0.138 mmBtu per gallon
Net thermal conversion efficiency (fuel oil)	79%
Removal rate of actual P	8 pounds per ton of switchgrass
Removal rate of actual N	10 pounds per ton of switchgrass
Riparian Buffer Zone width	75 feet
Corn average annual profit	$240 per acre
CO_2e offset replacing fuel oil with switchgrass briquetts[42]	68.4 kg CO_2e/GJ

*assumes $80 per ton at farm gate, $54 per ton processing costs[32] and $30 per ton for delivery and profit

TABLE 8. SWITCHGRASS BUDGET (4.5 TON / ACRE)

Establishment Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gross Returns/acre 4.5 tons @ $80/ton	0	0	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00
Operational Cost / acre																				
Establishment	$ 300.00	$ 150.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mow	0	0	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00	$ 15.00
Rake	0	0	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
Round Bale	0	0	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00	$ 77.00
Land Charge	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00
Bale Hauling	0	0	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00	$ 20.00
Total cost/ acre	$ 336.00	$ 186.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00	$ 166.00
Net Revenue/ acre without incentives	$ 336.00	$ 186.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00	$ 194.00
**Current VABP Incentives/ acre $123 Establishment $150 Rent for 5 Years	$ 273.00	$ 150.00	$ 150.00	$ 150.00	$ 150.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Additional Incentives / acre Needed to Match Corn Returns *	$ 303.00	$ 276.00	0	0	0	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00	$ 46.00
Net Revenue / acre with VABP & Additional Incentives	$ 240.00	$ 240.00	$ 344.00	$ 344.00	$ 344.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00	$ 240.00

* Provided corn return for Vermont 2014 $240

Sources (1) State of Vermont Agency of Agriculture, Food & Markets 2011

(2) Dr. Sid Bosworth - Extension Agronomist, University of Vermont

(3) Calvin Ernst - Ernst Conservation Seeds

** VABP Vermont Agricultural Buffers Program

TABLE 9. MISCANTHUS BUDGET (7 TON YIELD / ACRE)

Establishment Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gross Returns/acre																				
7 tons @ $80/ton	0	0	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00	$560.00
Operational Cost / acre																				
Establishment	$619.00	$150.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mow	0	0	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00
Rake	0	0	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00
Round Bale	0	0	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00
Land Charge	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00	$ 36.00
Bale Hauling	0	0	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00	$ 50.00
Total cost/acre	$655.00	$186.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00	$291.00
Net Revenue/acre without incentives	$655.00	$186.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00
**Current VABP Incentives/acre $123 Establishment $150 Rent for 5 Years	$273.00	$150.00	$150.00	$150.00	$150.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Additional Incentives / acre Needed to Match Corn Returns *	$622.00	$276.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Revenue / acre with VABP & Additional Incentives	$240.00	$240.00	$419.00	$419.00	$419.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00	$269.00

*Projected corn return for Vermont 2014 $240

Sources (1) State of Vermont Agency of Agriculture, Food & Markets 2011

(2) Dr. Sid Bosworth - Extension Agronomist, University of Vermont

(3) Calvin Ernst - Ernst Conservation Seeds

**VABP Vermont Agricultural Buffers Program

CONCLUSIONS

As the Wilson Engineering team explored opportunities for grass energy in Vermont, it became increasingly obvious that grass energy and environmental concerns go hand in hand, and **the marriage of grass energy and nutrient management had inherent synergy.** Tied together, grass energy and nutrient management could be molded into a viable business model meeting many of Vermont's renewable energy and environmental sustainability goals. The broad goals and objective of this report were to review research, interview stakeholders and provide summaries and direction for three key classes of findings:

The current state of scientific knowledge and technology is fairly broad and deep for growing, processing, and combusting grasses for fuel both in Vermont and throughout North America and beyond. We know the following:

- Switchgrass and giant miscanthus hold the most promise as energy crops due to yield on marginal land and combustion characteristics.
- Due to its deep and clumped growth pattern, switchgrass is an excellent crop for riparian buffer strips to reduce nutrient loading of watersheds from agricultural runoff.
- When marginal soils are planted to giant miscanthus or switchgrass, positive soil building characteristics result. Both feedstocks are effective for carbon sequestration in the soil.
- Grass crops can be pelleted using standard equipment but generally reduced throughput and increase wear of the mills compared to wood.
- There are pellet stoves, furnaces and boilers available that can burn grass pellets but the high ash content compared to wood requires more robust ash handling equipment.
- Larger boilers and equipment is commercially available that can burn grass from bale form to briquettes, cubes and pellets however; there are very few biomass-burning appliances of this large size currently installed in Vermont or the Northeast.
- Grass energy replacing fossil fuels can significantly reduce Vermont's carbon footprint.
- Concerns from combustion of grass energy are corrosion and alkali deposits from chlorine and potassium, higher particulate matter (PM) due to high ash content, potential increases in oxides of sulfur (Sox) and oxides of nitrogen (NOx) based on chemical composition.
- Ash content and composition can be controlled by managing soils, nutrients applied, and harvest practices.

The experiences of the early adopters in Vermont and the Northeast have taught us:

- We have significantly more experience and knowledge in switchgrass than giant miscanthus.
- At a yield of 4.5 tons per acre per year and $80 per ton at the farm gate, grass energy crops can be profitably grown.
- There are alternative markets for grass energy crops that can have higher values than energy.
- Switchgrass is the most challenging of the grasses to pelletize.
- Small scale on-farm production of grass pellets can be accomplished but is challenging.
- Briquetting and cubes are viable alternatives to pellets for densifying grasses.
- There are relatively few appliances currently installed in the Northeast for grass combustion.
- Pellet stoves have successfully burned grass pellets but nearly all require additional tuning or maintenance compared to wood pellets.
- The higher ash content in grass energy compared to wood causes challenges for consumer acceptance for use in pellet stoves.
- Finding financing for grass energy projects is challenging, and additional incentives are important to implementing projects.

The key next steps for moving forward with grass energy in Vermont are:

- Additional research on growing giant miscanthus to determine costs and yields in Vermont.
- Education to make the public aware of grass energy and its potential benefits to Vermont.
- Demonstration of viable models of grass thermal energy.
- Design incentives that can capitalize on all environmental benefits of growing grass for thermal energy.
- Fund and prepare a roadmap strategy plan to advance grass energy in Vermont that identifies critical thresholds for farmer subsidy and critical fossil heating fuel thresholds that will trigger a more viable future for grass energy in Vermont.
- Lead a delegation to Denmark to explore their successes in grass energy market development.

During the current state of investigation for grass energy in Vermont all parties remain cautiously optimistic about the outcome. **Stakeholders indicated that now is the time for a highly visible practical demonstration project.** Ideally the project chosen will demonstrate a sustainable business model. While several efforts are currently being made to develop various grass thermal energy business models in the Northeast and Vermont, there are clear market barriers unlikely to be overcome without additional incentives.

The Wilson Engineering team believes that **the most likely models for sustainable and repeatable success are Closed Loop No Processing and Regional Processing,** where equipment barriers can easily be overcome. Tied to these demonstrations needs to be a parallel public policy effort to establish incentives for all environmental benefits of grass thermal energy, including a thermal renewable energy incentive and a non-point source water pollution incentive. Adopting these incentives will help solve some critical issues facing Vermont's economy, including high energy costs, environmental threats to Lake Champlain and sustaining agricultural production.

The Wilson Engineering team believes **a grass thermal energy economy is viable in Vermont but it must take advantages of all environmental benefits.** Creating a "win-win" scenario allows Vermont farmers to keep farming, and at the same time create new, innovative, viable and profitable business models. We believe it is possible for the waters of Vermont to stay safe and pristine for drinking and recreation and for the end users of grass energy to know they are contributing to the growth and development of a safe and healthy economy, while also saving substantial dollars on their utility bills and keeping Vermont energy dollars in the local economy.

REFERENCES

1. Alexander, L. and Conroy, A. "Biomass, Nitrogen, and Ash Content in Switchgrass on Big Blue Stem in Northwestern Pennsylvania." Prepared for Allegheny College Center for Environmental and Economic Development. Downloaded from http://ceed.allegheny.edu/publications/20084_switchgrass_bio_nitro_ash_Oct08.pdf November 2013.
2. Bakker, R.R., and Eberson, H.W. (2010)"Managing Ash Content and Quality in Herbaceous Biomass: An Analysis from Plant to Product." *Journal of Plant Nutrition and Food Science* 173.1. Downloaded from http://www.wageningenur.nl/en/Publication-details.htm?publicationId=publication-way-333431333131
3. Bootle, J. 2013. "Crop Biomass Establishment and Production." Prepared for State of Vermont Agency of Agriculture, Food and Markets.
4. Bosworth, S., Kelly, T. 2013. "Evaluation of Warm Season Grasses for Biomass Potential in Vermont 2009 – 2012" Prepared for University of Vermont Extension. Downloaded from http://pss.uvm.edu/vtcrops/articles/EnergyCrops/Vermont_WSG_Biomass_Report4.2013revised.pdf
5. Bosworth, S. February 2013 "Establishing Warm Season Grasses for Biomass Production." Prepared for University of Vermont Extension. Downloaded from http://pss.uvm.edu/vtcrops/articles/EnergyCrops/Establishing_Warm_Season_Grasses_Biomass_Production_UVMEXT.pdf on
6. Bosworth, Sid (Plant and Soil Science Department, Extension Agronomist, University of Vermont). October 2013. Personal communication regarding research trends and projects for feedstocks in Vermont.
7. Carlisle, Mark. (Biomass Energy Works). September 7, 2013. Personal communication regarding current state of grass thermal energy in the Northeast and progress on development of a pellet stove to burn grass pellets by Biomass Energy Works.
8. Cherney, J. "Combustion Technology Issues."
9. Cornell University Cooperative Extension. "Grass Pellet Combustion – Summary of NYS Studies" Bioenergy Information Sheet #30. (2014) Downloaded from http://grassbioenergy.org/downloads/Bioenergy_Info_Sheet_30.pdf January 2014.
10. Cornell University Cooperative Extension. "Ash Content of Grasses for Biofuel" Bioenergy Information Sheet #5. (2014). Downloaded from http://forages.org/bioenergy/downloads/Bioenergy_Info_Sheet_5.pdf January 2014.
11. Dantzscher, Adam (Renewable Energy Resources Inc.). September 13, 2013. Personal communication regarding state of grass thermal energy in Vermont and RER, Inc. efforts in developing grass energy thermal projects and densifying grass for thermal energy.
12. Davis, Chris (Meach Cove Farms). December, 2013. Personal Communication regarding installation of grass densifying and combustion equipment at Meach Cove Farm.
13. El-Nashaar, H.M., Banowetz, G., et.al. "Genotypic Variability in Mineral Composition of Switchgrass" (2009). *Publications from USDA-ARS / UNL Faculty*. Paper 241.Downloaded from http://digitalcommons.unl.edu/usdaarsfacpub/241 November 2013.

14. Ernst, Calvin (Ernst Conservation Seeds). Multiple dates August – December 2013. Personal Communication regarding operation of Ernst Biomass, LLC pellet plant and alternative markets for switchgrass pellets.
15. Ernst, C. "Switchgrass Budget for Biomass Production." Prepared for Penn State Extension.
16. Follett, R., Vogel, K, et.al. "Soil Carbon Sequestration by Switchgrass and No-till Maize Grown for Bioenergy" (2012). Publications from USDA-ARS / UNL Faculty. Paper 1070. Downloaded from http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=2075&context=usdaarsfacpub January 2014
17. Griswold, J. (CEO Aloterra). Multiple dates August – December 2013. Personal communication regarding the feedstock Giant miscanthus.
18. Hansen, E.M., Christensen, B.T., Jensen, L.S., Kristensen,K., "Carbon Sequestration in soil beneath long-term Giant miscanthus Plantations as Determined by ^{13}C Abundance." Biomass and Bioenergy 26 (2004) 97-105.
19. Hill, E. May 2012. "Cows, Corn and Cash: Lake Champlain Water Quality Studies Net Frustrations." Download from http://www.vtdigger.org
20. Lee, K.H., Isenhart, T.M., Schultz, R.C. "Sediment and Nutrient Removal in an Established Multi-Species Riparian Buffer." *Journal of Soil and Water Conservation* 58.1 (2003): 7-8. Downloaded from http://www.nrem.iastate.edu/class/assets/For460_560/Managing%20AFS_hydrological%20functions/Lee%20et%20al_2003.pdf
21. McCardle, Matt (MESA Reduction Engineering & Processing, LLC). November, 2013. Personal Communication regarding experiences with densifying grass and agricultural residue for thermal energy projects.
22. Miller, Bob (Enviro Energy, LLC). September 6, 2013. Personal Communication regarding views on grass energy future in the Northeast and Enviro Energy's experience manufacturing and marketing grass pellets for thermal energy
23. Mitchell, R., Vogel, K., August 2013 "Sustainable Production of Switchgrass for Bioenergy in the Great Plains and Midwest." Prepared for Central East regional Biomass Research Center. Downloaded from http://conferences.igb.illinois.edu/bioenergyfeedstocks/sites/conferences.igb.illinois.edu.bioenergyfeedstocks/files/upload/Mitchell.pdf August 2013
24. Moore, Julie (P.E. Stone Environmental). November 2013. Personal communication regarding nutrient management plan for Lake Champlain.
25. Patterson Correspondence, see Appendix 1
26. Samson, R., Lem, C., et.al. "Developing Energy Crops for Thermal Applications: Optimizing Fuel Quality, Energy Security and GHG Mitigation" 2009. Downloaded from http://link.springer.com/chapter/10.1007/978-1-4020-8654-0_16# January 2014
27. Sprague, A., et.al. "Pelletizer Interim Assessment" (2012). Prepared for SOAR Vermont Tech. Downloaded from http://pss.uvm.edu/vtcrops/articles/EnergyCrops/VTC_Pelletizer_Interim_Assessment_7.24.12.pdf January 2014

28. Thomas, Bob (Hudson Valley Grass Energy). November 2013, Personal Communication regarding experience and status of mobile pellet mill projects in NY and PA.

29. USDA. "CropScape – Cropland Data." National Agricultural Statistics Service. Webpage downloaded from http://nassgeodata.gmu.edu/CropScape/ January, 2014

30. University of Vermont Extension. March 2013. "Evaluation of Warm Season Grasses for Biomass Potential in Vermont 2009-2012." Downloaded from http://pss.uvm.edu/vtcrops/articles/EnergyCrops/Vermont_WSG_Biomass_Report4.2013revised.pdf

31. US Energy Information Administration July 2012 http://www.eia.gov/state/?sid=VT

32. Wilson, T., McNeal, F., Spatari, et.al. "Densified Biomass Can Cost-effectively Mitigate Greenhouse Gas Emissions and Address Energy Security in Thermal Applications." Department of Agricultural Economics and Rural Sociology, The Pennsylvania State University (2011)

33. Vermont Grass Energy Partnership. January 2011 "Technical Assessment of Grass Pellets as Boiler Fuel in Vermont." Prepared for Vermont Grass Energy Partnership. Downloaded from http://www.vsjf.org/assets/files/RFPs/VT%20Grass%20Pellet%20Feasibility%20Study%202010.p

34. Penn State University Agricultural Research and Cooperative Extension. Renewable and Alternative Energy Fact Sheet. "Manufacturing Fuel Pellets from Biomass" Downloaded from http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CCYQFjAA&url=http%3A%2F%2Fpubs.cas.psu.edu%2FFreePubs%2Fpdfs%2Fuc203.pdf&ei=jczyUuniOcHXyAGZ94GwBQ&usg=AFQjCNE24WeSr7NGM4cmdWSVO9Uityx_zg&bvm=bv.60799247,d.aWc January 2014

35. Jacobson, M., Marrison, D. Helsel, Z., et. al., "Giant miscanthus Budget for Biomass Production." Prepared for Penn State Extension. Downloaded from http://sustainability.uiowa.edu/assets/Biomass-Fuel-Project/Giant miscanthus-information/Pen-State-Extension.pdf January, 2014.

36. Ernst, C., NEW-Bio "Switchgrass Budget for Biomass Production." Prepared for Penn State Extension. See Appendix 2.

APPENDIX A

Correspondence from Paul Patterson

Professor of Poultry Science, Pennsylvania State University

Hi John,

I wanted to follow up with you to see about some plant materials for our cooperator farms for the research/demonstration project. We have used giant miscanthus and other vegetation before to capture odor, NH_3 and dust (EPA regulated particulates) and viruses leaving poultry farms. We also have used the biomass species including giant miscanthus, poplar and willow as bedding, and then burned this litter as a fuel on farm in place of propane. We now have 3 commercial farms burning litter, but wanted to continue this work to document the riparian benefits of vegetation improving water quality leaving poultry and livestock farms. So any help with giant miscanthus for our demonstration/research farms would be helpful. We have 10 cooperators and would like utilize about ½ acre of giant miscanthus plugs on these sites around fans etc. Thank you for considering this request,

Sincerely, Paul

References:

Patterson, P.H. and A. Adrizal. "The Role of Vegetative Buffers." *Midwest Poultry Federation* Convention Proceedings. (2008) 22pp. CD.

Patterson, P. H., Adrizal, R.M. Hulet, R.M. Bates, C.A.B. Myers, G. P. Martin, R. L. Shockey, and M. van der Grinten.. "Vegetative Buffers for Fan Emissions from Poultry Farms: 1. Temperature and Foliar Nitrogen." *Journal of Environmental Science & Health-Part B.* 43 (2008): 199-204 Print.

Adrizal, P.H. Patterson, R.M. Hulet, R.M. Bates, C.A.B. Meyers, G.P. Martin, R.L. Shockey, M. van der Grinten and J. Thompson. "Vegetative Buffers for Fan Emissions from Poultry Farms: 2. Ammonia, Dust, and Foliar Nitrogen." *Journal of Environmental Science & Health-Part B*. 43 (2008): 96-103 Print.

Patterson, P.H., Adrizal, R.M. Hulet, R.M. Bates, D.A. Despot, E.F. Wheeler, and P.A. Topper. "The Potential for Plants to Trap Emissions from Farms with Laying Hens: 1. Ammonia." *Journal of Appl. Poultry Res*. 17 (2008): 54-63 Print.

Adrizal, P.H. Patterson, R.M. Hulet, R.M. Bates, D.A. Despot, E.F. Wheeler, and P.A. Topper and J. Thompson "The Potential for Plants to Trap Emissions from Farms with Laying Hens: 2. Dust and Ammonia." *Journal of Applied Poultry Research.* 17 (2008): 398-411 Print.

*Hulet, R. M., P. H. Patterson, T. L. Cravener and T. A. Volk. "Alternative Bedding for Broilers: From Vegetative Buffers to Fuel." *Poultry Science.* 89 Suppl 1. Print.

*Burley, H. K., A. Adrizal, P. H. Patterson, R. M. Hulet, H. Lu, R. M. Bates, G. P. Martin, C. A. B. Meyers, and H. M. Atkins "The Influence of Vegetative Buffers on Reducing Dust and Virus Transmission from Commercial Poultry Farms." *Proceedings: 81st Northeastern Conference on Avian Diseases.* (2009): Print.

Burley, H. K., A. Adrizal, P. H. Patterson, R. M. Hulet, H. Lu, R. M. Bates, G. P. Martin, C. A. B. Myers, and H. M. Atkins. "The Potential of Vegetative Buffers to Reduce Dust and Respiratory Virus Transmission from Commercial Poultry Farms." *Journal of Applied Poultry Research.* 20 (2011): 210-222 Print.

Patterson, P. H "Vegetative Buffers for Poultry Farms: "What Can They Really Do?" University of Md. Coop. Ext. *Poultry Perspectives*. 9(2009): 13 pages Print. Fall, R. Angel, and J. Timmons, eds.

Patterson, P., M. Hulet, T. Cravener, M. Hile and E. Wheeler.. "A Comparison of Pine Shavings vs. Chopped Willow as Bedding for Rearing Broiler Chickens." *Poultry Sci*ence. 91 Suppl 1 M71 (2012): Print.

Paul H. Patterson
Professor of Poultry Science
The Pennsylvania State University
Department of Animal Science
213 Henning Building
University Park, PA 16802-3501

APPENDIX B

Switchgrass Budget for Biomass Production

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SWITCHGRASS BUDGET FOR BIOMASS PRODUCTION

Switchgrass (*Panicum virgatum*), a perennial warm-season grass, is an excellent crop for soil and water conservation, wildlife habitat and more recently as feedstock for bioenergy. This fact sheet provides an enterprise budget for growing switchgrass as a dedicated energy crop. The objective is for growers to understand the inputs, costs, and potential revenues involved in cultivating switchgrass. An example budget is described, but b because each situation is different and prices can vary, a spreadsheet is available at extension.psu.edu/naturalresources/energy/field-crops/resources for adjusting inputs and prices to individual conditions. The scenario provided in this fact sheet is based on growing the crop in Pennsylvania. All quantities and prices are on a per-acre basis. The costs are based on farm custom rates published by Ohio State and Penn State Extension. The budget is based on a 15-year timeline. This fact sheet does not discuss transportation costs of harvested switchgrass from the field to processing facility, which will vary from site to site.

Soil Test

The first step is to evaluate the land quality for growing switchgrass, which includes a soil test. Switchgrass grows in moderately well drained or better soil with a pH of 5.5-7. It can also tolerate low pH levels, as well as low levels of nitrogen and phosphorus. A standard soil test is recommended to determine the nutrient availability for switchgrass establishment. The test is generally done based on a grid sampling of five-acre units every three years. Ignoring the cost for collecting the sample, on a per-acre basis, and assuming $15 per soil test, testing will cost $3 per acre in year 1 (establishment year) an average of $1 per acre for each year thereafter.

Site Preparation

The amount of work needed to prepare a site varies depending on the previous land use. If the growing site is already in crop production, there should be minimal site preparation. For land that has been fallow, clearing undesirable brush with a standard brush mower will cost about

$10 per acre. Next, the land should be plowed with a moldboard plow at a one-time cost of around $19 per acre. After plowing, the land most likely will require two disking passes and two soil finishing passes, at costs of roughly $28 per acre and $29 per acre, respectively.

Soil Amendments

Because it is adapted to many soil conditions switchgrass does not usually need significant amounts of soil amendments if it is allowed to fully mature and dry down before harvest. Nitrogen, phosphorus, potassium, and line requirements, as recommended by research at Penn State are as follows. Fertilizer application is charged at an annual cost of $7 per acre.

Nitrogen fertilizer is typically applied at about 10 pounds per ton of biomass after establishment and during the first year of harvest. As the yield increases, these costs will increase. Based on the assumption of yields in this scenario, the first application costs $28 per acre, increases to $42 per acre by year 4, and so on.

Phosphorus is typically applied at 4 pounds per ton of biomass (by soil test recommendation) 6 months before planting and each harvest season thereafter. As the yield increases, these costs will increase. Based on the assumption of yields in this scenario, the first application in year 2 costs $13 per acre, increases to $18 per acre by year 4, and so on.

Potassium is typically applied at 15 pounds per ton of biomass (by soil test recommendation) 6 months before planting and each harvest season thereafter. As the yield increases, these costs will increase. Based on the assumption of yields in the scenario, the first application in year 2 costs $36 per acre, increases to $50 per acre in year by year 4, and so on.

Lime, if needed, is generally added 6 months prior at 4 tons per acre for about $152 per acre, and then at 2 tons per acre every fourth year, which annualized is about $18 per year. This includes application costs.

Note: If harvest is delayed until after November, some of the fertilizer nutrients may have either leached to the soil or returned to the stem base or roots. This will likely reduce fertilizer needs for the following year thus making Switchgrass production more economical.

Planting

Switchgrass is planted by seed. About 10 pounds of pure live seed (PLS) per acre should be used. The assumed price per PLS is about $6 depending on the vendor. Total seed cost is about $60 per acre. Seeds are planted with a drill with a custom rate cost of about $19 per acre.

Weed Control

Weed management during the planting season is crucial for establishment as the crop is sensitive to weed competition. An initial burn down with 32 ounces of glyphosate should be applied in sufficient time prior to land preparation to kill perennial and other problem weeds costing an estimated $7 per acre. A post emergence herbicide using 8 ounces of quinchlorac is also suggested during the establishment year at a cost of about $23/acre and in year two 2,4-D may be needed to kill any winter annuals at a cost around $3 per acre. The sprayer cost for the three passes discussed above is conservative $7/acre per spray = $21.

Maintenance Costs

As mentioned above, some fertilizer applications are made over time as needed. By year 3 there should be no need for more herbicides because the grasses shade out the weeds. Currently no pests are found to significantly damage switchgrass performance.

Harvesting Costs

Switchgrass can be harvested in year 2 and every year thereafter. However, in year 2 only 70 percent of the yield is achieved (5 tons per acre); and in full production, year 3 and thereafter 7 tons per acre is expected. Traditional hay mowing and baling equipment is used. Mower/conditioning will cost around $13 per acre per year. Baling, assuming 15 percent moisture in the grass and a weight of 1,200 pounds per bale, costs about $82 per acre at full yield (i.e., to bale 7 tons). Baling costs are lower in the first year because yield per acre is lower.

Yield and Revenues

Switchgrass is expected to yield an average of about 7 dry tons per acre per year. At an assumed farm-gate price of $45 per dry ton for a mature yield of 7 tons per acre, annual revenue would be $315 per acre per year. There is no revenue in the first year. In the second year, we assume that only 70 percent of the yield, or 5 tons per acre, is achieved, for revenue of $225 per acre.

The last columns of the spreadsheet show the total costs, revenues, and present value of each item. The total costs over 15 years are estimated to be $3,504 per acre while total revenues are estimated at $4,320 per acre. Net revenue is $816 per acre for the 15-year budget period. The payback period – which tells investors how long it will take for revenues to cover establishment costs – is five years, using the financial assumptions in this scenario.

Since this project occurs over a 15-year period you need to account for the time value of money to get an accurate value. Money received in future years are not worth as much as in earlier years. The time value of money is reflected in a interest (discount) rate used by investors. This allows investors to compare alternative projects over same lifetime, especially since there are other uses for the land (i.e. opportunity costs). To account for future values, revenues and costs not received today are "discounted" to the present, hence net present value (NPV). If the NPV is positive, it implies that investors receive at least their acceptable rate of return (discount rate). The NPV in this scenario, using a 4 percent rate is $517 per acre. This NPV would obviously change if the discount rate, project length, and the cost and revenues were changed. Annualizing the NPV gives us an equal annual income (EAI) value of $46. The EAI compared to an annual rental on the land expresses NPV as an annual return, so it can, for example, be a good investment.

Summary

Switchgrass is one of the faster-growing warm-season grasses and has relatively lower establishment and maintenance costs than other energy crops. The five-year payback period can be shortened, especially if cost-share monies are available for planting costs and prices or yields per ton are higher. Switchgrass has other economic impacts on the whole farm operation. It has been used for summer grazing for livestock, particularly when cool season grass production slows during hot dry summer periods. It is an excellent grass to reduce soil and water erosion and for improved wildlife habitat. Management for these opportunities may reduce biomass energy yields but there are USDA programs that may be used to support such conservation options. Carbon sequestration is another potential benefit of Switchgrass which may produce "carbon credits".

Switchgrass Budget 2013		QTY	Unit	Price/Unit	Yr 1 (Establishment)	Yr 2	Yr 3	Yr 4-15	Total	Present value
			SELECT CASH EXPENSES							
Plant Material										
	Seed	10	10lbsPLS/A	$6.00	$60	$0	$0	$0	$60	$60
Soil Fertility										
	Nitrogen[1]	10	lb/expected ton per acre	$ 0.56	$ -	$ 28.00	$ 39.20	$ 39.20	$ 537.60	$ 403.00
	Phosphorus[1]	4	lb/expected ton per acre	$ 0.63	$ -	$ 12.60	$ 17.64	$ 17.64	$ 241.92	$ 181.00
	Potassium[1]	15	lb/expected ton per acre	$ 0.48	$ -	$ 36.00	$ 50.40	$ 50.40	$ 691.20	$ 519.00
	Fertilizer application[2]	annually	per acre	$ 7.00	$ -	$ 7.00	$ 7.00	$ 7.00	$ 98.00	$ 74.00
	Lime[3]	see inputs	ton	$ 38.00	$ 152.00	$ 17.54	$ 17.54	$ 17.54	$ 397.54	$ 337.00
	Soil Testing[4]		per soil test	$ 15.00	$ 3.00	$ 1.00	$ 1.00	$ 1.00	$ 17.00	$ 14.00
Weed Control										
	Burn-Down[5]	32 ounces	acre	$ 6.50	$ 6.50	$ -	$ -	$ -	$ 6.50	$ 7.00
	Post-emergence[6]	8ounces	acre	$ 23.00	$ 23.00	$ -	$ -	$ -	$ 23.00	$ 23.00
	Post-emergence[6]	8oz	acre	$ 3.00	$ -	$ 3.00	$ -	$ -	$ 3.00	$ 3.00
	Sprayer-3 sprays	3	acre	$ 7.00	$ 14.00	$ 7.00	$ -	$ -	$ 21.00	$ 21.00
Establishment & Maintenance										
	Brush Mowing[2]	1	acre	$ 10.00	$ 10.00	$ -	$ -	$ -	$ 10.00	$ 10.00
	Moldboard Plow[2]	1	acre	$ 18.20	$ 18.00	$ -	$ -	$ -	$ 18.20	$ 18.00
	Disking- 2 passes	2	acre	$ 13.70	$ 27.00	$ -	$ -	$ -	$ 27.40	$ 27.00
	Soil Finish- 2 passes[2]	2	acre	$ 14.20	$ 28.00	$ -	$ -	$ -	$ 28.40	$ 28.00
	Drill[2]	1	acre	$ 19.00	$ 19.00	$ 2.00	$ -	$ -	$ 21.38	$ 21.00
Harvesting										
	Mowing/conditioning[2]	1	acre	$ 13.00	$ -	$ 13.00	$ 13.00	$ 13.00	$ 182.00	$ 137.00
	Baling- Lg round[2&7]	11.67	bale	$ 7.00	$ -	$ 58.00	$ 82.00	$ 82.00	$ 1,120.00	$ 840.00
TOTAL CASH EXPENSES					$ 362.00	$ 186.00	$ 227.00	$ 227.00	$ 3,504.00	$ 2,724.00
REVENUES										
Biomass	Mature yield (estimation)	7	dry ton		$ -	$ 5.00	$ 7.00	$ 7.00	$ 96.00	
	Revenue Stream			$ 45.00	$ -	$ 225.00	$ 315.00	$ 315.00	$ 4,320.00	$ 3,241.00
REVENUE ABOVE EXPENSES					$ (362.00)	$ 39.00	$ 88.00	$ 88.00	$ 816.00	$ 17.00
EQUAL ANNUAL INCOME (Annualized over 15 years)										$ 46.00
BREAK EVEN PAYBACK PERIOD[8]										5 YEARS

Assumptions	
Interest Rate (%)	4%
Number of years of growth (YR 4-15)	12
Inputs	
Establishment lime (tons/acre)	4
Maintenance lime (ton/acre)	2
Weight of Bale (lbs)	1200

Footnotes:

[1]Based on 10#N, 4#P2O5, 15#K2O crop removal per ton of biomass

[2]Custom Rates from 2013 Penn State Extension & Ohio State Extension

[3]Based on 4 ton of lime per acre during establishment & 2 ton/acre every 4th year

[4]Grid sampling in 5 acre units, every 3 years (applied)

[5]32 o of flyphosate applied in sufficient time prior to plowing to control perennial & other serious weeds

[6]Post emergence with 8oz of quinchlorac in sestablishment year and 2,4-D in year 2

[7]Harvested at 15% moisture & the bale weight used was 1200#/bale

[8]Shows the discounted value over the production period.