VERMONT BIOENERGY INITIATIVE

A program of the Vermont Sustainable Jobs Fund

GRASS

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

ABOUT THE VERMONT BIOENERGY INITIATIVE

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

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

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

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

Learn more at

VERMONT BIOENERGY INITIATIVE

http://vermontbioenergy.com

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GRASS SUMMARY

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

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

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

1) Crop Production and Agronomic Research

2) Densification and Transportation Research and Development

3) Thermal Conversion and Economic Feasibility Research

4) Education and Outreach

These efforts have produced the following findings:

Crop Production and Agronomic Research

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

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

Densification and Transportation Research and Development

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

Renewable Energy Resources grass puck.

Thermal Conversion and Economic Feasibility Research

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

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

Educational and Outreach

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

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

THE OPPORTUNITY

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

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

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

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

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

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

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

STATEMENT OF PROJECT OBJECTIVES

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

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

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

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

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

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

Task E: Biomass — Feedstock Analysis & Production Techniques

SUB-TASK E.1: AGRONOMICS / RESEARCH

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

Sub-Recipients:

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

Staff Directed Projects:

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

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

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

SUB-TASK E.2: LOGISTICS / PRODUCTION

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

Sub-Recipients:

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

Staff Directed Projects:

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

SUB-TASK E.3 PROCESSING / DEMONSTRATION

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

Sub-Recipients:

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

TABLE 1: VBI GRASS BIOENERGY SUB-RECIPIENTS

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

Crop Production and Agronomic Research

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

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

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

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

Switchgrass at Borderview Farm (Alburgh, Vermont).

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

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

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

Switchgrass at Meach CoveFarm (Shelburne, Vermont).

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

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

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

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

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

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

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

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

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

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

—Dr. Sid Bosworth, University of Vermont Extension

Densification and Transportation Research and Development

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

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

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

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

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

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

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

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

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

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

BULK WOOD PELLET DELIVERY INVESTIGATION

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

Thermal Conversion and Economic Feasibility Research

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

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

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

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

Switchgrass clinker from Meach Cove Trust.

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

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

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

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

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

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

> “Receiving grant funding through the VBI from the U.S. DOE was instrumental in VFFC being able to afford to install a renewable energy biomass boiler in farmers’ hall. This installation, coupled with an onsite solar array, will enable VFFC to move forward on its goal to create a sustainable, resilient, and locally sourced energy footprint for our facility.
>
> Our goal is to turn local storm-damaged trees and meadow edges into a local source of fuel for the biomass boiler.”
>
> — **Greg Cox, Vermont Farmers Food Center**

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

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

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

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

The conclusions of this work indicate:

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

Economics — Cost of Production & Cost and Benefit Summary

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

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

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

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

Feedstock Costs

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

Densification Costs

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

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

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

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

Fuel Costs

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

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

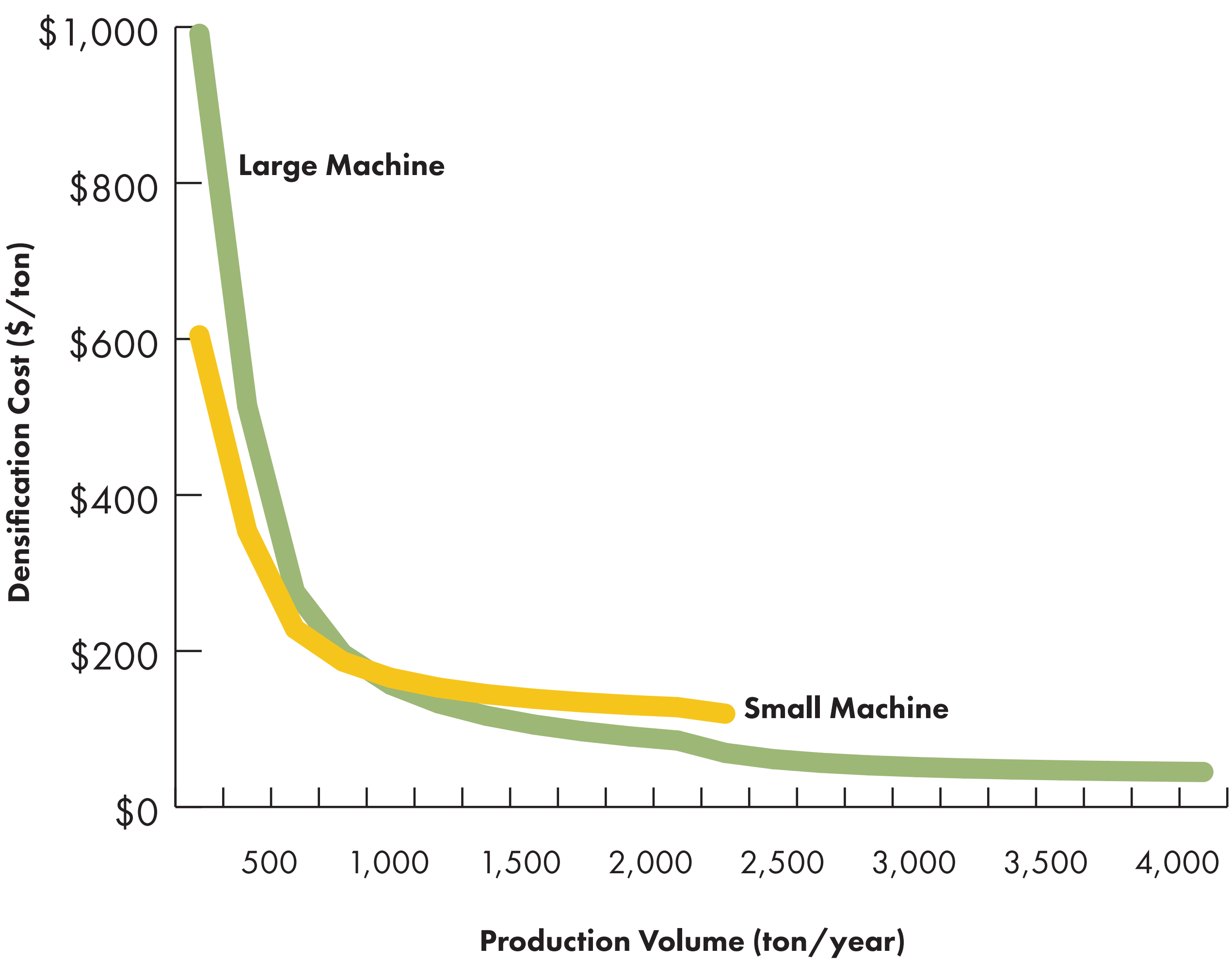


TABLE 4: COMPARISON OF FUEL COSTS IN NORMALIZED TERMS

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

Potential Fuel Savings

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

Appliance Premium

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

Cost / Benefit

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

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

RER biomass pucks bagged and ready for shipment.

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

— Chris Callahan, University of Vermont

Education and Outreach

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

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

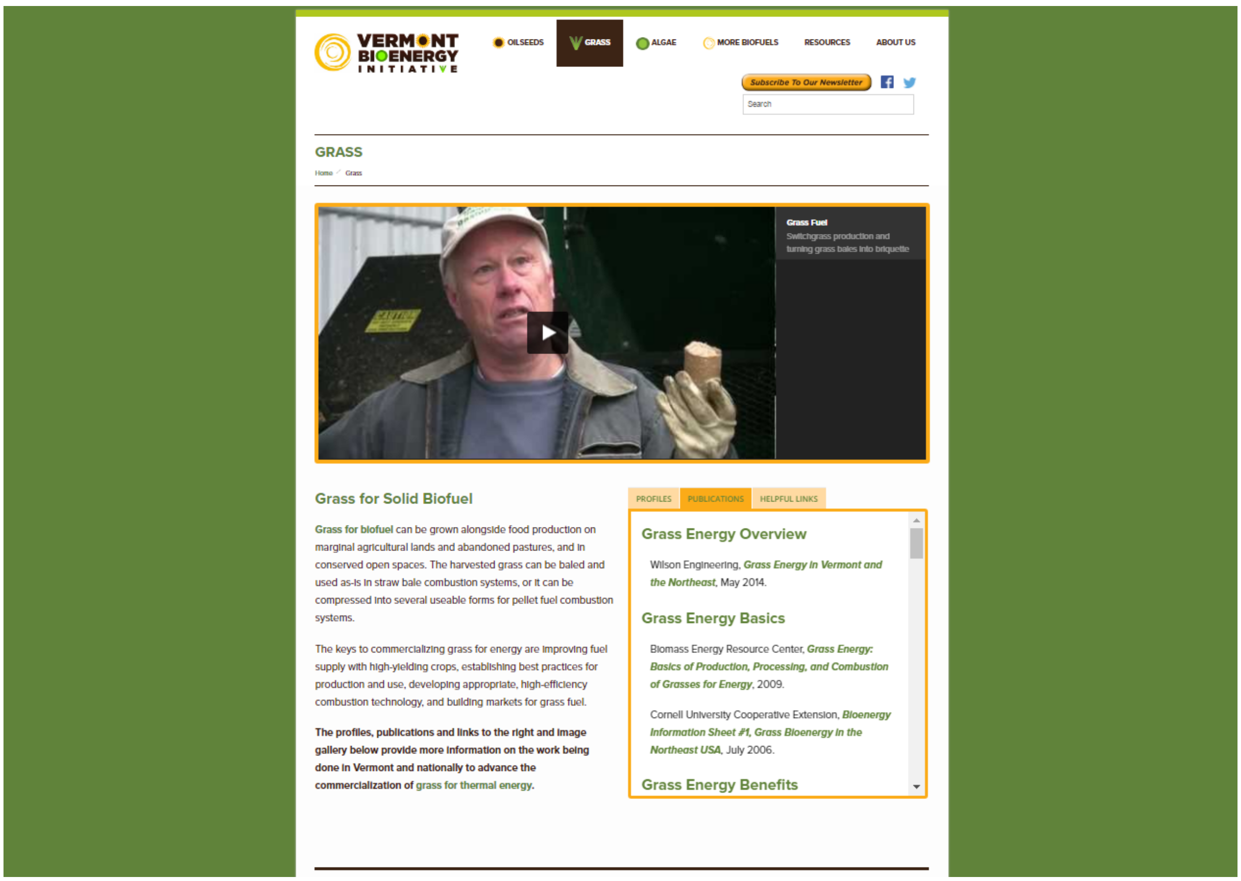
Question and answer session at the 2008 Grass Energy Symposium, Shelburne Farms, Vermont.

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

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

UVM Extension conducted several field days for grass production.

- VSJF staff worked with the **Northeast Biomass Thermal Working Group** for two consecutive years to expand panels and workshop offerings to include grass and agricultural biomass sessions in the regional Northeast Biomass Heating Expo and Conference. In 2013 there was a half-day dedicated regional conference held in Saratoga Springs, NY to explore the state of grass biomass.
- A variety of grass bioenergy resources—including reports, videos, links, and photographs—were compiled on the **Vermont Bioenergy Initiative** website. The **Grass Fuel video** made for the VBI's Bioenergy Now! series has been viewed over 12,000 times.



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

NEXT STEPS

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

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