Linking Nutrient Reduction Practices with Biomass Energy:

Quantifying Thermal Energy Demand and Supply Capacity for Representative Farms in Eastern Iowa

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A Report By:

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Acknowledgments

The Tallgrass Prairie Center at the University of Northern Iowa is a strong advocate of progressive, ecological approaches utilizing native vegetation to provide environmental, economic, and aesthetic benefits for the public good. The Center is in the vanguard of roadside vegetation management, native Source Identified seed development, and prairie advocacy. The Center primarily serves the Upper Midwest Tallgrass Prairie Region and is a model for similar efforts nationally and internationally.

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www.tallgrassprairiecenter.org

The Center for Energy and Environmental Education (CEEE) at the University of Northern Iowa helps children, youth, and adults make sense of complex environmental and energy-related issues while finding ways for the community to participate in positive, solution-oriented responses. The CEEE creates opportunities for UNI students and faculty to take leadership roles in creating more sustainable communities, and brings diverse stakeholders together to find common ground while working to solve problems. From know-how to do-now, the CEEE staff design community-oriented programs that focus on implementing what we already know.

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Luze Family Farm Corporation, Dysart, IA

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Swift Greenhouses, Gilman, IA

Wilson Farms, Cresco, IA

BMC Aggregates, La Porte City, IA

Pork and Plants, Altura, MN

Wilson Engineering, Montpelier, VT

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Image 0.1 Black swallowtail and bumble bee, a couple of the many pollinators attracted to prairie strips.

Executive Summary

The conservation practices of planting prairie strips on the agricultural landscape and covering unprofitable land back to natural areas have true potential to mitigate Iowa's soil erosion, water quality, and pollinator habitat problems. Although a number of "early adopters" have seen the long-term promise of this practice and planted prairie strips on their property, at this point widespread implementation has not yet been achieved. To get to that point, farmers will likely need a combination of incentives, and using aboveground prairie biomass as a heating fuel could be one such incentive that could make prairie strips start to make sense or more farmers.

Image 0.1 Biomass pellets, retrieved from Biomass Magazine.

Prairie biomass appears to have good potential to be utilized as a heating fuel for rural buildings such as greenhouses, workshops, and animal confinements. These buildings are mostly currently heated with propane, and although the price of propane is currently quite low, propane prices are subject to spike with little or no notice. Prairie biomass harvested from prairie strips would provide a stable energy source with little potential for price volatility.

Image 0.2 Tallgrass Prairie Center Staff member, Justin Meissen, planting a prairie strip on a farm near Cedar Falls, IA.

This report outlines options for prairie biomass harvesting, storage, processing, and conversion equipment, and it provides a payback period calculator to analyze a range of scenarios of biomass production and processing costs versus the cost of propane.

Introduction

According to the Iowa Nutrient Reduction Strategy, changing land use from row crops to perennial vegetation such as CRP or energy crops can reduce nitrate losses by 72-85% and phosphorus losses by a 34-75% in the area implemented (Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, Iowa State University College of Agriculture and Life Sciences, 2017). When placed strategically within the field, contour prairie strips reduce surface nutrient runoff as effectively, and for about the same cost as cover crops. While they do not carry the uncertainty of replanting every year, prairie strips reduce a landowner's options for switching crops or management techniques in response to market conditions. Increasing the number of farmers who adopt diverse, native perennial vegetation, will require attractive conservation incentives, viable economic uses, or some combination of both.

Economic uses of perennial vegetation will demand significant investment in infrastructure. There are two prominent options: cattle production and biomass energy. (Other more specialized options include the hunting/outfitter business and carbon markets). Cattle are no longer a common sight in many parts of Iowa, and it is unlikely that farmers will re-build the fences and barns that their fathers tore down. Biomass energy has been investigated (e.g. the Chariton Valley Project) and for the most part, rejected as an option in Iowa. Federal funding for renewable biomass energy development has focused on electricity or liquid fuel, e.g. cellulosic ethanol. Both involve large scale production, long-distance transport and energy-intensive processing. The net usable energy of biomass is greatly diminished by conversion to high quality, mobile forms. The scale of demand is incompatible with the scattered small patches of perennial vegetation which would be available as a byproduct of nutrient reduction efforts in the upper Midwest.

Perennial vegetation for biomass energy deserves another look in the context of Iowa's nutrient reduction and soil conservation efforts. Small areas of perennial vegetation used primarily to hold nutrients and build soil quality could serve as a source of energy for space heating in rural areas--currently dependent on liquid propane which is subject to major price swings. Direct conversion of biomass to thermal energy (heat) is the most efficient use for biomass fuels, capturing and using the maximum energy available. Furthermore, investment in biomass energy infrastructure could work in synergy with soil conservation practices. Once a landowner or cooperative has invested in densification and burner systems, the marginal cost to maintain or expand perennial vegetation in the landscape would decrease significantly.

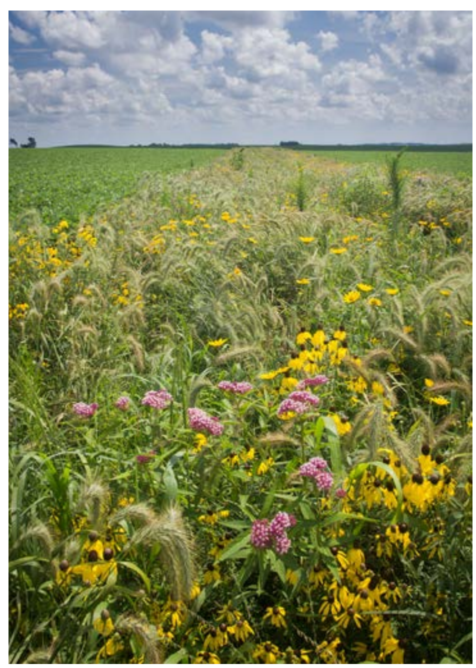

Image 1.1 High diversity prairie mix planted by the Tallgrass Prairie Center in Dysart, IA.

Section 1: Estimating/Modeling Biomass Energy Potential

A 2009 study by the U.S. Department of Energy entitled Simulating Potential Switchgrass Production in the United States (Thomson, et al., 2009) projected average annual productivity of switchgrass (Panicum virgatum) of 7.1 Mg/ha (3.16 tons/acre) in the Upper Mississippi Watershed. Data from the Tallgrass Prairie Center's Prairie Power Project (Abernathy et al., 2015) indicate that high diversity prairie mixtures (16- and 32-species mixtures) produce the same amount of biomass as a switchgrass monoculture on a range of soil types, so it is reasonable to assume that prairie strips that are planted in farm fields as a conservation practice could produce at least 3.0 tons/acre of harvestable above ground biomass.

Actual biomass production measured during the Prairie Power Project (hand clipped plots) averaged 3.67 tons/acre for switchgrass, 3.58 tons/acre for the 16-species prairie mixture, and 3.53 tons/acre for the 32-species prairie mixture. A 2009 study (Abernathy et al., 2015) assessing the discrepancies in biomass yield between clipped plot and field harvest concluded that field harvests yield an average of 60% of the biomass that is measured in clipped plots. Accounting for this discrepancy, expected average yields for the Prairie Power Project would have been 2.20, 2.15, and 2.12 tons/acre respectively, for switchgrass, the 16-species prairie mixture, and the 32-species prairie mixture if harvested by baling with traditional agricultural equipment. Several factors must be taken into account, however, when analyzing these figures. First, the Prairie Power Project plots were planted from seed in 2009, and then biomass production data were collected each year from 2010 to 2014. This time period includes two years of establishment when yields are lower than years when the prairie is at full maturity. Second, the research site is located in the floodplain near the Cedar River on land that is considered marginal for row crop production with a corn suitability rating of 50-79 (Natural Resource Conservation Service, 2016). Third, during the five years of the study, the site flooded extensively one year, it flooded moderately during another year, and the region experienced a significant drought during a third year. Considering the combination of these factors, it is assumed that biomass yields will be significantly higher in prairie strips that are planted in row crop agriculture fields and have grown to full maturity. These strips are strategically placed to intercept runoff which is laden with excess nutrients, and many strips will be located in fields with above average corn suitability ratings. So, although data does not yet exist for biomass production from prairie strips that are planted as a conservation practice, for the purposes of this study, we will assume that such prairie strips will produce a minimum of 3.0 tons per acre of harvestable biomass, and we will use this figure in all modeling calculations.

Image 1.1 Luze's 10 prairie strips including a diversity, pollinator, and economy mix planted by Prairie on the Farms in Dysart, IA.

Image 1.2 Tallgrass Prairie Center staff member, Greg Houseal, with recently extracted native grass root specimens.

Assuming a conservative management regime of harvesting biomass once every three years (with burning the second year and leaving fallow the third year), one acre of prairie would yield an average of 1.0 ton of biomass per acre per year. In order to always leave winter habitat for wildlife, this three-year rotation would best be implemented by harvesting one third of the total prairie acreage each year, burning one third, and leaving the remaining third fallow. Similarly, if fire is not used as a management practice, a two-year rotation of harvesting half of the prairie acreage each year and leaving the other half fallow would leave over-wintering wildlife habitat and would yield an average of 1.5 tons of biomass per acre per year. Harvesting all prairie biomass every year would yield an average of 3 tons of biomass per acre per year. Another permutation would be harvesting half of the prairie in the fall and harvesting the other half in the late winter/early spring. Biomass yield would be maximized in the half that is harvested in the fall while the half that is harvested in the spring would have a lower ash content. This scenario would optimize the balance of yield vs. fuel quality and would maintain winter cover for wildlife.

Image 1.3 A pheasant is a native bird to Iowa that makes its habitat in prairie strips. Image retrieved from Pheasants Forever.

Prairie biomass from the Prairie Power Project that was harvested, processed, and burned in a test burn at the Cedar Falls Utilities power plant had an energy content of 6561 BTU/lb (Cambardella, et al., 2015). Using this energy content as the basis for the calculations in this study and assuming an average yield of 3.0 tons of prairie biomass per acre per year, one acre of prairie that is planted as a conservation practice can reasonably be expected to provide an average of 39.4 MMBTU of energy per year.

Image 1.4 Prairie biomass combustion inside the Cedar Falls Utilities Power Plant boiler during Prairie Power Project test burn in 2013.

Section 2: Demand Case studies

Thermal energy needs in rural Iowa are almost exclusively met by liquid propane gas (LPG) (Iowa Department of Transportation, 2016). Therefore, a review of propane demand in Iowa serves as a proxy for an analysis of the thermal energy needs in rural Iowa.

Propane is used in Iowa for a variety of different purposes and varies by end user group. The primary end uses of propane in Iowa are agricultural (40%), residential (38%), and commercial (16%). Industrial, internal combustion, and portable cylinder end uses combined account for the remaining 6% of propane consumption in Iowa (Iowa Department of Transportation, 2016).

Residential space heating accounts for 49% of all residential propane consumption in the state (Iowa Department of Transportation, 2016). This application would present a significant opportunity for the introduction of alternative prairie biomass heating systems if appropriate and affordable biomass heating appliances were available. Currently, however, the limiting factor in the adoption of prairie or any other herbaceous biomass as a residential heating fuel is the EPA's New Source Performance Standards (NSPS) which are a part of the Clean Air Act. Residential heating appliances must be NSPS certified for the type of fuel that they are designed to burn. At this time, there are no residential scale heating appliances on the market that are NSPS certified to burn herbaceous biomass.

Agricultural uses of propane in Iowa include grain drying, weed control, fuel for farm equipment and irrigation pumps, and space heating in farm buildings for swine and other livestock. Agricultural propane use in Iowa is dominated by corn drying. This application could provide another potential opportunity for conversion to prairie biomass fueled systems, but there are no biomass fueled grain dryers that are commercially available today. Space heating in farm buildings for swine and other livestock could be a viable prairie biomass heating application due to the larger scale of heating demand, which closely matches appropriate biomass heating equipment that is commercially available today. Likewise, space heating of rural commercial buildings such as greenhouses or shop buildings could be another viable application for prairie biomass heating systems.

The seasonal pattern of demand for both livestock, greenhouse, and shop building space heating applications mirrors the seasonal pattern of demand for residential heating systems. This demand typically begins in October, rises steadily to a peak load in January, and then decreases almost linearly through the end of the heating season in April (Iowa Department of Transportation, 2016).

Given current economic conditions, i.e. artificially low prices of fossil fuels and relatively expensive biomass heating equipment, the most promising applications for rural space heating with prairie biomass as a feedstock appear to be livestock buildings or greenhouses. While propane prices are currently very low (around $1.00/gal. throughout the 2016/2017 winter months), price volatility and the threat of propane price spikes like that of January 2014 (peak price of approximately $4.70 per gal.) could potentially make prairie biomass heating an attractive option for owners of such buildings.

Image 2.1 Cedar Falls Utilities power plant.

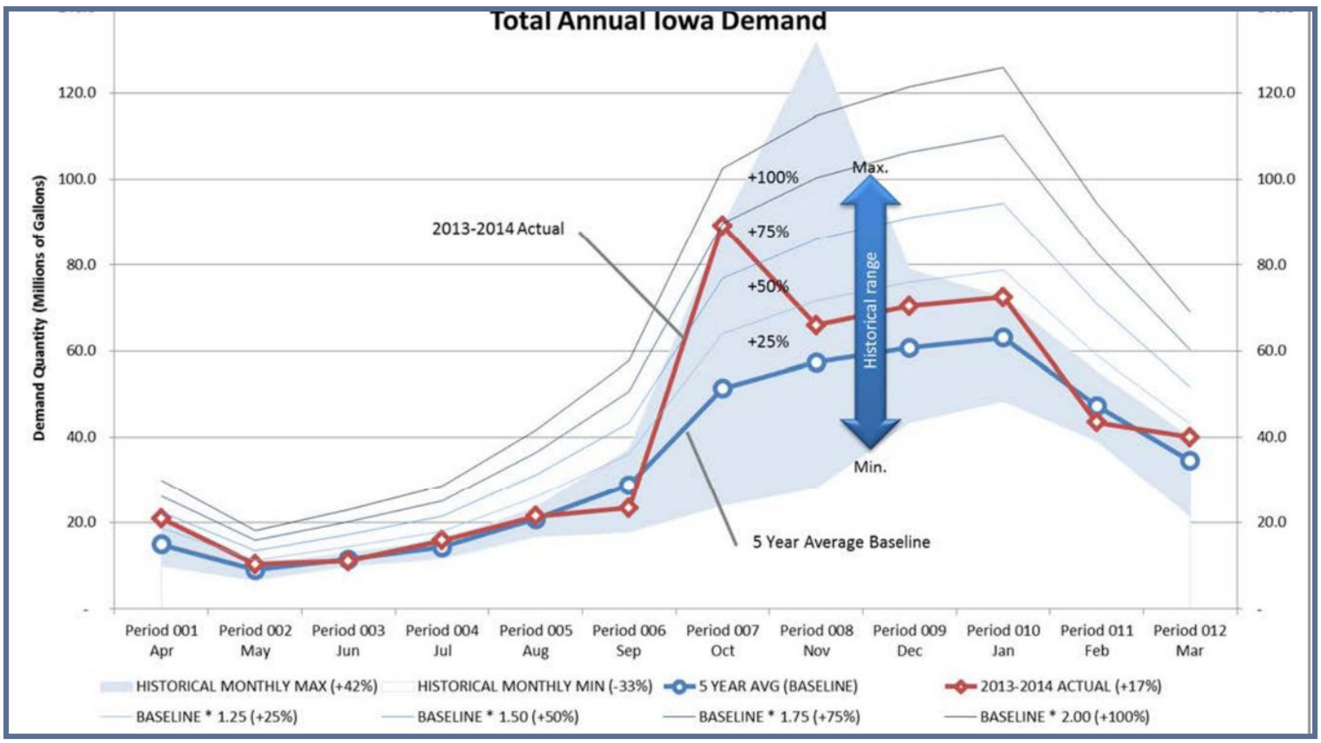

Image 2.2 Propane demand in Iowa, image retrieved from Iowa Department of Transportation.

Section 2: Demand Case Studies

The case studies on the following pages provide estimates of acres of prairie that would be needed to displace the rural facilities' current propane heating systems.

Table 2.1 Case studies for propane vs. priaire biomass

Case Studies: Propane vs. Praire Biomass	**Swift Greenhouses**	**BMC Aggregates**	**Wilson Farms**
Propane			
Total Gallons of Propane used per year	200,000	4,500	4,331
BTU/gallon	91,600	91,600	91,600
Appliance Efficiency	93%	80%	93%
Total Fuel MMBTU per season	18,320	412	397
Total MMBTU of Heat Delivered	17,038	330	370
Praire Biomass			
BTU per pound	6,963	6,963	6,963
Percent Ash	5.5%	5.5%	5.5%
Appliance Efficiency	80%	80%	80%
Total Tons of Prairie Biomass Required	1,529	30	30
Total Acres of Prairie Required	510	10	10
Total Tons Ash Produced	76.5	1.5	1.5

Case Study One: Swift Greenhouses - Gilman, IA

Swift Greenhouses has approximately 4.5 acres of greenhouse production space that is entirely heated by propane. The heating system consists of 45 units heating units that are 93% efficient. Some heating units are boilers and some units are forced air. Swift used approximately 200,000 gallons of propane over the 2015/2016 heating season, 205,000 gallons over the 2014/2015 heating season, and 215,000 gallons over the 2013/2014 season. The following table compares the current propane heating system to a prairie biomass heating system:

Table 2.2 Swift Greenhouses: Propane vs. Prairie Biomass	
Propane	
Total Gallons of Propane used per year	200,000
BTU/gallon	91,600
Appliance Efficiency	93%
Total Fuel MMBTU per season	18,320
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Total Tons of Priarie Biomass Required	1,529
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Total Tons Ash Produced	76.5

Image 2.3 Swift Greenhouses in Gilman, IA

Case Study Two: BMC Aggregates - La Porte City, IA

BMC Aggregates Waterloo South Quarry near La Porte City, Iowa, currently heats its 4,750 ft.2 shop with radiant propane tube heaters which are 80% efficient. This facility has used an average of approximately 4,500 gallons of propane per heating season over the last three years. The following table compares the current propane heating system to a prairie biomass heating system:

Table 2.3 BMC Aggregates: Propane vs. Prairie Biomass	
Propane	
Total Gallons of propane used per year	4,500
BTU/gallon	91,600
Appliance Efficiency	80%
Total Fuel MMBTU per season	412
Total MMBTU of Heat Delivered	330
Prairie Biomass	
BTU per pound	6,963
Percent Ash	5.5%
Appliance Efficiency	80%
Total Tons of Prairie Biomass Required	30
Total Acres of Prairie Required	10
Total Tons Ash Produced	1.5

Image 2.4 BMC Aggregates in La Porte City, IA

BMC Aggregates Waterloo South Quarry has a 4 acre prairie buffer strip that was planted as a part of the Tallgrass Prairie Center's Prairie on Farms Program. This buffer strip helps to treat runoff from row crop agriculture fields on the BMC property which flows into nearby Miller Creek. Miller Creek is designated as an impaired waterway and therefore its watershed has priority status for water quality project funding.

Case Study Three: Wilson Farms - Cresco, IA

Wilson Farms has four hog finishing buildings and one farm shop that are all heated by 93% efficient liquid propane forced air heaters. Building #1 (1000 hogs) is 8,568 square feet has three 225,000 BTU heaters. Buildings #2 and 3 (1000 hogs each) are each 8,200 square feet, and each have two 250,000 BTU heaters. Building #4 (500 hogs) is 3,960 square feet, and has two 60,000 BTU and two 150,000 BTU heaters. The farm shop is 2,310 square feet and has one 250,000 BTU heater. Total propane use to heat these five buildings was 4,048 gallons in 2016, 5,917 gallons in 2015, 5,333 gallons in 2014, and 6,025 gallons in 2013. For the purposes of this report, we will use the average propane use for these four years which is 4,331 gallons. The following table compares the current propane heating system to a prairie biomass heating system:

Table 2.4 Wilson Farms: Propane vs. Prairie Biomass	
Propane	
Total Gallons of propane used per year	4,331
BTU/gallon	91,600
Appliance Efficiency	93%
Total Fuel MMBTU per season	397
Total MMBTU of Heat Delivered	370
Prairie Biomass	
BTU per pound	6,963
Percent Ash	5.5%
Appliance Efficiency	80%
Total Tons of Prairie Biomass Required	30
Total Acres of Prairie Required	10
Total Tons Ash Produced	1.5

Image 2.5 Wilson Farms in Cresco, IA

Section 3: Biomass Harvest, Processing, Transport, and Storage

Prairie biomass that will be used as a heating fuel should be harvested after it has gone dormant in the fall. This can be done by field chopping and then bagging, or cutting and then baling the biomass. In Northeast Iowa, the appropriate time to harvest prairie biomass would basically coincide with the timing of corn and soybean harvest. Prairie biomass can be harvested and transported using traditional, locally available hay harvesting and transportation equipment. As moisture content is a big concern, harvested prairie should be protected from the weather and should be transported to the densification facility as soon as possible. If immediate transportation is not possible, bales or bags should be kept covered until they are transported to the densification facility. Once at the densification facility, bales should be stored under cover until they are processed.

Image 3.2 Bale of hay harvested by University of Northern Iowa's Biomass research group.

Image 3.1 Prairie biomass harvesting on University of Northern Iowa's campus natural areas.

Section 3: Biomass Harvest, Processing, Transport, and Storage

The National Wildlife Federation's report entitled Perennial Herbaceous Biomass Production and Harvest in the Prairie Pothole Region of the Northern Great Plains: Best Management Guidelines to Achieve Sustainability of Wildlife Resources (McGuire & Rupp, 2013), outlines the following harvest and storage management guidelines for balancing biomass production and wildlife habitat considerations:

Switchgrass bioenergy Best Management Practices (BMPs) and extension guidelines have been developed for most agro-ecoregions, but most BMPs for other native warm-season grasses have been developed primarily for grazing, haying, and conservation. Commercially available rotary-head harvesters and large round or rectangular balers can handle the volume of material in harvesting and baling operations in switchgrass fields producing 6—8 tons per acre. A cutting height of 4"maintains stands and keeps the windrows elevated to facilitate air movement and more rapid drying to less than 20% moisture content prior to baling. As previously mentioned, however leaving more than 10" is recommended to improve wildlife habitat and could increase yields the following year by capturing blowing snow and providing additional moisture to the stand.

The goal for biomass storage is to preserve the biomass so that it leaves the storage phase in the same condition that it entered storage. This requires the biomass to enter storage at low moisture levels (generally less than 18% is preferable) and to be protected from moisture during storage. Research is limited on dry matter (DM) losses during switchgrass storage but, in general, bales stored inside can be stored indefinitely with minimal DM losses (0 to 2%), regardless of bale type. However, when bales are stored outside, differences in bale type occur. Large round bales generally have less storage losses, whereas rectangular bales tend to be easier to handle and load on trucks or transport without road width restrictions. Storage losses were greater for tarped large rectangular bales than for tarped round bales. Tarped and untarped large rectangular bales had DM losses of 7% and up to 25%, respectively, after 6-months of storage in Nebraska. Large square bales can spoil from the top and bottom and lose DM rapidly. Wrapping big round bales with at least three wraps of net-wrap maintains the structure of the bale and reduces bale contact with the ground and tarping reduces dry matter loss to less than 3% in 6-months. Improper storage not only results in DM losses, but can change the compositional characteristics of the biomass. For a detailed review on harvest and storage management, see Mitchell and Schmer (Mitchell, Vogel, & Schmer, 2016).

However, an alternative that can provide wildlife benefits is to postpone harvest and temporarily store mature biomass in the field. Depending on the length of time that harvest is deferred, there may be some loss of material (yield or quality) but native warm-season grasses tend to be resistant to lodging and loss. In-field storage of mature, standing biomass can provide wildlife benefits even if only on a portion of the field and for a few months. In this case, harvest could occur after snow melt when the ground is still frozen, but prior to the early nesting season (~April 1st). Given the challenges of springtime weather in the Upper Midwest, however, greater benefits may accrue if some biomass could be stored in the field until the end of the following growing season. At that time, it could be harvested with new growth and the 'standing-storage' approach could be rotated to a different area. According to Harper and Keyser (2008), deferring as much as 50 percent of a field each year and harvesting on a biennial basis would not amount to losing 50 percent of the field each year because much of the yield from Year One is still present in the field when harvested at the end of the second growing season. In addition, letting biomass over-winter and harvesting in spring reduces ash and protein concentrations even more, but research has indicated that yield can be reduced by up to 40%. How much yield would be impacted by waiting to harvest until the end of the second growing season is an area in need of further research.

Section 3: Biomass Harvest, Processing, Transport, and Storage

There are a couple of good resources for estimating the costs of prairie biomass production. The Iowa Nutrient Reduction Strategy's Decision Support Tool has a cost sheet for converting crop land to prairie as a conservation practice (Tyndall & Bowman, 2016).

Iowa State University Extension and Outreach's Ag Decision Maker provides a spreadsheet tool called To Grow or not to Grow: A Tool for Comparing Returns to Switchgrass for Bioenergy with Annual Crops and CRP that can be used to economically compare how well switchgrass will perform compared to current crop production systems. (Jacobs, Mitchell, Hart, 1016) These tools can help producers estimate the cost of producing prairie biomass, including the opportunity cost associated with not producing row crops on the land that is converted to prairie.

Section 4: Biomass Processing and Conversion Equipment

After baling, prairie biomass must be densified because the only biomass heating systems that are readily available in the United States that are capable of burning herbaceous biomass such as prairie require the biomass to be densified. Biomass briquetting is the most energy efficient biomass densification process. C.F. Nielsen is a leading manufacturer of biomass briquetting presses that are appropriate for densification of prairie biomass (C.F. Nielson).

Image 4.1 C.F. Nielsen's BP 6510, capacity: 1100-2300 kg/hr, image retrieved from C.F. Nielson's website.

EvoWorld biomass boilers have been successfully burning switchgrass briquettes in two demonstration projects in Vermont (Callahan, An Update on Solid Grass Biomass Fuels in Vermont, 2016) (Callahan, Biomass Boiler Installation at The Vermont Farmers Food Center, 2016). Another form of biomass densification is pelletizing. The pelletizing process is more energy intensive than briquetting, resulting in less net energy from the end product (Niedziolka & Szpryngiel, 2014), but pellets are considered superior to briquettes in a number of ways. Pellets are easily handled, they flow well, they have a long shelf life, and they can be sold for a variety of alternative end-uses. We will assume that prairie biomass will need to be densified into briquettes or pellets for use in any prairie biomass heating system that would potentially be installed in Iowa. The cost of densification is significant, so it is unlikely that individual producers or biomass heat end users will purchase, install, and operate their own densification equipment. It is more likely that agricultural cooperatives will purchase and install densification equipment and begin to provide the service of biomass densification to their customers, or that other regional densification businesses could develop. An example of such a business is CHIP Energy in Goodfield, Illinois: http://www.chipenergy.com/. CHIP Energy's Biomass Conversion Facility is an innovative recycling center that handles waste stream wood and paper, municipal brush, storm debris, and other local sources of biomass. The facility is capable of processing up to 100 tons per day of biomass, turning raw material into biomass fuel, mulch, and other products. Yet another possibility for biomass densification is that an entrepreneur could start a mobile pelletizing business that would produce pellets on-site for clients throughout a given region. Buskirk Engineering manufactures biomass pelletizing equipment including a fully contained "Mobile Pelletizing Unit" system that includes a round bale processor (tub grinder), a hammer mill, a conditioner, one or two pellet mills, a cooling conveyor, and a diesel generator all mounted on a 25' gooseneck trailer (Buskirkeng).

Image 4.2 Buskirk Engineering's Mobile Pelletizing Unit, image retrieved from Buskirk Engineering's website.

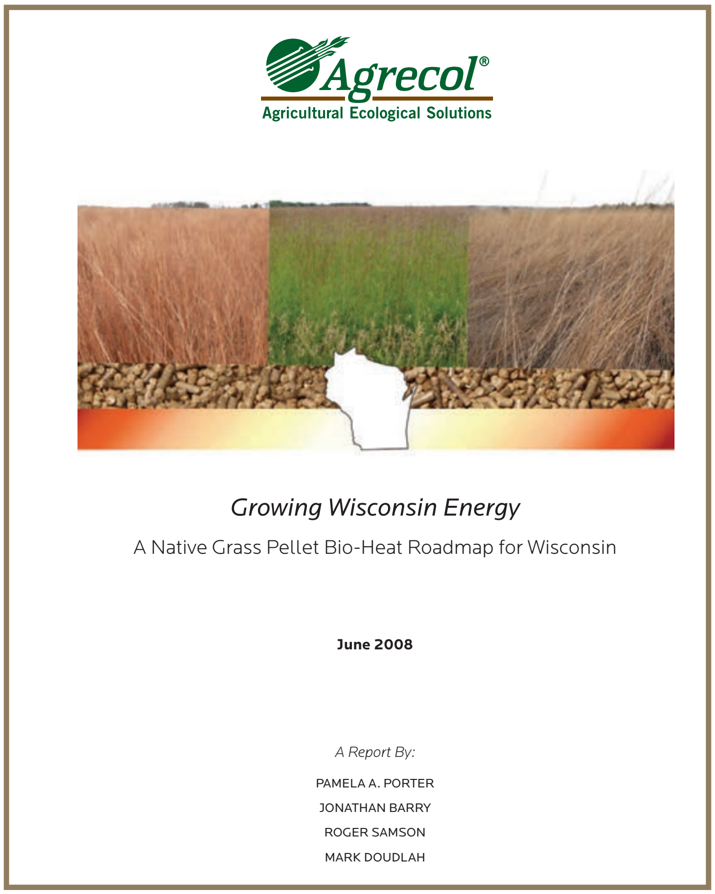
The cost of densification as briquettes or pucks has been estimated based on the experiences of Renewable Energy Resources in Vermont operating two scales of densifying machines (Callahan, 2016). The small machine uses two tubes and pistons and has a full load capacity of 700 lb/hr making 1.5” or 2” pucks. The large machine is made up of eight tubes and pistons and has a full load capacity of 4,000 lb/hr making 2” pucks. 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. This cost decreases with higher utilization (i.e. higher output of tons/year).

Table 4.1 Summary of grass fuel densification costs based on Renewable Energy Resources experience with two scales of processing machines. Reprinted with permission from Renewable Energy Resources.

	Small Machine	**Large Machine**	**Units**
Maximums			
Max Output	700	4,000	lb/hr
Max Operation	80	80	hrs/week
	50	50	weeks/yr
	0.8	0.8	uptime
Max Volume	1,120	6,400	ton/yr
Actuals			
Work Time	10	10	hr/day
Product Volume	7,000	4,000	lbs/day
	3.5	20	tons/day
Annual Volume	560	4,000	tons/year
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	4	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**
At volume of:	**560**	**4,000**	**ton/yr**
Fixed	**$25,096**	**$47,693**	**$/yr**
Variable	**$103**	**$38**	**$/ton**

The project in Vermont also produced very useful data on the relationship between densification costs (for producing biomass briquettes/pucks) and rate of production (Callahan, 2016). On their large machine, densification cost per ton began to level out at around 2000 tons/year and reached $45/ton at 4000 tons/year. On their small machine, densification cost per ton began to level out at around 1000 tons/year and reached $45/ton at 1500 tons/year. Note that these are densification costs only, net of feedstock.

The process and economics of pelletizing biomass is well described in Chapters 3 and 5 of a report by Agrecol Corp. entitled Growing Wisconsin Energy: A Native Grass Pellet Bioheat Roadmap for Wisconsin. (Porter, Barry, Samson, Doudlah, 2008)


Agrecol®
Agricultural Ecological Solutions

Growing Wisconsin Energy

A Native Grass Pellet Bio-Heat Roadmap for Wisconsin

June 2008

A Report By:

PAMELA A. PORTER
JONATHAN BARRY
ROGER SAMSON
MARK DOUDLAH

Image 4.3 Agrecol report on native grass biomass heating possibilities in Wisconsin

Penn State Extension also has an excellent fact sheet about manufacturing biomass pellets (Penn State). This fact sheet provides bulk density, energy content, and ash content for various biomass feedstocks.

Biomass Conversion Equipment

One of the most thoroughly field tested biomass boilers on the market in the United States that is capable of burning herbaceous biomass that has been densified into briquettes is manufactured by Troy Boiler Works in Troy, New York for EvoWorld of Austria. Renewable Energy Resources in Bennington, Vermont installed EvoWorld biomass boilers with great success in two projects in Vermont (EvoWorld). EvoWorld biomass boilers are available in sizes from 25kW (85,303 BTU/hr) to 500kW (1.706 million BTU/hr).

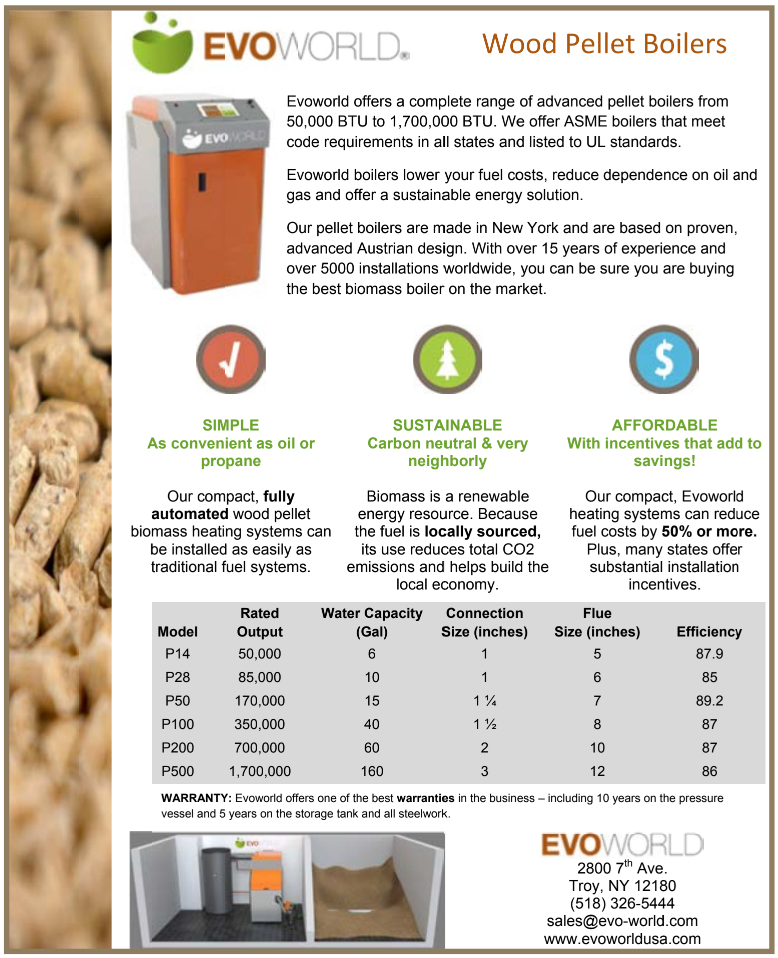


Image 4.4 EvoWorld biomass boilers

Perhaps the most important consideration that makes the EvoWorld boiler stand out above others is the fact that the company stands by its warranty when grass-based biomass is burned even though the boilers are designed for wood biomass. Another major concern with combustion of herbaceous biomass in boilers or furnaces is slagging (clinker formation) and fouling that are associated with the mineral content of the biomass. These issues have not been a problem in the two EvoWorld boiler installations in Vermont. EvoWorld boilers have a moving grate on which the fuel is combusted which breaks and removes clinkers.

Another option in biomass heating appliances is a forced air pellet furnace such as the A-Maiz-Ing Heat furnace by Nature's Renewable Products in Marshfield, Missouri: http://www.naturesrenewable.com/a-maize-ing/commercial/. These furnaces are much less expensive than boilers like EvoWorld's, and like EvoWorld, they will stand by their warranty when grass-based biomass is used as the fuel. The company claims that their NRP620-10 commercial model will effectively heat greenhouse spaces up to 7,000 square feet (A-Maize-Ing Heat, 2016).

Image 4.5 A-Maize-Ing Heatforced air biomass brochure

Researchers at Cornell University also tested several conversion appliances between 2005 and 2010. The results of their tests can be found at http://forages.org/index.php/grass-biofuels/research/demonstrations.

Payback Period Calculator

End users who are considering converting to a prairie biomass heating system will want to calculate the payback period for the system that they are installing. This period is dependent on a wide range of variables including the cost of the system, the facility's heating demand, the cost of producing prairie biomass fuel (which includes all costs associated with harvesting, densification, and transportation), and the cost of the fuel that is being displaced (presumably propane). The following Payback Period Calculator worksheet will be available on the Tallgrass Prairie Center website (url will be added when worksheet goes live). It is designed to assist a decision maker in calculating the payback period for a range of prairie biomass and propane prices given the cost of the new biomass heating system and the average annual amount of propane that is consumed in the facility for heating.

Table 4.2 Prairie biomass heating system payback period calculator

Prairie Biomass Heating System Payback Period Calculator

Biomass Heating System Cost	**500000**	$ in year 0
Annual Propane Use	**200000**	gal of propane
Annual Energy Use*	18320	MMBTU/yr
Annual Prairie Biomass Use**	1315.5	tons of prairie biomass
Acres of Prairie Needed***	1315.5	acres, if harvested once every 3 years
	877.0	acres, if harvested once every 2 years
	438.5	acres, if harvested once every year

		Propane							
Prairie Biomass		1	1.5	2	2.5	3	3.5	4	$/gal
$/ton	$/MMBTU	10.9	16.4	21.8	27.3	32.8	38.2	43.7	$/MMBTU
50	3.6	3.7	2.1	1.5	1.2	0.9	0.8	0.7	
75	5.4	4.9	2.5	1.7	1.2	1.0	0.8	0.7	
100	7.2	7.3	3.0	1.9	1.4	1.1	0.9	0.7	
125	9.0	14.1	3.7	2.1	1.5	1.1	0.9	0.8	
150	10.8	187.2	4.9	2.5	1.7	1.2	1.0	0.8	
175	12.6		7.2	2.9	1.9	1.4	1.1	0.9	
200	14.4		13.6	3.7	2.1	1.5	1.1	0.9	
225	16.2		124.8	4.8	2.5	1.6	1.2	1.0	
250	18.0			7.0	2.9	1.8	1.3	1.1	

Payback period table for different volumes of fuel use (i.e. heat load). The horizontal axis represents different different propane costs and the vertical axis represents different prairie biomass fuel costs. The balance of the table is the simple payback period in years for each combination of fuel prices given the biomass heating system cost and the annual propane use entered above the table in the blue cells.

- 0 to 5 years payback period
- 5 to 10 years payback period
- 10 to 15 years payback period

*based on 91,600 BTU/gal
**based on 6963 BTU/lb
***based on 3 tons/acre yield

Section 5: Examples of Successful Commercial Biomass Heating Projects

Pork and Plants – Altura, MN

Pork & Plants is a family owned and operated, organic certified farm, greenhouse plants, and pork business outside of Altura, MN. Eric Kreidermacher is a co-owner of the business who focuses on heritage animals and biomass energy. See the following video for more information on the biomass energy project which is officially a side-business called Alternative Energy Solutions, LLC: http://porkandplants.com/about-us/going-green/. (Link active as of November 2017)

Image 5.1 Pork and Plants in Altura, MN

In 2007, Eric planted 20 acres of prairie on previously row cropped land on his farm which he planned on harvesting and processing into pellet fuel to be burned in his biomass boilers that heat the business's greenhouses. Unfortunately, Eric says that the harvested prairie material did not work well as a biofuel feedstock. He thinks that one reason for this failure is the poor advice that he was given on what prairie seed mix to plant. He has torn out some of the prairie stand, and he is using the remaining prairie for grazing in an effort to shift more of his pasture from annuals to perennials.

Around the same time that Eric planted the original prairie, he purchased and installed pelletizing equipment that he is still operating today, albeit with a different feedstock that he originally set out to use. He now partners with Shooting Star Native Seeds, which is 60 miles away in Spring Grove, MN, to purchase the waste material generated from Shooting Star's seed production process. This material is baled and then transported to Pork & Plants. Eric also purchases sawdust from a sawmill in the area which he mixes with the seed production waste material to produce pellets. When Eric purchased the pelletizing equipment, he solicited guidance from a Minnesota organization called the Agricultural Utilization Research Institute (AURI) on the proper dies that should be installed in the pellet mills to make biomass pellets. Eric and his brother, who is an electrical engineer, have since tinkered with this equipment, made modifications and adjustments, added video equipment to make operation more manageable, and have settled on a rough ratio of 1 part seed production waste material to 1 part sawdust. Eric says that adding sawdust allows him to control moisture (15 to 16% moisture is optimal), and it keeps the ash content of the product down below 3%.

Image 5.2 Pork and Plants boiler

He says that he has tried to pelletize and burn every kind of feedstock that he could get his hands on over the years and this combination has worked best for him. He notes that agricultural residues are some of the worst feedstocks that he has tried. One huge problem with them is all of the foreign materials that find their way into the bales like metal objects and stones that can do damage to the pelletizing equipment. Another big problem is that these materials simply don't burn well. Eric notes that GMO corn stover is actually the worst burning material that he has ever tried.

Eric currently produces between 1,000 and 1,200 tons of pellets per year. This serves all of his greenhouse heating needs and he sells the rest to a hog farmer in the area who heats his hog building with the fuel. One of the pelletizers makes 1/4" pellets and the second one makes 5/16" pellets. Eric stated that he thinks that the 1/4" pellets bind the best. The process starts with a tub grinder that round bales of seed waste fit into. Then, he mixes ground seed waste material with sawdust in a hopper where it then passes through a ¼" screen, then to a mixer, then to the pellet mills, then to an air cooler, and then the pellets are conveyed pneumatically to a storage silo or directly to a truck or wagon. He noted that some pellet making processes have a pre-dryer, but his doesn't. He instead relies on mixing the right amount of sawdust with seed waste material to control moisture. Eric said that feed mills are basically the same type of equipment as his mills, but to produce biomass pellets they need different dies and ancillary equipment that are appropriate for biomass. Finally, Eric pointed out that these pellets can also be used as an adsorbent, so they could be marketed and sold as animal bedding, cat litter, etc.

Eric stated that his pellets will last as long as moisture is kept out of them. He said that dark colored bins cause condensation, so it is better to store pellets in light colored bins. Eric burns his pellets in three Pelco brand hot water boilers. Two of the boilers are 1.5 MBTU, and the third is 0.5 MBTU. These are simple, stoker boilers where the pellets are augered in from the storage tank, they burn on the center of a slowly moving circular grate, and the ash falls off of the periphery of the grate and is then convened into a nearby ash box. Twice a day, Eric opens the door on the side of the boiler and breaks up clinkers that form in the combustion area with a rod. The only other regular management of the system is to remove ash from the ash boxes when they are full.

Image 5.3 Pork and Plants boiler

Pork & Plants utilizes a radiant heat system to heat its greenhouses with the hot water produced in the Pelco boilers. From the boilers, water enters a 1000 gal. steel holding tank which acts as a heat sink to allow the boilers to run more regularly and hot water to be available more quickly during times when heating is necessary. The water is then distributed through lines that run through the greenhouse tables directly underneath the plants that are sitting on the tables. Eric has found this to be the most efficient type of distribution system for a greenhouse operation. He points out, though, that the Pelco biomass boilers could also be used with a forced air system by running the hot water through a radiator that the forced air passes through. Eric is a dealer for Pelco boilers and can advise any client on the best arrangement for his/her specific heating application.

Section 5: Examples of Successful Commercial Biomass Heating Projects

Meach Coves Farms - Shelburne, VT

Background – 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. The Grass Energy Partnership of the Vermont Bioenergy Initiative has been exploring an alternative form of fuel; grasses densified in a specially developed processor to take the form of 1.5" – 2.0" round cylindrical pucks. Grass fuels may be produced on otherwise marginal agricultural land, sometimes in perennial production and even in buffer strips offering environmental benefit. Additionally, fuel can be made by densifying agricultural residue or biomass harvested from idle pasture or fields. We have referred to this fuel as "ag biomass". The testing summarized in this report has demonstrated the technical and economic feasibility of such fuels.

Earlier tests were done using pellets of various feedstocks (mulch hay, reed canary grass, and switch grass) 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. 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 (clinkers), and relatively high levels of chlorine in the grass fuels which is suspected to accelerate corrosion of internal appliance surfaces. This report 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.

Image 5.4 Aerial photo of Meach Coves Farm in Shelburne Vermont

Grass Energy in Vermont and the Northeast

A review of the potential for a grass energy industry in Vermont has also been conducted earlier (Wilson Engineering, 2014). This work focused on assessing several production and marketing models (Closed Loop No Processing, Small Scale On-Farm Processing, Regional Processing, Consumer Pellet Market). The report concluded that Small Scale On-Farm Processing presents the greatest challenges and that Closed Loop No Processing would be the easiest to implement. Note: Please see the full report via the link in the references for explanations of each of these production and marketing models.

The Wilson Engineering report documents recent testing involving the densification and combustion of solid, grass biomass fuels in a small commercial boiler (342,100 BTU/hr output rating). Fuel briquettes (or "pucks") were made from Switchgrass, Miscanthus, Reed Canary, Mulch Hay and "Ag Biomass" / Field Residue as well as mixtures of these feedstocks with ground wood chips. Their findings were:

1. 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).

2. 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 timing adjustment.

3. 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 potential payback period of 3.6 years on the boiler. At higher production volume projects a path of $85 per ton ($5.2 per million BTU) and a potential payback period of 2.4 years.

Image 5.5 Close-up image of switchgrass

Section 6: Alternative Markets for Prairie Biomass

Building a commercial scale pellet plant or regional processing facility for prairie biomass 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. Alternative markets for prairie pellets can be a solution to allow early year financial success while prairie thermal energy markets are being developed. The following alternative markets have been identified and successfully developed by grass energy crop growers and processors in other parts of the country (Wilson Engineering, 2014):

- Animal bedding
- Compost for mushroom growers
- Absorbent markets

Animal bedding

Prairie biomass (both as pellets and loose) can be used as bedding in a variety of agricultural livestock production sectors. Prairie biomass has a high absorption rate and is in many ways superior to wood shavings and small grain straw. Switchgrass and giant Miscanthus are currently being used in other parts of the country 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. (Wilson Engineering, 2014)

Image 6.1
Image of biomass woodchips being used as animal bedding, image retrieved from Gruber pallets, Inc.

Compost

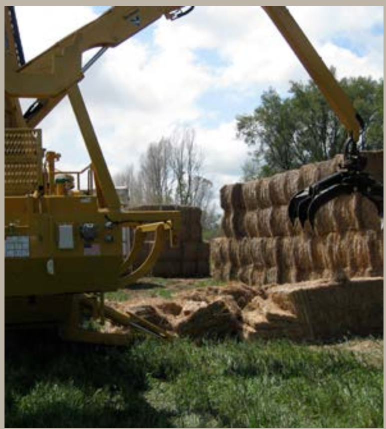
Switchgrass and giant Miscanthus are currently being used as a substrate for the commercial mushroom business in Ontario. Wheat straw, the substrate of preference in the past, is in low supply with a high price tag. Compounding the supply and price problem is the fact that modern hay baling and processing of straw is reducing fiber size and rendering straw as a less desirable substrate for mushrooms. In 2013, Ontario growers sold switchgrass to mushroom producers for 5% inclusion in their growing substrate. Trials in 2013 were being conducted at a 50% 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.

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 are required to comply with environmental regulations, and must be prepared to remove any potentially harmful products. Absorbents are used to capture these spills, so the pollutants can be processed and disposed of.

Recommended Next Steps

Demonstration of an operational prairie biomass heating system would be the next logical step in the development of prairie biomass heating as a replicable practice in Iowa. Setting up a demonstration system would require selection of a facility to heat which also has space to store the biomass fuel, an engineering design, procurement of processing, storage, and conversion equipment, installation of the system, and system testing. A demonstration system would provide very useful empirical operational data for any practitioners considering the adoption of a similar system for themselves.



Images left to right: baling, biomass pellets, boiler

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